AN INDIVIDUAL-BASED MODEL OF BASKING SHARKS AS A CASE STUDY OF MODEL COMMUNICATION FOR POLICY

by

Chelsea Gray
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Environmental Science and Policy

Committee:

Cynthia Smith	Dr. Cynthia Smith, Committee Chair
[signature]	Dr. Erin Peters-Burton, Committee Co-Chair
Dale S Rothman	Dr. Dale Scott Rothman, Committee Member
[signature]	Dr. Chris Parsons, Committee Member
[signature]	Dr. Gerald L. R. Weatherspoon, Associate Dean for Undergraduate and Graduate Affairs, College of Science
[signature]	Dr. Fernando R. Miralles-Wilhelm, Dean, College of Science

Date: ______________________

Fall Semester 2023
George Mason University
Fairfax, VA

AN INDIVIDUAL-BASED MODEL OF BASKING SHARKS AS A CASE STUDY OF MODEL COMMUNICATION FOR POLICY

by

Chelsea Gray
A Dissertation
Submitted to the
Graduate Faculty
of
George Mason University
in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Environmental Science and Policy

Committee:

________________________	Dr. Cynthia Smith, Committee Chair
________________________	Dr. Erin Peters-Burton, Committee Co-Chair
________________________	Dr. Dale Scott Rothman, Committee Member
________________________	Dr. Chris Parsons, Committee Member
________________________	Dr. Gerald L. R. Weatherspoon, Associate Dean for Undergraduate and Graduate Affairs, College of Science
________________________	Dr. Fernando R. Miralles-Wilhelm, Dean, College of Science
Date: ____________________	Fall Semester 2023 George Mason University Fairfax, VA

An Individual-based Model of Basking Sharks as a Case Study of Model Communication for Policy

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at George Mason University

by

Chelsea Gray
Master of Science
George Mason University, 2019
Bachelor of Science
University of Mary Washington, 2013

Director: Cynthia Smith
Department of Environmental Science and Policy

Fall Semester 2023
George Mason University
Fairfax, VA

DEDICATION

I dedicate this to my family, who have always encouraged me to stay curious and stay weird. Most importantly, I dedicate this to the family members who didn’t get to see me finish, but whose love carried me through this journey and will continue to carry me through life.

ACKNOWLEDGEMENTS

This dissertation was supported by a community of scientists. I would like to first acknowledge the contributions of my committee, who have consistently encouraged me to pursue the complex, interdisciplinary research questions that piqued my curiosity. With their support, I pursued my passion and have matured as a scientist.

I would also like to thank the Irish Basking Shark Group and Irish Whale and Dolphin Group for sharing the long-term sightings data sets. I would especially like to thank Dr. Emmett Johnston, Dr. Simon Berrow, Dr. Donal Griffin, Dr. Alex McInturf, and Dr. Tasha Phillips, whose support, expertise, and professional contacts made this research possible. Go raibh míle maith agaibh!

I would like to acknowledge the computational support and computing resources for this research from Alexis Garretson at The Jackson Laboratory.

I also want to recognize the uncredited contributions of those who interviewed with me. Thank you for taking such a long time out of your busy schedules to help out a poor PhD student.

I want to thank Dr. Andrew Crooks, whose introductory Computational Social Science course changed the course of my career. Thank you for encouraging me, a person with no modeling experience, to tackle complex problems with individual-based modeling. That course sparked a long-running fascination with IBMs and complex modeling, and is the reason this dissertation tackled the questions it did. I would also like to acknowledge Dr. Crooks' early critical support and advice, as the very first prototype of this IBM was made during one of his courses.

I want to acknowledge the support of Dr. Chris Jones, who has consistently assisted with funding and written me many letters of recommendation throughout my graduate career.

As a scientist in the modern era, I would be nowhere without a group chat to hype me up. Alex and Jenny; Alexis, Sammie, and Sam, thanks for always being there, allowing me to vent and providing PhD-life support.

Similarly, I would like to thank the contributions of the Bose Corporation to my sanity. I would not have survived dissertation writing without their noise-cancelling headphones.

Finally, I would like to acknowledge the support of my partner and dear friends. Galen, thank you for always encouraging me to not only be the best, but to take a break. Sudha, thanks for reminding me to be concise and to "just put it in the appendix." Emily, thank you for your unending enthusiasm and encouragement. Aurora and Tristan, thanks for keeping me young and reminding me why, and for who, environmental research matters.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Continuous Plankton Recorder .... CPR
Evidence-based Policy .... EBP
Individual-based Model .... IBM
Irish Basking Shark Group .... IBSG
Irish Whale and Dolphin Group .... IWDG
Operations Patterns Evaluation .... OPE
Overview Design Document .... ODD
Transparent and Comprehensive model Evaludation .... TRACE
Web of Science .... WoS

ABSTRACT

AN INDIVIDUAL-BASED MODEL OF BASKING SHARKS AS A CASE STUDY OF MODEL COMMUNICATION FOR POLICY

Chelsea Gray, Ph.D.

George Mason University, 2023

Dissertation Director: Dr. Cynthia Smith

An interdisciplinary dissertation, combining complex behavioral modeling and qualitative social science to address marine conservation issues. (1) The first individual-based model (IBM) of basking shark behavior was developed and used to determine the localized drivers of aggregations in Ireland. The results of the IBM indicate that a combination of food availability and social drivers provide a model output that most aligns with the long-term sightings data from the region. (2) A review of marine IBMs was conducted, to determine the rate of IBM use in policy. A review of international peer-review publications utilizing marine IBMs was conducted using Web of Science (WoS). The publications were assessed to determine if the WoS articles claimed that the IBMs were relevant or important to marine conservation policy or management. The results indicate that IBMs are used in marine policy less frequently than other methods. Finally, (3) the basking shark IBM was used as a case study for communication with mid-level policymakers. Interviews with nine mid-level policymakers who work on marine

policy in the Northeast Atlantic were conducted. A one-pager, based off the results from the IBM described in Chapter 2, was used to test communication strategies. The results indicate that there is no bias against IBMs, but instead a lack of expertise. Interviewees were overwhelmingly open to new and novel model methods. The one-pager was partially useful at communicating results for policy, but IBMs require more explanatory information.

CHAPTER ONE: INTRODUCTION

Basking sharks (*Cetorhinus maximus*) were listed as 'endangered' by the IUCN in 2019 but only protected under domestic legislation in Ireland in 2022. The Northeast Atlantic, in particular the Irish coast, is a hotspot of basking shark activity, where sharks are known to exhibit interannual site fidelity and to gather in aggregations, which may serve courtship purposes (Doherty, Baxter, Godley, et al., 2017; Johnston et al., 2019). Ireland is currently looking to expand their marine protected area networks (Marine Protected Area Advisory Group, 2020). This research seeks to provide additional evidence for conservation strategies for basking sharks, through the use of cutting-edge individual based modeling (IBM). However, this research also demonstrates a low rate of IBM use in marine policy development. Therefore, social science research into how policymakers[1] both choose and interpret evidence was also used to craft communication guidelines to help inform future researchers how to advocate for these results to influence conservation policy.

This research aimed to 1: create a model that will aid the in basking shark conservation policy, 2: assess model use in conservation policy through a review of scientific publications and policy documents and 3: use the basking shark IBM as a

[1] "Policymakers" in this research refers to a broad range of individuals who contribute to all stages of policy development. This research will focus on those who determine which evidence is used in policy. This can include agency researchers, individuals who draft recommendations, and lobbyists who advocate for policy.

case study, to assess policymaker understanding and trust through interviews. 4: Develop guidelines for other modelers, so that they can effectively and efficiently communicate model results for policy change.

1.1 LITERATURE REVIEW

1.1.1 Basking Shark Behavior and Conservation

While basking sharks are largely solitary, they gather in large, mixed sex aggregations, which can range from two sharks up to 1,398 individuals (Crowe et al., 2018; Sims, 2008). Nose-to-tail swimming, in a linear or circular formation, is very commonly observed in the North Atlantic (Harvey-Clark et al., 1999; Sims et al., 2000). In a five-year study, it was more commonly recorded than parallel and echelon swimming or following at a distance, though the other behaviors were observed as well (Sims et al., 2000). Sharks have been observed nose-to-tail following for up to 5.8 hours, though the average is 1.8 hours (Sims et al., 2000). Nose-to-tail following behavior may be a courtship behavior, as females have frequently been seen 'leading' other sharks; sharks partake in this behavior when not feeding, and juvenile sharks are rarely sighted in such aggregations (Harvey-Clark et al., 1999; Sims et al., 2000). Nose-to-tail following is most often observed by researchers in early summer, the time of the year when it is assumed that basking sharks mate (Sims et al., 2000). Other behaviors associated with aggregations, including breaching, are also hypothesized to be courtship behaviors (Sims, 2008). However, large aggregations have included what are assumed to be (based on size) juvenile sharks, further indicating that reproduction is not the sole reason for this behavior (Crowe et al., 2018), and there are some who argue that such behavior, like nose-to-tail following or other formation swimming, is meant to reduce drag and increase feeding efficiency (Sims et al., 2000). In the Northeast Atlantic, genetic studies have indicated that sharks that surface together are more likely to be related than not (Lieber et al., 2020), indicating mating is not always a factor.

As basking sharks feed on zooplankton on the surface of coastal water, these aggregations can pose a threat to boaters and the sharks themselves, especially because basking sharks do not generally attempt evasive action in the presence of boats (Speedie et al., 2009). The Malin-Hebridean Sea area is a locale of high boat traffic where these aggregations occur, and peak boat traffic times also correlate with peak basking shark surface feeding (Speedie et al., 2009). Currently, the main threats in the Northeast Atlantic to basking sharks are boat strikes, bycatch, and climate change (OSPAR Commission, 2015). In 2020, Scotland declared four new Marine protected Areas (MPAs), including the Inner Sea of Hebrides, which would encompass key basking shark habitat (Nature Scot, 2020). The importance of Hebrides to basking shark mating was cited as one reason for the placement of the MPA (Marine Scotland, 2020).

Basking sharks have not been extensively modeled. Habitat suitability models (HSM) have been applied to basking sharks in New Zealand (Finucci et al., 2021). The HSM incorporated zooplankton data and found a weak relationship between basking shark sightings and zooplankton, but the weakness of the relationship may be related to the dearth of data on both basking sharks and zooplankton. In another example, Ensemble Ecological Niche Modeling (EEM) has been applied to basking sharks (Austin et al., 2019; Doherty, 2017). Ecological Niche Modeling (EEM) (or species distribution modeling) has been applied to basking sharks (Doherty, 2017). While the model was effective at predicting the suitability of foraging locations, this didn't always correspond with shark sightings or with tagged data. Doherty (2017) noted that tagged basking sharks displayed a "dispersive nature" (pg. 126) and did not appear to make consistent, group migrations, especially with regard to areas where sharks winter and are assumed to be largely solitary (Sims, 2008). Doherty suggested that the model be refined to include an "exploration-refinement" hypothesis (2017). Exploration-refinement is a framework to understand the behavior of long-lived migratory species (Guilford et al., 2011), especially those that mature late in life, assuming younger individuals will feel less impulse to return to breeding sites (Fayet, 2020). It is assumed that these individuals explore different migratory routes before settling on a preferred one. Such a framework would require individualized agents and environmental stochasticity to accurately reflect basking shark behavior. While Doherty (2017) suggests the use of it, no mechanism for the inclusion of this hypothesis is suggested. Individual-based models (IBMs) are a potential method of testing this.

1.1.2 Individual-based Modeling in Ecology

The term "model" refers to many different methods of artificially representing the world, from simple mathematical models, to complex, multi-level models. Models are representations of the real world used for problem-solving. They can be unrealistic (i.e., a population growth model that assumes there is no immigration/emigration) or realistic, simple or complex[2] (i.e., a climate model that factors in ocean and wind currents as well as human behavior).

Models are frequently critiqued for their abstract nature (Silverman, 2018). Classical mathematical population level models generally do not incorporate behavior based on environmental cues, group-induced dynamics, or drivers of behavior (i.e., foraging, courtship). Classical mathematical models (i.e. ecosystem modeling with EcoPath with EcoSim) do not generally allow for adaptive behavior or environmental stochasticity (Christensen & Walters, 2004; Coll et al., 2015; Natugonza et al., 2020). Therefore, some researchers have argued that simulation models, like individual-based models (IBMs), are better suited to highly mobile marine species, because they allow for more realistic animal movements (Codling, 2008). Mathematical models often assume animal movements are random and uncorrelated, while IBMs can allow for more complex intra- and inter-specific relations, as well as environmental stochasticity (Codling, 2008). Mathematical models represent the essential aspects of a system while simulation models, like IBMs replicate systems (Durán, 2020; Serra & Godoy, 2011). The ability of IBMs to produce "emergence" and depict realistic, interacting systems makes them uniquely valuable to the study of animal behavior. Emergence refers to macro scale patterns that are the result of individual, micro-level behaviors. While all models remove features that would otherwise be impossible to remove in nature, in order to isolate the effect of other features, IBMs allow for this without sacrificing complexity or realism. For example, an

[2] Note that there is no correlation between the relative complexity of a model and its predictive capabilities or realism (Green & Armstrong, 2015).

IBM can test different decision making patterns of fish, to understand their migratory patterns in the face of complex and dynamic ecosystems (Snyder et al., 2019) with thousands of simulations run, over years, decades, or centuries (Silverman, 2018). Because IBMs, like all models, may hide assumptions, flawed code, or flawed input data, written documentation of model development and model testing is vital for the peer review process (Grimm et al., 2006; Silverman, 2018). Documentation should be in enough detail for another scientist to duplicate the IBM but should also use language that non-experts can understand, however this is not always the case.

IBMs are often used to understand questions that span multiple levels, allowing researchers to look at systems holistically. This allows for feedback between levels, where agents react to the system, and the system is impacted by the cumulative behavior of the agents, which then impacts the agents, who can adapt and again impact the system (Railsback & Grimm, 2011). Emergence, which arises at the macro level (i.e., a flock of birds) from the individual behavior of agents, can be used to understand system-level interactions that result from individual components (such as agents) interacting with each other and the environment (Railsback & Grimm, 2011). IBMs are a great way to test theories of adaptive behavior, which can require environmental conditions or time scales that impossible to replicate in a lab and which many other types of models cannot do (Grimm & Railsback, 2005a).

1.1.3 Model Use in Policy

Models are used in many fields, ranging from economics, to public health, to fisheries (Railsback & Grimm, 2011) and are tools of both scientific research *and* policy, as they can be used to answer scientific questions and/or to test the impact(s) of potential policy decisions (Paolisso et al., 2015). Modeling has been used in conservation for decades, with varying levels of success (Béland & Howlett, 2016). While there are examples of models that have been successfully applied to management (Anderson et al., 1981), it is not uncommon for models to be poorly designed or to be applied to policy questions that they were not designed to answer (Edmonds, 2017; Grimm et al., 2020). Models can also imply certainty or predictive capabilities where there is none (Pilkey, 2007), giving policymakers a false sense of confidence. This is reflective of the "certainty trough", where those with the most or least amount of direct knowledge of technology trust it the least, while those that are passingly familiar with technology trust it the most (MacKenzie, 1998).

A challenge to model use in policy is that models may be confusing to stakeholders, who can view complex or interdisciplinary models as a "black box" (Paolisso et al., 2015). Models that are used to develop, influence, or test policy, but are not well understood, can have significant impacts on those who are subject to the policies that result from such models (Paolisso et al., 2015). This lack of understanding can lead to a lack of trust in the model, and resistance to the policy implementation. Strong model communication can ensure that those impacted by such policies feel confident in the models and, by extension, the policies.

Assessing effective model use for policy is difficult in no small part because assessing the success of *any* policy is not a simple feat and can even be dependent on the stakeholder assessing the outcome (Cairney, 2016e; Sterling et al., 2017). For models that claim predictive power (e.g., fisheries stock and climate models), assessment is even more difficult. If a researcher wants to test a model's *true* predictive power, they must wait to see if the predicted outcome occurs (while models are often tested against *past* events, this has not shown to be a reliable way for testing predictions of future events) (Pilkey, 2007).

Model development processes and goals differ significantly between projects. Not all models need to have a policy goal, but those that do should consider the needs of policymakers and/or stakeholders as well as the way the model will be used to inform policy.

With the increase in computing power, it is likely that more policy-relevant IBMs will be created and that they will continue to grow in complexity. While many scientific publications often assert the usefulness of a model for ecological management, there is not always evidence that the model has been utilized in policy or management, or if the impact of model has been documented (either in a published paper or elsewhere, such as a government report).

While many policymakers have experience with classical ecological models, those are much easier to communicate due to the "common language" that is mathematics (Grimm & Railsback, 2005a). However, IBMs are vastly different from one another and do not have a common language that researchers, let alone policymakers, can refer to (it is worth noting that IBMs can be written in many different computer languages, so IBM modelers may not even be able to read one another's models). While written in plain language, TRAnsparent and Comprehensive Ecological modelling (TRACE) and Overview, Design concepts and Details (ODD documents) are often long, and may still be incomprehensible to policymakers, who are not familiar with the communication norms of modelers, though more simplified methods of documentation exist (Planque et al., 2022). Instead, communication with policymakers should adapt to *their* norms (Cairney, 2017; N. Rose & Parsons, 2015).

Researchers who are comfortable with IBMs and other complex ecological models may be best suited to understanding the policy process than other researchers, as it is arguably quite similar to complex individual-based models. Policymaking is itself a complex system. In fact, complexity theory has also been applied to policy theory (Cairney, 2016e), as policy development is neither top-down, nor bottom-up, but a complex interaction of actors. These actors interact with each other and with their environment, influencing other actors and the environment in a feedback loop not unlike complex ecological processes (Cairney & Oliver, 2017). In fact, the term "emergence" has been applied to policymaking in the exact same way that it's applied to complex modeling (Cairney, 2016e). Policymaking is not a linear process, and often results from multiple, intersecting actors responding to other actors, as well as their environment. Policymakers are responding not just to scientific evidence, but also to pressure from other stakeholders, other politicians, and situational concerns. This means that researchers are competing for time, trust, and attention from policymakers. Clear model communication can give researchers a competitive advantage when it comes to informing policy.

1.2 SIGNIFICANCE OF THE RESEARCH

1.2.1 Model Significance (Chapter 2)

While IBMs have been used for ecological research, they have never been applied to basking sharks. IBMs are often used to assess how individual or bottom-up interactions create large scale emergent behaviors. This IBM tested hypotheses on social behavior and impacts of environmental conditions to understand complex basking shark behavior.

Being able to understand why basking sharks gather in these large aggregations is vital to understanding which ecosystems may be important to their conservation success, as research has demonstrated that foraging suitability alone is not sufficient to explain basking shark migration (Doherty, 2017). While food is abundant in other areas of Ireland and Scotland, the Malin-Hebrides shelf may in fact be an area of *social*, rather than just foraging, importance, indicating such areas are likely important for reproduction. This model can inform policy regarding MPA placement or other conservation measures in Ireland. The findings of the IBM indicate that food availability is an insufficient explanation for the aggregations documented in the sighting reports.

1.2.2 Review of IBM Use in Marine Policy (Chapter 3)

This is the first review of IBM use in marine policy. This research assessed the number of marine IBMs that claim they are applicable for policy, then cross-references that with relevant marine policy documents, to determine if they were cited. Further reviews of government websites quantify the number of IBMs referenced over other model methods. While imperfect, this is the first study to conduct such research, and to attempt to quantify a difficult to quantify issue related to evidence use in policy development. The results indicate that even though the majority of marine conservation-oriented IBMs published in scientific journals claim relevance to policy, there is little evidence that they are actually being used to influence or inform policy, except on rare occasions, when compared to other model methods.

1.2.3 Case Study Significance (Chapter 4)

Currently, there is little research on how IBMs are implemented in policy. Understanding barriers to model use in policy development will help researchers communicate and advocate for their models, as it is important to communicate to policymakers in a way that works for them (Cairney & Kwiatkowski, 2017). This research tested a communication strategy commonly used in public health, using the basking shark IBM as a case study.

This is the first research of its kind applied to IBMs and has resulted in communication advice for other modelers, so that they can more effectively and efficiently communicate their models. This research also provides insight into the methods policymakers use to find "evidence" for use in policy and their understanding of and trust in different model methods.

1.3 RESEARCH QUESTIONS

1. What environmental factors lead to basking shark aggregations? [Chapter 2]
2. What social conditions lead to basking shark aggregations? [Chapter 2]
3. What is the rate of IBM use in marine policy development? [Chapter 3]
4. What is the policy theory held by the policymaker or developer? [Chapter 4]
5. What is the perception of scientists held by policymakers? [Chapter 4]

6. What is the level of trust in the model? [Chapter 4]
7. What is the level of understanding of the model results? [Chapter 4]
8. What is the level of understanding of the model's purpose? [Chapter 4]
9. Will policymakers indicate that the model has influenced their own policy in any way? [Chapter 4]

CHAPTER TWO: AN INDIVIDUAL-BASED MODEL OF BASKING SHARKS IN IRELAND

2.1 INTRODUCTION

Basking sharks (*Cetorhinus maximus*) are the second largest extant fish in the ocean and the only species in the family *Ceterohinidae*. In 2019, they were listed as endangered by the IUCN (they had been listed as ‘vulnerable’ since 1996) and internationally they are listed on Appendix 2 of the Convention on the International Trade in Endangered Species (CITES), and Appendix 1 and 2 of the Bonn Convention on Migratory Species. Targeted fishing of basking sharks is prohibited in EU waters and internationally by EU registered vessels (EC No41/2007). In 2022 they were listed in the Republic of Ireland under the Wildlife Act of 1976 (the first fish in Ireland to receive domestic protection).

Much is still unknown about basking shark life history, migration, and behavior, posing a serious challenge to their conservation. The worldwide population of basking shark has been estimated to be as low as 8,200 individuals (Hoelzel et al., 2006). Therefore, understanding their behavior and life history is vital and it is important to understand areas of habitat that are important for basking shark social or reproductive, as well as feeding, potential.

Basing sharks are known to gather in large aggregations, ranging from two to several hundred (Crowe et al., 2018). It is not known why basking sharks gather in these aggregations, though the reasons may be related to feeding, courtship, or both (Speedie et al., 2009). In the North Atlantic, the top threats to basking sharks are boat strikes and bycatch (OSPAR Commission, 2015). As basking sharks regularly feed on zooplankton at the surface of coastal waters, these aggregations can pose a threat to boaters and the sharks themselves, especially because basking sharks do not generally attempt evasive action in the presence of boats (Speedie et al., 2009).

The Malin-Hebridean Sea area is area locale of high boat traffic where these aggregations occur, and peak boat traffic times also correlate with peak basking shark surface feeding (Speedie et al., 2009). Recently successful arguments have been made in favor of a marine protected area (MPA) to be established in the Sea of Hebrides (Scotland). Some of the arguments for the establishment of the MPA emphasized that when the sharks gather in the Hebrides, a productive frontal area of the sea, they are more likely to engage in courtship behavior, implying reproductive importance to the region (Speedie et al., 2009). The Scottish Government cited shark behavior as an indication of why that particular region was valuable to basking sharks (Marine Scotland, 2020). Other observations have documented that basking sharks may exhibit social behavior, like nose-to-tail swimming, in order to reduce drag and increase feeding efficiency (Sims et al., 2000).

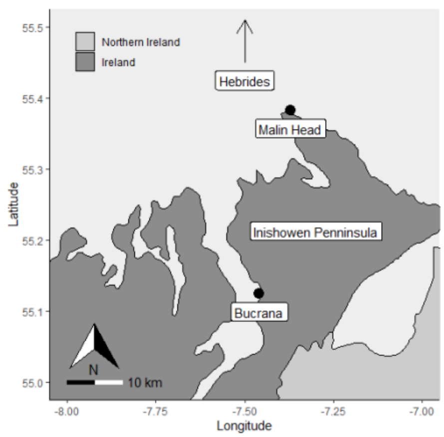


Figure 1: Model area.
Map by Alexis Garretson

2.1.1 Basking Sharks in Ireland

The waters around the Inishowen Peninsula (Co. Donegal; Figure 1), found in the Malin Sea, is a hotspot for basking shark aggregations. There is evidence that the same sharks spotted around Inishowen (specifically Malin Head) travel to the Sea of Hebrides (Johnston et al., 2019), indicating a shared population. In Scotland, basking sharks have been protected since 1998 (under Schedule 5 of the Wildlife and Countryside Act 1981). In 1999, the UK Government published a national Biodiversity Action Plan for basking sharks as part of their obligations under the Convention on Biological Diversity. Unfortunately, funding to conduct the conservation activities outlined in the plan did not follow.

Immediately to the east of the Inishowen peninsula are the waters of Northern Ireland. As Northern Ireland is part of the UK, it adopted the Wildlife and Countryside Act of 1981 and its provisions under the Wildlife (Northern Ireland) Order 1985 and basking sharks have been protected there since 2009. Protections for basking sharks in both Northern Ireland and Scottish waters extend 12 nautical miles from the coast. In the Republic of Ireland, basking sharks were only protected from harassment or direct harm in 2022.

There is a lack of conclusive data surrounding basking shark social and potential courtship behavior which may be a hinderance to effective conservation efforts. It is difficult to accurately assess the purpose of their behavior, as observational data relies on finding an elusive species and tagging data is prohibitively expensive. Therefore, an individual-based model (IBM) of basking shark behavior in the Malin Sea, centered on the Inishowen Peninsula, was created in Netlogo. This IBM explored what environmental or social conditions might lead to these aggregations and shed light on the likelihood that these aggregations include courtship behavior.

2.1.2 Why an IBM?

While IBMs have been used for ecological research, they have never been applied to basking sharks. IBMs allow for bottom-up modeling, with populations that include individuals that are heterogenous (while traditional models often assume uniformity or the "average of" individuals or environments) (Uchmański & Grimm, 1996). IBMs also allow for the consideration of how individuals interact with and affect, or are affected by, their (spatially explicit) environment (Grimm & Railsback, 2005b; Uchmański & Grimm, 1996). This allows for a stronger understanding of patterns, such as aggregations, at higher population levels (Squazzoni & Boero, 2010).

The IBM in this study tested hypotheses on social behavior as well as hypotheses on environmental conditions. Results were compared to sightings data collected over several decades in Ireland by the Irish Basking Shark Group (IBSG) and Irish Whale and Dolphin Group (IWDG).

Basking sharks are uniquely suited to an IBM because they follow highly individualized migration routes and demonstrate intermittent site fidelity (Doherty, Baxter, Gell, et al., 2017). They are largely solitary, with the exception of these aggregations (Sims, 2008). IBMs are also a strong proxy for field work, which is prohibitively expensive and not always feasible due to unforeseen circumstances (i.e. COVID—19; Murphy et al., 2020), making them an ideal method for elusive species.

2.1.3 MODEL PURPOSE

The model consisted of different submodels of behavior, including intentional social interaction, behavior focused solely on foraging for food, and a combination of these. The fourth submodel, Random Swim, served as a control.

The model tested if food availability, social attraction and/or a combination of food/social attraction, were sufficient to explain the aggregations sighted in Inishowen. The model did not include sex or age, so it could not test directly if aggregations were related to courtship, but most observational data indicates that these are likely courtship related (Sims et al., 2022). In a more practical sense, such a model can be used to help understand when the likelihood of aggregations is higher, which can then be used to inform policy. For example, if there is a correlation between certain zooplankton conditions and basking shark aggregations, policies can be put in place to warn boaters to reduce speed in certain areas at times of high aggregation potential. As this was the first model of its kind, it was narrowly focused on the Inishowen Peninsula in Ireland. This model was a qualitative model as described by Pilkey (2007). Rather than an output that includes a predictive number; the model's purpose was to understand a process or system. For this research, an aggregation was defined as: "the co-occurrence of two or more individuals in space and time due to the deliberate use of a common driver" (McInturf et al., 2023).

Despite research indicating that most tracking studies do not result in tangible policy changes (Jeffers & Godley, 2016; McInturf et al., 2023), basking sharks are a rare example where such research has tangibly informed policy (Hays et al., 2019). This may indicate a stronger willingness in shark conservation to work with imperfect data and/or apply new research to policy, indicating an increased likelihood that the research described here will be applied.

The Inishowen Peninsula was modeled as it is an area known for shark aggregations including breaching, a behavior that may have courtship purposes (Gore et al., 2018; Johnston et al., 2018; Rudd et al., 2021). The Inishowen Peninsula is also full of beaches and popular hiking spots, so a large portion of sighting reports have come from this area over time. The Sea of Hebrides, directly across from the Inishowen Peninsula, have recently been declared a Marine Protected Area (MPA), partly because basking sharks exhibit aggregation behavior there. However, conservation research focused in this area is still limited.

This IBM seeks to increase understanding of basking shark aggregation behavior and the purpose of these aggregations. This can be used to assess if the Malin shelf is important for more reasons than just feeding (i.e., reproduction). The IBM was also used to understand the environmental conditions that lead to aggregations.

2.1.3.1 Research Question and Hypothesis

Research Questions: What environmental or social conditions lead to shark aggregations?

Hypothesis: Food availability is not a sufficient explanation for aggregations in Malin. Social components (such as courtship) are also a driver of these aggregations.

2.2 METHODS

The model was created in Netlogo (version 6.2.2). Model development and testing was documented using the Transparent and Comprehensive model Evaludation (TRACE), Overview Design Document (ODD), and Objective Patterns Evaluation (OPE) methods (Grimm et al., 2006, 2014; Planque et al., 2022; Schmolke et al., 2010). See Appendix A.1 for the ODD and Appendix A.2 for the OPE. Basking shark sighting reports supplied by the Irish Basking Shark Group (IBSG) and Irish Whale and Dolphin Group (IWDG) were used for calibration and validation. Zooplankton from the Continuous Plankton Recorder Survey (CPR) was used to inform the zooplankton distribution in the model (Johns, 2020). The model area's visual map and sea depth was obtained through General Bathymetric Chart of the Oceans (GEBCO) (GEBCO Bathymetric Compilation Group, 2020).

2.2.1 Model Overview

Each time step in the model represents 24 hours. The model area represents 56n, 55n, & -8w, -6.5w, an area of 10,545 km^2, with patches of 1 km x 1km x 10 m (depth). This area was chosen as it is largely understudied compared to basing shark research in other parts of Ireland. One km by one km patches were selected to keep patch sizes small, but manageable, and to account for shark movements within 24 hours. The 10m depth was chosen as that's the maximum depth of the Continuous Plankton Recorder, and the IBSG/IWDG sighting reports are only of surfacing sharks. Sharks do not move through the water column in this model.

Each simulation depicts April 1st—October 31st[3] for 1982—2018. This time of year was chosen as IBSG/IWDG sightings data shows that this is when sharks are most likely to be surfacing in Ireland. While some basking sharks may remain in Ireland during the

[3] Due to a lack of CPR data from October 26th, 2018— November 1st 2018, the model ends the entire run on October 26th, 2018 instead of October 31st.

winter, the ones that do likely remain well below 10m depth (Doherty, 2017), and therefore are unlikely to be accounted for in publicly reported sightings.

Table 1: Key differences Between Submodels.

Submodel	Seek Zooplankton	Seek Other Sharks
Random	No	No
Food	Yes	No
Social	No	Yes
Food/social	Yes	Yes

The key differences within each submodel are how sharks decide where to move. In the Food submodels, sharks only seek out areas of high zooplankton, in the Social submodel sharks only seek areas where there are other sharks, and in the Food/Social submodel, sharks first seek areas of high zooplankton, then areas with other sharks.

2.2.2 Submodels

The model consists of four submodels of agent behavior (Table 1):

1. Social submodel: Sharks only search for other sharks. Sharks do not search for food.
2. Food submodel: Sharks only search for high zooplankton areas. The sharks retain a memory of previous high zooplankton and will search for those during times of overall low zooplankton. Sharks do not search for other sharks.
3. Food/Social submodel: Sharks first search for food, then other sharks, then use their memory if there is not sufficient food or other sharks.

4. Random submodel: Sharks swim at random at every time step. This serves as a control.

2.2.3 Agents

The model includes individual basking sharks as agents. The sharks are not distinguishable by size, age, or sex. Sharks do not give birth or die in this model. The model assumes annual fidelity at the start of the season. Each shark randomly "migrates" into the model area within the first 60 days of the start of the season (April 1st).

At each daily time step, the shark decides whether or not to move to a new patch. This decision is based on the level of zooplankton within their current patch (the threshold level required to force a move is set by the user; Table 3) and the number of sharks in the patch they are currently in (sharks determine if there is enough zooplankton to support the total number of sharks in a patch; Figure 2). The submodel then determines where/why a shark will move next. In the Food submodel, sharks move to areas of high zooplankton. In the Social submodel, sharks move to areas where there are other sharks. In the Food/Social submodel, sharks first seek out food, then seek out other sharks. The sharks retain memory of high zooplankton patches and return to those if they are unable to locate areas of high zooplankton (in the Food and Food/Social submodels) or areas of zooplankton *and* other sharks (in the Food/Social submodel) within their "sight" distance (Table 3 and Figure 2). When seeking other sharks, a shark's "sight" is doubled (the sense-distance is set by the user), under the assumption that basking sharks can either hear or smell other basking sharks at a further distance than they can zooplankton.[4] The sense-distance remains static throughout the model run and the model does not account for ocean currents, wind, or other factors influencing the distance sound and smell travel through water.

2.2.4 Zooplankton

Zooplankton were separated into two distinct categories: (1) *Calanus* species ("cal"), and (2) *Pseudo Calanus* and *Centropages typicus* ("other zp"). Zooplankton data came from the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), which conducts the Continuous Plankton Reorder Survey (Johns, 2020). Out of 7,918 dates, 6,264 (79%) dates were missing (unsampled) from the CPR data, so a linear interpolation was performed to fill in the data gaps. The monthly averages of the CPR data and the interpolated data were normalized to fall between 0 and 1 using min-max normalization, and the mean error (ME), root mean square error (RMSE), and mean absolute error (MAE) were calculated to compare the interpolated model zooplankton to the CPR data (Table 2).

The percentage of patches which contain each category of zooplankton is set by the user. Every time the model updates (every 24 hours), the abundance of zooplankton is taken from a csv file containing the linearly interpolated CPR data. The abundance is divided by 3 (CPR samples 3m^3 of water per sample and reports data in absolute numbers of zooplankton), then divided by the percentage of patches that should have zooplankton (set by the user) in order to calculate the average number of zooplankton for each patch containing zooplankton. The results of this equation are then distributed throughout the

[4] The method of detection basking sharks use to find other sharks and/or zooplankton is not clear. It is likely a combination of smell and sound. The distance smell or sound travels in water can vary depending on a variety of factors, which the model does not currently account for.

model by multiplying that previous result by the standard deviation of the CPR data, so the patches have a range of zooplankton values.

Table 2: Comparison of the interpolated Calanus data to the CPR data

	ME	RMSE	MAE
Cal	-0.32	0.49	0.40
Other Zp	-0.38	0.52	0.45

To fill in missing data, a linear interpolation was performed. The raw CPR data and the interpolated data were compared. The Calanus data was normalized (min-max) and compared. Results indicate the average distance between the model's values and the value in the CPR data.

2.2.5 Output Data

Simulated sampling of model zooplankton is recommended when using CPR data, (Everett et al., 2017) and this was done in the model, with ten random patches sampled every day. The number of zooplankton were averaged for all ten patches.

At each time step, each patch that contains two or more sharks is recorded. The number of sharks per patch, and patch location are recorded (Total Aggregations).

The model also includes Pseudo-Sighting Reports. Ten (for sensitivity and robustness analyses) or twenty patches (for preliminary and final tests) were randomly sampled every day, and any shark sightings were "reported". Both Pseudo-Sighting Reports and Total Aggregations output include the latitude, longitude, and zooplankton level of the patch, as well as the number of sharks. The results from multiple trials were averaged, then compared to the IBSG/IWDG data.

Table 3: User Input into the Model

Parameter	Explanation	Setting
Threshold_zp	Minimum amount of zooplankton (cal and other_zp combined) required for a shark to stay in or more to a patch. Counted in individuals zooplankton.	0—1000000000000
No_eat_min	Number of days a shark must encounter a patch that is less than the threshold_zp before leaving the model	0—100
Sense-distance	How "far" a shark can see (in km). This is doubled when sharks are locating other sharks.	0—100
Swim-speed	The distance a shark can swim (in km)	0—100
Return-season	How many days it will take a shark to return after they have left in response to reaching the no_eat_min	0—100
Cal_%	Percentage of patches with *Calanus* copepods	0—100
Other_zp_%	Percentage of patches with other large zooplankton	0—100
Friend_min	Number of other sharks a patch must have to attract a shark	0—100

Each parameter is set by the user using a slider variable.

If total zooplankton in patch is less than the threshold_zp when divided by the number of sharks in the patch	If Yes	→	Food	→	Seek patch with zooplankton above the threshold	→	If no patches with zooplankton > threshold_zp, Seek patch from memory of high ZP patches, choose closest patch	→	if no patches in memory, Random Swim		
	If Yes	→	Social	→	Seek patches with other sharks >= friend_min	→	If no patches with sharks >= friend_min, random swim	→	Random Swim		
	If Yes	→	Food/Social	→	Seek patch with zooplankton above the threshold	→	If no patches with zooplankton > threshold_zp, Seek patches with other sharks >= friend_min	→	If no patches with friend >= friend_min, Select high zooplankton patch from memory	→	If no patches with high zooplankton patch in memory, random swim
	If No	→	All Submodels	→	Stay put						

Figure 2: Shark Decision Pathway

Shark Decisions Pathway under different submodels. Each day, sharks complete this decision tree. Note that if a patch that meets the condition is identified, under all versions, sharks make the following action: If within swimming distance, move to it, if out of swimming distance, swim towards it. Random is not included in this table as sharks simply select a random patch to move to each day.

2.2.6 Data Analysis

Only IBSG/IWDG sightings from 1982—2018 between April through October were included in data analysis, with the exception that sightings in the last week of March were included in the April count. The total number of aggregations during the study period in the IBSG/IWDG was 2,136. Nine hundred and sixty-nine of those included aggregations of two or more sharks. When pulling out data for the study area (Inishowen), 458 sightings were reported, 210 of which were for two or more sharks (Table 4).

Kolmogorov–Smirnov tests were used to assess which simulated data sets most closely aligned with the IBSG/IWDG data, in terms of the distribution of daily sightings. Kolmogorov–Smirnov tests were also used to compare individual trials, and the percentage of trials that were considered "significantly different" from each other was reported. This was done as a proxy for consistency between model trials with the same settings.

Table 4: Total IBSG/IWDG sightings reports from 1982—2018.

	All of Ireland	Inishowen
All shark sightings	2136	458
Aggregations of 2+	969	210

All of Ireland includes sighting reports for the entire country, while Inishowen are the sightings reports from the model area only (Inishowen is included in the "All of Ireland" count).

The monthly average aggregation size for the Total Aggregations, Pseudo-Sighting Reports, and IBSG/IWDG data were then determined. The data was normalized using minimum- maximum normalization and then the mean error (ME), the mean absolute error (MAE) and the root mean square error (RMSE) were calculated between the Total Aggregations and IBSG/IWDG monthly averages. The same was done for the Pseudo-Sighting Reports and IBSG/IWDG monthly averages.

The normalized average monthly aggregation size was also graphed onto time series and box plots and qualitative comparisons were made between the model outputs and the IBSG/IWDG data.

The same tests were also used to compare the average number of aggregations per month.

2.2.7 Model Tests Runs

Three groups of tests were run. First, the sensitivity and robustness analyses (SA/RA) were conducted. The SA/RA tests were used to determine settings for preliminary tests. Preliminary tests were then conducted. From the preliminary tests, the two settings that provided the best fit when compared to the IBSG/IWDG data were then repeated for 50 trials per submodel.

2.2.7.1 Sensitivity and Robustness

Fifty setting combinations were tested (Table 5) in order to conduct sensitivity and robustness analysis (SA/RA), as well as to provide a general comparison to the entire IBSG/IWDG dataset. Each test consisted of ten repeat trials per submodel. These tests were conducted with 200 sharks[5] and 10 Pseudo-Sighting Reports (Appendix B.1). Sensitivity

[5] The largest IBSG/IWDG sighting in Ireland was 160 sharks.

and Robustness testing (Railsback & Grimm, 2019) was conducted on the total number of aggregations and the maximum aggregation size for each of the model settings.

Table 5: Settings for Sensitivity and Robustness Analysis.

Parameter	S-	C	S+	R--	R-	R+	R++
threshold_zp	9.5E+10	1E+11	1.05E+11	3000	3E+10	1.7E+11	3E+12
sense-distance	9	10	11	1	3	17	20
Swim-speed	8	9	10	—	2	16	30
No_eat_min	13	14	15	—	4	23	30
return-season	19	20	21	—	6	34	60
Cal_%	9	10	11	—	3	17	50
other_zp_%	9	10	11	—	3	17	50
friend_min	4	5	6	—	2	9	20

C was determined as the settings that give the most realistic results through preliminary experimentation. S+/- and R+/- were calculated from C. Sensitivity Analysis (S) was +/- 5% of each parameter setting. Robustness Analysis (R) was +/- 70% of each parameter setting. R++ and R-- denote extreme settings. 10 trials were conducted for each submodel under each setting, with levels only changed for one setting at a time. A total of 50 tests were conducted per submodel.

The results from the SA/RA tests were then used to provide generalized insight into the model settings that most closely aligned with the IBSG/IWDG data and those settings from the SA/RA underwent further testing. The output across all 10 trials were averaged, and the average aggregation size per month was calculated. Minimum-maximum normalization was applied to both the model output and the IBSG/IWDG data, and then the Mean Error (ME), the mean square MAE (Mean absolute error) and the root mean square error (RMSE) were calculated between the Total Aggregations and IBSG/IWDG monthly averages and Pseudo-Sighting Reports and IBSG/IWDG monthly averages. The lowest RMSE scores were identified and graphed onto time series graphs and boxplots, for qualitative comparisons. From these, repeat trials were chosen for preliminary testing. Combinations of the lowest RMSE scores from the SA/RA tests were also chosen for preliminary testing.

2.2.7.2 Preliminary Tests

Because the SA/RA tests showed high consistency among results for the Random and Social submodels, but low similarity with the IBSG/IWDG data (Table 6), preliminary tests were conducted only using the Food and Food/Social submodels to save computational power and time (Appendix B.2). Further, because of unrealistically high Total Aggregation numbers, but dramatically low Pseudo-Sighting Report numbers from the SA/RA tests, preliminary tests were conducted with 100 sharks[6] and 20 Pseudo-Sighting Reports.

Six settings, with 10 trials each, were run. The full settings tested can be viewed in Appendix B.2. The output across all 10 trials were averaged, and the average aggregation size per month was calculated. Minimum-maximum normalization was applied to both the model output and the IBSG/IWDG data, and then the mean error (ME), the mean absolute error (MAE) and the root mean square error (RMSE) were calculated between the Total Aggregations and IBSG/IWDG monthly averages and Pseudo-Sighting Reports and IBSG/IWDG monthly averages. The lowest RMSE scores were identified and graphed onto time series graphs and boxplots, for qualitative comparisons. From these, two settings emerged as the most comparable to the IBSG/IWDG data (Tests A and B).

[6] The largest IBSG/IWDG sighting in the model area was 60 sharks.

2.2.7.3 Tests A and B

Tests A and B randomly sampled 20 patches per day (Pseudo-Sighting Reports) and were run with both 200 and 100 sharks, due to inconclusive results about the impact of the total number of sharks in the preliminary tests.

Qualitative comparisons were made using time series and boxplots of the average number of aggregations and average aggregation size per month. The data were graphed comparing both the Total Aggregations averages and Pseudo-Sighting Reports to the IBSG/IWDG monthly averages. The IBSG/IWDG sighting reports for both the model area (Inishowen) and all of Ireland were graphed.

Sea Surface Temperature (SST) data for the model area were obtained from the European Union-Copernicus Marine Service and a daily average calculated for each day of the model run (European Union-Copernicus Marine Service, 2015). The average size of shark aggregations per day (taken from Total Aggregations) were graphed in a scatter plot against both the average amount of zooplankton in the same patches as shark aggregations and the daily average SST. The average total number of sharks in the model per day were also graphed in a scatterplot against the average daily SST. Data analysis on daily data was only conducted on model trials containing a maximum of 200 sharks as these produced the most realistic output when compared to the IBSG/IWDG data. The comparison to SST was another method of testing how realistic the model output is, when compared to historic environmental data, while the zooplankton comparison provided further insight into the internal mechanics of the model.

2.3 RESULTS

2.3.1 Sensitivity and Robustness Analysis

The model settings with the highest impact on aggregation size and number of aggregations were the threshold level of zooplankton, the sense-distance, the number of patches with zooplankton, and the number of days required for a shark to not find food before migrating out from the model (Tables 6—7; see Table 3 and Appendix A for detailed descriptions of the user-input settings). The settings generally had little impact when using the Social submodel, which rarely differed from the Random submodel, with the exception of the threshold_zp and no_eat_min settings, as sharks still migrate out of the model when they have not found food for the period of time set by the user (no_eat_min).

2.3.1.1 Total Number of Aggregations

The total number of aggregations (two or more sharks) in the sensitivity and robustness analysis varied greatly, but ranged between 1,700—80,000, with the threshold level of zooplankton having a strong impact on the number of aggregations.

2.3.1.2 Kolmogorov–Smirnov Results

The Total Aggregations for Social and Food/social submodels had high rates of differences among the trials, with the majority of trials having 87% difference or greater among trials, though one set of trials (Threshold_zp set to 3E+12) had a slightly lower score, with the Food submodel having a 42% difference between trials and the Food/Social submodel having a 73% difference between trials.

The Social and Random submodels had 100% rates of consistency (the Social and Random submodels rarely had aggregations of more than two-three sharks during the entirety of the model run under any settings). None of the Food or Random trials had similarity with IBSG/IWDG data. However, the rate of consistency among IBSG/IWDG and Food and Food/social models, had a range of differences between the IBSG/IWDG data.

Table 6: SA/RA Tests for Number of Aggregations

	S+ Per Submodel				R+ Per Submodel			
Parameter	Food/Social	Food	Social	Random	Food/Social	Food	Social	Random
Threshold_zp	-0.04	0.47	-1.04	-0.32	0.05	0.12	-0.32	-0.48
Sense-distance	-0.95	-0.59	-0.01	0.45	-0.49	-0.36	0.11	0.02
Swim-speed	-0.01	-0.12	-0.07	-0.61	0.00	-0.02	-0.03	0.01
No_eat_min	-0.17	0.12	3.02	3.79	-0.04	0.11	4.36	3.77
Return-season	-0.17	0.03	-0.23	-1.37	-0.13	-0.13	-0.04	-0.18
Cal_%	-0.13	0.04	1.20	1.37	-0.10	-0.02	1.21	0.99
Other_zp_%	-0.16	-0.15	0.12	0.81	-0.05	-0.04	0.23	0.45
Friend_min	0.11	0.01	-0.05	-0.02	0.08	0.01	0.01	-0.14

Results of SA/RA tests, when comparing the C values to the S+ and R+ settings (See Table 5 for settings). Ten trials were run under each parameter setting and the number of aggregations were averaged (from the Total Aggregations list). SA/RA tests, as described by (Railsback & Grimm, 2011) were conducted.

Table 7: SA/RA Tests for the Maximum Size of Aggregations

	S+ Per Model Version				R+ Per Model Version			
Parameter	Food/Social	Food	Social	Random	Food/Social	Food	Social	Random
Threshold_zp	0.07	-0.51	0.00	-0.77	-0.02	-0.04	0.05	0.05
Sense-distance	0.03	0.37	0.00	1.20	0.00	0.03	0.05	0.06
Swim-speed	-0.07	0.08	0.00	-0.32	-0.01	0.08	0.04	-0.09
No_eat_min	0.19	0.22	0.47	1.22	0.02	0.04	0.05	0.27
Return-season	-0.26	-0.83	0.00	0.77	-0.01	0.00	0.00	-0.16
Cal_%	0.01	-0.44	0.00	-0.69	0.01	-0.03	0.00	-0.25
Other_zp_%	-0.03	0.03	0.17	0.87	0.00	0.01	0.00	0.00
Friend_min	-0.01	0.17	-0.16	-0.36	0.00	0.04	-0.04	0.00

Results of SA/RA tests, when comparing the C values to the S+ and R+ settings (See Table 5 for settings). Ten trials were run under each parameter setting and the maximum size of aggregations were averaged (from the Total Aggregations list). SA/RA tests, as described by (Railsback & Grimm, 2011) were conducted.

2.3.1.3 ME/MAE/RMSE Results

The RMSE scores ranged from 0.19—0.94; the ME scores ranged from 0.05—0.92, the MAE score ranged from 0.12—0.96 (Appendix B.1). Unrealistic or extreme settings, such as sense-distance of 1, produced unrealistic statistical results of RMSE scores ranging from 0.51—0.88 for all models (Table 8). Setting the swim-speed to two km per day resulted in RMSE scores of 0.33—0.75 for all submodels.

Table 8: Statistical Scores for Trials with Sense-distance set to 1 km.

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.84	0.86	0.84	0.82	0.84	0.82
Food	0.87	0.88	0.87	0.85	0.87	0.85
Social	0.62	0.72	0.62	0.60	0.70	0.61
Random	0.42	0.52	0.43	0.41	0.51	0.42

Result of the average of 10 trials, when comparing the average size of aggregations per month to the IBSG/IWDG data. These tests were run as part of the SA/RA tests with the following settings: Threshold_zp (1.00E+11), Sense-distance (1), Swim-speed (9), No_eat_min (14), Return-season (20), Cal_% and Other_zp% (10), and Friend_min (5). Note the high ME, RMSE, and MAE scores, which indicate that no submodel trials are consistent with the sightings data. ME, RMSE, and MAE indicate the distance of the average model values from the IBSG/IWDG sightings values.

2.3.2 Preliminary Tests

Results for all preliminary tests can be found in Appendix B.2. One set of settings, which set the Threshold_zp to 3E+12, received a notably lower ME, RMSE, and MAE score than any of those in the SA/RA or preliminary tests (Tables 36—37). The results of the ME, RMSE, and MAE tests results in 0.10 lower scores for the Food/Social submodel when compared to the Food submodel. These settings were repeated as Test A (Table 9). The next lowest scores were repeated as Test B (Table 17).

Table 9: Parameter settings for Test A

Threshold_Zp	3E+12
Sense-distance	10
Swim-speed	9
Cal_%	17
Other_Zp_%	17
Friend_Min	5
No_Eat_Min	14
Return-season	20

2.3.3 Test A — Best Fit

ME, RMSE, and MAE comparison of the in-model zooplankton sampling indicated that the zooplankton samples are reflective of the CPR data (Table 10).

2.3.3.1 Total Number of Aggregations

The average number of aggregations was similar between the Food and Food/social submodels, but much lower for the Social and Random submodels (Table 11). The number of sharks (100 versus 200) had a large impact on the number of Total Aggregations and the Pseudo-Sighting Reports (which include single sharks). Both the total number of Pseudo-Sighting Reports doubled, and the Total Aggregations doubled when doubling the number of sharks in the model (Table 11).

Table 10: Comparison of model Calanus sampling with CPR data —Test A

Submodel	Number Sharks	ME	RMSE	MAE
Food/Social	100	0.02	0.20	0.13
Food/Social	200	0.03	0.20	0.13
Food	100	0.03	0.20	0.13
Food	200	0.02	0.20	0.13
Social	100	0.02	0.20	0.13
Social	200	0.02	0.20	0.13
Random	100	0.03	0.20	0.13
Random	200	0.02	0.20	0.13

This data compares the non-interpolated CPR data with the zooplankton samples from the model output. The results of 50 trials were averaged, the monthly averaged calculated, and the results normalized via min-max normalization.

Table 11: Average number of Shark Aggregations for 50 Trials Under Settings — Test A.

	Total Aggregations		Pseudo-Sighting Reports	
	100 sharks	200 sharks	100 sharks	200 sharks
Food/Social	1806	4099	110	208
Food	1712	3925	111	227
Social	143	568	88	170
Random	165	629	87	172

Total number of aggregations throughout the entirety of the model run (1982—2018). Pseudo-Sighting Reports include any shark "sighted" during a random sample of 20 patches, including single sharks, while Total Aggregations only count groups of two or more sharks, but count all aggregations in the model each day.

2.3.3.2 Kolmogorov–Smirnov Results

All results of Test A were significantly different than IBSG/IWDG data.

The Social and Random trails were 100% consistent when comparing trials to each other (Table 12). The Food model had more consistent trials than the Food/Social model when looking at Total Aggregations (Table 12). Both the Food and Food/social submodels had high consistently when comparing Pseudo-Sighting Reports. Trials with 200 sharks were slightly more consistent than those with 100 sharks.

Table 12: Kolmogorov-Smirnov Tests Between Trials of the Same Settings — Test A

	Total Aggregations		Pseudo-Sighting	
	100 sharks	200 sharks	100 sharks	200 sharks
Food/Social	68.00	74.45	1.71	0.00
Food	58.78	38.53	0.49	0.00
Social	0.00	0.00	0.00	0.00
Random	0.00	0.00	0.00	0.00

The percentage of trials (out of 50 trials) that were significantly different than other repeat trials is reported.

2.3.3.3 Results for Monthly Aggregation size

2.3.3.3.1 ME/MAE/RMSE

When comparing tests of 200 sharks to the IBSG/IWDG sightings data, the lowest RMSE score for Total Aggregations was in the Food/Social submodel (0.18), with the next lowest score being the Food only submodel (0.30). This trend was repeated by the ME and MAE scores (Table 9), for both the Total Aggregations and Pseudo-Sighting Reports for Inishowen. The trend was also seen when comparing the data to all of Ireland (Tables 13—14).

The ME, RMSE, and MAE scores were slightly higher in tests with 100 sharks, when compared to the same test with 200 sharks (Appendix B.3 Tables 38—39). There was little difference between the statistical results of the Total Aggregations and the

Pseudo-Sighting Reports in the same trials. Including 100 or 200 sharks had little impact on the results.

Table 13: Comparison of Average Aggregation Size Per Month to IBSG/IWDG Data (Total Aggregations; 200 sharks) —Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.10	0.18	0.13	0.08	0.18	0.12
Food	0.25	0.30	0.26	0.23	0.28	0.24
Social	0.62	0.70	0.63	0.61	0.68	0.61
Random	0.58	0.67	0.58	0.56	0.65	0.57

Total aggregations (averaged across 50 trials) compared to IBSG/IWDG sightings. Data was normalized via min-max normalization. Total Aggregations count groups of two or more sharks. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

Table 14: Comparison of Average Aggregation Size Per Month to IBSG/IWDG data (Pseudo-Sighting Reports; 200 sharks) —Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.07	0.16	0.11	0.05	0.15	0.10
Food	0.14	0.21	0.17	0.12	0.20	0.15
Social	0.38	0.43	0.39	0.36	0.41	0.37
Random	0.43	0.48	0.44	0.41	0.45	0.42

Pseudo-Sighting Reports (averaged across 50 trials) compared to IBSG/IWDG sightings. 20 random patches are sampled per day, and all shark sightings (including single sharks) are reported. Data was normalized via min-max normalization. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

2.3.3.3.2 Qualitative Comparisons

With 200 sharks, the Food/social submodel displayed the strongest qualitative similarities to the IBSG/IWDG data. However, spikes in the size of aggregation occur in the model with a slight lag when compared to the IBSG/IWDG data (Figure 3). The Social and Random submodels produced unrealistic outputs. The Pseudo-Sighting Reports for both the Food and Food/Social submodels depicted a similar delayed temporal trend with regard to average aggregation size per month when compared to the IBSG/IWDG data (Figure 4). The Food and Food/Social Pseudo-Sighting Reports still produced a more realistic output than the Social and Random submodels, though the Total Aggregations produced a closer time series than the Pseudo-Sighting Reports of the same run (Figures 3 and 4).

The boxplots demonstrated that the Food/Social model was the most comparable to the IBSG/IWDG data, but still had a higher average than both Inishowen and All of Ireland for both the Total Aggregations and Pseudo-Sighting Reports (Figures 5 and 7). The Food submodel had a higher average but was more similar to the IBSG/IWDG than either the Social or Random submodels.

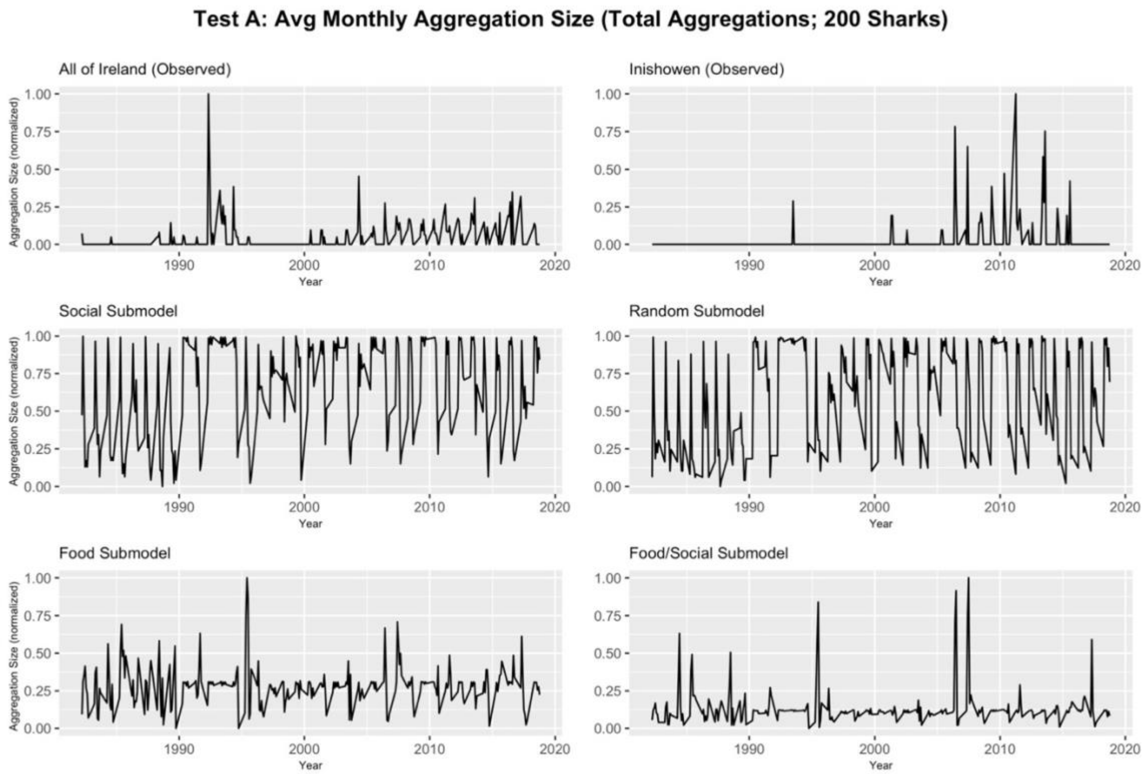


Figure 3: Comparison of average size of aggregation per month for Total Aggregations to IBSG/IWDG data.
Total Aggregations include all groups of two or more sharks. The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

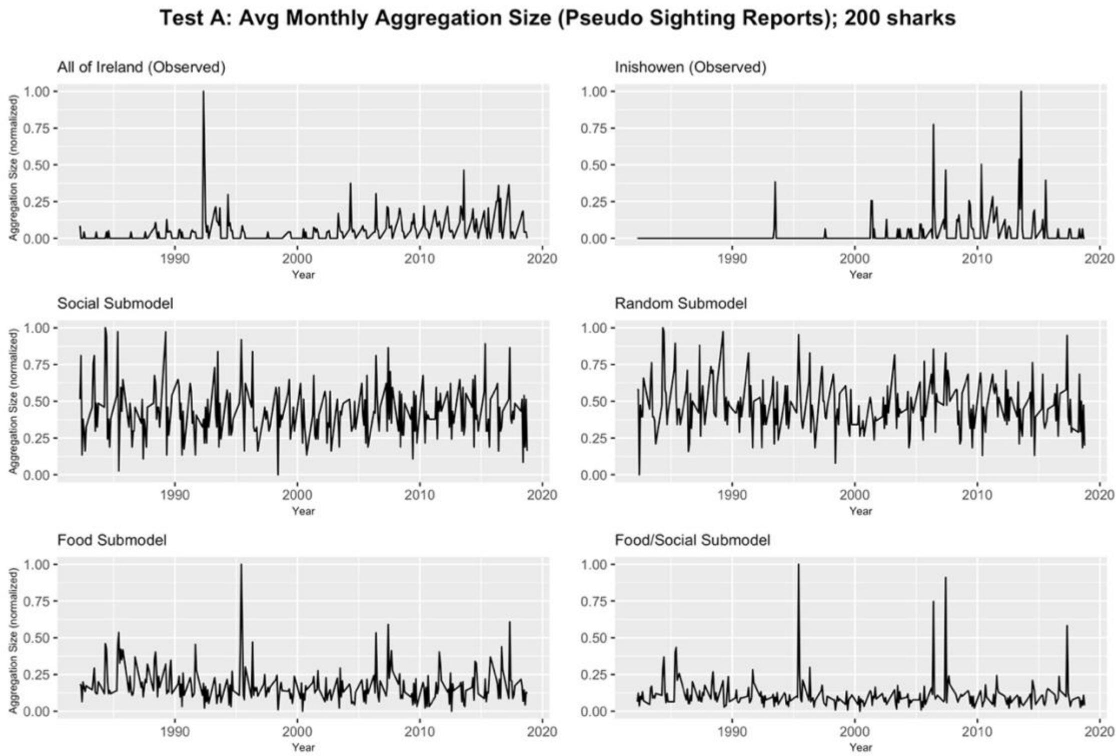


Figure 4: Comparison of average size of aggregation per month for Pseudo-Sighting Reports to IBSG/IWDG data.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

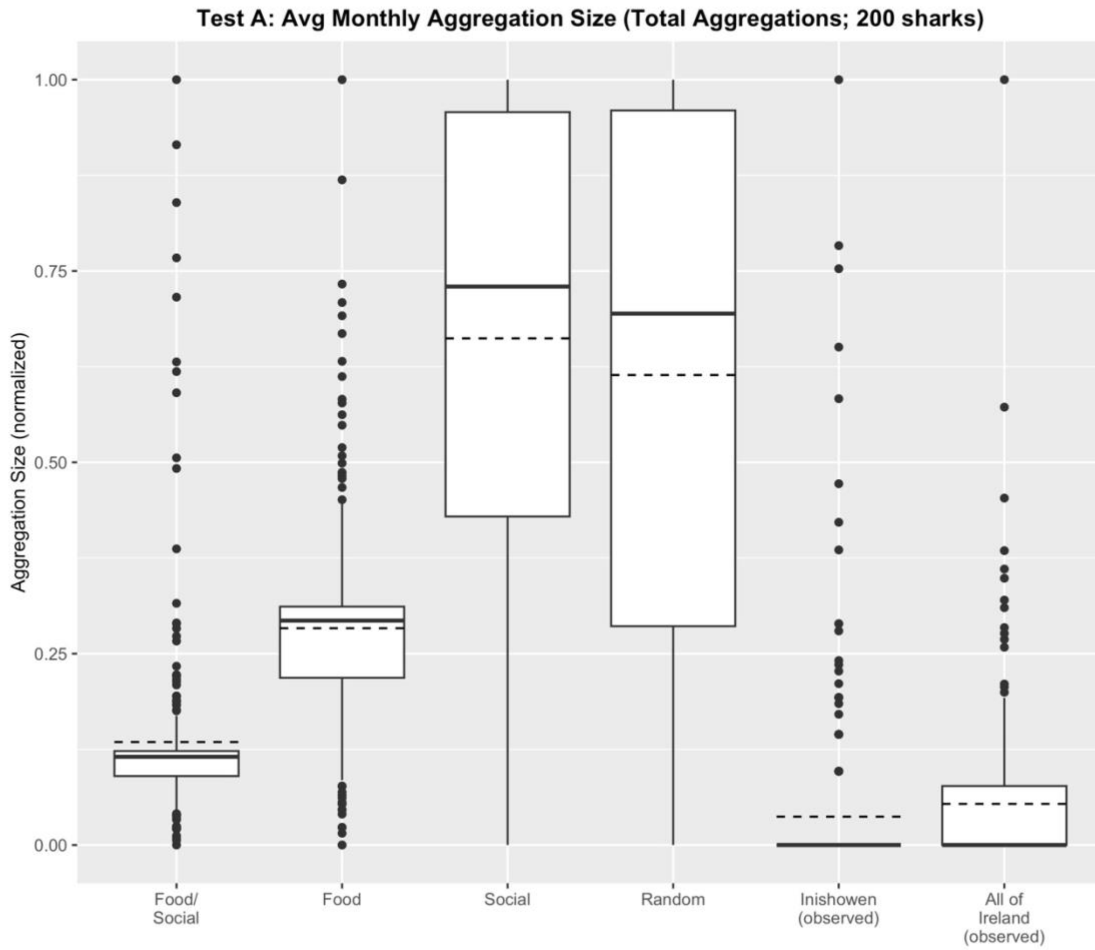


Figure 5: Boxplot comparing the average size of aggregation per month for Total Aggregations to IBSG/IWDG data.
Total Aggregations include all groups of two or more sharks. The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

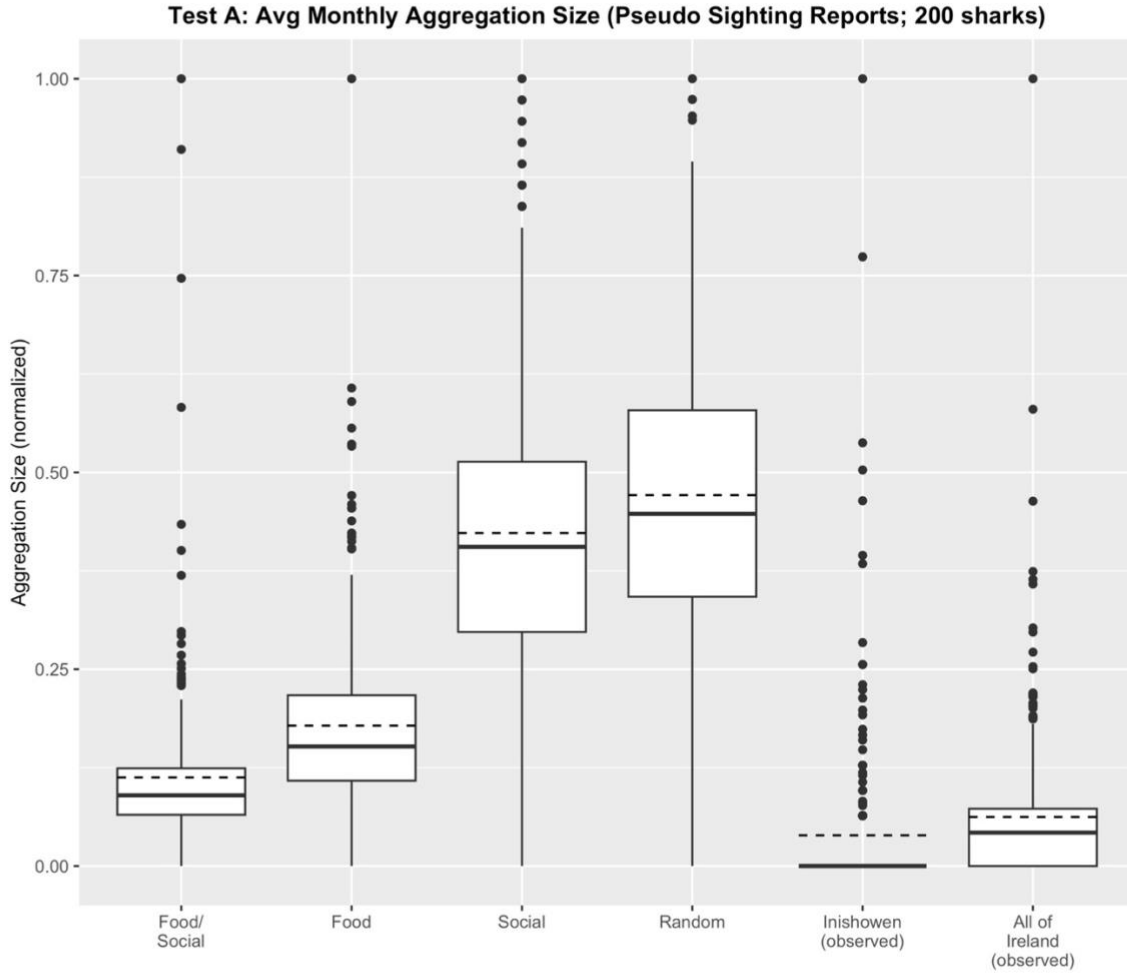


Figure 6: Boxplot comparing the average size of aggregation per month for Pseudo-Sighting Reports IBSG/IWDG data.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

2.3.3.4 Average number of aggregations per month

2.3.3.4.1 RMSE/ME/MAE

When comparing the average number of aggregations per month, there was little difference between the Food/Social and Food submodels in Test A (Tables 15—16). This trend was shown for both the Total aggregations and Pseudo-Sighting Reports (Tables 15—16). The Pseudo-Sighting Reports resulted in higher ME and MAE results than the Total Aggregations, indicating that the Pseudo-Sighting Reports had a higher difference to the IBSG/IWDG data than the Total Aggregations. However, the RMSE remained relatively consistent between Total Aggregations and Pseudo-Sighting Reports. The Food and Food/Social submodels still received notably lower results for the ME, RMSE, and MAE test than the Social and Random submodels, indicating that both the Food and Food/Social submodels produced more realistic results.

2.3.3.4.1 Qualitative Comparisons

The Food and Food/Social submodels were very similar, with results that were slightly less comparable to the IBSG/IWDG data than the average size of aggregations per month (Figure 7). The Pseudo-Sighting Reports were slightly less comparable to the IBSG/IWDG data than the Total Aggregations of the same model run (Figures 8).

Boxplots of the Total Aggregations depict almost identical results for the Food, Food/Social submodels and the Inishowen data (Figure 9). However, the boxplots for the Pseudo-Sighting reports depict a slightly higher average for the Food and Food/Social submodels (Figures 10). Like the average size of aggregations per month, the Social and Random submodels are notably different than the IBSG/IWDG data in both the time series and the box plots, for both the Total Aggregations and Pseudo-Sighting Reports. Similarly, the time series data was more realistic when comparing Total aggregations to the IBSG/IWDG data than when comparing Pseudo-Sighting Reports.

Table 15: Average Number of Aggregations Per Month to IBSG/IWDG data (Total aggregations; 200 sharks)—Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.03	0.16	0.06	0.00	0.17	0.08
Food	0.02	0.15	0.05	-0.01	0.16	0.07
Social	0.27	0.39	0.28	0.25	0.36	0.26
Random	0.16	0.24	0.17	0.13	0.21	0.16

Total aggregations (averaged across 50 trials) compared to IBSG/IWDG sightings. Data was normalized via min-max normalization. Total Aggregations count groups of two or more sharks. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

Table 16 Test A: Average Number of Aggregations Per Month to IBSG/IWDG data (Pseudo-Sighting Reports; 200 sharks) —Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.11	0.18	0.13	0.06	0.19	0.13
Food	0.11	0.20	0.13	0.07	0.21	0.14
Social	0.23	0.28	0.24	0.18	0.27	0.22
Random	0.27	0.31	0.27	0.22	0.29	0.25

Pseudo-Sighting Reports (averaged across 50 trials) compared to IBSG/IWDG sightings. 20 random patches are sampled per day, and all shark sightings (including single sharks) are reported. Data was normalized via min-max normalization. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

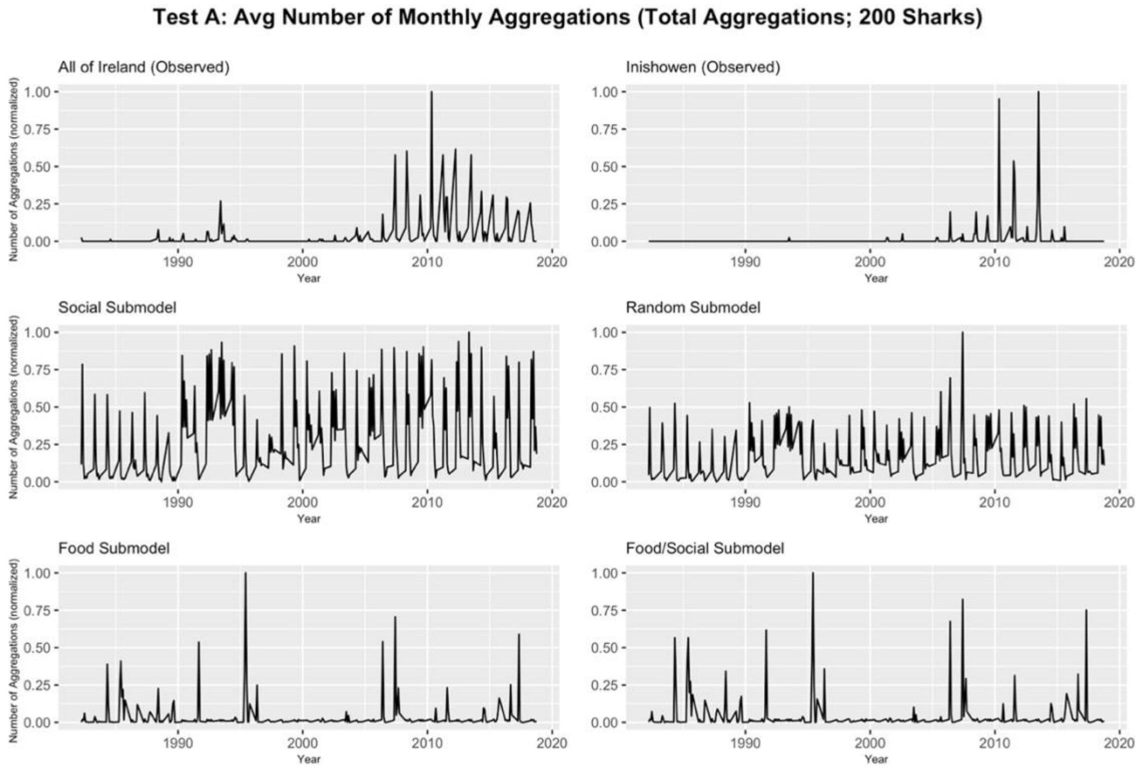


Figure 7: Comparison of average number of aggregation per month for Total Aggregations to IBSG/IWDG data.
Total Aggregations include all groups of two or more sharks. The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

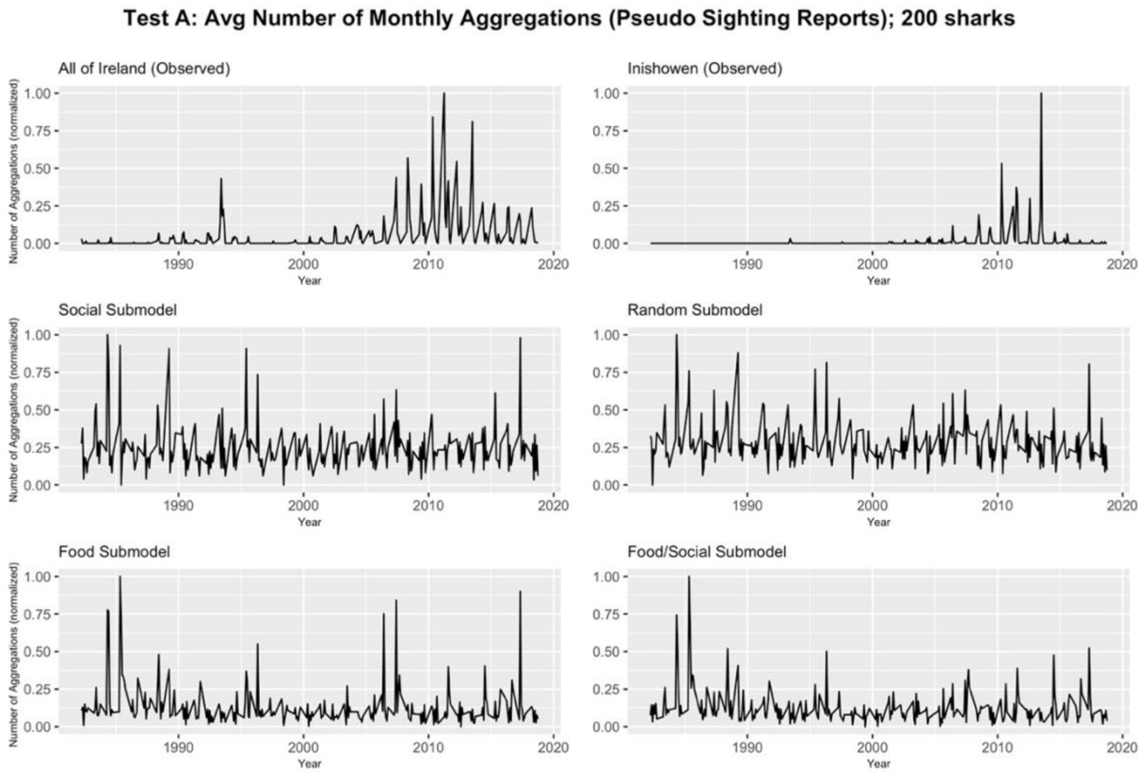


Figure 8: Comparison of average number of aggregation per month for Pseudo-Sighting Reports to IBSG/IWDG data.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

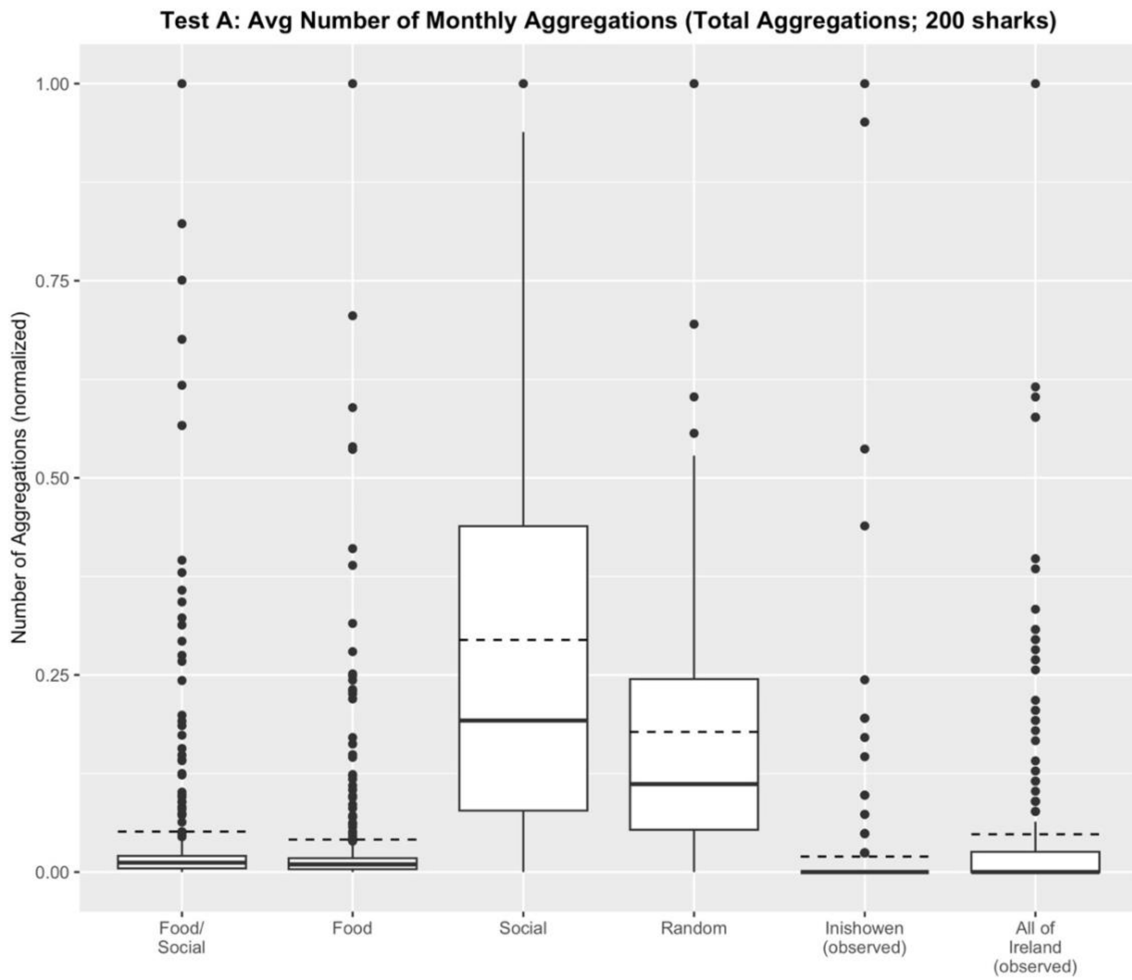


Figure 9: Boxplot comparing the average number of aggregation per month for Total Aggregations to IBSG/IWDG data.
Total Aggregations include all groups of two or more sharks. The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

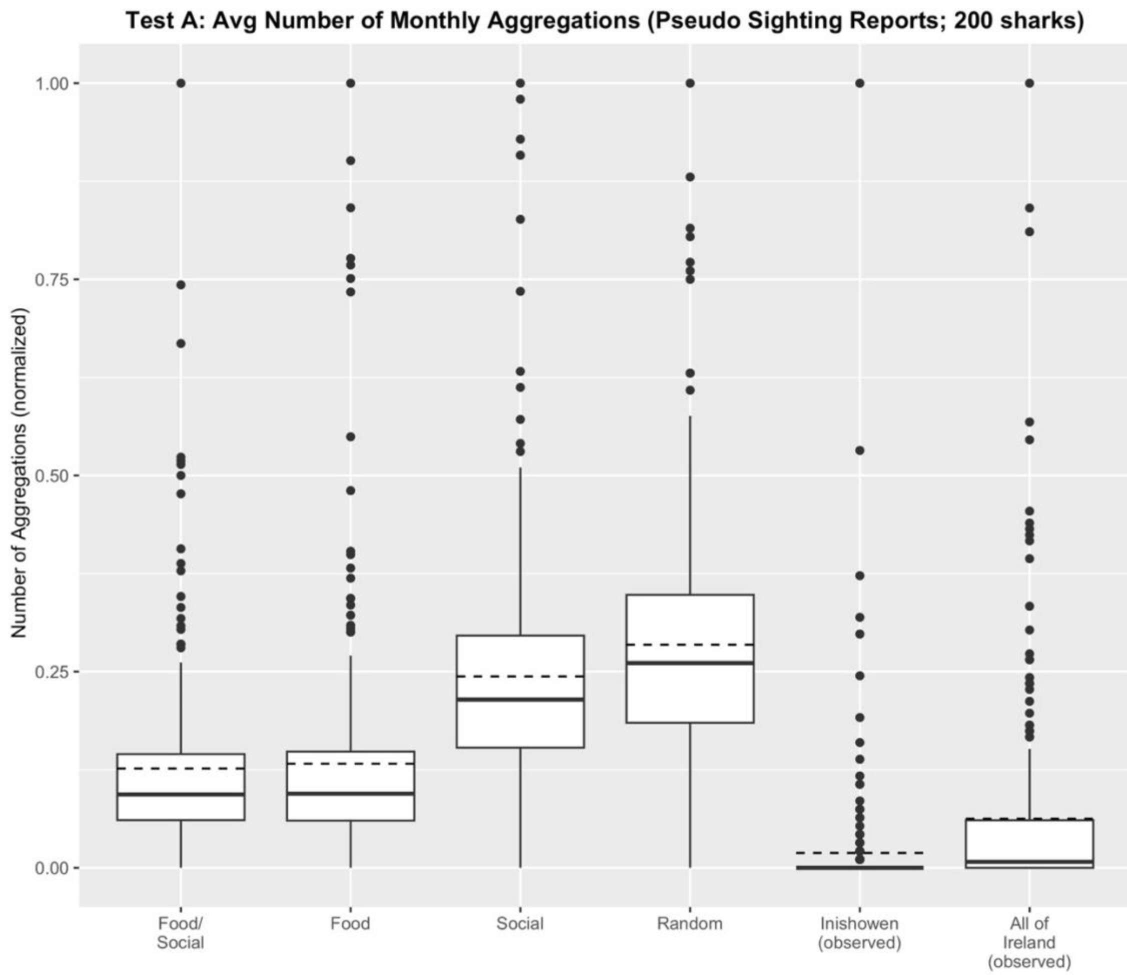


Figure 10: Boxplot comparing the average number of aggregation per month for Pseudo-Sighting Reports IBSG/IWDG data.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

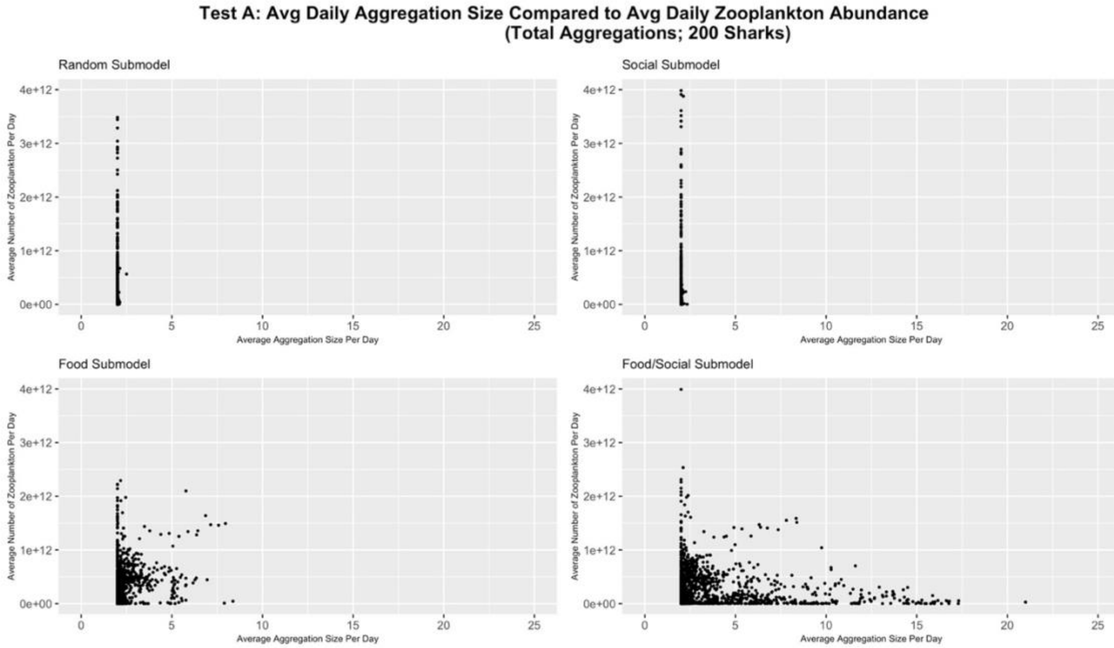


Figure 11: Daily Aggregation Size Compared to Zooplankton Abundance in Patch
The results of 50 trials were averaged together. The scatterplot depicts the average size of aggregation per day (taken from Total Aggregations), compared to the average amount of zooplankton in the patch where the aggregations were observed.

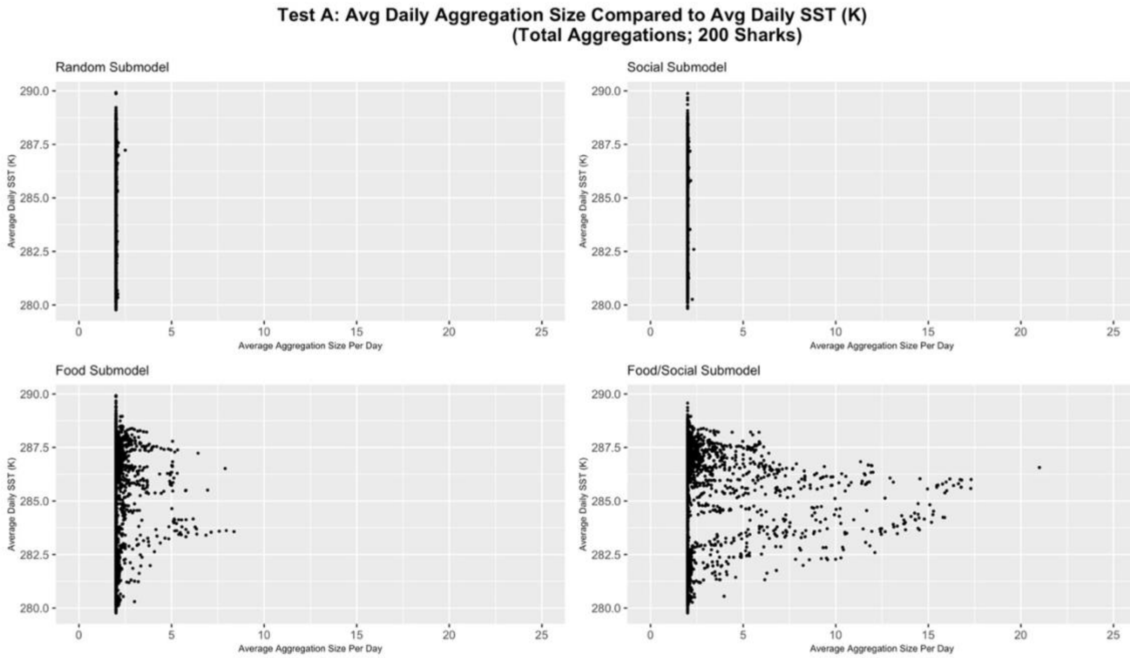


Figure 12: Daily Aggregation Size Compared to Average Daily Sea Surface Temperature The results of 50 trials were averaged together. The scatterplot depicts the average size of aggregation per day, compared to the average daily SST (in Kelvin).

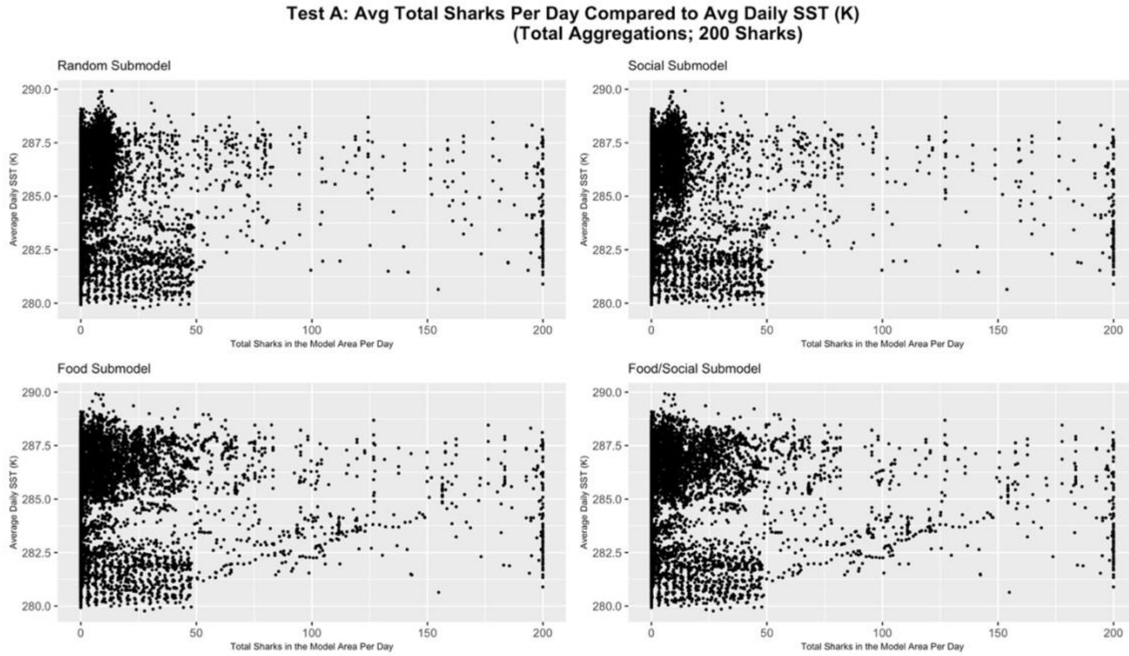


Figure 13: Daily Number of Sharks Compared to Average Daily Sea Surface Temperature
The results of 50 trials were averaged together. The scatterplot depicts the average number of sharks present in the model per day, compared to the average SST (in Kelvin). Sharks migrate into and out of the model area based on zooplankton availability.

2.3.3.5 Daily Comparisons to Zooplankton Abundance and SST

The comparison of average aggregation size to the number of zooplankton found in the same patch indicate that there is a slight relationship between the zooplankton abundance and aggregation size for both the Food and Food/Social submodels (Figure 11). The Food/Social Model resulted in larger aggregation sizes, even in patches of low zooplankton.

Aggregations of basking sharks had a slight positive relationship between temperature and aggregation size (Figure 12). When comparing the total number of basking sharks in the model each day, sharks were slightly more likely to be in the model area on days with temperatures between 285 and 288 K (Figure 13).

Table 17: Parameter Settings for Test B

Threshold_zp	3E+12
Sense-distance	20
Swim-speed	9
Cal_%	50
Other_zp_%	20
Friend_min	5
No_eat_min	14
Return-season	20

2.3.4 Test B — Second Best Fit

Test B increased the percent of patches with zooplankton from 17% to 50% for *Calanus* species and 20% for other zooplankton species (Table 17). Comparing the in-model zooplankton sampling to the CPR data resulted in ME, RMSE, and MAE scores which were to those from Test A (Table 18).

Table 18: Comparison of model Calanus sampling with CPR data — Test B

Submodel	Number Sharks	ME	RMSE	MAE
Food/Social	100	0.02	0.20	0.13
Food/Social	200	0.02	0.20	0.13
Food	100	0.02	0.20	0.13
Food	200	0.02	0.20	0.13
Social	100	0.03	0.20	0.13
Social	200	0.02	0.20	0.13
Random	100	0.03	0.20	0.13
Random	200	0.02	0.20	0.13

This data compares the non-interpolated CPR data with the zooplankton samples from the model output. The results of 50 trials were averaged, the monthly averaged calculated, and the results normalized via min-max normalization. Despite the difference in percentage of patches with zooplankton, the data is identical to Test A.

Table 19: Average Number of Aggregations and Sighting Reports — Test B

	Total Aggregations		Pseudo-Sighting Reports	
Submodel	100 sharks	200 sharks	100 sharks	200 sharks
Food/Social	281	1044	81	160
Food	271	998	78	168
Social	230	911	82	162
Random	236	931	81	161

Total number of aggregations throughout the entirety of the model run (1982—2018). Pseudo-Sighting Reports include any shark "sighted" during a random sample of 20 patches, including single sharks, while Total Aggregations only count groups of two or more sharks, but count all aggregations in the model each day.

2.3.4.1 Total Number of Aggregations

The total number of aggregations was notably lower for Test B (280—1,044) when compared to test A (1,806—4,099). The number of sharks (100 versus 200) had a significant impact on the number of Total Aggregations and the Pseudo-Sighting Reports (which include single sharks). While the Pseudo-Sighting Reports doubled, the Total Aggregations tripled when increasing the total number of sharks in the model from 100 to 200 (Table 19).

2.3.4.2 Kolmogorov–Smirnov Results

The total number of trials different from each other was comparable to Test A. like Test A, Test B was not comparable to IBSG/IWDG data. Total Aggregations (18—24% different) had lower rates of consistency than the Pseudo-Sighting Reports (0% different). Food and Food/Social submodels had slightly higher rates of inconsistency between trials than the Social and Random submodels (Table 20).

Table 20: Kolmogorov-Smirnov Tests Between Trials of the Same Settings — Test B

	Total Aggregations		Pseudo-Sighting Reports	
Submodel	100 sharks	200 sharks	100 sharks	200 sharks
Food/Social	18.86	19.10	0.00	0.00
Food	0.24	0.00	0.00	0.00
Social	0.00	0.00	0.00	0.00
Random	0.00	0.00	0.00	0.00

The percentage of trials (out of 50 trials) that were significantly different than other repeat trials is reported.

2.3.4.3 ME/MAE/RMSE Results

Similar to Test A, the RMSE scores for Food and Food/social submodels received the lowest score (Tables 21—22). However, Test B showed a smaller (or no) difference between Food/Social and Food submodels, especially when there was only a maximum of 100 sharks (Appendix B.4.i, Tables 43—44). The ME, RMSE, and MAE scores increased substantially in Test B when compared to Test A. See results Test B with 100 sharks in Appendix B.4.i.

Table 21: Comparison of Average Aggregation Size Per Month to IBSG/IWDG data (Total Aggregations; 200 sharks) —Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.22	0.27	0.24	0.20	0.24	0.22
Food	0.33	0.37	0.35	0.31	0.34	0.32
Social	0.80	0.84	0.80	0.78	0.82	0.78
Random	0.79	0.84	0.80	0.78	0.82	0.78

Total aggregations (averaged across 50 trials) compared to IBSG/IWDG sightings. Data was normalized via min-max normalization. Total Aggregations count groups of two or more sharks. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

2.3.4.3.1 Qualitative Comparisons

The time series data produced less realistic results for Test B than Test A (Figures 14—15). Like all previous tests, the Social and Random submodels produced unrealistic results. However, the Food and Food/Social models did not produce a time series that resembled the IBSG/IWDG data, indicating that Test B was less realistic than Test A.

Similar results for the boxplots of both Total Aggregations and Pseudo-Sighting Reports (Figures 16—17).

Table 22: Comparison of Average Aggregation Size Per Month to IBSG/IWDG data (Pseudo-Sighting Reports; 200 sharks) —Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.33	0.38	0.34	0.30	0.36	0.31
Food	0.31	0.36	0.32	0.28	0.34	0.30
Social	0.42	0.48	0.43	0.40	0.45	0.41
Random	0.43	0.49	0.44	0.41	0.46	0.42

Pseudo-Sighting Reports (averaged across 50 trials) compared to IBSG/IWDG sightings. 20 random patches are sampled per day, and all shark sightings (including single sharks) are reported. Data was normalized via min-max normalization. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

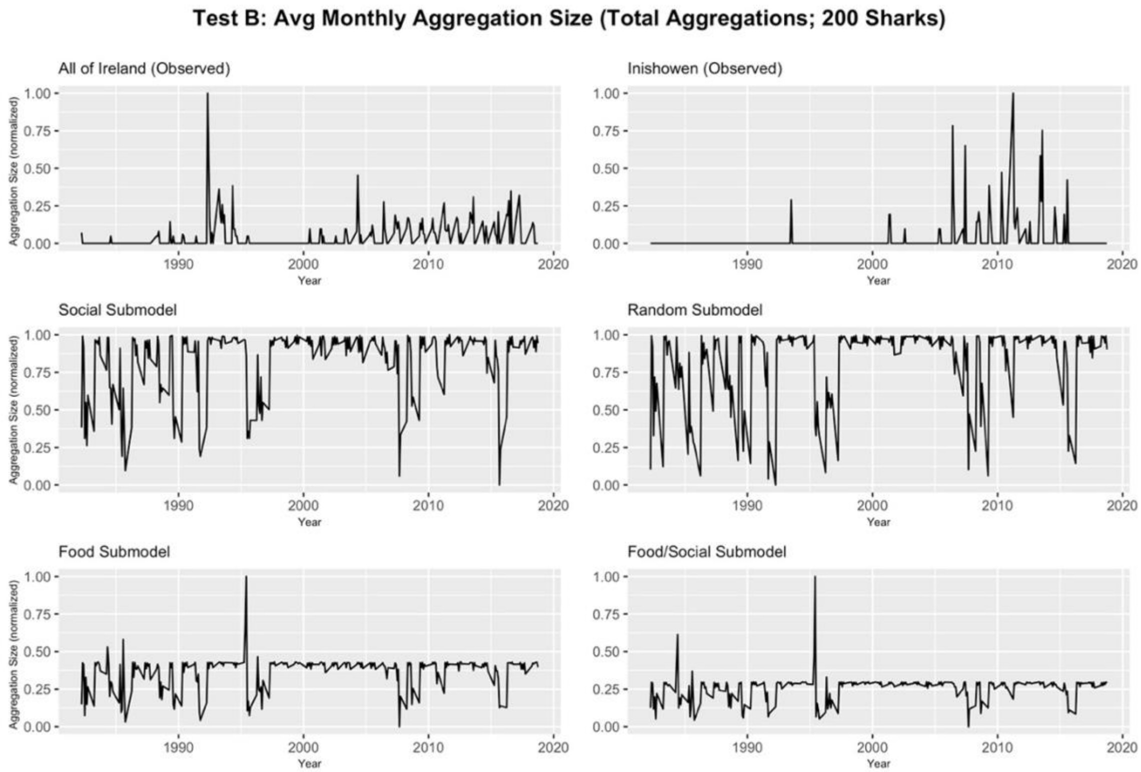


Figure 14: Comparison of average size of aggregation per month for Total Aggregations to IBSG/IWDG data for Test B.
Total Aggregations include all groups of two or more sharks. The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

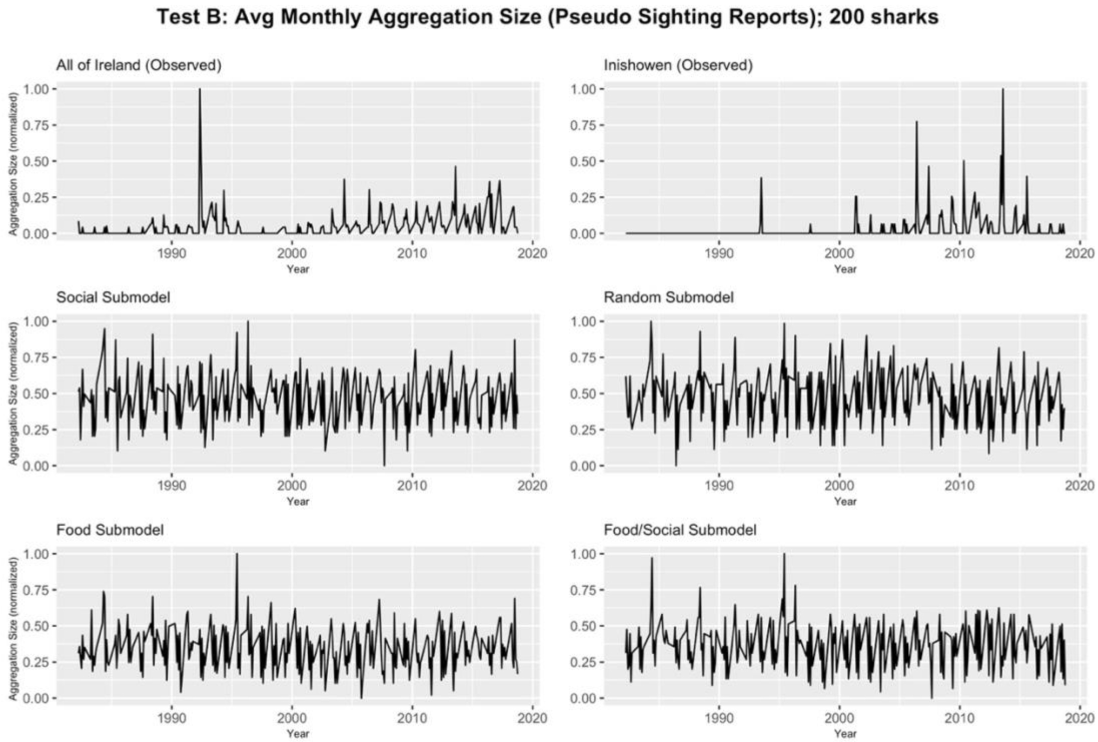


Figure 15: Comparison of average size of aggregation per month for Pseudo-Sighting Reports to IBSG/IWDG data for Test B.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

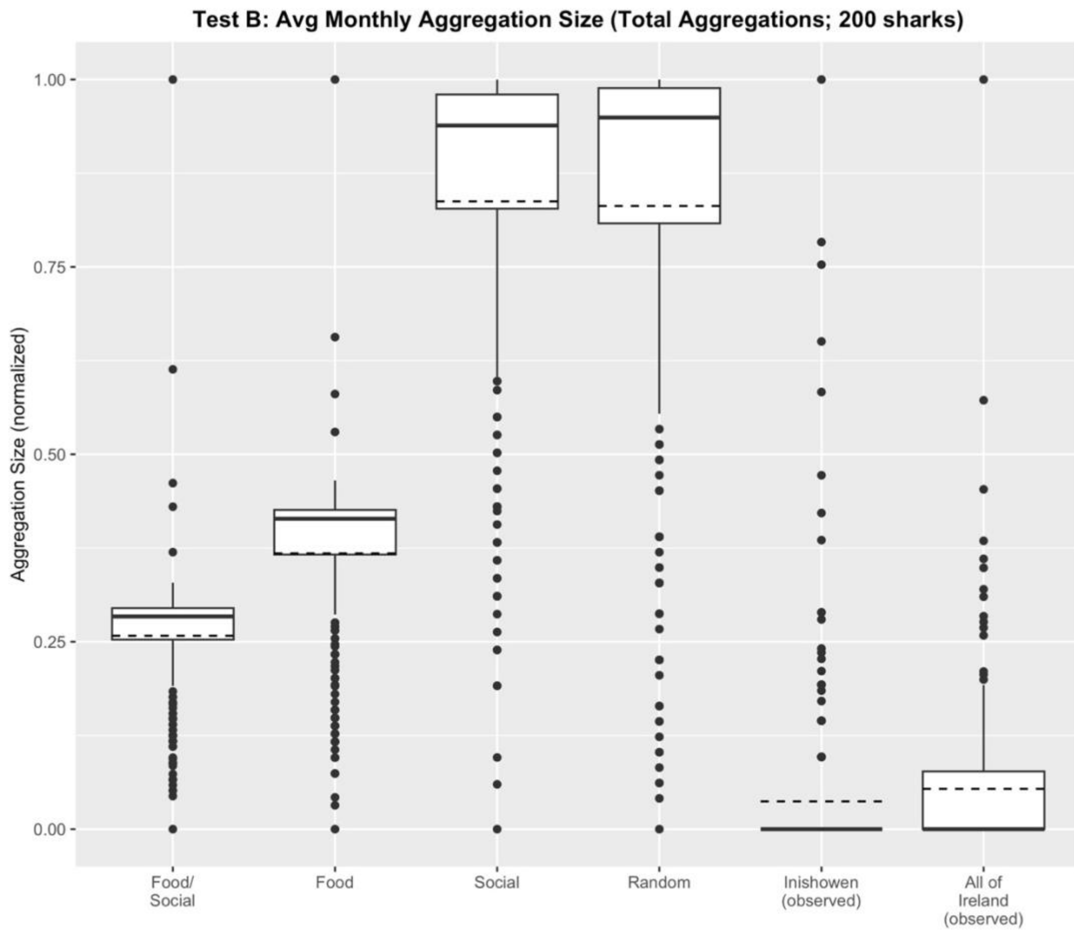


Figure 16: Boxplot comparing the average size of aggregation per month for Total Aggregations to IBSG/IWDG data for Test B.
Total Aggregations include all groups of two or more sharks. The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

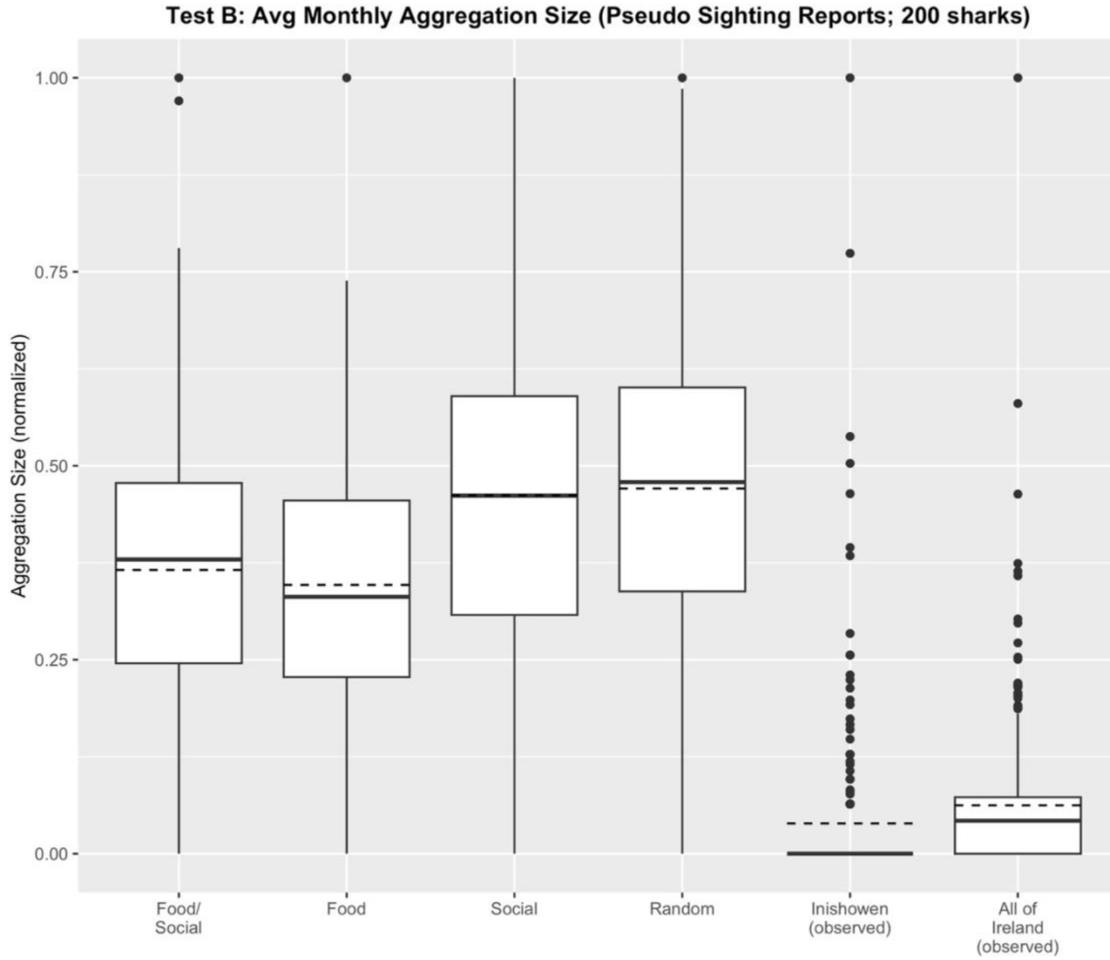


Figure 17: Boxplot comparing the average size of aggregation per month for Pseudo-Sighting Reports IBSG/IWDG data for Test B.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average size of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

Table 23: Comparison of Average Number of Aggregations Per Month to IBSG/IWDG data (Total Aggregations; 200 sharks) —Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.03	0.12	0.06	0.00	0.14	0.07
Food	0.05	0.14	0.08	0.02	0.14	0.08
Social	0.46	0.54	0.46	0.43	0.52	0.44
Random	0.33	0.40	0.34	0.30	0.38	0.31

Total aggregations (averaged across 50 trials) compared to IBSG/IWDG sightings. Data was normalized via min-max normalization. Total Aggregations count groups of two or more sharks. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

Table 24: Comparison of Average Number of Aggregations Per Month to IBSG/IWDG data (Pseudo-Sighting Reports; 200 sharks) —Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.26	0.32	0.27	0.22	0.30	0.25
Food	0.26	0.32	0.28	0.22	0.30	0.25
Social	0.27	0.32	0.28	0.23	0.30	0.26
Random	0.28	0.33	0.29	0.24	0.31	0.27

Pseudo-Sighting Reports (averaged across 50 trials) compared to IBSG/IWDG sightings. 20 random patches are sampled per day, and all shark sightings (including single sharks) are reported. Data was normalized via min-max normalization. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

2.3.4.4 Average number of aggregations per month

2.3.4.4.1 RMSE/ME/MAE

In model tests with 200 sharks, there was virtually no difference between any submodels (Tables 23—24). However, when there were 100 sharks, the ME, RMSE, and

MAE scores were generally lower for the Food and Food/Social submodels, which also received similar results (Appendix B.4.ii, Tables 47 and 48).

2.3.4.4.2 Qualitative Comparisons

The time series data for the Pseudo-Sighting Reports did not compare to the IBSG/IBWG data in any notable way (Figures 18—19), though the Food and Food/Social submodels produced moderately realistic results. When it came to the Total Aggregations, each submodel was notably different than the IBSG/IWDG data (Figures 18 and 20). The same trends depicted in the statistical score were viewable in the boxplots (Figures 20—21). See Appendix B.4.ii, for results for model runs with a maximum of 100 sharks.

2.3.4.5 Daily Comparisons to Zooplankton Abundance and SST

The trends observed in Test A were less strong and less notable in Test B. See Appendix B.4.iii for Figures 39 —41.

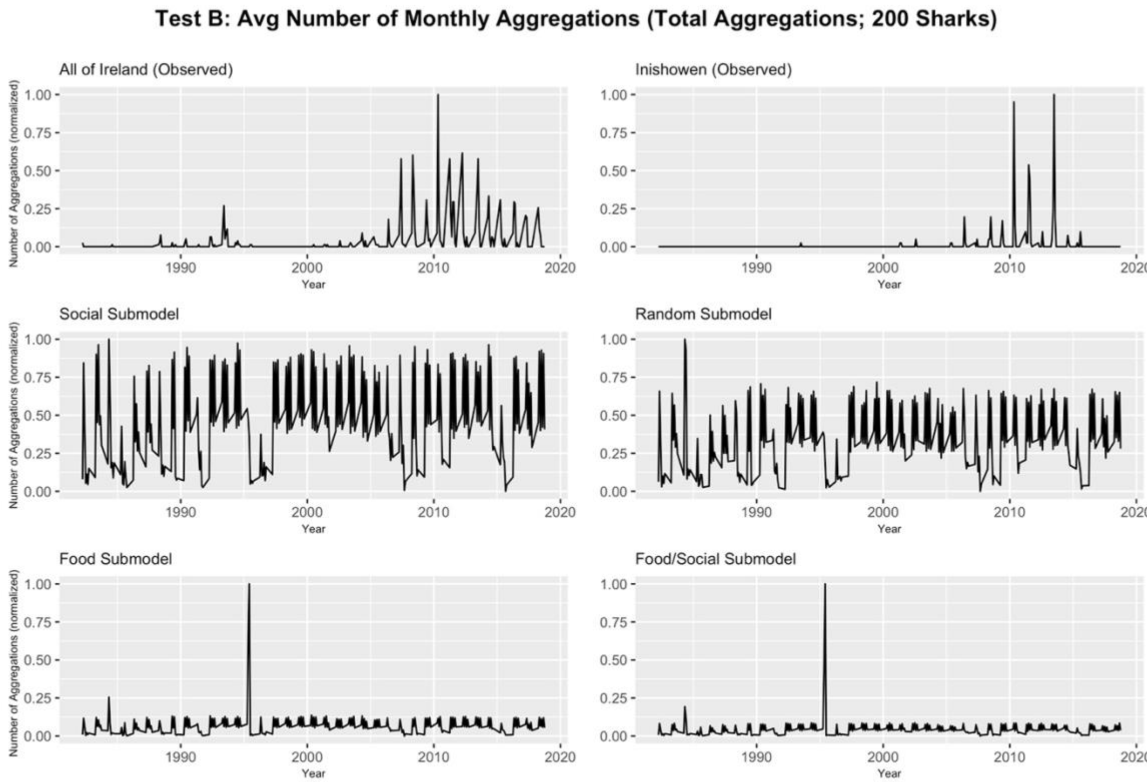


Figure 18: Comparison of average number of aggregation per month for Total Aggregations to IBSG/IWDG data for Test B.
Total Aggregations include all groups of two or more sharks. The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

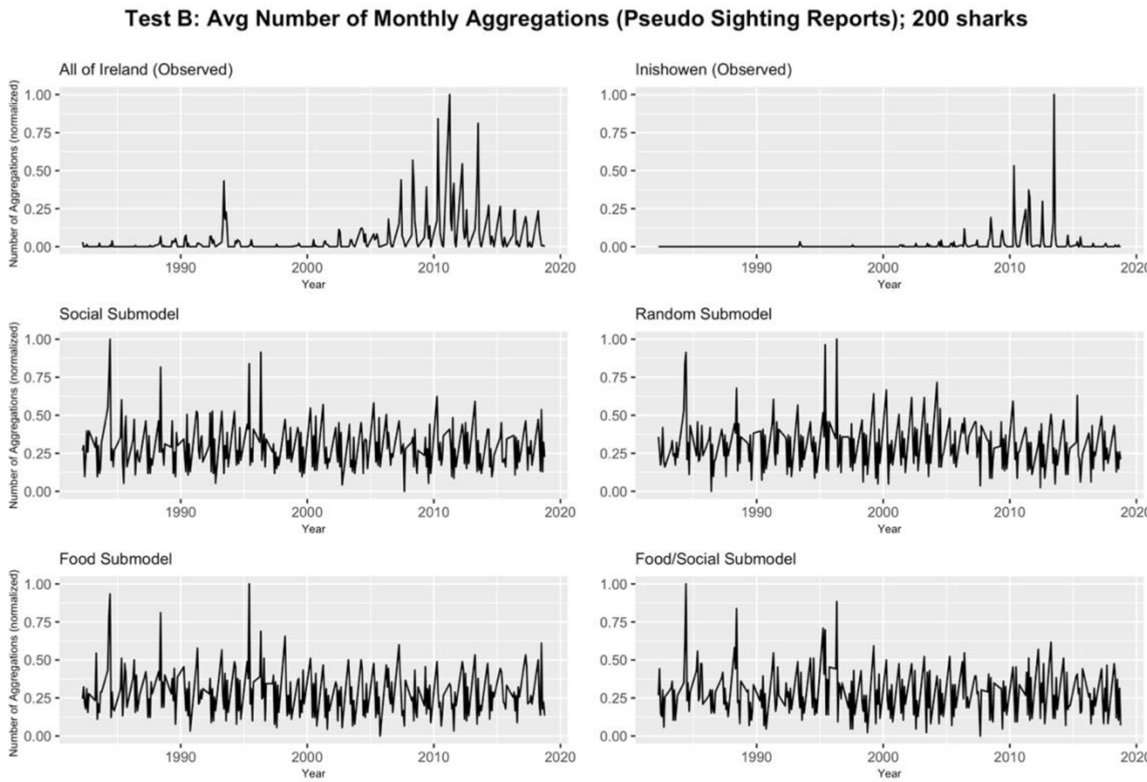


Figure 19: Comparison of average number of aggregation per month for Pseudo-Sighting Reports to IBSG/IWDG data for Test B.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

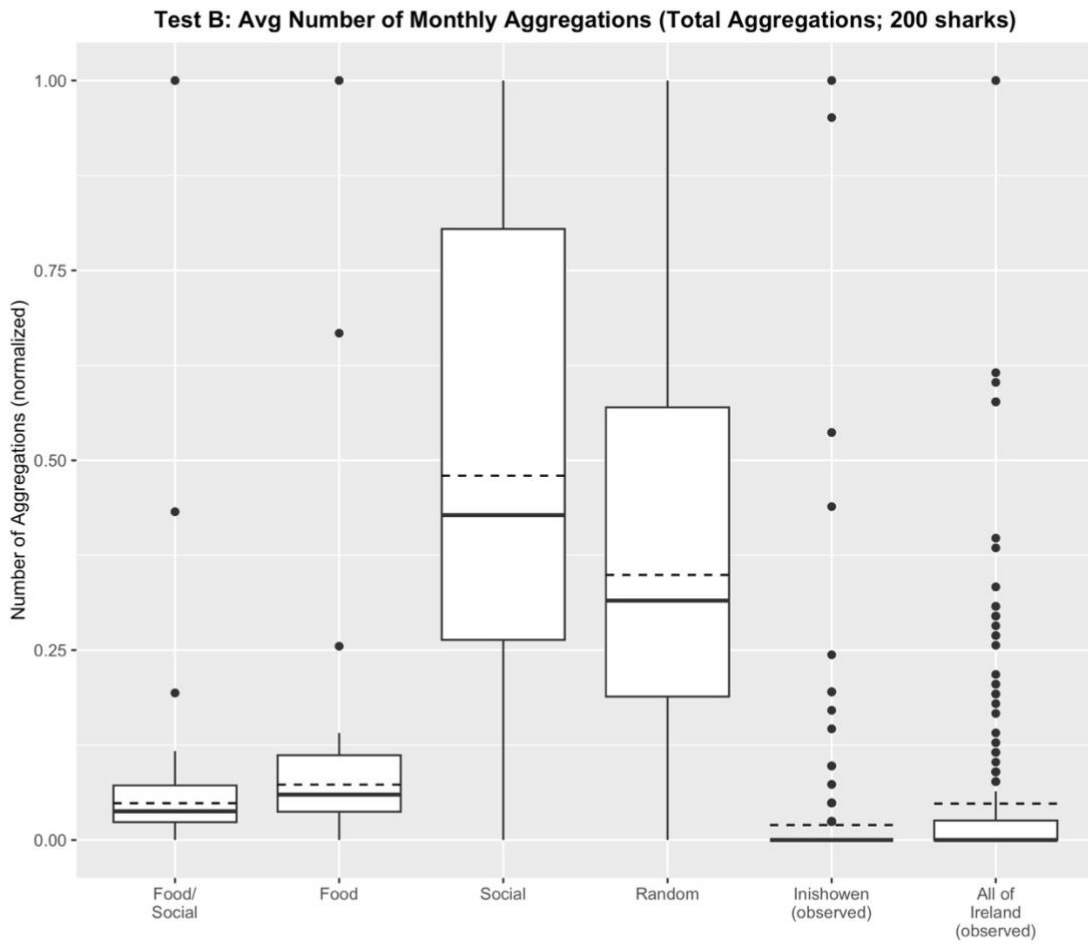


Figure 20: Boxplot comparing the average number of aggregation per month for Total Aggregations to IBSG/IWDG data for Test B.
Total Aggregations include all groups of two or more sharks. The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

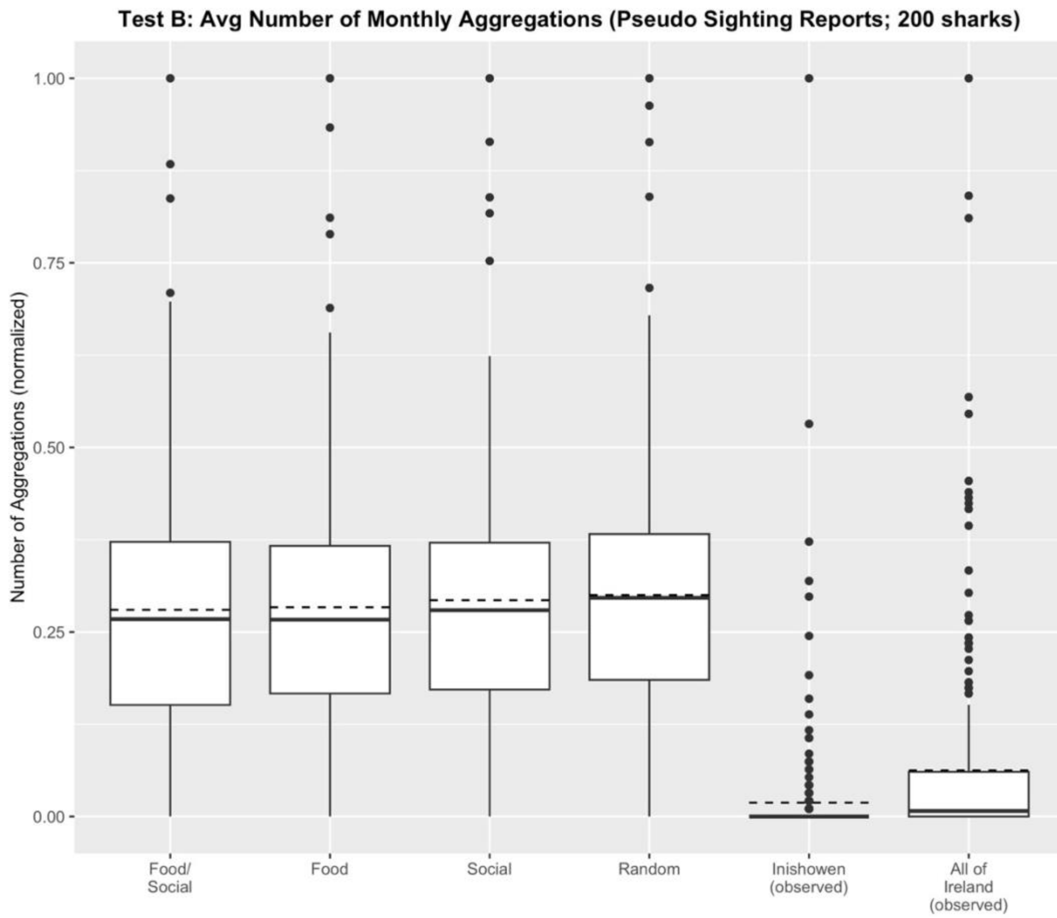


Figure 21: Boxplot comparing the average number of aggregation per month for Pseudo-Sighting Reports IBSG/IWDG data for Test B.
Pseudo-Sighting Reports result from a random sample of 20 patches each day. These reports include single sharks as well as groups of sharks (with the number of sharks in each group recorded). The average number of aggregations per month were calculated for 50 trials and normalized. This test contained a maximum of 200 sharks.

2.4 DISCUSSION

This model demonstrates that the most likely explanation for basking shark aggregations is a combination of both food availability and social interactions. It is not clear if the social interactions are directly related to courtship/mating, or to familial associations as some recent genetic research has found (Crowe et al., 2018; Lieber et al., 2020; Sims et al., 2022). In Test A, the Food/Social submodel received the lowest ME, RMSE, and MAE scores of any other model tests. Test A also produced the most realistic results, when compared to holistically to the SA/RA, preliminary tests, and Test B.

The impact of food availability on aggregations was clearly demonstrated in the model, as it is in the literature (Berrow & Heardman, 1994; Cotton et al., 2005; Crowe et al., 2018; Sims et al., 2000, 2022). Whilst the Food/Social submodel in Test A was most comparable to the IBSG/IWDG data, there were many cases where the Food and Food/Social submodel received similar statistical scores and resulted in similar time series plots, indicating that food availability had the stronger impact on basking shark aggregations, with social impacts being secondary. Zooplankton availability has been documented as a large-scale driver of basking shark movements in previous research but ineffective at explaining smaller scale movements (Sims et al., 2000; Sims & Reid, 2002). The results of Test A indicated that food drives the number of aggregations within the model, but on a small scale, social drivers impact the size of aggregations. The lack of realistic results in the social submodel, regardless of setting, indicate that food availability has a larger impact on basking shark aggregations and behavior. Previous research has proposed that the courtship-like behavior witnessed in aggregations may not be a result of the sharks intentionally seeking out others specifically for this purpose, but instead taking advantage of a mixed-sex, food-based gathering (Sims et al., 2022).

This research shows that a high threshold level for zooplankton is required for basking sharks to move to an area. This may have to do with competition, as the model codes concern for competition into the basking shark behavior. While this research is limited, previous research highlights that the precise drivers of aggregations need not be determining in order to consider a shark grouping an "aggregation", especially when combining research methods to understand wider social dynamics (McInturf et al., 2023). This research provides insight into some of the individual, and interaction between, potential drivers of basking shark movements.

Test A, which had a much lower percentage of patches that contained zooplankton than Test B, resulted in aggregation trends that were significant more likely to match the sightings data supplied by the IBSG/IWDG. This indicates that the Inishowen Peninsula may be an area of high patchiness of zooplankton, and that patchiness of zooplankton increases the likelihood of these aggregations. This may be a reason why the Food/Social submodel in Test A performed better than the Food submodel, while in Test B those two submodels were virtually identical. In patchy environments, sharks may rely on other sharks as a signal that food is available in a specific location (recalling that in the model, sharks can sense other sharks from a further distance than they can zooplankton). This is further demonstrated by the number of larger aggregations in the Food/Social Submodel that occurred in patches of low zooplankton (Figure 11). In Test B, due to the high number of patches that contained zooplankton, the sharks may not have needed to use the presence of other sharks as a proxy for identifying zooplankton. Further research is testing is needed to understand the impact of this.

The settings that produce the model outputs that most align with the IBSG/IWDG data are fairly realistic. While the time it takes a shark to either leave an area or return to it is not known, the 20 day “return-season” setting matches up with sighting reports, which show a spike in sightings in April, then a delay in sightings for 1—3 months (as sharks do not arrive on the same day, there would be a lag between both migrating out of an area, and then migrating back into an area before aggregations can occur). While we do not know the reasons sharks migrate to or from an area, the assumptions in the model have produced a reasonable recreation of shark behavior. The swim speed was based on rough estimations from field studies, which show that the average daily (straight line) distance travelled by a shark is around 9 km (Skomal et al., 2009).

The sense-distance is a little more difficult to assess, as the IBM does not distinguish between sound, smell, electroreception, and sight. While sharks can sense sound over thousands of meters, they may only be able to sense smells within hundreds of meters (Collin, 2012; Dove & Pierce, 2021). This distinction may matter for basking sharks, who may seek out zooplankton based on the smell of dimethyl sulfide (DMS) in plankton (Sims & Quayle, 1998), though it is not clear how far DMS travels in water and under what conditions. However, research has documented that whale sharks are attracted to areas of prey by noisy tuna (Dove & Pierce, 2021) and basking shark aggregations have been documented at the same time and in the same location as Humpback whales (*Megaptera novaeangliae*), minke whales (*Balaenoptera acutorostrata*), bluefin tuna

(*Thunnus thynnus*), common dolphins (*Delphinus delphis*) and seabird species, all of which would generate far-reaching sound (Sims et al., 2022). The results of this IBM may lend support to the idea that sound is a more important signal of prey for basking sharks than DMS. Future iterations of the IBM could distinguish sound and smell and perhaps include other species in the model environment. These preliminary findings may also indicate that, like marine mammals, sound pollution may impact their ability to navigate and find food.

Despite the need for more data regarding the model input settings, extreme settings (i.e., extremely high/low sense distances) produce unrealistic results when compared to IBSG/IWDG data. This demonstrates that the model is rooted in sufficiently realistic depictions of shark behavior, even though the precise nature of certain behaviors (i.e., swim speed, sense distance) are not known. Reducing the sense distance to one km had no impact on the Random or Social Submodels, but did dramatically increase the ME, RMSE, and MAE results of the Food and Food/Social submodels. The clear difference between the Random submodels and the Food and Food/Social submodels indicate that the shark behavior had a strong impact on the model results. This demonstrates that the aggregations were not a result of random chance, but of shark (agent) behavior.

Furthermore, the increased likelihood of basking sharks to be within the model area on days that had temperatures between 285 and 288 kelvin (Figures 12—13) matches real-world trends observed in the IBSG/IWDG data, which found that sightings were more likely to occur between 283 and 288 Kelvin (unpublished Data, IBSG, 2023). This is notable as SST is not an environmental factor within the model, though SST likely impacted the zooplankton data collected by the CPR.

2.4.1 Limitations

This model has several limitations. Most notably, the lack of real-world localized zooplankton data makes it difficult, if not impossible, to assess how realistic the surface environment in the model is for the sharks. Therefore, it is virtually impossible to make a realistic comparison about the *location* of sharks within the model to the IBSG/IWDG sightings data. However, the model is still useful in depicting *temporal* trends, as the CPR data acts as a passable proxy for the general zooplankton trends in the area. Further research could combine CPR data with satellite phytoplankton data to provide an even more realistic estimate of zooplankton. Incorporating more realistic zooplankton data into the model may also allow for future model versions to "predict" (or at least give a "high/low" risk estimate) of large aggregations under certain environmental conditions. This can be used for safety assessments for boaters (i.e., high aggregation risks result in higher risk of collision).

However, the patchiness of zooplankton in the model didn't impact the results of the statistical tests when comparing the in-model zooplankton samples and the CPR data. This may indicate that the CPR sampling does not reflect localized patchiness, and sampling dedicated to this specific question should be conducted in the model area. While the CPR is severely limited, previous research modeling basking shark distribution, but using Chlorophyll-*a* as a proxy for zooplankton, have only been moderately successful (McInturf et al., 2022). Further research should be conducted to get a clearer picture of the in-situ preyscape for basking sharks.

This research also shows the limitations of publicly reported sightings, which in the model missed a sizeable number of aggregations, even with randomly sampling 20 patches per day (an amount of consistent effort not seen in the IBSG/IWDG data). The model data is comparably more systematic than the IBSG/IWDG sighting reports, which are not consistent and rely on individuals to recognize a basking shark and know to report. Research in 2018 in Inishowen demonstrated that a large majority of people (both tourists and residents) were unaware that they could report a sighting (Gray et al., 2022), making the chance of an unreported sighting throughout the model time period quite high. Publicly reported sightings also lack data on true absences. Future systemic surveys can help provide a more comparable data set.

2.4.2 Conclusions

This research demonstrates that areas where basking sharks aggregate are areas of not just feeding importance, but also social importance as well. Further research is needed to determine if these aggregations are a result of food availability or courtship, though observational research in Ireland indicates courtship is the most likely occurring in these aggregations (Sims et al., 2022). This IBMs demonstrates the importance of these social interactions, regardless of the cause, as it demonstrated that food is likely the driver for the *number* of aggregations, while a combination of food and social behavior is the main driver behind the *size* of aggregations. This may indicate that individual sharks, if they are not seeking out other sharks for courtship, rely on these aggregations to locate food and/or reduce drag while feeding. Protecting areas where these aggregations occur, including making effort to prevent disturbance to these aggregations, is important to basking shark conservation.

Understanding how food drives both long-term migratory patterns and localized shark behavior is vital for conservation in the face of climate change. Long-term SST increases have been observed in the North Atlantic in the previous decades, and multiple studies have found that this increase in SST has led to a northward shift in zooplankton communities, with an increase in the range of warm water zooplankton, and a decrease in the range of cold water zooplankton, including *C. finmarchicus* (Gregory et al., 2009). On the smaller scale, *C. helgolandicus* may be replacing *C. helgolandicus* as a result of climate change (Wilson et al., 2016).

Climate change can also indirectly effect *C. finmarchicus* populations, by delaying chlorophyll blooms. *C. finmarchicus* can reproduce *before* nutrient blooms, due to internal lipid stores (part of the reason they are so large), but delayed phytoplankton blooms result in high juvenile mortality (Bresnan et al., 2015). While phytoplankton may not be directly impacted by sea surface temperature, increased temperatures can increase stratification and effect the seasonality of nutrient upwelling (Melle et al., 2014). It is already documented that in southern latitudes, *C. finmarchicus* are spending less time in diapause (Melle et al., 2014). Because *C. helgolandicus* spends more time in surface waters, they may be more affected by increased winter sea surface temperatures then *C. finmarchicus*, who dive to deeper waters in winter. Understanding how individual sharks make both localized and large-scale movement decisions will assist in the development of climate-resilient conservation strategies.

As the first IBM of basking sharks, this research demonstrated the possibility of modeling basking shark behavior via an IBM. This is particularly useful for such an elusive species and presents the possibility of reproducing tests of behavior based on limited field research. The IBM, with limited environmental data, was able to reproduce long-term trends found in publicly reported sightings to a degree comparable to other forms of modeling. The ability of the IBM to account of individualized behavior is notable and should be considered in light of current research focused on individualized social behavior of basking sharks (A. McInturf, personal communication, August 8, 2023). This kind of research on basking sharks, which allowed for individualized heterogeneity, is the next step in understanding their behavior and adapting conservation management approaches, especially in light of climate change.

In the future, this model could also be duplicated in other areas where basking sharks are sighted, with moderate changes to the underlying map and zooplankton data. Further research should expand the geographic range of this model, to bolster the behavioral hypotheses. Further analysis should also compare sea surface temperature and zooplankton levels, to understand their impact in the model on aggregations and to potentially identify real-world trends.

CHAPTER THREE: INDIVIDUAL-BASED MODEL USE IN POLICY: DOES YOUR RESEARCH HAVE THE IMPACT YOU THINK?

3.1 INTRODUCTION

Environmental[7] policies are improved with the input of scientists (Meyer et al., 2010). Research has shown that policymakers feel that scientists should take a more active role in policymaking, beyond simply reporting results (Akerlof, 2022; Steel et al., 2004). Researchers can act as "knowledge brokers", though this requires a balance between maintaining scientific credibility while also contributing to the policymaking process (Nelson & Vucetich, 2009; Turnhout et al., 2013). However, surveys of scientists who aim to conduct applied research, or research conducted for a specific application (i.e. conservation), show that researchers rarely present to governmental/agency meetings, nor do they regularly work directly with conservation managers (Akerlof, 2022; Thornhill, 2014).

Models are necessary and effective tools for understanding present and future environments and should be utilized along with other forms of research in conservation policy. Complex systems require complex adaptative modeling, which allows for the interactions of multiple phenomenon (Bruce & Gershenson, 2015; Squazzoni & Boero, 2010). Individual-based models, which simulate how micro level behavior in a system creates macro level behaviors, are particularly useful for understanding complex ecological systems (Squazzoni & Boero, 2010). When models are focused on conservation and

[7] This chapter is accepted for publication as:
Gray, C., Rothman, D., Peters-Burton, E., Smith, C., & Parsons, E.C.M. (2023). Individual-Based Model Use in Marine Policy. *Journal of Integrative Environmental Science*. (In press).

management, in particular of threatened, endangered, or exploited species, it is prudent that models be developed with policy implications in mind. This research focuses on individual-based models (IBM) and marine conservation policy and management. As IBMs are becoming more prevalent in the field of marine conservation, this is an ideal time to assess use in policy and assess communication and implementation strategies.

The term "model" refers to many different methods of artificially representing the world, from simple sketches, to complex, multi-level computer models. While many assume models are inherently mathematical, models are also used in informal, often implicit ways to explain the world. It is usually only scientific models that are documented, with assumptions and biases made explicit (Epstein et al., 2014). Models are also used as diverse tools, not always for prediction but for understanding as well (Epstein et al., 2014). Models are tools of both scientific research *and* policy, as they can be used to answer scientific questions and/or to test the impact(s) of potential policy decisions (Paolisso et al., 2015). They are also used to inform many different issues, ranging from economics to public health to fisheries (Railsback & Grimm, 2019).

When scientific publications assert the usefulness of a model for ecological management, there is not always evidence that the model has been utilized in policy, or if the impact of a model on policy development has been documented (either in a published paper or elsewhere, such as a government report). Methods of communicating the model results to relevant policymakers are rarely described in peer-reviewed publications. Furthermore, strategies for model implementation and/or information for policymakers is virtually never present in these publications or model documentation.

Modeling has been used in ecological conservation for decades, with varying levels of success (Béland & Howlett, 2016). Traditionally, these models were equation based (i.e. Gordon, 1954). Individual-based modeling (IBM)[8] is a type of modeling that allow for bottom-up modeling, with populations that include individuals that are heterogenous, with complex, individual life cycles, and describe population changes in number of individuals, rather than density (Uchmański & Grimm, 1996). IBMs also allow for the consideration of how individuals interact with and affect, or are affected by, their environment (and are often, but not always, spatially explicit) (Grimm & Railsback, 2005b; Uchmański & Grimm, 1996). With the rapid increase in computing power, it is likely that IBMs will continue to grow in complexity and applicability.

Because of their nature, IBMs may be able to contribute important information to conservation management and policy questions, as IBMs offer more complex methods of understanding ecosystems, animal behavior, and resource and population dynamics, by allowing for heterogeneity in both individuals and environments (while traditional models often assume uniformity or the "average of" individuals or environments) (Uchmański & Grimm, 1996). This allows for a stronger understanding of patterns at higher population levels (Squazzoni & Boero, 2010). However, the degree to which IBMs are actually used in conservation policy is unclear, as is the extent of IBM availability to address policy-relevant questions. The focus of this paper is to shed some light on these questions, with a particular emphasis on marine conservation. Here, marine is defined as relating to marine

[8] Also referred to as agent-based modeling (ABM). The term IBM is most commonly used in ecological research, while ABM is more common in social science literature. There is no fundamental difference between the two. In this paper, IBM will be used consistently throughout for clarity.

conservation and management, including, but not limited to, species and habitat conservation/management and anthropogenic impacts to species and habitats (i.e. fishing, climate change).

3.1.1 Overview of Model Use in Policy

The definition of “model use in policy” can be broad, including simply communicating model results to the target audience, training users, and one-off or routine use of the model for policy development and analysis (Kolkman et al., 2016). This paper will focus on IBMs used for policy development or management. While there are many examples of traditional mathematical models being used in environmental policy, there is not currently an exhaustive list of models used in policy (Kolkman et al., 2016), making a comprehensive assessment difficult (Chang et al., 2021). Still there are many documented examples of environmental models informing policy, such as Regional Air Pollution INformation and Simulation (RAINS) model (Tuinstra et al., 2002), Climate Options for Long Term (COOL) Project (Tuinstra et al., 2002), and Physical Habitat Simulation System (PHABISM) (Cartwright et al., 2016).

While traditional mathematical and ecosystem models are well accepted in conservation and policy development, IBMs are less frequently utilized, despite their potential for stronger, more dynamic, conservation impacts (Codling, 2008; Islam & Jørgensen, 2017; Ortiz & Jordán, 2021). IBMs can be spatially explicit and include realistic, complex elements, such as bounded knowledge (different levels of access to information),, something that may be important for the conservation of migratory species (Hare & Deadman, 2004).

One area conservation could learn from is the public health sector, where various types of models have long been utilized in public policy (Pullin & Knight, 2003). IBMs are commonly used in human health, (Gojovic et al., 2009; Lorig et al., 2021; McBryde et al., 2020; Milne et al., 2008), and epidemiological IBMs have been applied successfully disease outbreaks in animal populations (Eisinger et al., 2005; Railsback & Grimm, 2011). They have also been applied to human behavior with regard to climate change (IPCC, 2022).

IBMs are becoming more popular in fisheries research (Childress, 2014; García-Asorey et al., 2011). As of 2021, InSTREAM (individual-based Stream TRout Environmental Assessment Model) has been used for 22 years and applied to 50 sites in multiple countries (Railsback et al., 2021). IBMs have allowed researchers to understand fish behavior, with potential impacts for conservation policy (Railsback & Harvey, 2002) and have allowed researchers to understand anthropogenic impacts on fish more holistically (Grimm & Railsback, 2005).

3.1.2 Purpose

In this research, we looked at marine IBMs and assessed evidence of their use in marine policy. Marine IBMs were focused on due to the common use of various model methods (including IBMs) in fisheries science, among other marine-related topics, as well as the applicability of IBMs to marine research, due to the complex, migratory nature of many endangered, threatened, and exploited species. The limited focus on marine research also allowed for a more manageable data set that is more in line with the authors' expertise, as IBMs with policy relevancy span across all disciplines. While model use in policy for human health issues, like epidemiology, is well documented, it is less well documented in marine science, making this research a novel contribution to marine science and policy literature.

Furthermore, focusing on marine policy allowed us to find policy documents from a larger source pool, as many marine organisms cross international boundaries, meaning multiple countries could publish policy reports on the same species or marine conservation/management issue. This was especially vital for policy documents, as not all countries have searchable or accessible online databases of policy information.

The purpose of this research is to 1) assess the number of marine IBMs that are published in scientific publications and claim relevancy to policy and 2) assess the rate of individual-based model use in marine conservation policy. Use is being assessed by citations or references to IBMs in policy documents. This limits the source pool for policy documents, as many policy documents do not contain citations and a significant amount of scientific information is shared in informal meetings. However, this method was chosen as it is a documentable and quantifiable method of analysis.

3.2 METHODS

This research consisted of three components:

1. Assessing the number of scientific papers that use IBMs to address marine topics and claim the results are relevant for policy, as well as a determination if the scientific papers were cited in any policy documents related to the research topic.

2. Assessing the number of policy documents from the Government of Canada Publication website that cite IBMs and other model methods.
3. Searching generally for any references to IBMs on the following websites: National Oceanic and Atmospheric Administration (NOAA) Fisheries publications page (which includes published research, reports, and outreach materials; https://www.fisheries.noaa.gov/resources/all-publications), NOAA fisheries general website (https://www.fisheries.noaa.gov), the New Zealand Department of Conservation (https://www.doc.govt.nz), and the UK Government website (https://www.gov.uk).

3.2.1 Scientific Papers

To assess the number of scientific papers that utilize IBMs and argue that the results are useful for marine conservation policy or management, Web of Science (WoS) was searched. WoS is a global citation database for all indexed journals, which searches the title, abstract, and indexing (i.e. keywords) of its database. The scientific papers assessed were written in English, but the WoS results included research on marine areas in South America, North America, Africa, and Europe.

Two keywords searches for *Individual-based Model*, *Marine*, *Ecology*, and *Individual-based Model, Marine, Conservation* were conducted (WoS search included “or” *IBM*, *ABM*, and *Agent Based Model*; See Table 29 for the search criteria). Results were narrowed to peer-reviewed publications. Results for all searches were combined and duplicates removed (Table 25).

Papers were chosen for review if they fit the following criteria:

- Utilized an individual-based model in the methods.
- Were related to the marine environment. Papers relating to sea birds, marine mammals such as seals, and anadromous fish were included in this study, as was research on tourism, climate and other anthropogenic impacts on marine species/habitats.

The number of papers that stated that the research had management or policy implications and/or that were beneficial to management or policy were counted. This was assessed by context; the authors did not need to state explicitly that the paper was "beneficial to policy." For example, a paper that assessed the effectiveness of a fishing quota would be considered as having management or policy implications, without having stated that outright (see Appendix F for which abstracts qualified, and which did not). Only abstracts were read for this study, under the assumption that if this was a key takeaway of the paper, it would be in the abstract. The WoS search was conducted in January 2022.

For each paper that claimed relevancy for policy, a search was made for a policy document published on the same topic, after the publication date of the scientific paper. A policy document was defined broadly as any document written by or for any governmental agency, reporting information meant to inform marine policy. This could include, but were not limited to, management reports, population estimates of protected or exploited species for the purposes of management, best practices for mitigating anthropogenic impacts, policy recommendations published by or for governmental agencies and technical reports published by or conducted for governmental agencies. Only policy documents with citations were included in this component. For the purpose of this study, sources were counted as a "citation" even if they were informally cited (i.e. a footnote with a simple URL), though the majority were written in a formal, reference lists.

Search methods included copy and pasting the entire (APA) citation and the paper title into Google, searching a relevant agency or organization website for policy documents on the topic, and searching Google for terms such as "[marine topic] management", "[marine topic] conservation" or "[marine topic] plan" in order to find policy and management papers on the same conservation issue referenced by the scientific paper. For example, to find a policy document relevant to research on the impacts of fishing on spiny lobster populations in the Florida Keys, we would search key terms such as "spiny lobster Florida Keys", "spiny lobster conservation" in Google. When possible, government and agency databases of the country(ies) relevant to the scientific paper were searched. For example, in conjunction with the google search we would search the Florida Fish and Wildlife Conservation Commission website, along with any other relevant databases (i.e., NOAA's website), for information on spiny lobster.

If a policy document was found, it was then determined if it cited the WoS scientific paper *or* if it cited a different IBM. While the term "individual-based model" is used here for consistency, all documents were checked for references to either individual or agent-based models. Policy documents were also assessed to determine if they cited any other type of modeling method. This was done by searching for all references to the word "model" within the document and determining the model type. Determining the model type was done by contextual clues within the text (i.e. the model method was stated explicitly) or by checking the model methods of the cited source (the term "individual-based model" did not need to be used explicitly to be identified by this method). Both the text of policy documents and the references list were assessed, however searches of the reference list relied on the term “model” being used in the title of a cited paper (if the specific model method was not included in the title, the paper was reviewed to determine the method). This method was repeated for the terms “simulate” and “simulation”. Searches for policy documents related to the WoS articles were conducted in January and February 2022.

3.2.2. Government of Canada Publications

Because of a lack of comprehensive, international databases for policy documents, there was no method of conducting a thorough, systematic search of international policy documents comparable to the WoS search. The Government of Canada has an extensive searchable policy database (https://publications.gc.ca), which consists only of Governmental publications, as opposed to general webpages, employee biographies, or other general governmental information. This was used to conduct a search analogous to the WoS search. This was chosen specifically because of the quality and centralized nature of the search database, as well as the fact that Canada has two large coastlines. All documents found in this search were related to Canadian policy and only those with citations were included.

The Government of Canada Publications database was searched using the terms “individual-based model” and “marine conservation” (Table 27). The terms were entered into the “basic search” which searches the text (title, subtitle, series title, subject terms[9], abstract, author, department/agency) of documents. The option to “find variations of search

[9] Key words identified in the description of the document.

terms" was checked. Searches were sorted by relevance, in descending order. The number of articles with citations were counted. The written text and citations of these policy documents were assessed using the same method as the other policy documents to determine if an IBM had been referenced or cited.

Searching *individual based model* in the Canadian Government database returned 25 results, only six of which were marine relevant policy documents with citations. A search for *marine conservation* in the Canadian Government database resulted in 480 results. Due to the low results for *individual based model*, only the first 15 pages of search results for *marine conservation* were assessed (a total of 150 documents, or 30%). The search of the Government of Canada database was conducted in February 2022.

3.2.3 Other Websites

More general searches for mentions of IBMs in governmental websites were conducted in February and March 2022 to supplement the geographic limits of the Canadian Publication search. This more ad hoc method, which is not meant to be directly comparable to the previously described searches, included websites, employee biographies, and other more generalized information on government websites that may include information about IBM use in policy. Due to the diversity of publication types found, documents and webpages in this search were not required to have citations but were assessed solely for any mention of IBMs. This included workshop listings, employee publication lists, informational pages for the public, and press releases, along with formal policy and management documents.

The NOAA general website and New Zealand Department of Conservation did not have a separate search page or advanced search that allowed for narrowing results to policy publications (as opposed to webpages, event announcements, employee biographies, and other non-formal media). While the NOAA publication page and UK databases allowed for narrowing by document type, both contained small sample sizes for most searches, and so were combined with the general websites in data analysis.

UK searches were run by narrowing results to "Topic: Environment", "Subtopic: Marine" and searches were conducted by further narrowing to "Content type: Policy documents and Consultations" via the menu options provided in the search (Table 28). This was done to reduce search results to more manageable sizes and to exclude non-marine pages, as the UK government website indexes pages from all UK agencies. Narrowing the search criteria ensured only relevant pages were indexed. The NOAA publication search was not narrowed in any way, as it is already a marine focused agency.

The four websites were chosen because they a: had a high-quality search function, b: had a high volume of centralized documents/webpages, and c: are all from nations that have a marine coastline and for which the marine environment is economically important. For all websites, the search terms Model, Individual Based Model and Agent based Model were used. When appropriate, searches with and without quotation marks were conducted in order to narrow results. For all sites but NOAA, no difference in search results was found when Individual based Model or Individual-based Model; Agent-based Model or Agent based Model was used. When searching NOAA databases, no dash was used as it returned a higher number of results. For example, agent-based model returned three results (The same results as when using quotation marks), while agent based model returned 18 results.

3.3. RESULTS

3.3.1 Scientific Papers

The WoS search produced 621 scientific articles in total. Of those, 185 were not an IBM and 328 were IBMs that were not marine-related (Table 25). These were dropped from the study. A total of 108 marine IBMs were found, 55% (59 papers) of which claimed to have policy relevancy (Table 25, Table 2, Appendix F). A total of 52 relevant policy documents were located that were relevant to 49 (of the 59) scientific papers (Table 26. Note that multiple policy documents and scientific papers were published on the same conservation topic (i.e., there were multiple scientific publications that used IBMs to address sea turtle conservation, all of which were potentially relevant to the same sea turtle management reports). Policy documents that were relevant to more than one scientific paper are listed with each scientific paper but are marked as duplicates in Appendix F. Duplicate policy papers were only counted once for the policy document total.

Table 25: Web of Science Search Results

Database name	Search terms	Article hits	IBM	Marine IBM
Web of Science	Individual Based Model* Marine Conservation Marine Ecology	621	326	108

*Web of Science (WoS) results for "individual based model + Marine Conservation" and "Individual based model + Marine Ecology". Due to a high number of duplicates, all WoS results were combined and duplicates removed. Searches were narrowed to only include scientific papers that used IBMs in relation to marine issues. WoS indexes the title, abstract, and keywords of each article. *Agent based model, IBM, and ABM were also searched (See Table 29 for the search criteria and Appendix F for the full list of publications reviewed).*

Table 26: Assessing Model Use in Policy

Marine IBMs that claim policy relevance	Marine IBMs that were published before a relevant policy document	Number of Policy Relevant papers published after Marine IBMs	Number IBMs cited in a policy paper	Number of Policy papers that cite an IBM	Number of Policy papers that cite a different modeling method
59*	49	52	16	25	44

49 of the marine IBMs were published before a relevant policy document was published (some IBMs address the same species or conservation issue and would have been relevant to the same policy document). Nine policy documents cited two or more IBMs (including an IBM identified by the WoS search) and four policy documents cited an IBM not identified in the WoS search.
**Appendix F shows which line in the abstract demonstrated policy relevance.*

Of the 49 scientific papers that claimed policy relevance and had a relevant policy document, only 16 (32%) were cited in a policy document. Forty-four of the policy documents (85%) cited a different modeling method[10] (species distribution models, traditional mathematical population models, and non-IBM ecosystem models and climate models were common) but did not cite the WoS marine IBM nor a different IBM. Eight policy documents cited a scientific IBM that did not appear on the WoS Search. Five of those eight policy documents cited both the WoS IBM and an additional IBM. Four policy documents cited a single IBM, but one that was not identified by the WoS search.

3.3.2 Government of Canada Publications

The earliest policy document identified in the search was published in 1990, with the majority being published post-2000. Of the first 150 results, 60 contained citations. 54 of those 60 were a marine related policy document. Out of a total of 60 papers with citations, none referenced IBMs, but 45 (75%) cited other methods of modeling[11] (Table 27).

3.3.4 Other Websites

3.3.4.1 NOAA Fisheries.

A search in the NOAA Fisheries website for "model" returned 1540 articles. Due to the high volume these results were not analyzed. *Individual based model* returned 166 results, only three of which referred to an IBM (Table 4). Many results used the word "individual" to refer to "individual age class" or "individual stock assessment" or similar phrases. This is because a phrase without surrounding quotes will return search results for

---

[10] No policy document used "simulate" or "simulation" in place of the term "modeling" but 19 (36%) used both terms interchangeably or in combination (i.e. "model simulation").
[11] No policy document used "simulate" or "simulation" in place of the term "modeling" but 11 (18%) used both terms interchangeably or in combination (i.e. "model simulation").

each word individually. A search for "*individual based model*" (in quotes) returned six articles, all of which referenced IBMs. The use of quotes means the search will only index pages that use the entire phrase. *Agent based model* resulted in 18 articles, two of which referred to ABMs, and the same term in quotes resulted in 3 articles, all of which referred to an ABM (Table 4). All of three of these were employee information pages (Biography and publication list).

A search of the NOAA Fisheries publication page for *model* returned 45 articles, none of which referred to IBMs. *individual based model* and *agent based model* (with no other refinements) returned zero results (Table 28).

Table 27: Search of Government of Canada's Publication Database

Database	Search term	Total Article hits	Articles Assessed	Articles with citations	Articles that cite IBM	Articles that cite other models
Government of Canada Publications	Marine Conservation	480	150*	54	0	39
	Individual Based Model	25	25	6	0	6
Total	—	505	175	60	0	45

*Only documents with citations were assessed. Out of a total of 175 policy documents, 60 contained citations. Out of those 60, 0% cited an IBM and 75% cited a different modeling method. *Of 480 results, 150 (30%) were assessed.*

* *Of 480 results, 150 (30%) were assessed.*

3.3.4.2 New Zealand Department of Conservation.

A search for model in the NZ Department of Conservation website resulted in 389 articles (Due to the high volume of results, individual pages were not assessed). *Individual based model resulted in 60 articles, but no reference to an individual-based model was found. "Individual based model"* (in quotes) resulted in zero article results. A search for *agent based model* resulted in 13 articles (none of which referred to ABMs) and the same term in quotes resulted in zero articles (Table 28).

Table 28: Search Results from Government Websites

Database	Search term	Article hits	Articles that mention IBMs
NOAA Fisheries	Individual Based Model	166	3
	"Individual Based Model"	6	6
	Agent Based Model	18	2
	"Agent Based Model"	3	3
NOAA Fisheries Publication	Model	45	0
	Individual Based Model	0	0
	Agent Based Model	0	0

Database	Search term	Article hits	Articles that mention IBMs
New Zealand Department of Conservation	Individual Based Model	60	0
	"Individual Based Model"	0	0
	Agent based model	13	0
	"Agent Based model"	0	0
UK Government Publications	Individual Based Model	22	0
Search narrowed to "Topic: Environment", "Subtopic: Marine" And "Content type: Policy documents and Consultations"	Agent based model	18	1
UK Government Publications	Model	55	0
Search narrowed to "Topic: Environment", "Subtopic: Marine"	"Individual Based Model"	0	0
	"Agent based model"	1	1
Total	—	407	16

A general review of five government websites from the United States, UK, and New Zealand. Webpages were assessed for formal or informal mentions of IBMs. These included formal citations, workshop advertisements, employee biographies and other general informational pages. Four percent of all searches returned a reference to an IBM. Quotation marks indicate when searches included quotes around the phrase. Duplicate results were not removed from the total.

3.3.4.3 UK Government.

When search results were narrowed to "Topic: Environment", "Subtopic: Marine" and "Content type: Policy documents and Consultations”, *individual based model* returned 22 article results (none of which referred to an IBM), while *agent based model* returned 18 results, with one reference to an ABM.

When search results were narrowed to only "Topic: Environment", "Subtopic: Marine", *Model* returned 55 article results, none of which referred to an IBM. *“Individual based model”* returned zero article results, while *“agent Based Model”* in quotes returned the same single article found in the non- quotation search (Table 28).

3.4 DISCUSSION

A majority (73%) of the marine IBMs identified by the WoS search were *not* cited in policy documents, despite 55% of those IBMs stating that the findings were relevant to policy or management. Notably, other model methods were in high use and often referenced/cited directly, as shown by the fact that 44% of policy documents relevant to WoS IBM and 45% Government of Canada publications cited a different modeling model. The number of references to IBMs on the general website search was also very low (4%).

This indicates that agencies *are* using results from non-IBM model methods to inform policy but are either uninterested or unaware of the results from relevant IBMs. One UK document, a 2013 summary of the scientific evidence used to inform UK marine policy (*Marine Science*, 2013), even contained a review of acceptable model methods but did not mention IBMs. It is largely unclear why each policy document included the model methods (or other scientific evidence) that they did, nor is it clear what evidence may have been reviewed, but ultimately left unused by policymakers. Future research on policymakers may shed light on this decision-making process.

This research demonstrates an effort by governments to be transparent with regard to sources of information for policy development. A common complaint among scientists is that it is difficult to overcome the “evidence-policy gap”, and ensure that evidence, produced by scientists, is used by policymakers to inform policy. This application gap is well documented with regard to modeling (Chang et al., 2021; Kolkman et al., 2016; Mcintosh et al., 2008; Syme et al., 2011), but it is not clear that this research demonstrates that. A substantial percentage of the policy documents surveyed contained citations, specifying the source of the scientific information used to inform policy. However, this research also demonstrates the challenge of finding a coherent list of policy documents. Few governments have databases of policy and technical documents, searchable by topic, document type, or agency, something the Government of Canada provides. If other agencies adopted these database methods, it would increase transparency between government policy and the public.

It is important to note that policy is developed through more than just “scientific evidence”, as policymakers have more diverse external pressures (pressure from donors, voters, political parties, etc.) and/or different goals than researchers, who may also have their own policy goals (e.g., sustainable resource use) (Cairney & Oliver, 2017; Cash et al., 2003; Cockrell et al., 2018; McConnell & Hart, 2019), a fact demonstrated in marine policy development (Koehler & Lowther, 2022). It is also not desirable to have policy formed solely on the basis of a model’s output, but to include a model as one piece of scientific evidence (Süsser et al., 2021). This was observed in the policy documents assessed in this study, which always contained multiple research citations. Many policymakers are not able to access up-to-date scientific research (often published behind a paywall or written in confusing jargon), meaning they cannot use it to inform management decisions, regardless of their desire to do so (Pullin & Knight, 2005). Policymakers rarely have enough time to keep up to date on various topics, and may instead rely on scientists sharing the results of their research, though scientists are not always skilled at communicating to policymakers, nor do they always actively try to or have the time to do so (Akerlof et al., 2018; N. Rose & Parsons, 2015; Thornhill, 2014).

Some of the WoS IBMs may not have been keyed into the policy needs of conservation managers or policymakers, an issue documented in previous research on model use in policy. For example, Lorig et al. (2021) noted a discrepancy between what policymakers needed and what many COVID-19 simulation models tested (Lorig et al., 2021). Collaboration with policymakers, which has been documented to result in considerable environmental policy success (Tuinstra, 2022), is not without risks, however. A review of energy modeling use in policy found that, while collaboration with modelers and policymakers could produce more policy-relevant models, there was also evidence that policymakers influenced model development and/or pushed for familiar modeling methods to support existing policy aims (Süsser et al., 2021). Kolkman et al. (2016) found that a combination of a model's characteristics (i.e. complexity) and organizational factors, such as a lack of model "advocates" or the reputation of a particular modeler can impact policymakers decision to implement or use output from a model (Kolkman et al., 2016), which can contribute to the bias towards more established methods of modeling (Süsser et al., 2021). There can also be a bias towards well-established modeling tools because governmental agencies are more likely to turn to familiar modeling teams, despite political incentive to diversify methods (Süsser et al., 2021; Turnpenny et al., 2009). This may be an explanation for why there were few IBMs cited, as the general website searches, which included employee biographies and publication lists, did not result in a high rate of individuals listing expertise in IBMs. This bias can unnecessarily restrict modeling methods, limiting innovation.

Freshwater conservation provides examples of successful and long-term IBM use for policy. Railsback et al. (2009) created InSTREAM in response to the limitations of PHABISM (a non-IBM model). In collaboration with the United States Department of Agriculture (USDA), they have published a detailed user guide for not only how to set up the model, but how to apply it to management problems (Railsback et al., 2009). MORPH (an IBM most often applied to, but not limited to, coastal birds), a model documented in this study but not found cited in policy documents, has a more technical and less clear user-guide. The Bournemouth University Individual Ecology website, which manages MORPH, provides a vast list of scientific resources related to MORPH and IBMs, but few resources for non-experts in modeling and none for those without a science background ("MORPH," n.d.). While the model is downloadable to any potential user for free, a key step to accessibility (Cartwright et al., 2016), the website does not include any documentation for best practices for communication. That being said, the website does document case studies, many of which cite government-based funding sources ("Case Studies," n.d.), indicating a potential connection to policy development not documentable by the methods of this study. The case studies, which can be sorted by location and conservation topic, contain a standardized method of very brief "recommendations from modeling", a simple but effective communication method that could be adopted by other researchers. However, if researchers are not actively advocating for their model, it is not clear how relevant conservation managers will know if specific model methods or results can be useful for their needs, especially if they are unaware of their modeling options to begin with.

It does seem that researchers can advocate for their own models. One policy document located while assessing the WoS IBMs (Williams et al., 2017) actually described the use and updating of an IBM, while the rest of the policy documents assessed simply cited a paper that used an individual-based model. This is likely due to the fact that the original lead author of the IBM (Hall et al., 2006) was also a co-author on the Williams et al. (2017) policy document.

There is also evidence of public pressure for more complex modeling. One UK policy document contained public comment, noting the main complaint was that the cited model was "too simplistic" (Department for Environment, Food & Rural Affairs, 2012). More complex models, such as IBMs, may be an avenue for governments to respond to public pressure.[12] Notably, this public pressure only exists due to transparency of evidence used to inform policy. The issue of choosing model methods grows more complex when there are competing models of the same issue, sometimes with conflicting results (Mika &

[12] It should be noted that IBMs can require a high amount of data to parametrize, which may be a potential explanation for their limited use, despite public pressure within the last decade.

Newman, 2010) or when the "black box" nature of a model reduces perceived credibility (Cash et al., 2003). The policy documents reviewed did not indicate if there was competition between model methods or if one method is considered more credible than another. Further research should be conducted to understand how or why certain methods are chosen for policy development.

There also may be up-and-coming agency interest in IBMs. One search result from NOAA was a schedule for a previously held modeling workshop that included a section on IBMs, indicating interest in IBMs even if these have not become more prominent within the agency yet. As previous research showed a bias towards "in house" or previously used model methods (Süsser et al., 2021; Turnpenny et al., 2009), this may be evidence a gradual shift towards IBM use at NOAA, presumably as a result of expanding expertise.

3.4.1 Communication

Communication is always a challenge when it comes to model use in policy development (Lorig et al., 2021). Communicating model assumptions, methods, and results can pose particular challenges to those working with IBMs, due to policymakers' lack of familiarity with IBMs (or modeling in general). If a policymaker does not interpret the model output the way the modelers intended, there may be *undetected* misunderstandings, potentially negatively impacting policy (Syme et al., 2011). Therefore, models need to be communicated clearly, accurately, and transparently (Kolkman et al., 2016; Lorig et al., 2021; Mcintosh et al., 2008). While it is not always possible to predict the future policy landscape, modelers should thoughtfully consider how their models can be used and who the potential users of their model or model results could be.

Modelers who wish to conduct applied research should familiarize themselves with the policy landscape of their research topic and reflect on their role in the political arena, as it is *policymakers*, not researchers, who hold the most power when it comes to model use in policy (Süsser et al., 2021). Research has shown that understanding of policy theory can help researchers make progress advocating for their chosen issue (Weiner, 2011). However, most scientists are overwhelmingly ignorant of communication research or policy theory (Hayes et al., 2008). Researchers are often ill-equipped to participate in science communication, though ample research has been published on the topic (Fuller et al., 2014; Pullin & Knight, 2003; D. Rose, 2015; Stamatakis et al., 2010; Wilhelm-Rechmann & Cowling, 2011). Modelers can also utilize boundary organizations, which assist interactions between scientists and policymakers, something relatively few researchers use (Akerlof, 2022; Lemos et al., 2014; Suhay & Cloyd, 2018). A majority of American Association for the Advancement of Science members, an organization that works to connect scientists with policymakers, report having communicated their research with policymakers (Suhay & Cloyd, 2018), indicating the usefulness of such organizations. Institutions consistently undervalue science communication, but if institutional support for science communication increased, it may positively impact the evidence-policy interface.

Unlike the TRAnsparent and Comprehensive Ecological modeling (TRACE) and Overview, Design concepts and Details (ODD) documents (Grimm et al., 2006), which provide clear guidance on communicating models to other researchers, there is no broadly used or accepted procedure for communicating IBMs (or other complex models) to stakeholders or other non-experts (Cartwright et al., 2016). This suggests that while researchers are communicating with each other in increasingly uniform ways, they are not communicating models to policymakers and the broader public in a consistent or systemic way. TRACE and ODD do not require any information about communication strategies, making it difficult to assess if or how modelers advocated for their model results to be used in policy. The lack of any systemic framework or guidance means it is not even standard practice for researchers to consider communication with non-experts.

Some researchers have argued that communication frameworks similar to public health can be used by conservationists when trying to advocate for policy (Pullin & Knight, 2003). Those involved with medical research have advocated that scientists use "stories" to communicate scientific results (Stamatakis et al., 2010), though conservation researchers argue that story-telling is insufficient, and that influencing policy also requires that research be "framed" in a politically-salient context (Kolkman et al., 2016; Mcintosh et al., 2008; D. Rose, 2015; Syme et al., 2011). In other words, researchers should take advantage of relevant policy windows, or times when a policy issue may be influenced. Other researchers have argued that better model descriptions (i.e., ODD) are required to improve model use in policy, and that standardized, transparent communication methods are needed (Lorig et al., 2021). However, this assumes the target audience is familiar with and comfortable reading a model description, something a policymaker may not be, especially considering that many policymakers have large workloads and are unable to interpret scientific writing (Akerlof et al., 2018). Grimm et al. (2020) provided guidance for *policymakers*, to help them assess if a models' output should be used for decision-making.

In answer to the communication challenge, Cartwright et al. (2016) present a framework for communicating complex ecological models to non-experts, while Fischhoff and Davis (2014) have provided detailed guidance for scientists in how to assess and communicate uncertainty in research. Others have argued that uncertainty can be viewed by researchers as an opportunity to collaborate with stakeholders, allowing researchers to take advantage of local and shared knowledge, rather than as a weakness of the model (Paolisso et al., 2015). Researchers have also highlighted the importance of understanding the mental and cultural frameworks of stakeholders, which may impact understanding and trust in models (Paolisso et al., 2015). There exists ample literature on management strategy evaluation (MSE), which can assist with model implementation, evaluation, and communication between managers and policymakers (Holland, 2010; Kaplan et al., 2021).

While providing communication guidelines specific to models is outside of the scope of this paper, modelers should consider the most recent communication research to ensure successful application of their research. Further research could also evaluate the time between the completion of scientific research, the publication of peer-reviewed research, and the publication of policy documents. There have been recent efforts to improve communication between the scientific community and policymakers, the results of which may not yet be documentable.

3.4.2 Limitations of This Study

While a large number of IBMs were returned via the WoS search, 52% of the search results contained non-marine IBMs. The rate of IBM use in marine science compared to other, more established model methods is unknown, nor is it clear if marine IBMs were not appearing in search results for unaccounted for reasons. Notably, eight policy documents contained an IBM not identified by the WoS Search. Of those eight, four should have appeared in the WoS search (WoS indexes the journal they were published in) but they did not appear in the search results for unclear reasons. The other four were instances where original research that utilized IBMs were described in the policy document itself.

Another limitation is that the WoS indexes titles, abstracts, and keywords, so if the authors did not include any of the search terms (Table 5) in their title, abstract, or keywords, then their article would not appear in the WoS search. Further research could expand the use of keywords to include more generalized terms, such as “model” and “simulation”, however doing so would almost certainly identify a very large number of false positives (i.e., papers that use models that are not individual-based). The quality of research was also not assessed but may be a factor in the low rate of use for policy, especially in areas where IBMs are still new and unverified.

This research is not comprehensive nor representative of policy documents worldwide. It is difficult to find a comprehensive list of policy documents and many policy documents do not list citations, making it impossible to assess what, if any, evidence informed the policy, a challenge other researchers have noted (Chang et al., 2021). It is also not clear if this research documents evidence of absence, or simply absence of evidence of IBM use in policy. Evidence is often used in policy in a way that is difficult, if not impossible, to document, such as in committee meetings or in documents that lack citations. However, considering the number of policy documents that cited other model methods, the results seem to indicate evidence of absence. Notably, some policy documents included original research using IBMs, such as European Commission et al. (2020), which provided technical guidance resulting from new research conducted by the authors.

Some potential sources of error include language barriers and word choice. English is predominately the language in scientific publications, while conservation policy is conducted in the language of the nation. Several WoS IBMs were written on topics that impacted non-English speaking countries, making it difficult to search for policy documents using an English language search approach. Therefore, this research should not be considered representative of non-English marine policy. Future research should include scientific research and policy documents in languages other than English.

The methods were also limited by word choice. While many papers written on models will use the word “model” or “simulation” in the title (making them easily identifiable in the references list of policy documents), this is not always the case. Any scientific paper that used models but did not contain the terms “model” or “simulation” in the title would not have been counted in a review of the policy documents’ reference lists. Likewise, if a policy document utilized information derived from scientific evidence, such as estimated population sizes, they may not have cited the source or noted that this information came from a model. This could potentially result in undercounting the use of both IBMs and/or other modeling methods. It is also not clear how the UK, NOAA, and New Zealand websites index their searches. For example, they may not include meta tags, or may only search the title of a page, not the entire text of a webpage. The search engine used may have been a limiting factor in the use of these websites.

3.4.3 Conclusion

This research demonstrates that IBMs are not frequently used to inform marine policy, while other model methods are. This study also highlights the challenge of tracking research use in policy development, as the majority of policy documents did not cite sources, making it impossible to determine what, if any, scientific research informed the conservation policy. However, of the policy documents with citations, a majority did cite *other* model methods. It is not clear how scientific evidence (in this case, modeling methods) is found and why some evidence is utilized when others are not. While this likely varies between departments, agencies, and countries, this demonstrates a challenge for researchers who wish for their model results to be used in the development of "evidence-based policy". More research is needed to understand the decision-making process when it comes to evidence selection and inclusion in reports and/or policy development.

Modelers who work with IBMs and wish to develop applicable research should not assume that their model results will be useful for policy and should instead ensure that they are 1) explicitly addressing a policy need and 2) making the information accessible to policymakers, via crafting a communication and/or implementation plan for policymakers or by joining a relevant boundary organization.

Table 29: Web of Science Search Criteria

Keywords	Web of Science Search Criteria
Marine Conservation	((TS=("individual based model") OR TS=("IBM") OR TS= ("Agent based model") OR TS= ("ABM") AND TS=(Marine)) AND TS=(conservation)) NOT (DT==("BIOGRAPHICAL ITEM" OR "DATA PAPER" OR "REPRINT" OR "RETRACTED PUBLICATION" OR "POETRY" OR "BIBLIOGRAPHY" OR "ART EXHIBIT REVIEW" OR "DANCE PERFORMANCE REVIEW" OR "FILM REVIEW" OR "MEETING ABSTRACT" OR "RETRACTION" OR "SOFTWARE REVIEW" OR "EXPRESSION OF CONCERN" OR "CORRECTION" OR "LETTER" OR "NEWS ITEM" OR "BOOK REVIEW" OR "EDITORIAL MATERIAL"))
Marine Ecology	((TS=("individual based model") OR TS=("IBM") OR TS= ("Agent based model") OR TS= ("ABM") AND TS=(Marine)) AND TS=(ecology)) NOT (DT==("BIOGRAPHICAL ITEM" OR "DATA PAPER" OR "REPRINT" OR "RETRACTED PUBLICATION" OR "POETRY" OR "BIBLIOGRAPHY" OR "ART EXHIBIT REVIEW" OR "DANCE PERFORMANCE REVIEW" OR "FILM REVIEW" OR "MEETING ABSTRACT" OR "RETRACTION" OR "SOFTWARE REVIEW" OR "EXPRESSION OF CONCERN" OR "CORRECTION" OR "LETTER" OR "NEWS ITEM" OR "BOOK REVIEW" OR "EDITORIAL MATERIAL"))

Two searches were conducted for "Individual based model" and "marine conservation" and "individual based model" and "marine ecology." Web of Science allows for searches to include alterative terms ("or" in the table), so IBM, agent based model, and ABM were searched alongside individual based model. The results of both searches were combined.

CHAPTER FOUR: "GOVERNMENTS ARE NOT SCIENCE-BASED ORGANIZATIONS" — GUIDELINES FOR BRIDGING THE RESEARCH-IMPLEMENTATION GAP

4.1 INTRODUCTION

Policymakers desire adequate and reliable scientific evidence but are often not in a position to seek this out or create it (Cairney, 2019). Instead, the responsibility to communicate research in a way that is understandable and useful to policymakers often falls to the researchers themselves. Research has shown that individual-based models are used at lower rates than other model methods (Chapter Three). This study seeks to test a communication strategy for Individual-based models (IBMs), as well as to gain insight into policymakers' decision-making process. IBMs allow for bottom-up modeling, with populations that include individuals that are heterogenous and allow for the consideration of how individuals interact with and affect, or are affected by, each other and their environment (which can be spatially explicit). IBMs offer more complex methods of understanding ecosystems, animal behavior, and resource and population dynamics, by allowing for heterogeneity in both individuals and environments (while traditional models often assume uniformity or the "average of" individuals or environments) (Grimm & Railsback, 2005b; Uchmański & Grimm, 1996). Understanding policymakers' understanding of models, and the reason(s) they select and trust a particular model method when developing 'evidence-based policy', along with stronger communication frameworks for researchers can help ensure that models are used and used correctly, resulting in stronger environmental policy. Evidence-based policy is a framework where research evidence is used to inform a policy problem, with the assumption that the relationship between research and policy is linear (Greenhalgh & Russell, 2009).

Models are used in policies for a variety of problems, such as allowing policy makers to explore the impact of different policies or to answer policy questions when empirical data are absent or too expensive to collect (Maeda et al., 2021; Süsser et al., 2021). Many policymakers have experience with classical ecological models, as these are much easier to communicate due to the "common language" that is mathematics (Grimm & Railsback, 2005a). In comparison, IBMs are vastly different from one another and do not have a common language[13] that researchers, let alone policymakers, can refer to.

The majority of research on science communication focuses on journalism (Comfort & Park, 2018) or stakeholder involvement (Maeda et al., 2021), with little attention paid to scientific communication and understanding within different institutions, such as academic or non-governmental organizations (Akerlof et al., 2021). Research is needed to understand what are the barriers to the "translation" of scientific evidence to 'evidence-based' policy (Cairney, 2016a).

Policy research often focuses on the effectiveness of a specific policy, but not on what evidence is considered 'valid' or 'useful' (Nutley et al., 2019). Research methods can play a role in reassuring policymakers in their reliability' (Nutley et al., 2019), and it is

[13] It is worth noting that IBMs can be written in many different computer languages, so IBM modelers may not even be able to read one another's models.

important to understand their perceptions of different methods. This is especially challenging because there is no agreed upon definition of "quality" or "strength" with regard to evidence. There is an issue of bias (both in the scientific and policy development communities) against those research methods that don't fit within the scientific hierarchy, often disregarding observational and qualitative methods (Nutley et al., 2019). Policymakers are also not always concerned with the same hierarchy of evidence, so determining what makes research "good enough" for policy is also valuable (Nutley et al., 2019). The ability of a piece of evidence to garner attention and create engagement and therefore change is also frequently neglected when it comes to quality assessment (Nutley et al., 2019).

There is also little understanding of the "demand" for IBM for use in policy. Many researchers intuitively understand that research for knowledge sake is insufficient to address key environmental problems, especially when there are competing values or lack of political will (Leith et al., 2018), but as recent research shows, even applicable IBMs are underutilized in policy development (Chapter 3). Researchers need to be aware of the "demand" side of science for policy development and cater more research (the "supply") to this (Sarewitz & Pielke, 2007). Communication strategies (i.e. tailoring information to the policymakers' needs or interests) can play a strong role in influencing policymakers use of environmental research (Lemos et al., 2012; Sarewitz & Pielke, 2007).

4.1.1 Research-Implementation Gap – Is this the Problem?

A common complaint among scientists is that it is difficult to develop evidence-based policy. However, scientists do not always have the skill or desire to communicate to policymakers (N. Rose & Parsons, 2015; Suhay & Cloyd, 2018), who often have more diverse external pressures (from donors, voters, political parties, etc.) and/or different policy goals than researchers (e.g., economic growth over sustainable development) (Cairney & Oliver, 2017; McConnell & Hart, 2019). Furthermore, many policymakers are not able to access up-to-date scientific research (often published behind a paywall or written in confusing jargon), meaning they cannot use it to inform management decisions, regardless of their desire to do so (Pullin & Knight, 2005). Policymakers also do not rely solely on traditional science, and incorporate other types of knowledge, such as traditional knowledge, as well as cultural, political, and economic factors into policymaking as well (Sterling et al., 2017). In fact, cultural values may be one of the most significant influences on policy development[14] (Greenhalgh & Russell, 2009).

Policymakers are "time poor" and therefore struggle to keep up with scientific research, a challenge that grows the higher up in the policy chain one moves (Akerlof et al., 2018). Furthermore, policymakers often have not had scientific education beyond high school, so may struggle to understand scientific concepts (N. Rose & Parsons, 2015). Policymaking operates at a faster schedule than scientific research, which can take years (Powell, 2016). Often, policymakers need to craft policy on issues, even if scientific research is not available. Alternatively, the solution put forth by scientists may not be politically viable to the policymaker (Cairney & Oliver, 2017; Perl et al., 2018).

Scientists sometimes refer to the disconnect between policy and science as the

---

[14] It could also be argued that what research questions are asked and what research gets funded is also a result of individual or cultural values (Mandel & Tetlock, 2016). When communicating research, scientists should remain alert to their own biases and values.

“research-implementation gap”. Under this framework, research informs policy in a linear fashion (Toomey et al., 2017), with the evidence controlled by those who conduct scientific research, who then disseminate their work to policymakers, who presumably take the advice of scientists in order to craft “evidence-based policy” (Cairney & Oliver, 2017). Because of the non-linear nature of policy development, policy experts have argued that the “research-implementation” gap is not an accurate depiction of the problem, and instead that scientific research does not adequately address policy needs (Thornhill, 2014; Toomey et al., 2017). Conservation research is also often inaccessible to those who need it and rarely do scientists share findings beyond scientific publications, and much “conservation” research does not fit the framework that conservation occurs in (Cook et al., 2013; Fuller et al., 2014; D. Rose, 2015; Walsh et al., 2015). The focus on the “research-implementation gap” also ignores the fact that there is often only scientific evidence for the *problem*, not the *solution* (Cairney, 2016e).

4.1.2 Communicating Models

Communicating models is challenging as there is a lack of agreement about best practices for communicating models even *between* researchers. Individual-based models (IBMs) lack a consistent development, description, or analysis procedure (DeAngelis & Grimm, 2014), though guidelines have been published, such as the ODD (Grimm et al., 2006), TRACE methods (Grimm et al., 2014; Schmolke et al., 2010) and evaluation documentation methods (OPE; Planque et al., 2022) which are growing in popularity.

Communicating models outside the scientific community becomes more complex when there are competing models of the same issue, sometimes with conflicting results

(Mika & Newman, 2010) or when the "black box" nature of a model reduces perceived credibility (Cash et al., 2003). Unlike the ODD or TRACE methods, there is no broadly used or accepted procedure for communicating IBMs (or other complex models) to stakeholders or other audiences (Cartwright et al., 2016). This suggests that researchers are not communicating models in a consistent or systemic way to the public or policymakers.[15]

4.1.2.1 The Challenge of Complexity and Uncertainty

While policymakers often want scientific evidence (especially numbers), they can be confused by scientific uncertainty (Salajan et al., 2020). This may lead to scientists implying consensus and certainty (or lack thereof) within the scientific community when this is not the case (Cairney, 2016e). Notably, uncertainty is a fact of all models, including IBMs. If uncertainty is not communicated clearly, stakeholders can perceive uncertainty as an implication that the model is itself unreliable (Cartwright et al., 2016). Simply communicating the results of the models will not address this. Instead, scientists need to make it clear to policymakers that 'uncertainty' is a result of scientific unknowns, but that models can test a variety of potential variables (Cartwright et al., 2016). Scientists also need to be able to clarify what can be said, even with uncertainty (e.g., some conclusions can be disproven, even if others are unknown). Communication challenges magnify as the complexity of methods increase, making it challenging to establish not only understanding, but also trust in the model or researcher (Maeda et al., 2021).

Policymakers may misinterpret successful results from a policy as proof that they

[15] While communication strategies should center on the target audience (as highlighted by Cartwright et al. (2016), the lack of any systemic framework or guidance means it is not even standard practice for researchers to assess the needs of their audience before communicating. Any framework of model communication should incorporate guidelines for how to assess audience need and understanding.

understand the models used to inform that policy, when this may be not be the case (Setterfield, 2018). Models that are based on politicalized topics, such as climate change, may be distrusted, as media discourse (common in the United States at least) can impact the trust or distrust of model results along political party lines (Akerlof et al., 2012). Policymakers may uncritically accept preferred model outputs or uncritically disbelieve model outputs that are politically challenging (Cartwright et al., 2016). An added challenge with regard to IBMs is that, while a policymakers may achieve strong understanding of one IBM, IBMs are not universally similar, and each one can have dramatically different assumptions and internal mechanisms. This is less true for other commonly used modeling methods, which will often have similar or even identical assumptions across multiple models.

4.1.2.2 How are scientists trying to address the communication-gap?

From the majority of modeling papers, it's not often clear *if or how* the models are to be used in policy. For example, will the models rely on scientists to communicate the model results, or be will the model be implemented by conservation managers? Are the models meant to test the implementation of future policy, or are the models meant to serve as a tool to persuade policymakers in favor of certain policies[16] (Cairney & Oliver, 2017)?

Research has shown that understanding of policy theory can help researchers make progress advocating for their chosen issue (Weiner, 2011). However, most scientists are

[16] Researchers may wish to avoid admitting this outright, for fear of appearing biased, but such an intention can also impact model design, develop, and implementation. This is especially true when stakeholders themselves have had input in the model design or collaborative relationships with the researchers (Paolisso et al., 2015).

overwhelmingly ignorant about communication research or policy theory (Hayes et al., 2008) which poses a significant challenge to model communication, which requires clear and concise communication about complex topics (Cartwright et al., 2016).

Some researchers have argued that communication frameworks similar to public health can be used by conservationists when trying to advocate for policy (Pullin & Knight, 2003). Influencing policy also requires that research be “framed” in a politically-salient context (D. Rose, 2015). In other words, researchers should take advantage of relevant “policy windows”, i.e., a time period during which there is positive policymaker interest in an issue and it is therefore more feasible to advance a policy agenda successfully (Béland & Howlett, 2016; Perl et al., 2018).

Another issue is that many policymakers lack time and/or the ability to interpret scientific writing (Akerlof et al., 2018; N. Rose & Parsons, 2015) and standard model documentation may be both complex and time consuming to read. Although some researchers have provided guidance specifically for *policymakers*, to help them assess if a model’s output should be used for decision-making (Grimm et al., 2020).

While effectiveness of evidence and what should be considered “good evidence” is often debated, a stronger question might actually be “*how* policymakers actually use evidence” (Cairney, 2019, pg. 35) or even *if* policymakers want or will use evidence (Parsons et al., 2015). While ‘knowledge brokers’ or ‘boundary agents’ are often the individuals who translate evidence into policy (fluent in both languages; Reed & Meagher, 2019) in the case of IBMs, which are unique and complex, it may be more effective if IBM modelers act as their own knowledge brokers. Research has shown that the majority of models used in policy were only used because researchers specifically advocated for them (Will et al., 2021), highlighting the importance of modeler advocacy.

Enabling and incentivizing individuals, and providing instructions for individuals to play the knowledge-intermediary roles can create a two-way dialogue between researchers and stakeholders that can assist the development of evidence informed policy and practice (Reed & Meagher, 2019). This is the goal of this research.

Izumi et al. (2010) described how to craft an efficient one-page document (one-pager) to communicate scientific research for public health policy. This one-pager is a simple, easy to follow, but a standardized method of communication. The brief format is easy to skim, ensuring that information can be found quickly by the end users (policymakers). This specific one-pager method also ensures that, at the very least, contact information is preserved in the one-pager, serving as an informal citation. This study adapted the design described by Izumi et al. (2010) for communicating model results for marine policy.

4.1.3 Research Purpose

The Republic of Ireland is currently revaluating their marine protection policies (Marine Protected Area Advisory Group, 2020), the needed “policy window” for changes to basking shark conservation policy. Considering the time and attention given to basking sharks in Hebrides in recent years (Marine Scotland, 2020), it seems reasonable that policymakers will look closely at nearby Malin Head (a popular tourist location in in the Inishowen Peninsula), in order to assess if the sea around Malin Head is significant to basking sharks for similar social (perhaps reproduction) reasons. The IBM developed in

Chapter 2 has shed some light on the importance of the region, especially in combination with field research and tagged studies currently being conducted. This makes the model directly relevant to current policy.

This study also:

- Tested if the model described in Chapter 2 was useful for policy and if it answered the kinds of questions that policymakers in the area are asking.
- Assessed how policymakers interpret and implement the results from such an IBM.
- Assessed the level of trust policymakers have in an IBM.

4.2 METHODS

A one-pager document was written, highlighting preliminary results of the basking shark IBM (Chapter 2) and expert policy recommendations. The document was based on commonly used one-pagers from public health (Izumi et al., 2010). The guidelines of Izumi et al., were partially followed, with modifications. Izumi et al. (2010) recommends that a committee come up with key policy interests and that the committee consist of both researchers and impacted communities. A proper committee was not convened due to time constraints. However, the one-pager was reviewed by the Irish Basking Shark Group (IBSG), of which active members live and work in the relevant locale. Members of the IBSG were aware that this was a document meant to be used as an experimental example, in an interview setting, rather than as a true policy document.

The advice provided by Izumi et al. (2010) for verbally communicating the one-pager were not included in the study design, with interviews instead focusing on the more likely scenario of policymakers having received the one-pager in an email exchange or other form of digital/written communication. As this is meant to test the one-pager's usefulness as a method of sharing (unrequested) information for marine research, with a focus on model data, we felt it important to test the impact of the one-pager alone without an associated "elevator pitch" (a ~thirty second oral summary).

4.2.1 One-pager Design

The one-pager consisted of the following sections, based on recommendations from Izumi et al. (2010):

Policy Statement: One sentence overview of the main policy action required to address the issue of concern.

Partnership Overview: List of community and academic partners involved in the research.

Background: Provided key context to the policy statement and policy implications.

Research Findings: Described the research findings that directly relate to the policy statement and lead policymakers to the policy recommendations. This also included a very brief overview of the model method.

Policy Recommendations: A bulleted list of key policy recommendations, which resulted from the research findings.

Contact Information: Name, contact, and professional affiliation.

MARINE PROTECTED AREAS FOR BASKING SHARKS

Ireland is critical habitat for basking sharks, where they have been documented to gather in large groups. Such areas should be made marine protected areas as evidence suggests sharks are both breeding and feeding there.

Project Overview

This research was conducted between 2019-2022 by Chelsea Gray, a PhD Candidate from George Mason University, USA, in partnership with the Irish Basking Shark Group (IBSG).

Background: Basking sharks are endangered worldwide (IUCN) and were recently protected under the Wildlife Act of 1972 in Ireland. Now, attention will need to be paid to the habitat needs of basking sharks in conservation policy.

- Basking sharks gather in large groups in areas such as Achill, Cork, and Malin. The reasons for these aggregations are not well understood but is has been theorized that reproduction plays an important function.
- The seasonal availability of important, nutrient rich food which may also be important for basking sharks which undertake long, ocean-spanning winter migrations, though some sharks have been documented to remain all year in Ireland.
- Understanding the ecological significance of these aggregations and environmental conditions that cause them will allow Ireland to develop stronger conservation policy.
- Recent research has shown that basking sharks are also an untapped tourism market in some areas of Ireland, providing economic incentive to protect them.

Research Findings

- Results from an individual-based model (IBM) show that basking sharks gather in large aggregations around Malin Head for primarily social reasons, such as courtship or reproduction.
- The IBM is a simulation that incorporates zooplankton data from the Continuous Plankton Recorder from 1982 to 2019.
- The IBM allows for individual sharks to interact with a heterogenous environment, giving a more realistic simulation of shark behavior.
- Simulated aggregations were significantly more likely to match observations collected by the IBSG when sharks were initially drawn to areas where other sharks congregate than when they were simply seeking zooplankton. A minimum threshold of zooplankton was required to be met in the model, with social behavior following, indicating that food availability may be the initial draw but is not sufficient to explain these aggregations.
- When seen in conjunction with other research from Ireland, this indicates that aggregations are likely significant for *reproduction,* rather than food intake alone. However, high food availability may increase reproductive success. These findings agree with previous research.
- This model does not address what impacts climate change will have on shark behavior, food source, and migratory habits. However, if these areas are significant for reproduction, they will be vital for future climate resilience.

Policy Recommendations

- More research should be funded to understand the impact of climate change on migration patterns and food sources of basking sharks.
- Areas where aggregations occur, including, but not limited to, Malin Head, are vital for protecting and increasing the population of basking sharks in the North Atlantic and potentially worldwide. These should be investigated for potential MPA areas.
- Management measures to protect basking sharks within MPAs can be seasonal. Sharks are known to gather most often in spring and late summer but are not present in winter.
- Other protective policies should be put in place, such as boat speed limits (< 6 knots) in regions were basking sharks aggregate.

Contact Information

Chelsea Gray | Cgray21@gmu.edu | www.DivingwSharks.com
Irish Basking Shark Group | www.BaskingShark.ie

Preliminary findings. *Do not cite unless you contact the author for further information.*

Figure 22: The one-pager utilized in this study.
The one-pager is based on preliminary results from the IBM described in Chapter 2. Notably, there is a mistake in this document, as it should say Wildlife Act of 1976, but only one interviewee noticed this mistake.

4.2.1 Interview Strategy

This case study sought to understand a "common case", or "circumstances and conditions of an everyday situation" (Yin, 2014, pg. 52). While policy development isn't exactly a common everyday occurrence, the process of choosing appropriate evidence to inform policy development is an everyday occurrence for those who work in policy development. Due to time and monetary constraints, this research consisted of a single case study.

Cognitive interviews[17] were used to assess understanding of the model one-pager, and understanding of the model methods, reliability, and application. Cognitive interviews increase content validity by ensuring particular aspects of the interviewees experience are thoroughly understood (Knafl et al., 2007). They also allow for questions to be clarified, enhancing reliability (Knafl et al., 2007). Cognitive interviews are particularly beneficial to small scale studies, as questionnaires are subject to misinformation, and, in small case studies, misunderstandings can significantly skew results (Ryan et al., 2012). Finally, cognitive interviews allow for interviewers to understand the working memory, or 'thinking aloud', of the interviewees, something questionnaires do not allow for (Ryan et al., 2012). Cognitive interviews also allow for verbal probing, which will be used extensively in these interviews, although a hybrid model will be used (Ryan et al., 2012).

In-depth interviews were conducted at the same time as the cognitive interviews (These occurred consecutively in each interview but are being separated out in methods

[17] Cognitive interviewing is a method that seeks to understand how survey respondents mentally process and respond to survey questions ("Cognitive Interviewing," 2008).

descriptions for clarity). In-depth interviews allow researchers to get “deep” information, in this case, more clear information about the challenges and process of data collection and evaluation (Johnson, 2001).

The goal of this research was to identify a *range* of responses, so that the research can be used to inform modelers how to communicate with the diverse populations they may need to. Therefore, a range of interview types was more important than the number of interviews.

Semi-structured interviews were conducted, using an adaptive design (Yin, 2014). This means that questions were modified as needed in order to ask deeper questions when statements, ideas and other unexpected comments arose organically. Emergent concepts or themes influenced who to interview next and what questions to ask (Foley et al., 2021).

4.2.2 Interview Methods

Individuals were selected via snowball sampling, starting with professional connections from the Irish Basking Shark Group. Individuals with experience in midlevel environmental policy (i.e., carrying out policy and/or advising managers and lawmakers) were selected for interviews. Interviewees did not need to specialize in marine policy or science to be interviewed, just for marine-related issues to fall under the purview of their past or present policy experience.

All interviews were recorded on zoom, with auto-captions generated by zoom (but edited for accuracy). The average interview length was 55 minutes, with a minimum of 44 minutes and maximum of one hour and 16 minutes. The auto captions were anonymized, but transcripts are not provided in full as some statements, in the broader context, can reveal identifiable information. Zoom recordings were deleted following data analysis, for privacy reasons. Interviewees were assigned pseudonyms that bore no relation to their age, ethnicity, or personality characteristics. While there is literature on the sociocultural importance of selecting pseudonyms for both the interviewee and interviewer (Allen & Wiles, 2016), all pseudonyms were randomly chosen from TG4's *Ros na Rún* in order to ensure anonymity, due to the close-knit nature of marine research and policy in the North Atlantic. Pseudonyms that reflected the interviewees may have made them identifiable to colleagues. Pseudonyms were chosen over numbers or letters to increase readability. They bear no relation to the interviewees.

All interview subjects were emailed the one-pager (Figure 22) at least 24 hours prior to the interview (subjects were emailed on Friday if the meeting was on Monday). They were told "I have attached a sample one-pager, which we will discuss in the interview. You are welcome to look over it ahead of time, but not obligated to do so." They were given this option in order to simulate a real-world scenario, where they are often presented information on short notice, without much chance to review. During the interview, interviewees were asked to summarize the one-pager. They were allowed to review it beforehand and to look over it while summarizing. These summaries were assessed for key points (i.e., what did they feel were the important parts) as well as ease of understanding. It was also noted if interviewees included the model method in their summary.

Interviewees were asked how they felt about the one-pager, and what they liked or didn't like. They were asked if they trusted the information within the one-pager, and why. They were asked also if they had ever seen or used this format of communication tool before and if they would like to receive further information in this manner. They were also asked if/how they might use the one-pager, if the topics in the one-pager fell under their jurisdiction, or hypothetically, if they had received a similar document relevant to their work.

Interviewees were also asked to define both "evidence-based policy" and the term "model". They were asked questions about how they find evidence, what disqualifies or qualifies evidence for use in policy and how they determined reliability of evidence. These questions were also posed in the context of modelling, specifically. Interviewees were told they could decline to answer any question for any reason.

Interview questions and methods were approved by Institutional Review Board at George Mason University. See Appendix C.1 for the Case Study Protocol and Appendix D for full list of interview questions.

4.2.2.1 Data Analysis

This case study was descriptive and meant to shed light on the research questions. The interviews were analyzed for overarching themes and whether recipients correctly understood the one-pager. Grounded theory, which allows for questioning, rather than hypothesis testing or measuring (Auerbach & Silverstein, 2003), and is best used with small sample sizes, was used for data analysis (Deterding & Waters, 2021). Theoretical coding was then used to answer research questions and identify themes generated during the course of data analysis (Auerbach & Silverstein, 2003).

There were no assumptions about the framework (i.e., the mental model) followed by the interviewed policymakers. Instead, the framework that the subjects followed was identified as this study sought to understand the perspective of the interviewed policymakers, rather than fit them into a predetermined paradigm (Mayan, 2016). Manifest content analysis (identifying what the interviewees explicitly expressed) was used to identify common ideas (i.e., statements around reliability of some evidence over others) and latent content analysis (identifying the implied meaning of what was said by interviewees, i.e., distrust of science) was used to delve more deeply into these common themes (Mayan, 2016). A matrix of categories that encompassed all the major themes (headings and subheadings in the results section) was created, and evidence from the transcripts were categorized into each theme during data analysis (Yin, 2014).

In the interview transcripts, ellipsis were used to denote deleted sentences or words (not repeated words) and em dashes were used to denote pauses. Verbal tics (Um's, like's, stuttering, excess repeated words) were removed for readability (Corden & Sainsbury, 2006; Thorne, 2020).

4.3 RESULTS

Eighteen individuals were contacted, with nine agreeing to be interviewed. Interview subjects consisted of individuals involved in the policy development or policymaking process in The Republic of Ireland, Northern Ireland, Scotland, and the Isle of Man. They worked at 'environmental' or 'environment and anthropogenic' agencies, environmental non-governmental organization (NGOs), and as researchers, who also served on advisory panels (Table 30). A distinction was made between 'environmental agencies', which have conservation as a sole focus, and 'environmental and anthropogenic agencies', which may include conservation, but also participate in policy issues related to recreation or exploitation of natural resources (i.e. fishing).

4.3.1 Overview of the Background of Each Interviewee

The interviewees were categorized into NGOs, agency work, and academic. For the purposes of this research, the definition of policymaker was used loosely, to refer to anyone who provides policy guidance for governmental work. All interviewees worked at the mid-level of policy development (informing and/or influencing the implementation of policy, making recommendations and/or alterations to already existing policy). Although some individuals may have been at a high level in their particular agency or department, they were not high up in the overall policy process. No one worked at the 'ground' level (i.e., developing new policy proposals) or the 'top' level (i.e., writing or voting on new policy).

4.3.1.1 NGO Interviewees

Laoise's work centers mostly on national policy. She works very closely with government agencies (consultations and task forces) and helps with conservation strategy. Her work encompasses a wide breadth of policy, from climate, to development, to fisheries.

Berni currently works as a science communicator at her NGO, where she uses conflict management to address conservation efforts, such as fisheries and aquaculture. She therefore has experience with stakeholder engagement. She also has experience writing policy recommendations, as well as community engagement and outreach.

Table 30: Job and Educational Level of Interviewees

Pseudonym	Agency	Job Level	Educational Level
Laoise	NGO	Midlevel	Masters, Ecology/Conservation
Berni	NGO	Midlevel	PhD, Conservation Conflict
Mack	Government Environmental Agency	High level	PhD, Marine Science
Vince	Government Environmental & Anthropogenic Agency	Senior	PhD, Marine Science
Colm	Government Environmental & Anthropogenic Agency	High level	PhD, Marine Science
Jason	Government Environmental & Anthropogenic Agency	Senior	Degree (unspecified level), Zoology
Briain	Government Environmental Agency	Midlevel	PhD, Marine Science
Peadar	Academic	Professor	PhD, Evolutionary Biology
Tadgh	Academic	Professor	PhD, Unspecified

Nine out of eighteen individuals agreed to be interviewed. Individuals were contacted via snowball sampling from professional contacts supplied by the Irish Basking Shark Group. Seven interviewees were male and two interviewees were female. Pseudonyms were used to improve readability of the interview text and were randomly chosen. They do not reflect any characteristics of the interviewees.

Table 31: Location of and Type of Job Held by Interviewee at Time of Interview

Agency	Number of Interviewees
NGO	2
Government Enviro Agency	2
Government Enviro/Anthropogenic Agency	3
Academic	2
Job Level	
Senior	2
High Level	2
Midlevel	3
Professor	2
Country	
Ireland	3
Northern Ireland	2
Scotland	3
Isle of Man	1

Government agencies centered solely on environmental concerns were separated out from those that also look at human interests (i.e. fisheries). Senior job levels were determined by those with "senior" in their job title, while jobs were categorized as "high level" if the individual served any sort of supervisory role. Midlevel jobs were all other jobs, with the exception of professor, which was categorized separately. Job level was assessed only for current, primary employment, though interviewees often discussed prior jobs or previous professional experiences.

4.3.1.2 Agency Interviewees

Mack works on national marine conservation policy. He is often tasked with creating conservation strategies, including fisheries management and protected areas. His job includes conducting scientific research related to policy (i.e. monitoring programs) as well as stakeholder engagement and policy-related consultations.

Vince engages with stakeholders and deals with a diverse array of conservation issues. His agency also does applied research, including for fisheries management and management of protected areas.

Colm’s main job is implementation of governmental policies. His agency does environmental monitoring in order to provide status assessments and fill in knowledge gaps. He works with other government agencies and departments to improve or maintain the environmental status of marine areas, meaning he will address issues such as fisheries and runoff pollution. He also contributes to international policies and agreements as parts of his work.

Jason’s work relates heavily to fisheries. His agency will conduct surveys and determine the ecology and distribution of valuable species. His personal work often involves management of people and administration work. The main goal of his agency is to provide evidence for use in policy (applied research). His agency will work with different agencies and academic institutions, as well as work with environmental authorities. Occasionally, Jason will work with international partners, but only in relation to internationally shared resources.

Briain’s work involves implementing national policies and international agreements. Briain’s agency conducts routine monitoring of species and habitats (as directed by law), but his agency can be involved with case building in order to advocate for a policy.

4.3.1.3 Academic Interviewees

Peadar was an outlier with regard to interviewees, as he did not directly engage with policymakers or stakeholders. Based on his publication list and CV, he appeared to meet the requirements for this research, but upon interviewing, it was determined that this was not the case (See Appendix C.2 for Interview Criteria). However, he has been kept in to provide a unique “other side” view. Peadar is an academic, whose work focuses specifically on modeling. He models both ecological and social science questions (often combining the two). His publication list included research on stakeholder involvement, however Peadar does not actively engage with stakeholders (although he has witnessed this during collaborative research), instead he partners with colleagues for this aspect of his work. He has however crafted ecological models at the specific request of a local agency and participated in policy discussions there, making him slightly within the purview of this research.

4.3.1.3.1 Unique NGO/Academic

Tadgh was another outlier. His work was unique amongst all the interviewees. Whilst an academic, whose research involves complex modeling, Tadgh volunteers as part of an international “boundary organization”, in this case an NGO that receives information requests and creates task forces to collate and summarize the research (most requests are policy-related). This NGO does not conduct independent research or lobby.

The NGO in question follows an ethical framework, and has a methods expert group, a knowledge coordination body, and a management body. Scientists are able to join the NGO and contribute their expertise in different capacities based on their skillsets.

The NGO does not lobby for policies, but instead strives to facilitate knowledge sharing in a transparent way (Appendix E.1)

The NGO follows a very specific framework, where:

1. Information requests are put in by governments, agencies, and/or companies.
2. The NGO creates a working group on the topic.

3. The NGO puts out a call for experts/individuals to submit information related to the knowledge request.
4. The working group sifts through the submitted information.
5. A report is compiled for the requester. The report will include information on the limitations of the data. The report will also include how the evidence *could* be used for policy (but does not advocate for a specific policy).

4.3.2 Evidence-based Policy

When asked to define “evidence-based policy” (EBP), none of the interviewee described a linear method of evidence to policy (i.e. research informing policy in a linear fashion; Toomey et al., 2017). Most described something that aligned with multiple streams analysis (Chow, 2014; Kingdon, 1984; Weiner, 2011). Many identified that policymaking is divided up into the problem stream (problems the public views as something the government should solve), policy stream (policy solutions proposed by experts), and political stream (factors influencing the implementation of policy, including public support, political turnover, and special interest lobbying) (Béland & Howlett, 2016; Kingdon, 1984), even if they did not use those words themselves. Interviewees described using science to identify or understand problems but noted that the policy and political streams had a significant impact on their work.

For their definitions, everyone highlighted scientific evidence as the key to EBP, along with non-biased evidence and transparency of evidence as a secondary, but a nonetheless important, component. Whilst only a few described the importance of a “policy window” explicitly, most noted the importance of relationship building for effective policy development. Policy windows are notably unpredictable, and therefore long-term relationship building may be required to be able to influence policy during a period where the "window" is open, when the three streams align, and a solution to the identified problem can be solved with a politically viable policy (Béland & Howlett, 2016), something most interviewees intuitively understood.

4.3.2.1 Robust Evidence as the Base of EBP

The majority of the interviewees stated that the basis of evidence-based policy (EBP) was "robust", "credible" or the "best" scientific evidence, with almost half of the interviews (Berni, Vince, Colm and Tadgh) also including traditional and local ecological knowledge[18] in their definition of "evidence" (See Appendix E.2 for all definitions of EBP).

> *Berni: So, evidence-based policy is, to put it very simplistically, is policy that is derived directly from a scientific evidence space, or…From my perspective, it's typically used to reference policy that is derived from science, specifically. But I also think that we should also include local knowledge into that as a form of evidence as well. So yeah, policy that comes from a robust evidence space.*

Notably, Berni's definition contrasts what she considers the generally accepted definition of evidence-based policy and what she thinks it *should* include. Colm raised similar points:

[18] "Indigenous", "local", "cultural knowledge" and/or "stakeholder" expertise (Berni, Mack, Vince, Jason, Briain, Tadgh)

> *Essentially, it's the use of scientific evidence. But also in certain cases other levels of knowledge. It might be traditional or local knowledge. It might be indigenous knowledge, for example, in helping to shape what we want to do for the for the environment. So, I mean, policy is... what does government want to do? And, so, it's, drawing the information strands together, and then, you know, setting up options for government ministers and cabinet to make decisions on what we want to do.*

Colm noted the complexity of governance, and the competing interests of different agents within the system. Briain differentiated 'evidence-based policy' from simply 'policy':

> *I think [evidence-based policy is] probably more reliant on science than it is on maybe external factors. A lot of policy puts equal weight on stakeholder involvement and the scientific drivers for developing a policy. I would imagine evidence-based policy and development will be more likely to exclude some of the stakeholder feelings or "there might be loss of income possibly" or things like that.*

Vince was the only interviewee who, in his very definition of EBP, included communication as a key aspect:

> *I think it's basically using data… as applied to a specific problem, or to justify policy and predict outcomes and expectations of what it is that you're doing…but also a mechanism of collecting those data, [and] presenting it in a way that people understand.*

Tadgh displayed the most nuanced of understanding of EBP and included a definition of a policy window (Cairney, 2016e) and the multiple streams framework of policy development (Kingdon, 1984):

For me the term can be quite strong because it says evidence-based policy, and I think that that can be very strong in the way that we are using evidence. That is, I would often connect the scientific evidence to base our policy on, whereas I think there is a bit of a discussion that in evidence, in full policy— because I think that there is a bit of an issue still, that when we collect this evidence, how is that translated into policy? And that's where evidence-based policy might be really difficult, because there might be lots of other things that play a part, whether that is something political or there could be budget constraints, or — not everything is directly based on evidence, but more often kind of informed by it. So sometimes I think that can be a bit strict in the way that it doesn't always necessarily benefit the system or the decisions that are made.

Notably, Tadgh highlighted the multifaceted pressures of policymaking, including political and budgetary constraints. He noted that evidence is not always the *base* of policy, but instead supplementary, something that can improve or impact policy within the confines of other political concerns. Tadgh also succinctly described a policy window and its importance. Upon reviewing the one-pager, he stated:

I think your intention is good, but just producing [a one-pager], I don't think they'll get us anywhere unless they are targeted at a very specific group at a very specific time, that fits in with the kind of policy cycle they are in, and the policy needs they have.

4.3.3 Evidence

Evidence collection, for informing EBP, was a constant challenge for the interviewees, who described having to find up-to-date evidence and having to ensure that the evidence is reliable. They also highlighted the challenges of finding sufficient evidence for "data deficient"[19] species, a challenge common in marine policy.

4.3.3.1 Locating Evidence

Many of the methods used to locate evidence described by interviewees were ad hoc and not systematic. The majority of interviewees stated that they relied quite heavily on peer-reviewed literature reviews (something reflected in previous research; Pullin & Knight, 2003) and search engines, such as Google Scholar. Only Berni kept personal notes regarding reliable or unreliable sources, which she did not share with colleagues. Interviewees also noted that the marine science community in the North Atlantic is quite small, therefore they are often able to locate a person with relevant expertise through personal or professional connections — an avenue both used to find and vet evidence.

Several interviewees highlighted that they had formal professional connections or partnerships with research agencies and academic institutions. Vince also used professional societies centered around species of interest to his work.

Only Berni and Mack stated that they received unsolicited scientific research papers.

Those interviewees who worked with government agencies also conducted their own research and synthesized research from other agencies, in combination with reviewing external evidence. Academics also conducted their own research, which often had policy

[19] Data deficient species lack sufficient evidence to assess its extinction risk, but policymakers can misinterpret this to mean species of "least concern", which is often not the case (Parsons, 2016).

implications due to their research focus and/or collaborative relationships (i.e., with agencies or politically engaged colleagues).

4.3.3.2 Ensuring Quality and Unbiased Data

Interviewees had different methods of ensuring that they found reliable, quality data in an unbiased manner. Vince relied heavily on post-doctoral researchers to conduct literature reviews. Colm noted that he felt "responsible" for utilizing the most up-to-date research and technology, whilst still ensuring his research methods were not biased:

> *I suppose there's a responsibility on us as policymakers to try to capture the state of the art in terms of, or the state of knowledge, in a way that doesn't introduce bias.*

While many interviewees described a desire to avoid bias, Colm was the only interviewee who actively read research on the issue of non-biased review methods:

> *There's a paper I can send you which I just got this morning from [colleague], which I'm going to read [soon]…But it talks about that type of systematic approach to compiling information.*

Tadgh described the most systematic and transparent method of evidence location. Tadgh's membership of a boundary organization meant that the method of evidence selection followed a consistent and unique protocol, where the NGO puts out a call for information related to the research topic. These calls are placed in listservs, online (websites, social media) and through snowball sampling. The NGO then accepts any/all data submitted, which is then synthesized, assessed for quality, and summarized by a volunteer group of experts. Tadgh made a point to note that *all* of the submitted evidence is read, including non-formal submissions, such as anecdotal reports (they will follow up anecdotal data with interviews or other methods of quality assessment). The reports that summarize the data make explicitly clear the limitations of each methodology and the potential impacts of these biases on the data:

> *Tadgh: I will say it will come with that stamp of that method, that the method can be biased towards the perception of the experts that were involved. But that is publicly available and transparent. How this knowledge was acquired, and the kind of warning- maybe it's [the] wrong word. But like the caveat of that method being problematic in terms of bias.*

Every interviewee described a desire to locate diverse, unbiased, accurate and reliable evidence, from any sources at their disposal. Several, however, also highlighted challenges to that goal.

4.3.3.3 Challenges to Finding Evidence

The most cited challenge to locating evidence was simply "time", something everyone noted that they were short of (Table 32).

The sheer amount of evidence and diverse ways of finding evidence was highlighted as a challenge by Laoise:

> *I think there's so many ways to share information now. It's almost [about] not being overwhelmed. I don't think it's through the lack of not having enough places to share information. It's too much, that people are missing certain venues [Twitter, email, in-person meetings]…and it gets a bit complicated to stay on top of it all.*

Berni also noted that science, especially marine science, is often rapidly changing, so it can be challenging to stay up to date.

Table 32: Top Challenges to Finding Evidence Identified by Interviewees

Time
Volume of research available
Methods of communication
Timing mismatch between researchers & policymakers
Difficult to stay up to date

The top reasons that interviewees cited as a challenge to finding evidence for use in policy development.

Another challenge was the well-documented timing mismatch between policymakers and scientists, which was described by some interviewees (Berni, Tadgh, and Jason). Notably, that science simply works at a slower pace than policymakers want, something well documented in the literature (Cairney, 2016e).

Tadgh noted that due to the specific framework of his NGO, time and trouble were saved by bringing together diverse experts at the start, when a request is made, to address this issue of timing mismatch:

> *Before I joined organizations, these consulta[tion] kind of requests, they came at the totally wrong time of year, very short term, you constantly have to monitor it. So, it's much better to be a bit organized, set aside, maybe 10 or 20% of your time, and say, 'okay, I'm going to join this policy group' or 'I made my time available to this in this Government department so that they contact me when they need [me]... when they have their policies.'*

4.3.3.4 Policy Development with Limited Data

Contrary to the problem of *too much data*, there is also the issue of limited data. Several interviewees described the challenge of making policy with limited data.

> *Laoise: Our evidence base is really, really low for our local species. So, having conversed with [government agency that Laoise's NGO frequently works with] on that and some of the other industries, we're finding it quite challenging to lay down the exact specific management measures. Is it going to be species specific? Do we need some kind of wider, ecosystem-based management for these species? but because we don't have that baseline data, for [agency], they're finding that quite difficult, because...you're kind of required to lead with evidence that way, for an evidence-based policy….and I guess it applies to the NGOs as well. Like [other NGO]… they will only support a specific stance if it's got that scientific evidence base behind it.*

Vince described the importance of governmental agencies in retaining contacts with scientific experts, as governments are often unable to conduct the necessary research to inform policy. Vince described contracting or partnering with multiple labs, research organizations and citizen science initiatives:

> *I think if the world was a perfect place…we'd be able to survey and collect all the evidence that we needed. But it frankly, as time, money, people, it just doesn't happen...particularly in a smaller jurisdiction…. We certainly can't do it….governments…especially small governments, are not science-based organizations, so they frequently contract out. What we've done is [contract with a lab]…we will also fund, for example, the fishing industry to undertake surveys that are a benefit to them, and then we help create the data. We use it for the management of*

> *[species-specific fishery]…. But we'll absolutely take information on data from any source that we can. Where it's critical we will specifically fund it usually as part of a longer-term program.*

Jason expanded his definition of evidence-based policy to address the limitations, but highlighted the competence and expertise of managers who have to be adaptable in areas of low-evidence:

> *I think managers will make decisions, as I said earlier, based on whatever is available….maybe then a quick analysis based on their goals, let's say, and what they would have experienced, as maybe younger staff members, [what they] observed on the ground in their area, or feeling, perhaps…So managers have to manage, and I would accept that, and they make the best decision with the available information that they have. It may not be evidence, but it is probably grounded in a certain amount of sensibility.*

Many interviewees also described the challenges of working with limited, or non-comparable data sets. For example, Briain described the challenge of working with data sets that were outdated or collected in non-systemic ways:

> *Almost every data set will have some sort of caveat on it and it becomes very difficult for you to let those data sets communicate with each other with accuracy, if they're not collected with the same standard methods. That would be something we'd be concerned about when we were collecting, when we were designing a protocol, particularly for monitoring. We try to be as consistent as possible with... the methods we produce.*

4.3.3.5 Qualifying Versus Disqualifying Evidence

When asked to describe the type of evidence that was "reliable" for evidence-based policy, many interviewees listed various methods of research. Vince noted that evidence is both "qualitative [and] quantitative data" (as already described, non-scientific data was still considered reliable). Many relied heavily on the scientific method as a proxy for determining which evidence is reliable.

Those who worked at government agencies also conducted their own research (generally, routine monitoring) through which they were able to personally assure quality and reliability. When they could not conduct research directly (i.e., due to a lack of time, personnel and/or funding), necessary research was done via third party contract work. Mack and Vince described funding necessary research via third party contracted work. Mack noted that out of necessity (i.e., lack of time), he must trust that they have selected qualified candidates for such projects:

> *If the reports…that are being put forward for policy recommendations are based off, you know, inaccurate or not the best models available, then, yeah… it might end up telling a completely different story…we kind of trust that, as policy people, that those issues have been ironed out during whatever the scientific process is. A lot of the time it's us that's funding it. So, we will fund a project, say, for a year, and we have to trust that the people we have paid to do this work have taken all the right steps to be as impartial as they can.*
>
> ***Interviewer: So, from the policy end, you're really relying on the peer-review process and quality assurance process?***

Mack: Yeah, yeah, I mean, from time to time you get people like me who have c[o]me through the science side. And just, we know what happens in the background… once it hits our desk we have to have confidence that those issues have been accounted for, and that this is the best available piece of work that that institute could have done in this space of time we gave them.

Mack also noted that his science background allowed him to view research with a more critical eye, even though he may not be able to assess individual evidence himself.

Most of the interviewees described a nuanced understanding of the limitations of peer-review. In his work with the NGO, Tadgh addressed this most directly, stating that the "caveats" and "bias" of each method were made explicit in final reports. Whilst many other interviewees described an understanding of the impact methods can have on results, only Tadgh had a standardized method of disclosing limitations when doing policy advisory work, as is the standard practice of his NGO.

4.3.3.5.1 Perception of Reliability

According to many interviews, a notable challenge to evidence selection for policy had nothing to do with the quality of evidence itself, but rather with the way the evidence would be perceived by specific audiences, namely policymakers and/or stakeholders. Briain, while he had no personal opposition to modeling, noted that he rarely used it to justify or inform management decisions:

Modeling can introduce debate the thing, and any model has a degree of confidence in it. You know we will always have confidence intervals that [are] at one range or another, and depending on if they were extremely tight, maybe you'd say, "Well, there's no there's no debate there," but…

if somebody can introduce doubt into a process, then that becomes more difficult for us to implement the policy.

Interviewer: When you're talking about introducing doubt, do you mean not necessarily like scientific doubt on the methods, but really from a conflicting political or—?

Briain: Yeah, but maybe both, because I guess…[if] The science is robust, and it probably is of the best standard, anyway, and how you would derive the model is likely to be done in the best way you could do that. But when you don't have certainty, people can come in and they can refute the evidence that you have to an extent.

The lack of certainty, I think, is the thing that…could be influential for people who are non-expert[s] in the field. So, if you're dealing with politicians, they don't necessarily understand the nuances of having a high degree of confidence in, let's say, a model rather than direct observation. Direct observation is easier to explain to somebody who doesn't have a scientific background.

Vince described challenges similar to both Briain and Mack, with local fisheries representatives not trusting specific models. Initially, Vince's agency collected data, which they used to inform the models. In response to distrust, his agency allowed fishers to observe the data collection, which still did not adequately increase trust between agency and fisheries. Tather than disregard the modeling methods themselves, Vince's agency utilized industry-based surveys for model input and development. This took more trust-building and effort to create an established relationship. As Vince described:

Hence we ended up with industry surveys. So, they were more confident in the data. And so, the two sets of data are the scien[tists'] data and *there's the industry[‘s data]. All of it's coordinated and looked at and then stuck in a big pile, and it's used in various ways. But it still requires people to a believe in the data and believe in the output, and if either of those things don't match up, then they say: “Well, it's rubbish. What's the point?”*

.....

Interviewer: Does it seem like there's [been] an increase in confidence with model results now [that you have collaborated with the fishing industry]?

Vince: [pause] Yes. [pause] I hesitate a little bit, because when it was only researcher derived data and the opportunity for fishermen to go and have a look at it being collected was fine, but there's always a criticism: “They don't know what they're doing” or “the boat is too big or too clunky” or “you fish in the wrong place”. So, it improved by allowing fishermen to collect data, definitely.

Vince’s final point was another key aspect of evidence-based policy, as described by many of the interviewees. That of trust between policymakers and stakeholders. Trust wasn’t based on the reliability of the science. “Belief” in the reliability of the research backing a policy was a key talking point of many interviewees. This was achieved through collaboration and transparency of information, including data collection. A reduction of (perceived) uncertainty was also achieved via collaboration.

Mack described a similar situation of policy-industry collaboration, which resulted in increased trust and better management:

We had originally proposed almost like a square box going, "This is the MPA [marine protected area]. This is where it's being closed." The fishermen themselves came and said "Look, there's a deep-water channel that runs in the middle of your polygon. That is the main area we fish, and it [isn't] affected by all the conservation features that you've outlined for the site, so could you split your big square into a couple of smaller polygons of protected areas and allow us to fish." So, we went and we did a survey ourselves, based on the [fishermen's] anecdotal evidence. And sure enough, we find that there wasn't really much [species of conservation concern in the channel area]… We actually could take on board what they said. So, we actually disqualified a lot of sea area from our designation based on the feedback from the fishermen. So, the fisherman actually were quite happy that their ideas [were listened to and] they're still allowed to fish, and we [were] able to shift where that MPA was [located] around their suggestions.

4.3.3.5.2 Disqualification

While most of the interviewees were able to confidently list research methods or data types they considered reliable, ranging from scientific research to localized, experiential knowledge, most struggled with a definition of what they would consider unreliable, though "opinions" and "hearsay" were cited as disqualifying by their nature (Berni, Jason, Peadar, Tadgh). Generally, the definition of "unreliable" evidence was contingent on the methods themselves. This sentiment was shared by every interviewee.

Interviewer: Are there any factors that would disqualify something from being used as evidence? I know you talked about quality assessment, so what would make something fail a quality assessment?

Mack: Say it was something that needed a repeat analysis or a random design. So, if the design, first of all, hadn't been set up right… It's not representative of the site. So, it has to be proportional to the decision that we're trying to make.

Another disqualifying factor for evidence was not related to the quality of evidence, but rather the policy question at hand:

Colm: I suppose it's very much down to the policy need. And as I said, the objective of the of the work, the whole process of elimination of certain types of information and/or not- as the case may be— how you select and how you try to avoid bias and the selection of information. So, I think it depends very much, really on the objective of the work. From our perspective, we would seek to be objective as far as humanly possible.

Another key factor that, while not outrightly disqualifying evidence, could reduce the perception of reliability of the data, is the author of the information itself and their potential allegiance. Jason described the challenges of industry funded "research", which hid or ignored evidence that was inconvenient:

The impact of [species a] on [species b] [is] often ignored by [industry]. Here [in the management area, where industry supplies evidence] either [species a] has no effect or is pretty benign. [However] we have strong evidence to show the opposite. And again, depending on the reporter, you get the story that fits the bill… To be honest, we've rarely seen a document that would give both sides of the argument…

Interviewer: Do you think that that's a result [of] an intentional ignoring of inconvenient information? Or do you think that that's maybe just a result of an unintentional bias?

Jason: ...I think, it comes back to the original point about the provenance of the document, and of the individuals involved, in terms of who is covering their costs, let's say.

However, Jason didn't think that this was a net-negative, but rather a challenge that is overcome by the policy process itself:

I think, that on the policy side of things, well, there would be consultants involved as well, but generally they're [about] conservation as opposed to development. So, if they're developing policy... whereas the other documents [industry evidence] we're referring to would be in in support of planning [development]. So, I think the policy side for fisheries management for conservation [is] probably delivered by neutrals. Well, maybe I'm being optimistic here, but I would have hoped that it would be delivered by 'neutrals.'

4.3.3.6 Transparency of Evidence

Berni noted a challenge between her desire to cite everything, and the limitations imposed by communicating to policymakers, stemming from her scientific background. Her personal compromise was to ensure that "big statements" contain a citation. She described the limitations imposed by word limits for policy documents and communication as a particular challenge when it comes to citations.

Mack highlighted that he had to be able to transparently support his decision-making process, as did those in his agency:

For us, we have to stand over everything that we decide on. The fishing industry really holds us to account on that because anything they don't like, they really stress… "what evidence did you use to come up with this decision? On what evidence?" And they seem to think that… we are making decisions on a single point of evidence whenever we try and get as broad of a spectrum as possible... For us, it is definitely: How many sources we can find? But it's not just the number of sources, is it reliable sources? Or is it peer reviewed [or] has a Q. A. [quality assurance]? Is it from a company or a source that we have used before, and can stand [by] their data? And we always have to have that evidence trail backing up any decisions we make.

Tadgh's NGO utilized a systemic approach to knowledge collection, and in doing so produced a very transparent method of data analysis/collection (See Section 4.3.3.2 and Appendix E.1).

4.3.4 Connecting Evidence to Policy

Laoise and Tadgh described the challenges of connecting evidence to policymaking. As Tadgh stated:

I think there is a bit of a discussion, that in evidence, in full policy (because I think that here is a bit of an issue still) that when we collect this evidence, how is that translated into policy? And that's where evidence-based policy might be really difficult, because there might be lots of other things that play a part: Whether that is something political or there could be budget constraints. Not everything is directly based on evidence, but more often kind of informed by it.

Laoise described how challenging it was to translate model results to policy, noting that additional training would assist:

> *When I'm looking at [models] and trying to take whatever the research is, whatever the results being modeled, or whatever techniques being used, and then trying to filter that into some sort of recommendation for policy— But yeah, it's not something that I have the greatest expertise with. So, if there was some... kind of... quick workshop on that, or something that would maybe be really useful.*

4.3.5 Communication & Stakeholder Involvement

Mack, Vine, and Colm described stakeholder involvement as a key component of their work, while they, along with Briain, also described the importance of communication and trust between stakeholders and government. Colm, Jason, Briain, and Tadgh went onto describe public pressure and policy challenges. Peadar described involving stakeholders in research, although he relied heavily on colleagues for that (see section 4.3.7 *Diversity of Expertise*).

While Vince was the only interviewee who included communication in his direct definition of "evidence-based policy", most other interviewees discussed the importance of this throughout the interviews. Often, however, they made distinctions between the challenges of communicating with *policymakers*, *stakeholders*, and the *public*.

4.3.5.1 Policymakers

When it came to policy, Berni made a point that you should ensure the policy recommendations are being interpreted correctly:

> *I think when it comes to when you influence some policy (and we're talking about evidence-based policy specifically), you want to make sure that the information that you're giving to those policymakers cannot be taken in any other way than [in] the way that you've presented it, right?*

Because you want the policy to be reflective of the evidence. So, for me, that's a really integral part.

Laoise noted that unclear communication doesn't help policy. For example, frequently scientists present their information but do not have a clear conclusion, or "ask" for the policymakers at the end of their presentation:

> *If it is coming from a research perspective, there's different objectives…. If we work with researchers say — and we have worked with researchers— and they've given us the presentation of an incredible piece of work they're doing…. and then we'll ask them, "What would you want to see done in policy, to make sure this work continues?" And sometimes… that hasn't been a thought [for them]… Sometimes it's something as simple as just more funding to continue this work.... [But] Trying to pick out or to understand what would be helpful [for researchers], it can be more time consuming, if [policy goals are] not outlined quickly. That's always what we're looking for, just clear, straight conclusions.*

Similarly, Vince highlighted the need to not only collect quality data, but present it "properly and clearly" because in doing so:

> *It's very hard [for people] to dispute [the evidence], just because [they] don't like it. You know, political, false truth: "I don't like the result; therefore, I contest it." You know, [people asking], "Where's your evidence?"... But I can show you where this stuff is. It exists. Which gets back to properly planning your data collection and your methodology.*

4.3.5.2 Stakeholders

When it came to communication with stakeholders, interviewees frequently described a need to market ideas. Vince described effective collaboration with industry:

> *If you look at what the [conservation] threats are, then fisheries is obviously one of them, and unless you manage it holistically — you can't manage conservation and fisheries, as separate entities…*
>
> *We interact quite closely with industry. And we get much, much better results by using marine protected areas to benefit the fisheries, because then they're more compliant and cooperative. It comes to saying, "Well, you know, you don't need to fish everywhere. You can fish in this bit, and the bit you don't fish is actually having a benefit." That and [the] actual application of the science, you need the results, obviously. Rather than it being a schism between the two components — actually applying it to people's livelihoods, I think, is the way to go because... then it gets everyone on board with you.*

For Vince, he felt it was a workable and useful strategy to market conservation as beneficial to industry. Briain also noted that he had to "sell the message" to the stakeholder, especially for issues that are unclear or have limited data. He described a need to appear "reasonable" and to advocate for policies that will seem practical to stakeholders:

> *We try our best [to apply the precautionary principle], and we do try to have best practices. We want to offer good protection, but also [conservation effort] that is practical for people. We don't want to just close everything off because that [conservation measure then] becomes subject to debate. So, if you seem to be reasonable [about] it, [about] what people want to [do], then that will be an advantage.*

I think what we would always try and do is [to] sell the message to, let's say, a stakeholder, that if you don't apply the precautionary principle, then there's a risk for you in not applying it. That you could be seen to be damaging this feature for the majority of the species that we're protecting.

People really would be very reluctant to have an impact on those species, because you know, [on the] PR side of things, it would be very bad if you're… conducting seismic surveys for oil and gas, and all of a sudden, you know, a hundred pilot whales wash up on the shore. The finger is going to point to you straight away, so at least what we have to say, "I was able to do everything… I was applying everything we were asked to do by the regulator", so they generally don't push back very much. So that's the way... we want to infer as well. We ought to be overly precautionary, but we [also] do want to give the appropriate conservation measures to those species.

Interviewer: Do you find that getting that stakeholder support is really important for impactful policy?

Briain: Yeah. Well, government policy can't be just a one-way street. You have to have a discussion with the people who are going to be impacted by [it]. If you don't, then they won't either won't buy into it, or grow and resist it, or won't do it… So, if you don't get them to buy into it, then there isn't really much point in doing it [the conservation action].

In Briain's experience, public opinion impacted not just policy, but also industry, a fact that could be leveraged by policymakers. He also noted that a lack of collaboration or 'buy-in' can result in failure of a policy. Briain's experience was reflective of other interviewees, who also described the impact of public, rather than stakeholder, pressure on policymaking. For example, Colm felt that public were the "customers" of his work:

> *It's definitely a challenge… It depends on the, you know, what for? Like, what is that analysis informing and where is it going in terms of output and decision making? I think there's always a challenge communicating complex scientific information, either internally or even from inside to the outside world and you know I'm thinking of the public as well in this.*
>
> ***Interviewer: So, I'm curious why you've brought the public into it?***
>
> *Colm: Because ultimately the public are the customer. We're funded by taxes, and we work in the Civil Service, which is answerable to the to the [Elected official], and also an [Elected official is] answerable to the public. So, the public, and certainly in terms of my policy area and my work ethic, [are] very much in mind at all times. I'm very conscious of that. But I think that can be quite a personal thing. Some people see the public, as a group of stakeholders over there, you know, but I think, really for us, for our policy to really be implemented and carried forward and recognized as the right thing, then the public need to be part of it. They need to be informed of it, anyway, and have a chance to have their say.*

This was a perspective that was not expressed quite as directly by most of the other interviewees, though other interviewees (such as Vince) noted the importance of strong community links. Colm felt that it was very important to connect with the people impacted by his work, not just with researchers or policymakers:

> *The information on the ground, and some of the subtleties around the information and it's quality, and so on— So, it's very important to*

maintain strong linkage into the research community. And beyond that also, you know, the actual people involved in, say, activities that are impacted or activities that that support that area of work.

Interviewer: Do you think that that's like a vital component of policymaking that staying keyed in helps produce stronger policy?

Colm: Yeah. Absolutely. Yeah.

However, Colm also noted that involving the public in marine policy can cause issues, as the public perception of the goals of policy, and the actual goals of policy, often do not align. He highlighted communication as the key to addressing this:

Colm: The level at which we're trying to make decisions is not really at the group size, or the social unit of a particular species. It's much more at the population unit of the species, and I think that there [are] sort of pluses and minuses around that. But from a legal perspective that's quite an important distinction.

Interviewer: Could you talk a little bit about the pluses and minuses of that? How, maybe, that impacts the kind of research that you end up utilizing?

Colm: Just in terms of in terms of outreach and communicating the message, one of the minuses is that it's hard. It's hard to convince people that that individual dolphin that washed up on the shore dead, you know, last week. That that that's one of one hundred thousand… In terms of protection of the species, it may not be that significant. And so, the communication piece is very important.

Briain also noted that initial public support for a policy, such as an MPA, may wane or even turn to hostility and a loss of credibility if the evidence used to suggest the policy doesn't align with public perception or is inaccurate. He provided the example of an MPA:

> *Trying to propose a site just on the basis of, let's say, one species has risk involved in it, especially when you can say there is uncertainty as to how much that species is present in the location. If it's present all of the time, people can't refute it. But if it's only there once every couple of years, or you only have 10 observations of the species in the location. then people go, "Well, Is there any really benefit to that? Maybe [the agency should] commission some other work to challenge that?" And [then] it's an embarrassing position for us to go, "Well actually you're right. It's not a good site".*

Briain demonstrated a concern that, regardless of scientific evidence, if the policy is seen as useless or ineffective by the public, it may cause issues for his agency. If the public identifies a policy decision as poorly thought out, especially if later research validates public concern, it will impact trust in his agency's decision-making ability.

4.3.6 Models

The interviewees had varying degrees of experience with models (Table 33). Peadar and Tadgh both worked with and developed complex models for their day jobs. Whilst Berni was passively familiar with Individual-based models (IBMs), Peadar and Tadgh were experts, as they had both developed IBMs during their careers. No other interviewees had heard the terms Individual-based or agent-based modeling before and/or were familiar with the model method.

Aside from Peadar and Tadgh, the interviewees did not indicate a strong understanding of models, the diversity of model types, nor the diversity of research questions that can be applied to models. Most only had experience with spatial and population models. None described models as potentially qualitative, instead focusing on the idea of "input[ing] data" into a model, which in turn "outputs data".

Table 33: Each Interviewee's Background in Modeling

Laoise	None
Berni	Some experience (10 years prior)
Mack	Some experience (Spatial/habitat)
Vince	Basic modeling
Colm	Basic modeling
Jason	None
Briain	Basic modeling
Peadar	Expert
Tadgh	Expert

Only two of the interviewees had expertise in modeling. The majority of interviewees had no or limited experience with models. Only Berni and Mack had personally worked directly with models themselves. Those with basic modeling experience worked with more knowledgeable colleagues to use or develop models.

Mack was familiar with the adage "all models are wrong, but some are useful". Many also described the impact of poor data or poor assumptions, with two interviewees using the very similar phrase "garbage in and garbage out" (Vince) or "put poor data in… you're going to get poor data out" (Jason). In other words, interviewees understood that models are limited by assumptions used in building the model and the quality of the inputted data.

Jason, whose agency uses models, but whose personal experience was limited, stated that models are "over his head". However, Jason's agency "encourage[d]" younger staff to engage with "predictive modeling". Laoise, who had the least experience and confidence with models, viewed them as black boxes:

> *To be honest, it's not my area of expertise, differentiating them. I think I just take it as it comes. If I'm presented with a certain ... piece of research that's used a certain... form of modeling, you know, I haven't gripped them in my head.*

Vince had little personal experience with modeling, but works closely with colleagues who do, giving him more experience with model methods than either Jason or Laoise. Those who had used modeling in their graduate degrees were more likely to use modeling in their current work.

4.3.6.1 Definition of a Model

When asked to define the term "model", Laoise declined[20] to define it at all. Berni, Colm, Jason, Peadar, and Tadgh described a model as a "simulation". Vince and Jason highlighted that models are often (but not always) used for predictions, while Jason, Peadar and Tadgh understood that models can also be used for explanatory or exploratory purposes (see all definitions in Appendix E.3 Definition of a Model). This is notable as the model used in the one-pager was not a predicative model, but a qualitative, explanatory model.

---

[20] Interviewees were told they could decline to answer any question for any reason.

Berni: It's a simulation, right? So, it's like you plug in variables into your model, and… You're asking the model to predict what is going to happen in the future or predict what's happening with those variables… It's replicating or imagining a real-world scenario.

Mack: I think I've heard a hundred times, but [that] all models are wrong, but some are useful. So, to me a model is our best guess. I've predicted something that we have a little bit of information on, so I know the better information we put in there, be it volume of data or quality of data, the better results we're going to get out…. But there are confidence issues with [modeling], so the better the model the better the data.

Vince: I think a model is a structured process or program, which is used to convert data into a specific kind of output which can be then used for other applications. It's clearly formulaic. I mean, you can talk about algorithms, but it basically puts a whole pile of data in one end and outputs a relatively simple and applicable output at the other end.

It should be noted that, while Vince's definition is generally correct, he neglected to see that the output of a model could be complex, including as complex as observational data.

Colm: I suppose a simulation of a set of circumstances, using samples of information.

Notably, Colm did understand that models can have a strong difference in complexity, stating:

You know [“model” is] a really broad term. Models can take days and days to run in supercomputers, or models can be done in Excel.

Colm also demonstrated a strong understanding of how spatial scales can impact the usability of a model:

> *Sometimes when you do [model] on an international basis, the scale is critical. You can get a picture representing European waters as a whole that actually, from a national perspective, doesn't really project the output that we have nationally…. There are subtleties involved in that too,*

Briain had a very brief, limited definition of model:

> *Well, [a model] can be lots of things, but I guess in the context here it's where you infer from a small set of data, what's happening on a larger area.*

Briain's definition appeared to really center on spatial and perhaps predictive modeling. This demonstrated a bias towards recognizing only specific model methods.

In his definition, Jason noted that models can be complex and depict interactions. He understood that models can be both predictive and exploratory:

> *I would see it as an approach to understanding and presenting the data we would have. And using that to define potential patterns into the future. And possibly even just to explore what we've been presenting in different ways and in terms of currency. So that we'd be able to say: "Well, yes, it fits a model" or "it's a good fit to the model. So therefore, it's telling us about the performance of a stock or the performance of a fishery." Or, in general, the performance of maybe certain interactions as well.*

Unlike most other definitions, Jason's highlighted the explanatory potential of models.

Due to their expertise in modeling, both Peadar and Tadgh had highly theoretical and in-depth definitions of models:

> *Peadar: I take a very broad view of models. So, a model is essentially a representation of the world in some way, and it's almost necessarily a simplified representation of the world. So, the kinds of classical models that we think of in my field of study would be like a mathematical representation of the system… the components that we're interested in and ignoring things that we're not interested in. Or a computer simulation model that… replicates the system in a sort of simplified form…. It's a tool for clarifying thought.*

> *Tadgh: I think [a] model is a simplification, a kind of simplified idea of what we think [and] how the system that we want to model works. So, it's not the real world, and it's not... It's often easier to say where it's not, but I think it's... It's not a mirror of the of the real world…. It's an idea how the world sits together, rather than trying to have a mirror of the reality.*

Both Peadar and Tadgh took extremely broad views of models, focusing on their use as a *method* rather than on their output, a key difference between their definitions and the definitions provided by those with less modeling expertise.

While most interviewees lacked expertise in modeling, they were able to understand the basics of model verification and validation.

> *Vince: The models were developed for different species under different circumstances, and so applying it to a different species on a different circumstance means that it's going to be flawed to some extent. I mean the fundamentals of modeling is "garbage in and garbage out"…. So it's*

really about fine tuning it [the model] so that you understand what [the model is] doing to the data that you're putting into it… as the models can predict what [the] population is doing… It only works as far as it's in counter with reality.

4.3.6.2 Trust in models

Much like the determination of what "qualifies" or "disqualifies" evidence, the interviewees couldn't articulate an overall level of trust for models, but instead for the appropriateness of the model methods for the question at hand and reliability of the model methods (i.e. the assumptions). They were frequently aware that models could be manipulated or poorly made but they weren't always confident in their own ability to assess the reliability of the model itself. Instead, many would rely on a colleague with modeling expertise (See section 4.3.7 *Diversity of Expertise*).

When asked about assessing the reliability of a method, Mack explained that the higher up the chain you go in the organization, the less thorough the assessment gets. Individuals at his agency often rely on him to assess the quality:

Interviewer: If someone sent that [the experimental one-pager] along with… a one-pager on "this is what an IBM is. This is where it's used in the marine field," would that be a useful thing to provide you?

Mack: Again, subjective, so to me personally? Yes, because I have a general interest in it. You'll get people that wouldn't even look at it if [the paper said], "Here's a summary of the model I used." That will be enough for them to turn the page. Because when it comes to the policy people, all they want to see is what are the recommendations and do the results represent it?... People that make the policy, really rely on the *people below them. So, it's my level, to sus out: Has all this been done accurately and above board? So, if it was sent to me, I would have a general look, but if it was sent to my boss or the head of [department], they don't really care what models were used, they just want to know that it done right and you're not making your results up.*

4.3.6.3 Bias in Model Methods

With the exception of Briain, who had a general opposition to the use of models, everyone was generally open to new model methods, feeling that model methods should be selected based on the research question at hand:

> ***Interviewer: From your own personal perspective, or perhaps a policy within [your agency], is there a preference for any particular model methods? Are there some that you feel are more trustworthy or reliable than others?***
>
> *Mack: Not really. I mean, there's none that I would say, trustworthy over others, because it really depends on what you're looking at, and whether you're trying to predict [the] spatial distribution of the species, or whether you're trying to predict climate change, or whether you're trying to predict sea surface temperature. So, I think different models have their different strengths, depending on how they're used.*

Mack's emphasis on "predict" is noted, which demonstrates a slight bias for how, or why, models will be used in policy.

Vince described proscribed model methods, due to international agreements, which require population-level goals for certain species. These goals can impact the types of models used and developed. He noted optimistically that the advent of increased computing power has allowed for newer models to be developed:

I have noticed in the last few years increasing use of the standard issue models that have come out of fishery science [within] several decades. But I've noticed increasingly... modeling [with] the application of R [studio]… I don't use it. I've seen it used. And it allows an awful lot of very responsive type approaches to it. So, I've seen a lot of researchers coming through recently that that have a basic understanding of starting to apply (really quite nicely) in these types of things. So, I think the technology has freed up the ability to model quickly and responsively, and… If it doesn't work, then you go back and think about it, but it's nowhere near as clunky, or even that, for that matters potentially complex as it was [to make models in the past].

This demonstrates an openness to new methods, although Vince himself lacks the expertise to apply them, which was a theme across most of the interviews. Vince also described how his agency would go about testing new model methods, something he has previously been open to:

This is the sort of place that we would try [new model methods], because we can. We say, "You know what? We're not going to get rid of the original [hypothetical research method], but we can run this [new model] in parallel." We can trial it — so that is a feature of how we operate here, is that we're more than happy to run pilot scale trials of things… So, if [the new method] passed a series of assessments and tests and scrutiny, and we take it from there. But, as I said, I think this is the sort of place that we would be open to trialing things.

Colm described using model methods that are recommended by standardized national and international practices, as a part of compliance with legislation:

I suppose where it comes in really, for us nowadays is in relation to things like the [national marine legislation] or the [international agreement], where there are standard practices, and there are international experts who have the technical skills, who are providing the modeling information and… the analyses and the reports on those analyses. So, it's not like we're the only department that's implementing this model. We're using something that's tried and tested and is supported then and backed up by science, you know?

In contrast, Jason, whose work focused more on national, rather than international policies, did not experience pressure from policymakers (top down) or mangers (bottom up) to use a specific model method and had relative flexibility of choice:

I think [resource managers] probably feel we've done the research required to use the best available model for the data that are available.

Interviewees also described collaborating with colleagues in order to determine the best model methods to use. For example, Mack described his experience with a model workshop:

We have this workshop to look at the pros and cons of the different type of species distribution models that were right there in literature. And as part of that, I asked, different speakers to take a model, [to] go and do some research, and [to] present the pros and cons of it. And then at the end of the day, we kind of broke off into groups. So, we discussed "Okay, based on the data that we're all using which model might be best suited for our needs in this project."

At the time of interviewing, Laoise's NGO was evaluating monitoring and model methods for a government agency:

> *[My NGO is] going through an MPA strategy review at the minute. So, we're kind of asking the questions, maybe not with specific asks, but just for [the government agency] to look at their current monitoring and modeling techniques. Are they up to scratch? Does anything need to be refined?*

This assessment demonstrates an openness to new methods, especially if the current ones are found lacking.

The strongest bias for or against model methods didn't have much to do with the methods themselves, but with concern for stakeholder or policymaker distrust of models in general. This distrust often resulted from either a distrust of the data collection methods for input or a lack of scientific expertise. As Briain described:

> *Modeling can introduce debate into the thing… if somebody can introduce doubt into a process, then that becomes more difficult for us to implement the policy…. The lack of certainty, I think, is the thing that… Direct observation is easier to explain to somebody who doesn't have a scientific background.*

However, Colm specifically noted that sometimes relatively new, and under-tested, models may still be the best available method (this reflects Jason's similar notion that "managers have to manage" with whatever limited tools they have):

> *Colm: At the same time, though, if you're seeking an answer on a particular question, like a particular policy question, you've got to start somewhere, so you know, if that [new model] technique will help point you in the direction of an action that seems to make sense, based on the sample size and the robustness of the method. Well, then, you've got to call on that tool. Rather than have nothing, and just, you know, make it*

up. So, it definitely would have merits, but I think there would obviously be assumptions and caveats working with it.

Tadgh was an outlier when it came to model use in policy. In his experience, which involved a wider range of government entities than the other interviewees, he noted:

What [academic colleagues and myself] found is actually the only real success stories [of model use for policy] are stories where government has made a commitment to development of a model over, let's say, a 10-year period… not five years or three years. I'm talking [about] a 10-year period [when the government] has committed to paying the scientists to develop these models, then has paid the policymakers, and the managers, on the ground, that they have to work with these scientists and with the models.

So, after like three to five year's time, the iteration, the understanding of both the real-world situation and the models, and how these two link — because the model is not a mirror of the real world, it is a helpful tool, not a mirror. And then the link between these two was finally kind of seen, and, therefore, used at the end by both sides. So, the managers, the policymakers, fed into the models, and the modelers took on board what the real-world kind of needs of the model was.

So, yeah, but it's very rare. It's very rare, and the commitment, I think, is what is wrong, because if you don't have a 10-year commitment, there is not enough time to develop this [al]together.

Interviewer: So, it almost sounds like what you're describing as kind of a barrier to model use has nothing to do with the type of model—?

Tadgh: Yeah

> ***Interviewer: —but it has to do with the way that it's developed, and then how it gets calibrated and utilized in the real world as like a two-way interface between the scientists and the managers. Well, I guess, a three-way interface [between] scientists, managers, and policymakers. But the method itself doesn't matter at all?***
>
> *Tadgh: No, I don't think so. It's… also how you communicate, or the method, how the iterations work, and how committed everyone is to these iterations. Yeah.*

This was moderately reflective of the other interviewees, many of whom described the use of models over years, by the same agency employee(s), as well as a loss of model development when those employees left and no one with a comparable level of expertise replaced them.

4.3.6.4 Inertia

Some interviewees described using a certain model method simply because that is already what was in use. For example, Jason described using a model method that was created by a previous staffer, which he and colleagues regularly updated. His agency has been limited in new model methods due to a lack of expertise:

> *We've a staff member here who's recently moved on. He's still associated with this, but he was very keen on modeling approaches, and we've used and developed and adapted an existing model to apply in different sorts of situations. For instance, we looked at local environmental knowledge… with a new approach. So, there's a willingness here to engage with the best as we would see it [and] the most novel practices in terms of models, but I suppose using standard models as well. So, it's probably a matter of training and a combination of training and reading*

> *literature and an understanding of the processes around models to see what might be the best fit to the data. So, there'd be a lot of exploration of potential best fits, and that, see what offers best scope for the type of data we have.*

The willingness in Jason’s agency to use novel model methods is reflective of interviewees describing (dis)qualifying evidence based on the appropriateness of the method. Models were not considered by any interviewee to be separate from other research practices, but instead as one of many tools for data analysis. The challenge for Jason’s agency was not a lack of willingness to try new methods, but a lack of those who have a strong “understanding of the processes around models”.

Mack didn’t describe a preference for model methods (i.e., no bias for or against specific methods), but he did describe clearly how bias can arise due to personal expertise (full quote: Appendix E.3.i):

> *Sometimes you come up with people who [have] used a certain model before and [they’d] be like, “Oh, no! This model is really good”, and it's not that it's really good. It's just they're familiar with it.*

Notably, Mack described his lack of knowledge about models as a benefit in this kind of scenario, as it prevented personal bias:

> *I came… from a point of view— I had never done [a] species distribution model, so all of it was new to me, so I didn't have a preference. I was able to look at it and go: “Okay, based on this bunch of papers and this bunch of papers… I conclude that a maximum attribute model is the best for my data.”*

No interviewee expressed distrust for any specific model method. Tadgh, who has experience developing IBMs for policy related questions, in particular, had not experienced any specific bias against IBMs.

> ***Interviewer: This probably is a little redundant, but I want to ask it just to be clear, because you've worked with [individual]-based modeling. So, you've not seen any bias… against [individual]-based modeling, or in favor of other more mathematical models?***
>
> *Tadgh: No, I don't think so. I think… maybe 20 years ago, or something. I think there… was maybe a bit of a bias towards mathematical modeling, because it [always] sounds great when you have a solution, and [with those mathematical models] you arrive at the solution. "Let's solve this equation, and here's our solution"… [but] I don't think it's that [there is a bias against IBMs]. I think it's the commitment from all sides to work together.*

4.3.7 Diversity of Expertise

Another key aspect of the work described by all of the interviewees was the importance of diversity of expertise. Each interviewee described relying heavily on the expertise of colleagues, professional contacts, and stakeholders.

Because Berni had limited modeling expertise, she would combine background reading with conversations or emails to colleagues in order to determine if model methods are sufficient.

As previously noted, Mack described working with colleagues to learn about and identify model methods via workshops. Mack also described letting the fishing industry view data collection methodology and comment on potential policies, to get their experiential input. He provided an example where fishers positively informed their research methods for use in policy:

> *We had originally proposed almost like a square box going, "This is the MPA [marine protected area]. This is where it's being closed." The fishermen themselves came and said "Look, there's a deep-water channel that runs in the middle of your polygon. That is the main area we fish, and it [isn't] affected by all the conservation features that you've outlined for the site, so could you split your big square into a couple of smaller polygons of protected areas and allow us to fish." So, we went, and we did a survey ourselves, based on the [fishermen's] anecdotal evidence. And sure enough, we find that there wasn't really much [species of conservation concern in the channel area]… we actually could take on board what they said, so we actually disqualified a lot of sea area from our designation based on the feedback from the fishermen. So, the fisherman actually were quite happy that their ideas [were listened to and] they're still allowed to fish, and we [were] able to shift where that MPA was [located] around their suggestions.*

This is notably in contrast with Vince's experience collaborating with fishermen, where it was more about developing trust than about sharing of expertise:

> *Vince: They came to us with a problem, and we essentially (It didn't really happen like this), but they came to us with a problem, [for example] they can't make any money. We said: "Well, that kind of ties in with what we're trying to achieve here, so let's stick it all together", and what you end up with is a long-term management plan which addresses all of these issues [related to the fishing industry and conservation]. So, was it absolutely driven by industry? The initial problem was… [but] industry doesn't develop a long-term management plan. That's*

absolutely facilitated by government and by the science. But at every point [the fishing industry] approved it. They discussed it. So, it was their document. It was just that it had a lot of technical policy help on development by the people who do that for a living.

Vince also discussed how he would check unfamiliar methods (in this case, the IBM in the one-pager) with an expert, something that Laoise, Berni, Mack, Colm, Jason and Briain also described:

Vince: And [colleagues] would have a look at the [one-pager]. They would [probably] come back and say: "Well, you know…. we have heard of this [model method]. We're talking about it in… the working group", because it's unlikely to come from Mars, you know?

Jason specifically highlighted the influx of younger staffers as a source of new expertise, especially with regard to more cutting-edge research methods. Like many of the other interviewees, Jason expressed an enthusiasm for diverse and unfamiliar model methods:

What's been fantastic to see, maybe in the last five or more years, is the younger people coming on board and seeing the potential in the older data and mobilizing that to a certain extent and producing more from it by way of predictive tools, in particular, which have been of most interest to [our agency].

Peadar provided a complimentary perspective to those of the NGO and Agency workers. Rather than reaching out to colleagues, he is often the person colleagues call when they need modeling advice. While, when it comes to scientific expertise, Peadar is certainly qualified, he did state that he relied heavily on his colleagues when it came to communication with stakeholders and other forms of outreach.

> *Peadar: Most of the colleagues that I do this kind of stuff with [stakeholder-related research], are so much better at working with people and working with stakeholders than I am. I'm very happy to just sit back and allow them to go do that. And when they say: "Okay, we've got a massive [amount of] data that needs to be organized. We need to build this model." I'm very happy to step up and be the person that takes charge in those situations.*

Similarly, Laoise, who lacks experience with models, described that she struggles to understand how model results are translated into policy recommendations, stating that she would like more assistance from experts on this issue:

> *Iif there was some way to [take a] quick workshop on [model methods], that would maybe be really useful.*

Diversity of expertise was a theme in every interview, as every single interviewee described the positive benefits of collaboration with regard to policy development. Much like their definition of "evidence", which often included non-scientific evidence, interviewees viewed the lived experiences of stakeholders, the professional experience of other policymakers, as well as scientific knowledge, as "expertise".

4.3.8 One-pager

Only Mack, Tadgh and Briain had seen the one-pager format before. Almost everyone appreciated the brevity of the one-pager, but stated that, if this were to be emailed to them in a real-life scenario, they would want the supporting documentation to be supplied at the same time. The majority appreciated the brief summary, the clear organization, and noted that it allowed them to quickly determine what they'd specifically want to look into or double check in the supporting documentation (See Appendix E.4 for each interviewee's overall response to the one-pager).

> ***Interviewer: Considering that you [said you] receive, it sounds like quite a few one-pagers like this, or at least documents of this similar kind of structure—***
>
> *Briain: Well. No, I'd say this is very good. [laughs] This is a very good one. No, I get an email. It might be it might be a little bit all over the place. I might get a phone call…. I could get information secondhand from somebody. I could get a 20-page document sent to me advocating for a change in policy. Things like that. So, this is a particularly well-structured and it's a good document, and I will be happy to get more like this [one-pager].*

No interviewees said that the one-pager was sufficient to use alone, but that it would be sufficient in conjunction with other research or evidence. A majority of interviewees highlighted the overall lack of time they, and their colleagues have to read documents, noting that the one-pager would save them time by helping them discern if the research is relevant to them and worth reading in more depth. Colm stated that because the one-pager was easy to skim, he is more likely to give a response and Briain said he would probably save the document for later, if it wasn't the right time for the policy recommendations.

Laoise specifically liked that the one-pager contained a clear policy recommendation:

> *It's just when you see those policy recommendations. Sometimes [it's] really rare to see them so clear. So, we [at our NGO] kind of take every opportunity, if we see them, to try to incorporate them into our own [policy recommendations] that way.*

Berni also felt that the policy recommendation was useful and noted that the brevity was welcome. Berni particularly liked the headers and felt the one-pager was useful for previewing the document:

> *I [would] like to have this kind of thing before I would read a paper. Just because it helps to give me a sort of idea, a general idea, and it's very concise, and you've got the different headings there which makes it really easily digestible. I think for me this is very helpful. It gives you the overview of what you want it to do, and where you hope to go with it at the end.*

Jason noted that short summaries are helpful due to time constraints, however, he also expressed concern about "nuances" being lost in such a brief document, expressing a preference for more detail despite the time challenges.

Mack appreciated that the one-pager was very brief, noting that he usually receives documents with more background information, despite the fact that he usually just skips straight to the recommendations (something that Briain also described doing).

> *Mack: [Myself and colleagues] will look at the overall project, and then we'll skip down to the recommendations. And then, if there's anything that stands out as consensus, or that might cause [some] issues if I were to implement that, then we go back and go higher [and read earlier in the document]… It's almost like you start from the back and you work forward. The way people present work to us is almost like a small thesis*

where they would have their overview, what they did, and then what their what their main findings are, [then] the [policy] recommendation.

Much like the use of scientific evidence, the use of the one-pager (or need of further scientific evidence) was determined by the policy question at hand.

Vince: The type of data I would need [for a policy problem] would dictate whether a broad [one-pager] template was sufficient or not. In some cases it would be more than adequate. In some cases it might not be. But… I'm also saying the principle of using a standard form is a helpful thing.

In contrast to the other interviewees, who all expressed a desire to receive information in a method like the one-pager, Tadgh didn't believe that sending one-pagers without a request was very effective:

From my experience… you have to respond to a knowledge [request] or [an] evident need from a certain department.

Tadgh felt that without an adequate policy window, the one-pager would not actually be used. He said that this is the main reason that he joined the NGO he was working at:

So, this is one of the motivations [for] why I join[ed] the [NGO]. Because we have definitely, in my research group or something, we've written these kind of one-pagers, but it's not quite clear who reads it, or who is it addressed to, [or] who will actually get to see [the one-pager], and who will do something with it. So, I don't normally produce [one-pagers], because I'm not quite sure where they go and what is going to happen with th[em]. So I think your intention is good, but just producing *[a one-pager], I don't think will get us anywhere unless they are targeted at a very specific group at a very specific time, that fits in with the kind of policy cycle they are in, and the policy needs they have… [That's why] I stopped doing this kind of thing.*

4.3.8.1 Trust in the One-Pager

The majority of interviewees stated that, overall, they had high trust in the one-pager, but that they would independently vet both the research described, and the author, for reliability. According to interviewees, this required reading the associated peer-reviewed publication and/or vetting the credentials of the author. Many also indicated that they would like to set up a meeting with the author of the one-pager, and/or a meeting with their colleagues who have expertise in modeling (or, in the case of this specific one-pager, basking sharks). This need to assess the author and/or research was not related to its usefulness, but it was described as a form of best practice, to be applied to any one-pager. For example, Mack noted that he'd have to stand by the one-pager if he used it to inform a policy that was later challenged.

Laoise noted that she would assess the author by asking members of her social circle:

I think… because the work is so relevant [to the NGO], we would be really interested in it. But yeah, we would probably want to chat more, or maybe organize a quick zoom to get an idea. Again, it's one of those funny things... because [the marine community] is so small… everybody does know [everyone else]. Or if I knew you were associated with the Irish Basking Shark Group, I would probably reach out to [acquaintance who is knowledgeable about basking shark research] and say: "Got this *piece of work. Do you think this would be useful to you, trustworthy, et cetera,?"… But I guess it's interesting, because if we find papers online that are recently published and getting a lot of traction and a lot of positive response, we would probably take quotes from those for our consultations, or take recommendations as well. So yeah, it depends. But… probably, we would reach out for [a] zoom [call].*

Laoise noted a contradiction in her desire to vet the author of the one-pager, something she does not do for peer-review publications.

Similarly, Mack would reach out to the author:

I would find out a bit more about your model first. I would basically ask you to summarize what the model is and how you choose [it], and what it actually shows, [i.e.] the type of data that [went] into it, et cetera. And then I would ask you how would that address the spatial issue?… I would also ask you for the paper, if there was a paper published, just to read that, more out of curiosity for myself, about the general methods and get a bit more background on [the model], and to get an idea of why you think, based on the data you have, that [basking sharks] congregate for courtship or for feeding…. Are those references backed up by solid data, or— because they're all interesting points. But, obviously, you have to have some sort of justification for stating [the conclusions], or are these just your thoughts and feelings?

So [those are] the type of things I want to know. Are these actually backed up by something? If I was to turn any of your recommendations into policy, and I have to stand [by] the evidence of it, am I basing it on "you think they're [basking sharks] there for courtship" or is there data to suggest to that they're there for courtship?

Interviewer: So, would you prefer having actual data results included in this one-pager as opposed to the summary

Mack: Absolutely, for me… not necessarily the full suite, but definitely some of the statistics. [So] that I could then go back to you and say: "Could we set up a zoom chat to discuss your results?" and then maybe you could present a little bit more detail to me.

When asked about the model method more directly, Mack noted that the model method wouldn't even really be relevant in most policy discussions at his job:

Interviewer: Since this is based off… a modeling method that you're not familiar with, that you don't come across very often, that [agency[probably doesn't come across very often. Do you think that would like make it seem unreliable, and therefore [you'd be] less likely to use it? Or would you just want to meet with the researchers and talk more about the modeling method?

Mack: Yeah, most of the time it wouldn't even come down to talking about the model method just because it's not a model we've seen ever. [If] we weren't familiar with [it, it] wouldn't make it any less reliable. It would just mean that if it falls to me to take what you're saying… and package it up to sell to the senior management, who make the policy decisions, I would have to go and probably familiarize myself [with]: What is the model? Is it a suitable model for this type of work? I don't need to know the full insight of it, but it would really be maintenance. You [could] tell me a bit more about the model. Is it used for things like this routinely?... Is it suitable for the study you've done?

Jason specified that he would be sure to vet the funding source and affiliation of the research. Briain similarly described vetting the author for a conflict of interest:

I need to come back into all of this and find out: Who you are? What's your background? Things like that. How credible you are, whether you have another angle… This [the one-pager] could be lies. This could be misinformation.

Interviewer: But how would you assess my credibility?

Briain: I guess I would try and find out a bit about you. See if you had a publication track record. You have given us all the information as to where you are. That's very useful. That is not always the case. You could be "Cg at Gmail", you know? And we don't know where that is, or who you are. So that can be less credible than a person giving an address. And the phone number is a start that helps.

Interviewer: Does affiliation with an institution of higher education lend reliability?

Briain: It was. But I'm not sure if I would give it more weight than just an individual person. I think it does probably suggest that you're not messing about, of course. I don't think I would discount an individual just because they weren't associated with an organization. I don't think that would be an issue.

Briain and many other interviewees display a striking openness about the sort of people they would accept one-pagers from. No one felt that the affiliation with the Irish Basking Shark Group or academic credentials made the one-pager more reliable, however they did often feel that it simplified the process of verification. Similar to their descriptions of "evidence-based policy", the interviewees displayed an openness to receiving evidence from people who lack formal authority to inform their organizations' policy.

Interviewer: So [is]… the peer-review process… an added layer of reliability, perhaps?

Briain: Oh, yeah, yeah… But then some of the best information is just published on websites, and that's not peer-reviewed. And people share information that they have freely without having a peer review. I don't think that discounts it, but certainly [peer-review is] a higher level of status, and especially when it comes to, you know, real science, [peer-reviewed science is] actually going to be a lot more useful than something that is maybe just an opinion or a notion that somebody has… [But there are] a lot of volunteers… people [who are] rich in in biodiversity… [who] don't have a [scientific] background. They just have an interest. That's okay. I mean, some of the best marine mammal observers never went to university to study that. They just have the main thing, which is patience, and then they can just wait there and collect information. You know that bit of passion, whereas you don't always get that from people who've gone to university.

Because of the evidence collection method that Tadgh's NGO follows, he would not prefer the one-pager, but rather an associated scientific paper. Because the team of experts who volunteer in a working group at the NGO read everything that is provided, the one-pager was not considered useful to him. However, he noted that the one-pager still seemed reliable:

Yeah, it looked good. Of course, this is also partly my job…. It looks like... good work has been done, and there are some research findings, and there are also some policy recommendations [based] on this research findings…. Yeah, this is our bread and butter. Why would I not trust this?

Peadar, whose expertise is in individual-based modeling, also noted that the one-pager seemed reliable to him, though he had technical questions regarding parametrization.

> ***Interviewer: I'm curious as your perspective from a person who has expertise in modeling, do you trust the information in this one-pager? Does it seem reliable to you?***
>
> *Peadar: Yeah, I do. I trust it. I have questions, but I trust it. Yeah… I might be reading between the lines in a few places here and saying, "Okay, well, you you're obviously going to be leaving out a couple of things that would go into a full-length paper." But this this seems sensible to me. I don't see anything wrong with it.*

While Peadar wasn't involved in policymaking, he had a notable response to the one-pager itself. Peadar stated that he would "would love to be able to talk to people that have the power to make policy or change things", but that "[he] do[esn't] know what [he] would say to them."

> ***Interviewer: From your perspective as somebody who does modeling… that could be really relevant to conservation outreach, if someone produced, guidelines for how to make a one-pager like this, would you consider that [to be] something useful or valuable to have in your back pocket?***
>
> *Peadar: Yeah, yeah, absolutely. If I had some kind of document that I could go to, it might tip me from saying: "No, this isn't worth it," to "Okay, well, I've got this document that walks me through it, bit by bit. Maybe it's not such a big deal to actually do one of these for myself." I think the only thing that would be stopping me would be okay. Who's really going to read this? And who's really going to act on it?*

Peadar felt that guidelines would be immensely helpful for him in reaching out to policymakers, but like Tadgh, he had concerns about the effectiveness of this method of communication for effective policy. However, one interviewee, whose work directly related to the policy recommendations in the one-pager had the following to say:

> *Interviewee (anonymized[21]): I certainly want something like this now [that the Republic of Ireland is] so actively working on the whole MPA area at the moment and on the law. This [one-pager] would be something that would go into the back of my management system, in relation to OSPAR [Convention for the Protection of the Marine Environment of the North-East Atlantic] species (because basking shark is listed under OSPAR)…. I wouldn't have [a file of relevant information] for every species on the OSPAR list, for example, but because [the] basking shark comes in on the Wildlife Act, as well, I already had a whole basking shark thing happening before the Minister added it to the Wildlife Act there during the summer.*
>
> ***Interviewer: If you got this… assuming that there was a peer-reviewed publication included… would this be the kind of thing that you would be interested in citing in policy documents, kind of like that expanding Ireland's MPA Network [document]?***
>
> *Interviewee (anonymized): Absolutely. Yeah.*
>
> ***Interviewer: And would it be good, then, for, a researcher to email it to you like? Is that helpful to you?***
>
> *Interviewee (anonymized): Yup.*

[21] When referencing specific country legislation, regulations, or treaties, interviewees will be anonymized, as strong familiarity with a national policy can indicate their country and risk making them identifiable.

4.3.8.2 Understanding of One-pager

When it came to understanding of the content of the one-pager, virtually everyone understood what the policy recommendation was (each interviewee's summary of the one-pager are found in Appendix E.5). In their summaries, only four of the interviewees included the model method (notably, these were Berni, Mack, Peadar, and Tadgh, all of whom had the most modeling experience of the interviewees).

Only one individual (From the Republic of Ireland) identified the error contained in the one-pager (the date for the Wildlife Act was incorrect). Both Irish and non-Irish interviewees noted that because of the recent protections for basking sharks in the Republic of Ireland, they were particularly interested in basking shark research and conservation policy. Irish interviewees (from both north and south) also highlighted the current shift in MPA policy in the Republic of Ireland, noting that this research could be relevant to current events.

Only a handful of the interviewees understood the model's purpose. This may be due in part to the fact that the majority of interviewees saw models as only predictive, with few seeing their potential for explanatory purposes. The understanding of models as "input data/output data" as opposed to complex, behavioral simulations, may have also influenced the understanding of the model's purpose.

Berni (who has heard of IBMs and has experience with modeling) understood that the purpose of the model was to determine why sharks aggregate and thought that food availability was an insufficient explanation.

Berni: Your background for the project was that basking sharks are aggregating in certain parts of Ireland… but we don't really know why, and… we don't know why [basking sharks] do many things. And the aggregations are particularly interesting. A lot of people think it's linked to food availability.

You did an IBM, which is an individual-based model, which I have used before (the name rings a bell). And so, you used that to simulate basking shark aggregations and incorporated Zooplankton data from the CPR [Continuous Plankton Recorder]. And what this showed was that, whereas food might be the initial draw, it's not enough to explain why they aggregate.

And when you compare that with other research in Ireland, it seems like these aggregations are also for reproduction rather than just simply based on food availability, which is very interesting. But we need to explore this more and to… basically, we need more information on why this happens and what areas are important for these aggregations, especially with relation to climate change.

The majority of interviewees were able to identify that the one-pager found that the area of Malin was likely important for basking sharks' courtship behavior, although most homed in on the policy recommendations derived from the model results (this is consistent with how they described reading documents similar to the one-pager).

Mack noted that basking sharks needed protections, that Ireland was a hotspot for their reproduction and feeding, that they were seasonal, that they had a wildlife tourism potential, and that the model indicated courtship. Likewise, Colm highlighted Malin as an area of potential protection. He noted that more research and more funding is needed, especially with regards to climate change. Jason's summary of the one-pager was brief, but he highlighted the protection of basking sharks, the potential designation of a protected site as a policy option:

> *Well, I felt it was a document about the protection of basking shark. That was what I picked up from it. And I did read it quickly. Possibly looking at designations of sites, and what the approaches might be. But the fundamental [takeaway] was the protection of basking sharks. And there was some discussion around, maybe some of the issues in potentially impacting on basking sharks.*

Briain's summary noted that the one-pager was advocating for a protected site in Malin and that reproduction was a driver of the hotspots, along with a discussion of his current knowledge of the research:

> *It appears to me that you're advocating an area that could be protected, as a protected site, and… that Malin Head could be a good location.*

Peadar understood that the IBM provided reasons for the aggregation and that it included recommendations (although the recommendations were not intuitive to him, as a person without experience in marine mammal or shark conservation):

> *Interesting. So, you're looking at another species that might be of some value in terms of tourism interest, and it sounds like the life history [of basking sharks] is not entirely worked out. But you've done some individual-based modeling. That suggests some reasons for the aggregation. So, I've got questions, I guess. First of all,… I'm curious as to how you would parameterize the individual-based model to answer questions about aggregation. But yeah, okay, so that's [the one pager is]*

> *making some policy recommendations here. I see for… boat speed limits… I'd be curious as to what boat speed limits by themselves are going to do.*

Peadar understood that the purpose of the model was not predictive, but to understand the reason behind the aggregation behavior. However, Peadar didn't understand the usefulness of the boat speed recommendations, indicating a failure of the one-pager to communicate the reason for this recommendation.

Tadgh noted that the model was an IBM, that it included aggregations near Malin at certain parts of the year, and that, based on the model, the one-pager advocated for seasonal protections because of migration:

> *So, it looks like you have done some modeling of basking sharks, and where they go and what they do…. in relation to some kind of migrations, and it is an individual-based model. And that then shows that they aggregate… in Malin Head for certain parts of the year. So now, based on this kind of modeling, you kind of suggest that it would be good to protect this this area, and it should be that this protection should be seasonal because of the migration of these sharks. And yeah, you just recommend more protection.*

4.3.8.2.1 Understanding IBMS

When it came to individual-based modeling specifically, the understanding of the one-pager declined, and there were notable instances of confusion around what the model described in the one-pager could or did show. All but three interviewees had never heard the term individual or agent-based modeling before. Despite many interviewees claiming that the model method didn't matter to them, the low understanding of the model method (IBM) did cause some level of distrust for the results presented in the one-pager.

Mack critiqued the model, as it lacked the ability to "practically test" any of the reasons sharks may return to an area, stating that the model contained "assumptions" about behavior, rather than recognizing that it tested different simulations of behavior. Mack described the use of CPR data as a separate model, instead of environmental data input into the IBM, with which the individual (simulated) sharks interacted.

> *Mack: So, you use an individual-based model, to look at aggregations with potential courtship suggested. Oh, another method used [was] continuous plankton recorder [data]. So, you assessed food availability. Made note to other observations from the Irish Basking Shark Group, probably [researcher]'s work. Then summarize why they're seasonal.... In summary, you have looked at observations and food availability compared that to some sort of temporal scale to suggest seasonality, and then proposed why these animals are here seasonally. So, food production, reproduction status, habitat need and then [proposed protections], based off of your assumptions, because based on this, you don't actually have the data to practically test that any of these are actually the reason why [basking sharks] are there.*

Mack's summary of the model method implied a correlative study, rather than a simulation that allowed for testing of different behavioral hypotheses. This may be indicative of the bias towards more spatial/temporal models, which Mack often used in relation to his own work and he is therefore most familiar with.

Colm demonstrated a poor understanding of emergence, a key component to many IBMs (including the IBM in the on-pager):

> *If the only tools that we have for some things are, individual-based models rather than population level models, because we have access to this cohort of individuals from a North Atlantic population, that— God only knows where the rest of them are most of the time— Well, then… the only thing we could work on is that sample of, you know— No doubt it's not a statistically sound sample. But you've got to work with something.*

The name "individual-based model" appears to have caused confusion, with Colm assuming they are only used for individuals (IBMs can and are used to model at the population level). When asked if he felt had an opinion about the trustworthiness of IBMs, he stated:

> *Working on the basis of individual specimens in the marine environment, which is, you know, notoriously difficult to study, I think there's always going to be caveats around the use of that [IBMs]. And the representativity of the sample that's used, you know, the sample size, the demographic… and also the nature of the ecology that the animal finds itself in, in space and time... In the marine space we don't really understand a lot of the motivations of individual animals and what they do.*

Like Mack, Colm demonstrated a lack of understanding that IBMs can be used to study *behavior*, through hypothesis testing, instead assuming that the model in the one-pager required *input of behavior data*.

Briain whose definition of a model was quite brief and who didn't often use models in his work, also didn't quite understand that the model in the one-pager was being used to test the behavioral theories, as an alternative to observational data. In his one-pager summary, he stated this as an aside:

> *I guess, the observations we have [of] them is passively feeding along... I've never heard anyone seeing any reproductive activity, and I don't know what level information there is on that. [We'd] probably have to go deeper into it.*

4.3.9 Critiques of the One-pager

Mack was the only interviewee who stated he wished the one-pager included numerical results (i.e. statistics), though everyone requested the associated scientific paper to be included in the initial email. They all said that this would allow them to share key information with colleagues and/or explore further questions that the one-pager didn't answer (see section 4.3.7. Diversity of Expertise)

Berni noted that a visual (e.g., map or infographic) could help speed up the process of knowledge sharing:

> *In my experience policymakers love visuals, they love something that they can look at and understand rather than having to read through. Because, like I said, you have to think in the mindset of someone who is reading multiple of these [documents] a day.*

Laoise raised the point that research can overlap with different policy goals and that most policy goals are not species specific.

> *It is tricky sometimes, because there's so many different pieces of [policy] work that are going on at the moment, but so many of them do relate to each other. We've got a [species] conservation strategy here…*

being developed and a blue carbon action plan being developed, and a [more general] biodiversity strategy being developed, which everything else will fit within. So, a lot of [policy work] is… repeat information with the biodiversity strategy. We would mention basking sharks and elasmobranchs with the elasmobranch strategy. We'd mention it again with the [specific marine policy] strategy review…. And yeah, it's just building up your evidence base, and then using it… when you think it's going to have the most impact.

Because Laoise's work encompasses a wide breadth of policies, which may need evidence at different times, it was useful for her that the one-pager covered multiple policies. However, as Briain noted, this is a difference between those who work at NGOs and those who work at agencies:

We are all in the business of conservation, I mean. I might work for the government, but I am in nature conservation, and that's what I want to do. But I also have to kind of keep in mind, a wider context, maybe, than, let's say, an NGO.

Tadgh specifically recommended against crossing policies and had much to say about the one-pager containing multiple policy recommendations:

In this case, for example, your shark research… might be in relation to much more specific [policy, like] climate change… or it might be in relation to, I don't know, trade, or pandemics, or something… There's a lot of things covered in here… there's food availability, there's migration in here, there's— I saw climate in here somewhere. There's social behavior somewhere in here... I mean that is a hell of a lot… Lots of policy is divided into a policy that is about trade, or that is about food, or is about climate, and they often have very clear needs of what [kind *of] information they need to move that forward. Crossing across all of them is very, very hard for policymakers, and so any one area of policy would probably get very little out of this.*

The interviewee from the Isle of Man, a unique legal landscape, also expressed the need for policy recommendations to come from people well-versed in the complex policy landscape:

Interviewer: I'm just curious if you find [a policy recommendation] useful to include if someone's sharing scientific research with you, or if you'd rather read the research and pull out those policy conclusions on your own?

Interviewee (anonymized): I'll give you an example: if I work with the organization and they have credibility (and again, I think, working with people over time develops that)… If they understand the landscape that we're working in, [then] that's appropriate. [However] if someone from the UK, for example, comes along and says: "I've got this data that I think it's really good for you guys. And here's a policy that will come out of it." It's like: "Well, who are you on? Do you understand the policy environment?"

…

What we frequently get is (because we actually have our own legislation)… [is] people— UK consultants using UK law and processes… [they make assumptions] that are right to make [in the UK], but those [assumptions] don't apply here, and so that's one of the dangers of using external consultants as they… frequently don't even visit. So, they have no idea of how things operate [in the Isle of Man], *the policy landscape, how we go about things. And actually, from… an unprofessional point of view, that's actually quite insulting and quite annoying.*

However, if I work with someone over many years, and they say: "Look, we've been doing this for a decade. We want to propose this"— and frequently an organization like that, we'll [already be] supporting in some way or another— "And this is where we want it to go." I'll be like: "Yeah, Saves me the trouble… You're the guys that know what you want to achieve." I'm happy to accept that.

Interviewees who worked at agencies noted that different pieces of national and international legislation can impact their work. One Irish interviewee noted how, because basking sharks are not listed in the Habitats Directive (an EU level policy), it is unlikely that The Republic of Ireland will dedicate a protected site for basking sharks.

Interviewee (anonymized): The Habitats Directive— It's not likely to have a revision of the species that are included in it. So [the agency is] not likely to be designating sites for these.

One interviewee noted that the work of his agency was made easier because their efforts were backed by EU legislation.

Interviewee (anonymized): Maybe this organization has had some success in [specific conservation effort] [because it was] backed by European legislation.

Colm highlighted the fact that policies are often set at population levels, not individual levels. That means that policymakers are not making decisions at the small group level (because the model worked with a small area and small (sub)population of basking sharks, he felt the model results may not be impactful for policy):

> *[There's a little more comfort] if you're working at the species level or at the population of the species level, in terms of interpreting the [model] output. I think it's very important from a policy perspective (and this is something that that can be hard to get across to stakeholders and to the public sometimes), is quite often, from a legal perspective, governments and ministers and departments are there to protect the population level of an organism. Not necessarily the individuals. So, I think that's quite important when it comes to… species, distribution or species modeling as a whole, [that] the level at which we're trying to make decisions is not really at the group, size, or the social unit of a particular species. It's much more at the population unit of the species… But from a legal perspective that's quite an important distinction.*

An interviewee from the Republic of Ireland had a strong critique of the policy recommendations related to basking sharks in the one-pager:

> *Interviewee (anonymized): The avenue that we have at the moment, the status of this species in Ireland, is… it's recently been added to Section 23 of the Wildlife Act, which gives it a protected status from interference essentially. But that is a very limited set of protections, and it's a really very narrow one, and it wasn't a species that was vulnerable to a lot of interference anyway, because people (from my experience) largely were respectful of the species. When they encountered [a basking shark], they may have got slightly too close, but rarely, really. And then protected areas for that species is something that will take a lot of effort to establish.*

Just as another tangent, [but] at the moment we're looking at offshore sites for [marine species], okay, and we have quite a lot of work done on that over the last 20 years in Ireland. There were a lot of different types of survey work [conducted]. There [were] dedicated boat-based surveys, aerial surveys, a lot of work, really… but…. then it d[id]n't really lead us to a hotspot for those species, because they are just randomly distributed. There doesn't seem to be a feature that is a telling point for them. There isn't a geographical location which is essential for reproduction, like you are suggesting for basking shark, or a critical area for feeding that's consistent and isn't dictated by seasonal oceanographic conditions, or by the reproduction and spawning of other species…

So the position I'm trying to take is that if we have features that we know, if we have a reason for testing management location, that is certain, let's say, [from] the habitat point of view, [for example] an offshore reef habitat, which we have 100% degree of certainty is occurring in that location, and we know also that [the] bottle nose dolphin does occur there, but maybe infrequently, then we should add bottle nose dolphin as an additional qualifying interest for that location, rather than having it as the primary reason for designation.

And that's what I'm trying to get at… Because trying to propose a site just on the basis of, let's say, one species, [doing that] has risk involved in it. Especially when you can say there is uncertainty as to how much that species is present in the location…

And that same is true for basking shark. I don't feel like [the] basking shark is going to be the tent pole for a designation because I don't think it's going to have a strong enough location. Unless people put a huge effort into more ecological research on the species, and it [is]

> *established [that] there's an area that it's mating or it's spawning or it's critical for the rearing of very young. Then… nobody's going to refute that. But if it's an occasional site that every once every five years you get an aggregation of 20 of them in the bay, and then another four years before you see anything coming back again, it's going to be harder to put that designation in place.*

4.4 DISCUSSION

This research sought to understand how policymakers select evidence, with a focus on model method selection. It also tested the use of a one-pager, a common method of written communication in agencies, as a tool to communicate the results of a complex individual-based model for policy. The example IBM used in the one-pager for this study was used to determine how policymakers view scientific evidence, the value of a one-pager for communication, but was also used to investigate the perceived usefulness of models, particularly IBMs.

In this study, the policymakers interviewed described a high demand for evidence to base policy decisions upon, but low ability to seek out such evidence. The one-pager is a potential method for bridging that gap, that, per the experience of the interviewees, is not widely used for science-based policymaking in Ireland, the UK, and the Isle of Man. The issue of non-standard communication methods for models has been highlighted by previous research (Cartwright et al., 2016; Grimm et al., 2006, 2014; Planque et al., 2022), but several of the interviewees also noted that they would prefer a standardized method of communication when receiving scientific information *in general* from researchers. Previous research has found that not only is conciseness vital, but policy advocates must present the *evidence* that supports the policy recommendation (Stringer & Dougill, 2013). The science-based one-pager used in this study lacked specific, numerical or graphical results, something at least one interviewee requested (Mack), and which may have increased confusion around the model purpose/results and reduced trust. Policy advocates must also be clear on whose responsibility would it be to implement the policy (Stringer & Dougill, 2013). While the one-pager does not specifically indicate which agency should be responsible for implementing the policy recommendations, catering recommendations to the target audience and their policy needs/goals can serve as a proxy for this.

Previous research has highlighted that scientific research on environmental policy rarely references policy theory, and in particular, that scientists rarely understand the need to identify relevant policymakers or to frame scientific advice in a way that is useful to a specific policy or the political timeline (Cairney, 2016b; Stringer & Dougill, 2013). This was reflected in Mack's description of "long-winded emails" that they get from scientists, Laoise's description of research presentations that don't specify a clear policy goal, and Tadgh's emphasis on the importance of relevant timing. Furthermore, knowledge producers (researchers) should know how to package knowledge for their target audience (Lemos et al., 2012; N. Rose & Parsons, 2015), something the interviewees themselves were skilled at. Reducing the effort required of these midlevel policymakers, by providing the "policy relevant package", can help increase the likelihood of evidence, provided by scientists, being used.

The interviewees all acted as knowledge brokers, translating science to policy. Embedding scientists into government agencies to aide in knowledge transition has been documented by previous research as an effective strategy (Cook et al., 2013). This study demonstrates, however, the challenge of researchers who work in agencies, who simply cannot be experts in all scientific fields. Instead, researchers who use IBMs can also act as their own knowledge brokers, providing key information about the modeling methods to policymakers who may hold a scientific background, so they can confidently address questions related to IBMs (i.e., assumptions, confidence).

4.4.1 Evidence

Previous research has noted that the evidence needs of international policy and localized decision making are often different, something described by several interviewees (Cairney, 2016c). It is therefore important that researchers produce evidence and advice that can be incorporated into the specific policy practice, meaning that it is vital to know the policy landscape into which individual policymakers and/or agencies intend to provide advice.

Research methods can play a role in reassuring policymakers in the reliability of evidence (Nutley et al., 2019), however interviewees demonstrated a more nuanced understanding of this. It was the appropriateness of the research method to the scientific or policy question, not the method alone, that was the deciding factor of reliability for the interviewed policymakers. Contrary to previous research that found that there is a bias towards more quantitative methods (Nutley et al., 2019), many interviewees accepted qualitative, anecdotal, and experiential data from sources such as stakeholders.

Previous research has found that policymakers rely more heavily on personal experience and expert advice, not systematic searches of the literature (Cairney, 2016b).

This research found this to be partially true, with many of the interviewees describing literature reviews as a key component of their work, although personal experience and expert advice also played a significant role. Scientific researchers often define evidence as "scientific" while policymakers take a wider range of definitions, including non-peer reviewed or unpublished "gray literature" and experiential expertise (Cairney, 2016d). This was reflected in everyone's definition of evidence-based policy, despite their science backgrounds. This demonstrates the adaptability of the interviewees, who straddle both the scientific and the policy worlds and who often need to make policy choices with low levels of data to which they can refer (e.g., "managers have to manage" as Jason stated).

The interviewees anticipated how others (i.e., stakeholders and other policymakers) would perceive the evidence. This informed their decision whether to use or not use evidence when informing policy. Notably, the interviewees felt that models would be perceived as less trustworthy than observational/experiential knowledge by impacted stakeholders and/or upper-level policymakers. This biased the mid-level policymakers interviewed against using models, even if they had no personal qualms about this type of evidence for decision-making. Briain's description of non-experts not trusting models was reflective of previous research (Paolisso et al., 2015).[22] Previous research has also found that policymakers often want scientific evidence (especially numbers), but are confused by scientific uncertainty (Salajan et al., 2020) and, if it is not communicated clearly, stakeholders can perceive uncertainty as an implication that the model is itself unreliable

[22] This study did not interview upper-level policymakers or impacted stakeholders, so this research cannot confirm or deny the perception held by the interviewees that policymakers and/or stakeholders are distrustful of models and prefer observational data.

(Cartwright et al., 2016). Simply communicating the results of the models will not address this and scientists need to make it clear to policymakers that 'uncertainty' is a result of scientific unknowns, but that models can test a variety of potential variables to help 'fill in the gaps' of our knowledge (Cartwright et al., 2016). Most of the policymakers interviewed lacked specific expertise in models, which may have made them less confident in communicating uncertainty, something Tadgh and Briain highlighted as a specific challenge. This influenced their decision to use observational research over model research, regardless of the scientific validity of a specific model. Researchers seeking to encourage the use of their model results should anticipate this when talking to policymakers and should supply talking points to preemptively address these common concerns.

4.4.2 Models

While none of the interviewees described an outright bias for, or against, a model method, some interviewees described a bias towards specific methods as a result of top-down recommendations or even requirements, which are often based on international agreements. The use of models, and potential biases for (or against) modelling in multi-lateral, international decision-making is beyond the scope of this current study.

However, many interviewees in this current study described a strong openness to unfamiliar model methods. Previous research has found that researchers can advocate for their model to be used in policy (Will et al., 2021), something reflected in the interviews, which described (often younger) researcher's proposing a new use of old data or a new model method. Like previous research has found, actors in de-centralized systems (of which all the interviewees were a part of) who are more local and closer to day-to-day activities, and were therefore better able to adapt and to find new methods of evidence collection and implementation, as described by Vince, whose restricted area of work increased his ability to try new methods (Cairney, 2016b).

4.4.2.1 IBMs

Personal experience with model methods did bias individuals in their perception and understanding of the IBM described in the one-pager. Mack misunderstood aspects of the IBM, with his misunderstanding filtered through the types of models he was already familiar with. Including visuals (see Figure 3 for an example) in the one-pager may have helped mitigate some of this confusion. Seeing a simulated output, which is similar to observation data (something all the interviewees were familiar with) may have mitigated assumptions about the model output and how model data can be used.

A separate one-pager on IBMs may have been helpful for individuals, such as Mack, who indicated he would be like to read such a supplemental document. However, providing clearer information about the model purpose, specifics about the model tests and model output, and/or a one to two sentence description of IBMs and how they can be used for research may have been helpful to include in the one-pager. Providing information to combat biases about model methods (as the majority of policymakers were biased towards more predictive, mathematical models) should be done in the future to increase understanding of IBMs specifically.

It should be noted that the misunderstandings were a result of unclear communication in the one-pager itself. The interviewees, who worked jobs that required a diverse set of skills, simply cannot be experts in all model methods. Therefore, one-pagers should be written assuming zero background knowledge of a model method, even if the target audience has a scientific background. This is especially true for model methods that are uncommon, such as IBMs, which are still rare in the marine field.

Models have been accused of being a 'solution in search of a problem' (Radaelli, 2004, p. 734). However, when asked about the usefulness of the IBM described in the one-pager, many indicated that, were they working on basking sharks, they be interested in and probably refer to the results of the model. Notably, one Irish interviewee who *will* be working on basking shark policy noted that he would save the information (were it not presented in an experimental one-pager) for use. While Tadgh felt that one-pagers are generally not useful, he did specifically highlight the need to cater to a specific policy need. The model described in the one-pager was designed with the current policy landscape in mind, which may have influenced its perceived usefulness (See Chapter 2). Research has shown non-IBM models to be in fairly high use in marine policy (Chapter 3), and this research does not show the low rate of IBM use (Chapter 3) to be related to a bias against or distrust of models (as previous research has found; Cairney, 2016b) or IBMs specifically. Instead, the low rate of IBM use may stem from a lack of knowledge and expertise. This presents an opportunity for researchers who use IBMs to advocate for their model use in policy.

4.4.3 Are Researchers the Right People to Communicate IBMs?

Researchers who are comfortable with IBMs and other complex ecological models may be primed to understanding the policy process, as it is arguably quite similar to complex individual-based models. Policymaking is in itself a complex system. In fact, complexity theory has also been applied to policy theory (Cairney, 2016e), as policy development is neither top-down, nor bottom-up, but a complex interaction of actors (or, perhaps, agents?). These actors interact with each other and with their environment, influencing other actors and the environment in a feedback loop not unlike complex ecological processes (Cairney & Oliver, 2017). In fact, the term “emergence” has been applied to policymaking in the exact same way that it’s applied to complex modeling (Cairney, 2016e). Policymaking is not a linear process, and often results from multiple, intersecting actors responding to other actors, as well as their environment (i.e. political pressure). Policymakers are not just responding to scientific evidence, but also to pressure from other stakeholders, other politicians, and situational concerns. This means that researchers are competing for the time, trust, and attention of policymakers. Clear model communication can give researchers a competitive advantage when it comes to informing policy.

Briain dealt with this issue by simply avoiding model use altogether. While it is well documented that scientists’ lack of knowledge of the policy process negatively impacts their ability to advocate for their research (N. Rose & Parsons, 2015), researchers who use IBMs may be particularly well suited to learn the policy process and adapt communication strategies around it. As policy development is complex, but (as noted above) in a way similar to many IBMs, those who use IBMs, may be more primed to understand the policy process and their place in it. Furhtmore, IBM researchers, more so than other modelers, have thought extensively about communication guidelines, due to the push to standardize IBM documentation (TRACE, ODD, OPE). As IBMs can use different programming languages, computer programs, assumptions, and internal logic (rather than a more universal "language" like mathematics, which traditional models commonly use), researchers who use IBMs developed standardized documentation to communicate their model methods in a format that allows for them to be repeatable. Having already developed communication strategies for other researchers, it is not a huge leap for IBM researchers to develop communication strategies for non-researchers.

4.4.3.1 Policies

A lack of familiarity with the policies or legal landscape of an area can negatively impact outreach and communication efforts by scientists and other advocates. Colm's experience with concerned members of the public, who conflate risk to individuals with the risk to species, especially at the population level, is reflected in previous research on NGOs, which finds those who are not up-to-date on scientific research tend to misunderstand current risks and overvalue their concern towards single organisms rather than threats to the species as a whole, and therefore ineffectively advocate for policy change (Shiffman et al., 2021).

Researchers should also know what policies their targeted agency works on. This may mean that multiple one-pagers must be produced, each with a policy recommendation tailored to a specific target audience. As Tadgh noted, "Crossing across [multiple policies] is very, very hard for policymakers". In many cases, researchers should also make sure that IBMs for policy development can be applicable to a population-level policy and management framework and demonstrate that clearly in communication with policymakers. The one-pager for this research failed to make clear how the policy recommendations could impact the basking shark population as a whole.

Researchers who do not have familiarity with law or policy, or who lack the time to familiarize themselves, may find it more productive to engage with NGOs that advocate on the issue or members of boundary organizations similar to Tadgh, over direct communication with policymakers (Akerlof, 2022; Cook et al., 2013; Lemos et al., 2014; Rose & Parsons, 2015; Suhay & Cloyd, 2018). They may also, like Peadar, collaborate with colleagues who share this expertise in the drafting of a one-pager.

4.4.4 Limitations

Due to the nature of the snowball sampling method used in this study, which relies on contacts, interactions and familiarity between potential interviewees, all of the interviewees in this current study had some kind of background in science. While it is common for those who work at marine agency and/or NGO to have a scientific background, this may limit the findings. Those who found the one-pager readable may be predisposed to understand and/or trust it due to their science background. However, many did note how this made it easy for them to communicate or share the information with other colleagues who do not have science backgrounds. They also noted that when it came to those completely lacking expertise (i.e. legislators), they would not be receiving or reviewing a one-pager personally, and the format would allow the interviewees (the science experts) to communicate information easily, were they to be briefing a high-level policymaker or legislator.

This research also only sampled a small portion of individuals focused on marine policy in the North Atlantic. Further research should look at different agencies and levels of policy development to create a more holistic picture.

4.4.5 Future Research

This research should expand the one-pager communication method to include other research methods. Future research could also include some of the changes suggested by interviewees, such as supplying the scientific paper with the one-pager, in order to assess how that impacts trust in and understanding of the IBM, or adding infographics or other types of visuals. It should be emphasized that this study is very focused on the use of one-pagers in one region, for a limited marine issue, with mid-level policymakers.

This study sample clearly showed a lack of one-pager use by scientists as a communication tool in the marine conservation field in Ireland, the UK, and Isle of Man. Further research should assess the rate of one-pager use in other scientific fields or regions, including non-scientific issues. The one-pager used in this study was based off recommendations from United States public health researchers, but it is not clear if these are used in public health in other nations, let alone other fields. Furthermore, it is difficult to assess the rate of use one-pagers. The American Association for the Advancement of Science have produced one-pagers, the Centers for Disease Control and Prevention have produced a guide that includes how to write and utilize a one-pager (CDC, 2010), and scientists who have worked in US agencies describe one-pagers as common place, especially among high-level personnel (E.C.M. Parsons, personal communication, 2023). Further research should assess the "demand" for one-pagers in different policy areas.

Despite clear policy relevance, the absence of one-pagers in academic literature is, in and of itself, notable. Therefore, research should also be conducted on scientists, to see if guidelines such as those outlined by Izumi et al. (2010) increase the likelihood of researchers to share their results with relevant policymakers. As Peadar highlighted, researchers may need additional guidance identifying who to contact and if/how their research can contribute to policy.

4.4.6 Final Tips for Researchers

Izumi et al. (2010) highlight other avenues of information dissemination, including op-eds and policy briefings. However more neutral documents, which highlight the appropriateness and/or reliability of the methods seem to be a better choice when talking to midlevel policymakers, who are often concerned about bias or the appearance of bias.

Many of the interviewees highlighted the importance of relationship building in policy development. Therefore, researchers who wish to contribute to policy should be prepared to establish long-term relationships with policymakers or colleagues who have relevant expertise (Maeda et al., 2021). Researchers may even consider taking professional training to improve both communication and the interpersonal skills required for collaboration, which can assist with both policy advancement and collaborative, interdisciplinary research (Cheruvelil et al., 2014; Mintrom & Norman, 2009).

While Izumi et al. (2010) provided a strong starting point for one-pager development, any researcher preparing a one-pager that describes complex modeling for marine policy should do or consider the following:

- Include name, contact info, and affiliations (including funding sources).

- Add a supplemental peer-reviewed publication or associated documentation when sharing the one-pager.
- Be open to a dialogue (zoom call, emails) and be available to answer questions, although researchers should understand that they may not get a response quickly or, conversely, they may be asked to respond in a very short amount of time.
    - Relationship building with policymakers can aide future policy advocacy and increase the likelihood that policymakers will seek a researcher out when expert advice is needed.
- When possible, tailor the policy recommendation to the agency/organization of the individual receiving the one-pager (NGOs can be broad and advocate for multiple policies, but agencies are often more limited).
    - Be aware of the current laws and policies around the issue and learn which agencies work with or under certain policies. Cater policy recommendations to individual agencies.
- If possible, tailor the one-pager to current issues (i.e., current public concern or public pressure to take action for a particular species).
- Provide a 1—2 sentence overview of the research method (e.g., IBMs) and do not assume prior knowledge:
    - Specifically for IBMs, be aware that the recipient of the one-pager may be biased to see models as only predictive or mathematical and may not understand that models can simulate and tests behavior. Be prepared to define or explain an IBM.

- If time is an issue and/or reaching out individually is not a good fit for either the researcher or the research topic, consider contacting an NGO that advocates on the issue or similar boundary organization.
- Consider collaboration with colleagues on communication strategies, although care should be taken to involve colleagues with proven communication and advocacy/outreach expertise. Individuals who have *policy expertise of an issue* should be selected for collaboration.

4.4.7 Conclusion

This research sought to determine if the IBM described in Chapter 2 was useful for policy. It also sought to assess the usefulness of a "one pager" as a medium for communicating evidence that might be useful for decision-making and policy formation. The results are inconclusive for the former question, as all interviewees needed more information before they could answer such a question. Many tentatively said the model was *potentially* useful, but a single-species policy was unlikely to result from this particular one-pager (rather it would inform a more holistic ecosystem approach).

This research also sought to understand how policymakers interpret IBMs. The interviewees demonstrated several misunderstandings with regard to IBMs, and researchers using this model method who are seeking to communicate with policymakers should be aware of this. Researchers should make sure that they explain the basics of what an IBM is and what it can be used for, especially when IBMs are used for explanatory, non-predictive modeling.

Notably, this research did not identify any bias for, or against, any particular model method, and instead found a high openness to new and cutting-edge model methods. The lack of IBM use in policy documented in Chapter 3 appears to be attributable to a simple lack of expertise. Researchers using novel model methods could advocate for, and education about, their own models to help bridge this gap.

All interviewees understood the complexities of the policy process and the multiple pressures that can impact policy decisions. Even those with high-level science backgrounds demonstrated a very sophisticated understanding of policy development. They all noted a desire to be transparent in their evidence collection and decision-making and they wanted their decision making to be based on reliable, traceable research.

Communication guidelines and research on policymakers often assumes that policymakers have no scientific background, but the interviewees were adept at both policy and science. This presents an opportunity for researchers who use IBMs to engage in more complex dialogue with such policymakers, who, while they may lack modeling expertise, have a high level of scientific knowledge. Many interviewees described themselves "translating" scientific research for non-expert policymakers or stakeholders. Targeting individuals like these for science communication may help with science communication challenges, as they would speak both "languages"— Science and policy.

CHAPTER FIVE: CONCLUSION

This research developed the first IBM of basking sharks, was the first research to identify IBM use in marine policy and produced guidelines for researchers seeking to communicate IBMs for use in policy.

5.1 RESEARCH QUESTIONS REVISITED

5.1.1 What environmental factors lead to basking shark aggregations? [Chapter 2]

High rates of zooplankton patchiness produced the most realistic model results. Due to a lack of realistic zooplankton data to input into the model, it is not clear how the spatial distribution impacts basking shark aggregations.

5.1.2 What social conditions lead to basking shark aggregations? [Chapter 2]

Social conditions (whether for courtship, reducing drag, or other reasons) drive the size of basking shark aggregations, but do not impact the number of aggregations.

5.1.3 What is the rate of IBM use in marine policy development? [Chapter 3]

Despite a majority of marine IBMs claiming relevancy for policy, IBMs are used at a significantly lower rate when compared to other models. The reasons for this are not clear.

5.1.4 What is the policy theory held by the policymaker or developer? [Chapter 4]

The policymakers interviewed all followed the multiple-streams theory.

5.1.5 What is the perception of scientists held by policymakers? [Chapter 4]

The results of this question are inconclusive, as all interviewees identified as both a scientist and a policymaker. They often described straddling both the science and the policy world.

5.1.6 What is the level of trust in the model? [Chapter 4]

Interviewees didn't outright distrust the model, but did not feel they could assess it's reliability without more information (i.e. a peer-reviewed paper, expert advice from a colleague).

5.1.7 What is the level of understanding of the model's purpose? [Chapter 4]

Most interviewees displayed a lack of clear understanding that the model was simulating and testing hypotheses of behavior. The understanding of the purpose and specifics of the model method were low, with the exception of those who had previous experience with IBMs.

5.1.8 What is the level of understanding of the model results? [Chapter 4]

All interviewees displayed a strong understanding of the policy recommendation, and most understood that the model result indicated that courtship was a likely driver of shark aggregations. They were not confident in *how* the model came to these results.

5.1.9 Will policymakers indicate that the model has influenced their own policy in any way? [Chapter 4]

Interviewees expressed an interest in the information on the one pager but wanted to check the model methods with a colleague. There were mixed reactions to the policy recommendations, with NGO employees finding them helpful for covering a wide swath of policies, and agency employees feeling that crossing multiple policies limited the usefulness of the one-pager, because of the limited purview of their specific agencies.

5.2 ONE-PAGER SUMMARY

As this research is meant to test communication methods for complex research, the entirety of this interdisciplinary dissertation was distilled into a one-pager:

A Model of Basking Sharks as a Case Study for Communication

Project Overview
This interdisciplinary dissertation research was conducted between 2019—2022 by Chelsea Gray, as part of her PhD in Environmental Science and Policy at George Mason University, USA

Background: This research contained three parts:
(1) The first individual-based model (IBM) of endangered basking shark behavior was developed and used to determine the localized drivers of shark aggregations in Ireland.
(2) A review of international peer-review publications utilizing marine IBMs was conducted using Web of Science (WoS). The publications were assessed to determine if the WoS articles claimed that the IBMs were relevant or important to marine conservation policy or management and then policy documents were assessed to determine rate of IBM use.
(3) Interviews with nine individuals who work on marine policy in the Northeast Atlantic were conducted. A one-pager, based off the results from the IBM (part 1), was used to test communication strategies.

Research Findings
- Results from the IBM show that basking sharks gather in aggregations in Ireland for both food and social reasons, likely (based on field observations) for courtship purposes. Food availability drives the number of aggregations, while social aspects drive the size of aggregations.
- IBMs can be used to model the behavior of elusive species, such as basking sharks, but more research is needed on zooplankton distribution to produce a more realistic model environment.
- Despite the majority of marine IBMs claiming relevancy for policy, IBMs are still rarely cited in policy. This is not due to a bias against IBMs, but rather a lack of expertise. Agency employees have a high willingness to try new model methods but require expert advice.
- The one-pager is a useful and efficient format of information dissemination for individuals working at agencies and NGOs. Such individuals would be receptive to receiving one-pagers unsolicited from researchers.
- There is no documented bias against IBMs, but instead a lack of expertise. Agencies and NGOs are open to new model methods but require expert guidance.

Recommendations for Policymakers
- The IBM indicates the importance of these aggregations for both feeding and reproduction, therefore conservation measures to prevent harassment or boat strike in areas/places where these occur should be implemented.
- Further research is needed to understand the localized distribution of zooplankton data, to model the spatial distribution of sharks more realistically. Funding should be allocated for long-term localized zooplankton research.

Recommendations For Researchers
- Researchers should make use of the one-pager communication method, while simultaneously supplying supplemental information (i.e., associated peer-reviewed publication), when reaching out to agencies or NGOs. Policy recommendations in one-pagers should be catered to the agency or NGO that the one-pager is sent to.
- Researchers who use IBMs should anticipate that even those with scientific backgrounds will likely be unfamiliar with IBMs and will filter their understanding of the model method through their experience with more traditional models. Readers may be biased to assume models are quantitative and predictive.

APPENDIX A: MODEL DOCUMENTATION

A.1. OVERVIEW, DESIGN CONCEPTS AND DETAILS FOR AN INDIVIDUAL-BASED MODEL OF BASKING SHARKS IN IRELAND

TABLE OF CONTENTS:

1. PURPOSE AND PATTERNS

This research will develop the first individual-based model (IBM) of basking sharks (*Cetorhinus maximus*). Basking sharks are currently endangered worldwide, and in 2022 Ireland, a hotspot of basking shark activity, protected basking sharks under the Wildlife Act of 1976. The country is now looking to expand their MPA network and develop stronger marine conservation efforts.

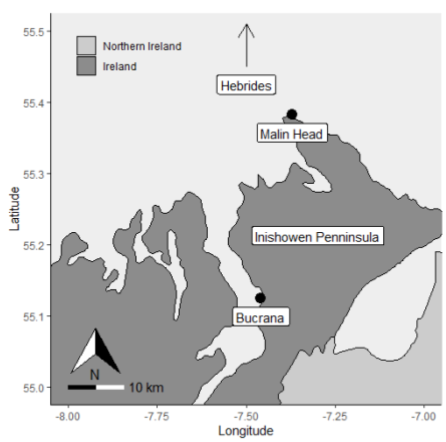


Figure 1: Map of the modeled area.
Map created by Alexis Garretson at Tufts University.

Basking Sharks gather in aggregations, ranging from a small (2+) to a large number (100+) of individuals. They do so unpredictably (i.e. in one location, at the same time of year, on any given year, there can be a single shark, five sharks, or 100 sharks). When in groups, sharks are known to interact (echelon swimming, parallel swimming, nose to tail swimming), indicating that aggregations may be intentional and serve a social or even reproductive function. This model seeks to understand the environmental and/or social drivers of this shoaling behavior.

The coast of the Inishowen Peninsula (Figure 1), located in Country Donegal, Ireland, and part of the Malin-Hebrides shelf, will be used as a localized case study for this research, as basking sharks visit this area most years and are known to aggregate there. This IBM will be used to assess whether this aggregating behavior is solely based on food availability, a social function, or both.

By understanding environmental and social drivers of these aggregations, we can understand their conservation importance. This may inform geographic or temporal protective measures (i.e. ideal areas for MPAs, seasonal boat speed limits) by identifying times of year or environmental conditions when aggregations are most likely.

Purpose

This model seeks to reproduce basking shark aggregation behavior in the Inishowen Peninsula and to test what environmental and/or behavioral drivers lead to basking shark aggregations.

It is important to understand why sharks come to an area, especially in large aggregations which can increase the risk of human-wildlife conflicts, such as ship strikes or harassment (Speedie et al., 2009). It is also documented that zooplankton, the main food source for basking sharks, are gradually shifting North due to climate change (Cotton et al., 2005), potentially altering the preyscape for sharks. Therefore, policymakers may need to shift the conservation strategies in response to changes in environmental conditions. If these aggregations are prey-driven, this could mean that the aggregations themselves could shift (geographically and/or temporally) in future decades. If they serve a reproductive purpose, protecting areas where these during peak aggregation times could potentially increase reproductive success. If these aggregations are a combination of social or prey-driven, then climate change could create a future timing mismatch between food availability and reproductive needs.

To understand the drivers of aggregations, the model reproduces a 10,545 km^2 area around the Inishowen Peninsula of Ireland (Figure 1), divided into 1 km x 1 km patches of only the top 10 meters of the water column. The model contains a maximum of 200 sharks (sharks migrate in/out of the model so the number at any time is variable between 0—200 sharks).

Research Questions

1. What environmental factors lead to basking shark aggregations*?
2. What social conditions lead to basking shark aggregations?

*An aggregation is defined as two or more sharks (McInturf et al., 2023). Singular sharks are also separately documented.

Patterns

Shark Aggregations

Research and sightings data has shown that sharks return to the same area on a semi-regular basis and exhibit site fidelity (Berrow & Heardman, 1994; Crowe et al., 2018; Doherty, 2017; Skomal et al., 2009). Generally, basking sharks are sighted in Ireland between April and October (though some outliers exist). Individuals have been documented returning to a site after 1+ years and sharks have also been verified to travel across the Malin-Hebrides shelf, between Inishowen and Hebrides Scotland (Johnston et al., 2019; Sims & Reid, 2002). Shark aggregations are unpredictable, though well documented (Sims et al., 2022). According to sightings data collated by the Irish Basking Shark Group (IBSG) and Irish Whale and Dolphin Group (IWDG), groups of 4—60 individuals have been sighted around the Inishowen Peninsula, while aggregations of up to 150 have been sighted in other areas of Ireland. Sea surface temperature (SST) and Zooplankton have both been correlated with basking shark abundance, but not consistently. Research indicates that SST is better for understanding large scale movements and trends, while zooplankton are better for small scale trends (Braun et al., 2018; Miller et al., 2015; Sims et al., 2000; Sims & Quayle, 1998).

While publicly reported sightings have limitations, the IBSG/IWDG sightings data set is the widest and longest running data set available on basking shark movements in Ireland.

Zooplankton Patchiness

Zooplankton exhibit localized patchiness, which has been documented to impact basking shark movements and behavior, as basking sharks are more likely to be found in areas with higher *Calanus* species (Sims & Merrett, 1997). Zooplankton in the North Atlantic exhibit a boom and bust cycle (Bonnet et al., 2005; Conover, 1988; Häfker et al., 2018).

The majority of zooplankton research uses biomass and looks at large scale populations. There is no real-world long-term study on localized, zooplankton patchiness/distribution in the north Atlantic. Therefore, this model will reproduce localized patchiness by randomly distributing different amounts of zooplankton throughout the model area, based on the percentage of patches that will have zooplankton (set by the user) and the estimated average amount of zooplankton for that day. Daily average zooplankton is based on data supplied by the Continuous Plankton Recorder (CPR).

2. ENTITIES, STATE VARIABLES, AND SCALES

Entities

Spatial Units

Model area represents 56n, 55n, & -8w, -6.5w, an area of 10,545 km^2, with patches of 1 km x 1km x 10 m(depth). This area was chosen as it is largely understudied compared to basing sharks research in the south. The Hebrides, directly across from the Inishowen Peninsula, have recently been declared an MPA, due in large part because basking sharks exhibit aggregation behavior there. Therefore, this area is in key need of more conservation-focused research. As this is the first model of its kind, only a small area was selected.

The Inishowen Peninsula was chosen as it's a known tourist attraction, as well as a local hiking spot, and has been highlighted in international media as a hotspot for basking sharks. There is also a large fishing community in the area. Long-term local partnerships between the IBSG (formerly the Inishowen Basking Shark Study Group) and community leaders and organizations have ensured a high rate of reports in the area.

1 km x 1 km patches were selected to keep patch sizes small, but manageable, and to account for shark movements within 24 hours. The 10m depth was chosen as that's the maximum depth of the Continuous Plankton Recorder, and the sightings reports are of surfacing sharks.

- State variables
  - The amount of zooplankton per patch
  - Land/water

Agents

Individual basking sharks are the agents. Each shark represents a single shark.

- State variables:
  - Hidden/not hidden (represents migration into/out of the model area)
  - Number of days without eating
  - Number of days spent outside the model area

Time

Each time step in the model is 24—hours. Aggregations can last up several hours, or even days, and sharks can come/leave (Sims et al., 2022). The research question is not interested in duration of the aggregation, nor in the length of time individual sharks spend in the aggregation. Instead, it is simply interested in whether or not an aggregation occurred on a single day and the size of the aggregation.

The model depicts April 1 through October 31, from 1982 to 2018. This is because the majority of sightings reports in the IBSG/IWDG data set corresponds to this time. While some basking sharks may remain in Ireland during the winter, the ones that do likely to remain well below 10m depth (Doherty, 2017), and therefore are unlikely to be accounted for in publicly reported sightings. The model ends on October 26, 2018, because that was the last October sampling day for CPR in 2018.

- State variables:
  - Month
  - Day
  - Year

Zooplankton

Data from the Continuous Plankton Recorder (CPR) for 50—60 N and ~ 3—12W was used. This data is slightly lager than the model area but was included in order to maximize the amount of input data that could be used. The CPR data included species, date, time, and abundance. *Calanus finmarchicus* and *Calanus helgolandicus* were totaled together (labeled "Cal" in the model). *Pseudo Calanus* and *Centropages typicus* were totaled together (labeled "Otherzp" in the model). Daily abundance was combined for these two groups of species. The input data of zooplankton differentiates *Calanus* copepods from other species of zooplankton, as basking sharks are documented to prefer *Calanus* copepods, but are also documented to each other larger zooplankton species (Sims, 2008).

The daily abundance of zooplankton was multiplied by 50, per CPR methods (Richardson et al., 2006) with true zeros recognized. However, due to a lack of data points for 6264 of 7918 (79%) dates, a linear interpolation was performed, to estimate zooplankton amounts between CPR sampling dates.

State Variables

Zooplankton

The percentage of patches which contain zooplankton (*Calanus* species, and the other species) is set by the user. Every time the model updates (every 24 hours), the abundance of zooplankton is taken from a csv file containing the CPR data that has been linear interpolated. The abundance is divided by 3 (CPR samples 3m^3 of water per sample), then divide by the percentage of patches that should have zooplankton (set by the user). The results of this equation are then distributed throughout the model by multiplying that previous result by the standard deviation, so the patches have a range of zooplankton values. Zooplankton are counted in individuals (population size) not biomass.

Two zooplankton variables are set by the user (Table 3):

1. Cal_%: The percentage of patches that contain *Calanus finmarchicus* and *Calanus helgolandicus*
    a. Slider variable
2. Otherzp_%: The percentage of patches that contain *Pseudo Calanus* and *Centropages typicus*
    a. Slider variable

Sharks

Shark behavior is determined by the submodel (Table 2 and Figure 2).

Sharks are either hidden or not hidden. Hidden indicates that they have left the model area, and do not execute any behavior functions.

Sharks maintain a list of previous patches with high zooplankton (this is utilized in submodel Food and submodel Food/Social).

Multiple shark variables are set by the user (Table 3). These include:

1. Sense-distance: how far a shark can "see".
    a. Sense-distance is doubled when sharks are sensing other sharks.
    b. Slider variable
2. Swim-speed: how far sharks swim in a 24 hour period.
    a. The speed is set to (swim-speed + 1) when sharks are not eating.
    b. Slider variable
3. Thresohold_zp: The amount of zooplankton required to make a patch worth visiting and is used to determine if a shark should leave a patch.
    a. Sharks assess if the amount of zooplankton in a patch meets the threshold level of zooplankton *when divided by the total amount of sharks in the patch*.
        i. Sharks will not move to or remain in a patch if the amount of zooplankton cannot support all the sharks in the patch
    b. A rough estimate of individual zooplankton weight was used to calculate the threshold population size (CPR data counts individuals, not weight).
        i. It is estimated that basking sharks can eat ~3,000 grams zooplankton / 24 hours.
        ii. A rough estimate converts 3,000 grams of zooplankton to approximately 1.5E+11 individual copepods.
4. No_eat_min: the number of days it takes for a shark to not eat (be in a patch below threshold_zp) before they leave.
    a. Slider variable
    b. This does not account for number of sharks in a patch.
    c. This number resets once a shark visits a patch that contains zooplankton above the threshold_zp level.
5. Return-season: The number of days it takes a shark to return after leaving for the season.
    a. Leaving determined by no_eat_min

    b. Slider variable

6. Friend_min: The number of sharks required to attract a shark to an area.
    a. Slider variable

Ideal Range of Variables:

Table 1: Ideal Range of Variables

Threshold_Zp	3E+12
Sense-distance	10
Swim-speed	9
Cal_%	17
Other_Zp_%	17
Friend_Min	5
No_Eat_Min	14
Return-season	20

3. PROCESS OVERVIEW AND SCHEDULING

1. At each time step, the model imports the zooplankton data and date (month, year, day).

2. If it is the start of the season (April 1), sharks are assigned a random number of days (between 0 and 60) to wait before entering the model ('migrate"). When they first enter the model, they are distributed in the north, east, and west edges of the model, to mimic "swimming" into the area.

3. Zooplankton data from the CSV file is distributed throughout the percentage of patches set by the user.

4. Sharks assess whether they need to leave where they currently reside (Figure 2). They will only do so if the total amount of zooplankton in their 1 km x 1 km patch cannot support the number of sharks in the same patch (calculated by dividing total zooplankton by (number of sharks * threshold_zp)).

    a. If sharks do not need to move, they remain put.

5. If they need to move, sharks will select patches in their sense-distance to move to. Their choice of patch is determined by each submodel (Table 2 and Figure 2).
    a. In the Food submodel, sharks will select a new patch to move to that contains zooplankton (both cal and otherzp) that exceeds the threshold_zp level. If such a patch cannot be identify, the shark will choose the closest match from its memory of high zooplankton patches.
    b. In the Social submodel, sharks will select a new patch to move to that contains a number of sharks that exceeds the friend_min level.
    c. In the submodel Food/Social, sharks will first select a patch that contains zooplankton that exceeds that amount set by threshold_zp. If it cannot find such a patch, it will look for a patch that contains more sharks than the friend_min level. If a shark cannot, it will then select a high zooplankton patch from memory.
    d. If sharks can't find any patches that fulfill the requirements to move to a patch (set by submodels), they will select a random patch in their sense-distance to move to.

6. For all movements, sharks assess whether or not land is an obstacle, and will keep searching for a patch until they find one they can reach without crossing land (see: *method of avoiding land*).

7. After moving, sharks then determined if they are in a patch with enough food or not (track-no-eat). If they are in a patch without sufficient food, they count +1 for days they have not eaten.

a. If they are in a patch with food, they reset the no-eat count to 0.

8. If a shark has not eaten for the minimum number of days (set by the user), it leaves the model (sets itself to hidden). Sharks count each day that they are hidden. Sharks will migrate back into the model area after a period of time set by the user (return-season). They will enter the model from north, east, west, the location is randomly chosen.

9. The sharks assess whether the patch they are in contains zooplankton above the (threshold_zp multiplied by three). If it does, the patch is added to the list of of high zooplankton patches.

10. The model tracks if any sharks have crossed over land (for visual debugging).

11. The model samples 10 random patches for zooplankton (this is averaged).

12. Total number of sharks and number of single sharks is recorded.

13. Any aggregations of sharks are recorded. Aggregation size, latitude and longitude, and the zooplankton amount of each patch with an aggregation is recorded.

14. 10 random patches are sampled for sharks and recorded if and how many sharks are in the patch. Latitude and longitude, and the zooplankton amount of each area is also recorded.

15. If the patch they are currently in contains sufficient zooplankton, sharks record the location of the patch.

16. If the year is 2018 and the date is October 26, the model stops. Three sample files are exported.

Method of Avoiding Land

(1) Sharks select patches that meets their submodel requirements (Table 2 and Figure 2)

(2) Sharks sort the list of qualifying patches by descending amount of patch_cal, number of sharks, or memory of a patch with high zooplankton (determined by submodel).

(3) Sharks then select the first patch on the list.

   (a) Sharks Assess if there is any land between them and the target patch.

   (b) If there is land between shark and patch, sharks select next patch on the list.

   (c) Sharks repeat this process until there is no land between them and a target patch.

(4) If there is no land between sharks and the target patch, sharks determine if the target patch is more or less than the number of patches equivalent to the [swim_speed] away.

(5) If the patch is more than number of patches equivalent to the [swim_speed] away, sharks move towards it; if less than that, move directly onto the patch

(6) If there are no patches that meet the requirements set by the submodel, or if there are no patches that can be reached without land, the sharks move at random

   (a) Random-move follows the same list/avoid land method, but only selects random patches of water and does not sort based on any criteria.

4. DESIGN CONCEPTS

Basic Principles

Classical mathematical models and ecosystem modeling (e.g. EcoPath with Ecoism) do not generally allow for adaptive behavior or environmental stochasticity (Christensen & Walters, 2004; Coll et al., 2015; Natugonza et al., 2020). Therefore, some researchers have argued that individual-based models (IBMs) are better suited to highly mobile marine species (Codling, 2008). IBMs can allow for more complex intra— and inter-specific relations, as well as environmental stochasticity.

Basking sharks have not been extensively modeled. Habitat suitability models (HSM) have been applied to basking sharks in New Zealand (Finucci et al., 2021). The HSM incorporated zooplankton data and found a weak relationship between basking shark sightings and zooplankton, but the weakness of the relationship may be related to the dearth of data on both basking sharks and zooplankton. In another example, Ensemble Ecological Niche Modeling (EEM) has been applied to basking sharks (Austin et al., 2019; Doherty, 2017). While the model was effective at predicting the suitability of foraging locations, this didn't always correspond with shark sightings or with tagged data. Doherty (2017) noted that tagged basking sharks displayed a "dispersive nature" (pg. 126) and did not appear to make consistent, group migrations, especially with regard to areas where sharks winter and are assumed to be largely solitary (Sims, 2008). Doherty suggested that the model be refined to include a "exploration-refinement" hypothesis (2017). Exploration-refinement is a framework to understand the behavior of long-lived migratory species (Guilford et al., 2011), especially those that mature late in life, assuming younger individuals will feel less impulse to return to breeding sites (Fayet, 2020). It is assumed that these individuals explore different migratory routes before settling on a preferred one. Such a framework would require individualized agents and environmental stochasticity to accurately reflect basking shark behavior. While Doherty (2017) suggests the use of it, no mechanism for the inclusion of this hypothesis is suggested. Individual-based models (IBMs) are a potential method of testing this.

Emergence

- Aggregations (number, size, location)

Adaptation

- Avoiding obstacles (land)
    - Choosing a new patch to move to if land is in the way
- Selecting patches within a defined area that meets specific criteria
    - Criteria defined by submodel
    - Defined area = sense-distance radius
- Keeping a list of patches that had a high amount of zooplankton
- Leaving if they haven't eaten enough

Objectives

- Size and frequency of aggregations
    - This is driven by sharks seeking food or other sharks

Learning

- Memory, but only in Food and Food/Social
    - Otherwise, they're responding to environmental cues
- Number of days they haven't eaten
    - Migrate out when that minimum has been set and migrate back in when needed

Prediction

- Model does not currently predict anything

- Implies correlation between zooplankton and aggregation size/frequency that can potentially be predictive

Sensing

- "Sense" distance
  - Likely using smell to find zooplankton but smell in water is highly dependent on a variety of factors (Sims, 2008; Sims et al., 2022). This can include the source of the smell, currents, and density of particles in the water. This is why it is a slider variable.
- Memory retention
  - List of patches that 3x the amount of zooplankton compared to the threshold_zp set by the user
- Swim Speed:
  - Based on swim speeds from Sims 2000 who calculated the swimming speed of both feeding and non-feeding basking sharks to be an average of $0.85ms^{-1}$ and $1.08ms^{-1}$ respectively, it is estimated that a feeding shark can travel 73 km in one day. The model assumes that the distance traveled is *not* a straight line. Research from Sims and Quayle 1998 found that sharks traveled 1—2 km per hour, which would be 24—48 km/h. (Skomal et al., 2009) tracked sharks for (avg) 203 days, with an average straight line distance of 1904 km = 9.3 km/day. This is why swim speed is a slider variable.

Interaction

- Mediated interaction between sharks
  - In the Social submodel, the number of sharks in a patch determines which patch a shark will move to (more sharks increases likelihood a shark will choose that patch)

Stochasticity

- The percentage of patches that have zooplankton (set by the user)
- Fine scale location of zooplankton
    - Patches are randomly chosen to have zooplankton each day
    - The amount of zooplankton is randomly assigned, based on the CPR average and the standard deviation of the CPR data.

Collectives

- Shark aggregations [emergent property]
    - Sharks may select patches that have aggregations of sharks already in the Social and Food/Social submodels

Observation

- Hiker list (Pseudo-Sighting Reports)
    - Every day, 10 patches are randomly selected and sampled. The number of sharks in each sampled patch is recorded. This is to mimic reports from boaters and hikers. Data is only recorded if sharks were seen. Date and zooplankton amounts are recorded.
    - Sampled daily.
- Shark list (Total Aggregations)
    - Any time that a shark shares a patch with another shark, the model records the number of sharks in that patch along with the zooplankton amount, lat/long and date.
    - The number of patches with single sharks are recorded separately.
    - Sampled daily.
- Zp sample (Pseudo CPR Sampling)

- The average of ten patches are sampled and the average Cal and Otherzp are calculated.
- Sampled daily.

5. INITIALIZATION

Set-up loads the General Bathymetric Chart of the Oceans (GEBCO) map, which includes depth. It opens up the CPR data and begins pulling from the respective day. It also loads up the latitude and longitude only at setup. *Set-up* starts all three observational lists, which are updated each time step. It sets up 200 sharks to migrate in.

Go sets the sharks migrating in. Sharks randomly migrate from east, west, and north in the model. The sharks do not migrate in at once but migrate in at a randomly determined rate. This process is repeated every April (the start of the model season).

On *Go* the sharks are randomly distributed on the west east and north sides of the model. This is to mimic migration from the south and from Hebrides, Scotland. The model sets the date zooplankton are loaded as environmental variables in each patch.

Initialization is the same for every submodel.

GEBCO:

- Contains depth data
- Upload once at start

Lat/lon

- Manually calculated in excel
- Upload once at start

6. INPUT DATA

Zooplankton

- Daily CPR average
- Updates every day
- Chosen for species specific abundance (not biomass)
- Long-term study sample
- In individual zooplankton (abundance)

GEBCO map

- Uploaded once.

User settings:

See Table 3.

7. SUBMODELS

The model consists of five submodels, including a Random control. The difference between each submodel is the behavior and decision making of the sharks within the model. All zooplankton and patch characteristics remain consistent in each submodel. All non-random submodels operate the same, with the exception of how sharks choose a new patch to move to. In the random submodel, sharks do not decide to leave a patch based on food availability, but instead move at every time step.

Food Submodel

In the Food submodel the sharks only seek areas that contain zooplankton that exceed the threshold zooplankton (Threshold_zp, set by the user).

In the food submodel, sharks retain a list of high zooplankton patches. If they cannot find a patch with sufficient zooplankton, they will select the closest patch from their memory list. They choose the patch with the least distance. If this patch faces land, they choose the patch with the second least distance, etc. If no patch can be found, the shark swims at random.

Social Submodel

In the Social Model (submodel Social), sharks are still urged to move from a patch if there is not sufficient zooplankton. However, they only select a patch based on the number of sharks in the patch (this must be greater than or equal to the friend_min set by the user). It is assumed that sharks can "sense" other sharks from a further distance than zooplankton, due to the significantly larger size of basking sharks and because of the sharks' slime coat (Lieber et al., 2020), which likely contains sensory information. It is also hypothesized that sharks may be attracted to aggregations via pheromones from other sharks (Sims et al., 2022). Therefore, when seeking other sharks, the sense-distance is set to double. Sharks sort potential patches by number of sharks (highest first) and assess if land is an obstacle. If it is, they choose the second highest number of sharks, etc. If no patch can be found, the shark swims at random.

Food/social Submodel

The Food/social Model (submodel Food/Social) is a combination of the Food Model (submodel Food) and the Social Model.

In this submodel, sharks first search for a patch with zooplankton. They sort patches by the highest amount of *Calanus* ("cal" in the model). If they cannot find one that contains zooplankton above the threshold zooplankton level set by the user, they then search for a patch with other sharks that meet the friend_min (the assumption being either that other sharks indicate food, or perhaps that they desire to mate). They sort those patches by amount of sharks. If the sharks cannot find a patch with a sufficient amount of other sharks (in sense-distance x 2), they then search for a patch from memory. If no patch can be found, the shark swims at random.

Random Submodel

Sharks select a random patch to move to. They will assess if land is an obstacle and re-select patches until it is not. Shark will still complete migration in and out of the model area, based on food availability and the time set in no-eat-min and leave-season.

8. TABLES & FIGURES:

Table 2: Key differences between submodels.

Submodel	Seek Zooplankton	Seek Other Sharks
Random	No	No
Food	Yes	No
Social	No	Yes
Food/social	Yes	Yes

Table 3: User input into the model

Parameter	Explanation	Setting
Threshold_zp	Minimum amount of zooplankton (cal and other_zp combined) required for a shark to stay in or more to a patch. Counted in individuals zooplankton.	0—1000000000000
No_eat_min	Number of days a shark must encounter a patch that is less than the threshold_zp before leaving the model	0—100
Sense-distance	How "far" a shark can see (equivalent of ~5km)	0—100
Swim-speed	The distance a shark can swim (in km)	0—100
Return-season	How many days it will take a shark to return after they have left in response to reaching the no_eat_min	0—100
Cal_%	Percentage of patches with *Calanus* copepods	0—100
Other_zp_%	Percentage of patches with other large zooplankton	0—100
Friend_min	Number of other sharks a patch must have to attract a shark	0—100

Each parameter is set by the user using a slider variable

Figure 2: Shark Decision Pathway

If total zooplankton in patch is less than the threshold_zp when divided by the number of sharks in the patch	If Yes	→	Food	→	Seek patch with zooplankton above the threshold	→	If no patches with zooplankton > threshold_zp, Seek patch from memory of high ZP patches, choose closest patch	→	if no patches in memory, Random Swim		
	If Yes	→	Social	→	Seek patches with other sharks >= friend_min	→	If no patches with sharks >= friend_min, random swim	→	Random Swim		
	If Yes	→	Food/Social	→	Seek patch with zooplankton above the threshold	→	If no patches with zooplankton > threshold_zp, Seek patches with other sharks >= friend_min	→	If no patches with friend >= friend_min, Select high zooplankton patch from memory	→	If no patches with high zooplankton patch in memory, random swim
	If No	→	All Submodels	→	Stay put						

Shark Decisions Pathway under different submodels. Each day, sharks complete this decision tree. Note that if a patch that meets the condition is identified, under all versions, sharks make the following action: If within swimming distance, move to it, if out of swimming distance, swim towards it. Random is not included in this table as sharks randomly select a patch to move to each day.

A.2. OBJECTIVES, PATTERNS, EVALUATION

Name of the study:

An Individual-based Model of Basking Sharks in Ireland

Author(s): Click or tap here to enter author(s).

Date: August 2023

DOI (if applicable): NA

Repository (e.g. GitHub): Click or tap here to enter repository.

Prior model developments and historical context:

Model made for Chelsea Gray's PhD dissertation. The model was developed from 2019—2023.

OBJECTIVES

Context and motivations

1. What are the objectives of the model application

   The model seeks to describe what social and/or environmental factors drive basking shark aggregations around the Inishowen Peninsula. The model contains 4 submodels (A food-seeking model, a social-seeking model, a combination of food both food/social seeking model, and a random model for control). The model will compare model output with historic sightings data (1982—2018).

2. Why is the model suitable to address the objectives?

   There are two main hypotheses of what drives basking shark aggregations: Food availability and/or courtship (See ODD for details). This IBM allows researchers to isolate the two types of behavior, as well as combine them, to test which behavior results in aggregations most comparable to the real-world data from the region.

3. What would count as successful in achieving these objectives?

   Aggregations, through time.

Specific model setup

4. Are there any deviations from the original model description?

   a. In the model assumptions?

   b. In the model structure – submodels, variables, components, scales?

   c. In the model details – parameter values, functional relationships

   d. In the model forcing – initial conditions, boundary conditions, observation forcing, maps?

   See ODD

PATTERNS

Selected patterns

5. Which ecological patterns are used for the model evaluation?

    a. temporal patterns such as cycles, regime shift or trends, measures of temporal variability, and autocorrelation.

    b. spatial patterns such as spatial synchrony, traveling waves, patchiness, and autocorrelation.

    c. structural and functional patterns, such as taxonomic diversity, biomass ratios, integrated production, diet fractions, and trait distributions.

    d. Other relevant patterns

    Averaged across model trials: Number of aggregations per month and size of aggregations per month. Spatial patterns are gathered in model output, but not used in model analysis (because the input zooplankton data lacks spatial realism).

6. Why are these patterns important/essential to address the objectives?

    The model output was compared to sightings data supplied by the IBSG/IWDG (statistical tests were used to compare accuracy of the model output). The sightings data does not contain catch per unit effort and is not systematic (sightings are reported by the public). Monthly averages were selected to account for inconsistency through time with regard to reporting.

Independent data

7. Where do the independent data originate from?

    The input zooplankton data was corrected by the Continuous Plankton Recorder (CPR): David Johns (Marine Biological Association of the United Kingdom) (2020): CPR_SelectzooUK. The Archive for Marine Species and Habitats Data (DASSH). (Dataset). http://doi.org/10.17031/64d23cc3a1069

8. What are the extent and resolution of the independent data?

   Zooplankton data comes from CPR Standard Areas: C4,C3,D5,D4. CPR identifies Calanus *species,* Pseudo Calanus *and* Centropages typicus.

9. How representative of the ecological processes are the independent data?

   The CPR is not spatially accurate and does not provide localized spatial data. It supplies a good overview of long-term seasonal averages, though # days are missing. It is a rough estimate of the amount of zooplankton in an area.

10. Are there estimates of independent data accuracy, precision, bias, or uncertainty?

    Due to a lack of data points for 6264 of 7918 (79%) dates, a linear interpolation was performed, to estimate zooplankton amounts between CPR sampling dates.

11. How are the independent data processed to represent the selected patterns? Are assumptions made to derive these patterns from the data?

    CPR: Linear interpolated to fill in missing data

    IBSG/IWDG: monthly averages for comparison to the model output

Model outputs

12. Which model outputs are used for the evaluation?

    The Total Aggregations report (all aggregations of 2+ sharks) and the Pseudo-Sighting report (Every model time step, 24 hours, 20 patches are randomly sampled and any sharks of 1 or more are reported).Total aggregations and Pseudo-Sighting reports list the number of sharks, the lat/lon and the amount of zooplankton in the patch.

13. Have the outputs been post-processed, and how?

    For repeat trials, the monthly averages are calculated for number of aggregations and then size of aggregations. These monthly averages are then averaged across the model repeat trials (i.e. if there are 50 trials, July 1982 is averaged across all 50 trials).

14. Are there estimates of model output accuracy, precision, bias, or uncertainty?

    Sensitivity and Robustness tests were conducted on the maximum size of aggregations and the number of aggregations for settings.

15. Are additional assumptions made when deriving patterns from model outputs?

    Only surface sightings/aggregations are used.

EVALUATION

Evaluation methodology

16. Are sanity checks conducted? If so, what is the method used? If not, explain why.

    a. Which data and patterns are used for this?

    b. Does this apply to patterns that are not otherwise evaluated for this model application?

    Visual debugging was used (i.e. agents and patches changed colors when enacting certain functions). Land patches that have a shark swim over them turn (and remained) colored, and the number of patches that have a shark cross them is counted by "landshark" (sharks no longer cross land). Netlogo's print function was used to track order of operations and to make sure functions were performing correctly (These are removed in the final model version because they dramatically slowed down computing power). Frequency of aggregation sizes were used as a quick proxy for model realism (i.e. majority of aggregations consisted of 200 or 2 sharks was considered unrealistic). Frequency of aggregation sizes was compared to the IBSG/IWDG frequency of aggregation size.

17. What is the methodology used to compare ecological patterns derived from independent data with patterns from the model?

    a. What is the rationale for choosing this method?

    b. How are observational and/or model output uncertainties handled?

    c. Does the methodology rely on specific assumptions?

    d. Were other methods experimented? If they didn't succeed, explain why.

    ME/RMSE/MAE are used in time series forecasting, and is less forgiving to large errors than small ones (RMSE is sensitive to outliers). These tests are also good for time series with no trend but seasonality (basking sharks have inconsistent aggregation but fairly consistent seasonal sightings). All data is normalized via min-max normalization, because the model output has a significantly higher number of observations when compared to the IBSG/IWDG data.

18. Is there a threshold level (match between observed and modelled patterns) that can separate acceptable from unacceptable models?

    There is no current "threshold level"; however the lowest *ME, RMSE, MAE scores, combined with time series which compare the monthly trends of all submodels to IBSG/IWDG data, are used to identify the best match. Box plots are also used to compare the normalized data.*

19. How comparable are the patterns derived from the model and those derived from the independent data?

    There is a strong correlation in the time series data and the boxplots for the model settings that also get notably lower MAE, RMSE, and MAE scores.

Sensitivities

20. Has a model sensitivity analysis been performed? If so, how? If not, explain why.

    a. on the model structure?

    b. on the model parametrization?

    c. on other aspects of the model?

    See Appendix B.1

21. Which elements are the modelled patterns most sensitive to?

    a. input parameters

    b. priors and assumptions

    c. structural elements

    d. processes

    See Tables 6—7.

22. How sensitive are the modelled patterns to the choice of initial conditions, boundary conditions, spatial and temporal resolution?

    Unable to determine at this time.

23. How sensitive is the model evaluation to the independent data availability and uncertainty?

    Unable to determine at this time.

24. How much is the model evaluation constrained by computational or theoretical limits?

    Could not run SA/RA tests on combinations *of the model settings, due to the time/computational power this would require.*

25. How does the perceived performance of the model depend on the chosen evaluation methodology?

    All analyses (Stats, graphs) were used on the outputs from the SA/RA tests. We feel confident that SA/RA tests reflect the impact on number of aggregations/size of aggregations.

APPENDIX B: SUPPLEMENTAL MODEL RESULTS

B.1. TOP RESULTS FOR SENSITIVITY AND ROBUSTNESS TESTS:

All model outputs were compared to all of the IBSG/IWDG sighting reports (All of Ireland) and the sighting reports from the model area (Inishowen).

Table 34: Statistical Results for Total Aggregations, when compared to IBSG/IWDG data.

	Inishowen			All of Ireland			Parameter Settings							
Submodel	ME	RMSE	MAE	ME	RMSE	MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Food/Social	0.13	0.25	0.17	0.12	0.24	0.16	10	11	1.E+11	10	9	5	4	20
Random	0.18	0.27	0.20	0.16	0.24	0.18	10	11	1.E+11	10	9	5	4	20
Food	0.15	0.27	0.19	0.14	0.26	0.18	10	11	1.E+11	10	9	5	4	20
Social	0.26	0.37	0.29	0.24	0.33	0.26	10	11	1.E+11	10	9	5	4	20
Food	0.16	0.29	0.20	0.14	0.28	0.19	10	10	1.E+11	10	8	5	14	20
Food/Social	0.17	0.29	0.21	0.16	0.28	0.21	10	10	1.E+11	10	8	5	14	20
Random	0.41	0.51	0.42	0.40	0.49	0.40	10	10	1.E+11	10	8	5	14	20
Social	0.64	0.73	0.65	0.63	0.71	0.63	10	10	1.E+11	10	8	5	14	20
Food	0.09	0.21	0.13	0.07	0.20	0.13	10	10	1.E+11	10	9	5	14	20
Food/Social	0.16	0.28	0.20	0.15	0.27	0.20	10	10	1.E+11	10	9	5	14	20

Submodel	Inishowen ME	Inishowen RMSE	Inishowen MAE	All of Ireland ME	All of Ireland RMSE	All of Ireland MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Random	0.39	0.49	0.41	0.38	0.47	0.39	10	10	1.E+11	10	9	5	14	20
Social	0.63	0.72	0.64	0.61	0.70	0.62	10	10	1.E+11	10	9	5	14	20
Food	0.17	0.29	0.20	0.15	0.28	0.20	10	10	1.E+11	10	9	5	14	20
Food/Social	0.17	0.29	0.21	0.16	0.28	0.21	10	10	1.E+11	10	9	5	14	20
Food/Social	0.20	0.32	0.24	0.18	0.31	0.23	10	10	1.E+11	10	9	5	14	20
Random	0.39	0.50	0.40	0.38	0.48	0.38	10	10	1.E+11	10	9	5	14	20
Social	0.62	0.71	0.62	0.60	0.69	0.60	10	10	1.E+11	10	9	5	14	20
Food	0.16	0.27	0.20	0.14	0.26	0.19	17	10	1.E+11	10	9	5	14	20
Food/Social	0.22	0.34	0.25	0.20	0.33	0.24	17	10	1.E+11	10	9	5	14	20
Random	0.50	0.60	0.50	0.48	0.59	0.49	17	10	1.E+11	10	9	5	14	20
Social	0.73	0.81	0.73	0.71	0.79	0.71	17	10	1.E+11	10	9	5	14	20
Food	0.15	0.28	0.19	0.14	0.27	0.19	10	11	1.E+11	10	9	5	14	20
Food/Social	0.20	0.31	0.23	0.18	0.31	0.23	10	11	1.E+11	10	9	5	14	20
Random	0.39	0.48	0.40	0.37	0.46	0.38	10	11	1.E+11	10	9	5	14	20
Social	0.64	0.73	0.64	0.62	0.70	0.62	10	11	1.E+11	10	9	5	14	20
Food	0.15	0.28	0.19	0.14	0.27	0.19	10	10	1.E+11	10	9	5	14	20
Social	0.63	0.73	0.64	0.61	0.71	0.62	10	10	1.E+11	10	9	5	14	20
Random	0.43	0.53	0.44	0.41	0.52	0.43	10	10	1.E+11	10	9	5	14	20
Food/Social	0.12	0.22	0.15	0.10	0.21	0.14	10	10	3.E+12	10	9	5	14	20
Food	0.28	0.34	0.30	0.27	0.33	0.28	10	10	3.E+12	10	9	5	14	20
Random	0.50	0.59	0.51	0.49	0.57	0.49	10	10	3.E+12	10	9	5	14	20
Social	0.59	0.66	0.59	0.57	0.64	0.57	10	10	3.E+12	10	9	5	14	20
Food	0.07	0.20	0.12	0.05	0.19	0.12	10	10	1.E+11	20	9	5	14	20
Food/Social	0.15	0.27	0.19	0.13	0.27	0.19	10	10	1.E+11	20	9	5	14	20

Submodel	Inishowen ME	Inishowen RMSE	Inishowen MAE	All of Ireland ME	All of Ireland RMSE	All of Ireland MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Random	0.40	0.49	0.41	0.38	0.47	0.39	10	10	1.E+11	20	9	5	14	20
Social	0.65	0.75	0.66	0.64	0.73	0.64	10	10	1.E+11	20	9	5	14	20
Food	0.16	0.28	0.19	0.14	0.27	0.19	10	10	1.E+11	10	10	5	14	20
Food/Social	0.19	0.31	0.23	0.17	0.31	0.22	10	10	1.E+11	10	10	5	14	20
Random	0.42	0.52	0.43	0.40	0.50	0.41	10	10	1.E+11	10	10	5	14	20
Social	0.64	0.73	0.64	0.62	0.71	0.62	10	10	1.E+11	10	10	5	14	20
Food	0.13	0.26	0.17	0.12	0.25	0.17	10	10	1.E+11	10	9	9	14	20
Food/Social	0.21	0.33	0.24	0.19	0.33	0.24	10	10	1.E+11	10	9	9	14	20
Random	0.41	0.51	0.42	0.39	0.49	0.40	10	10	1.E+11	10	9	9	14	20
Social	0.65	0.74	0.66	0.63	0.72	0.64	10	10	1.E+11	10	9	9	14	20

Note that Total Aggregations only include groups of two or more sharks. These tests included a total of 200 sharks and were each run for ten trials. This table shows the results of each submodel, for the 10 lowest RMSE scores for each setting.

Table 35: Statistics for Pseudo-Sighting Reports

Submodel	All of Ireland ME	All of Ireland RMSE	All of Ireland MAE	Inishowen ME	Inishowen RMSE	Inishowen MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Food	0.02	0.15	0.09	0.04	0.16	0.09	10	10	1.00E+11	10	8	5	14	20
Food/Social	0.05	0.19	0.12	0.07	0.20	0.12	10	10	1.00E+11	10	8	5	14	20
Random	0.47	0.54	0.47	0.49	0.57	0.50	10	10	1.00E+11	10	8	5	14	20
Social	0.48	0.56	0.49	0.51	0.59	0.52	10	10	1.00E+11	10	8	5	14	20
Food/Social	0.03	0.16	0.10	0.05	0.17	0.10	10	10	9.50E+10	10	9	5	14	20
Food	0.09	0.23	0.15	0.12	0.24	0.16	10	10	9.50E+10	10	9	5	14	20

	All of Ireland			Inishowen			Parameter Settings							
Submodel	ME	RMSE	MAE	ME	RMSE	MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Random	0.44	0.52	0.45	0.46	0.54	0.47	10	10	9.50E+10	10	9	5	14	20
Social	0.49	0.56	0.49	0.51	0.59	0.52	10	10	9.50E+10	10	9	5	14	20
Food	0.01	0.15	0.09	0.04	0.16	0.09	10	10	1.00E+11	10	9	5	14	20
Food	0.05	0.17	0.10	0.07	0.18	0.11	10	10	1.00E+11	10	9	5	14	20
Food/Social	0.07	0.22	0.13	0.09	0.23	0.13	10	10	1.00E+11	10	9	5	14	20
Food/Social	0.08	0.23	0.14	0.10	0.24	0.15	10	10	1.00E+11	10	9	5	14	20
Random	0.47	0.54	0.47	0.49	0.56	0.50	10	10	1.00E+11	10	9	5	14	20
Social	0.47	0.54	0.47	0.49	0.57	0.50	10	10	1.00E+11	10	9	5	14	20
Random	0.47	0.54	0.47	0.49	0.57	0.50	10	10	1.00E+11	10	9	5	14	20
Social	0.48	0.54	0.48	0.50	0.57	0.51	10	10	1.00E+11	10	9	5	14	20
Food	0.02	0.14	0.08	0.04	0.15	0.09	17	10	1.00E+11	10	9	5	14	20
Food/Social	0.06	0.21	0.13	0.09	0.22	0.14	17	10	1.00E+11	10	9	5	14	20
Random	0.54	0.62	0.55	0.56	0.64	0.57	17	10	1.00E+11	10	9	5	14	20
Social	0.54	0.61	0.55	0.56	0.64	0.57	17	10	1.00E+11	10	9	5	14	20
Food/Social	0.02	0.17	0.10	0.05	0.17	0.10	10	11	1.00E+11	10	9	5	14	20
Food	0.04	0.17	0.10	0.06	0.17	0.11	10	11	1.00E+11	10	9	5	14	20
Random	0.45	0.52	0.45	0.47	0.54	0.48	10	11	1.00E+11	10	9	5	14	20
Social	0.45	0.52	0.46	0.48	0.55	0.49	10	11	1.00E+11	10	9	5	14	20
Food/Social	0.01	0.15	0.08	0.03	0.15	0.08	10	10	3.00E+12	10	9	5	14	20
Food	0.10	0.21	0.15	0.12	0.22	0.16	10	10	3.00E+12	10	9	5	14	20
Random	0.28	0.35	0.30	0.30	0.37	0.32	10	10	3.00E+12	10	9	5	14	20
Social	0.36	0.42	0.37	0.38	0.44	0.39	10	10	3.00E+12	10	9	5	14	20
Food/Social	0.00	0.16	0.09	0.02	0.16	0.08	10	10	1.00E+11	20	9	5	14	20
Food	0.01	0.16	0.09	0.04	0.17	0.09	10	10	1.00E+11	20	9	5	14	20

	All of Ireland			Inishowen			Parameter Settings							
Submodel	ME	RMSE	MAE	ME	RMSE	MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Social	0.46	0.54	0.46	0.48	0.56	0.49	10	10	1.00E+11	20	9	5	14	20
Random	0.47	0.54	0.48	0.50	0.57	0.50	10	10	1.00E+11	20	9	5	14	20
Food	0.04	0.17	0.11	0.06	0.18	0.11	10	10	1.00E+11	10	10	5	14	20
Food/Social	0.08	0.23	0.14	0.10	0.24	0.15	10	10	1.00E+11	10	10	5	14	20
Random	0.48	0.56	0.49	0.51	0.59	0.52	10	10	1.00E+11	10	10	5	14	20
Social	0.50	0.58	0.50	0.52	0.60	0.53	10	10	1.00E+11	10	10	5	14	20
Food/Social	0.04	0.18	0.11	0.06	0.18	0.11	10	10	1.00E+11	10	9	9	14	20
Food	0.09	0.23	0.15	0.11	0.24	0.15	10	10	1.00E+11	10	9	9	14	20
Random	0.49	0.56	0.50	0.52	0.59	0.53	10	10	1.00E+11	10	9	9	14	20
Social	0.50	0.57	0.50	0.52	0.60	0.53	10	10	1.00E+11	10	9	9	14	20
Food/Social	0.03	0.18	0.10	0.06	0.19	0.11	10	11	1.00E+11	10	9	5	4	20
Social	0.30	0.37	0.32	0.32	0.40	0.34	10	11	1.00E+11	10	9	5	4	20
Food	0.04	0.17	0.10	0.06	0.18	0.11	10	11	1.00E+11	10	9	5	4	20
Random	0.26	0.33	0.27	0.28	0.36	0.31	10	11	1.00E+11	10	9	5	4	20

Statistical results for total aggregations for the ten settings that gave the most realistic results out of the sensitivity and robustness tests for the Pseudo-Sighting Reports. Pseudo-Sighting Reports are randomly sample 10 patches every day and report how many shark(s) were found in each patch.

B.2. PRELIMINARY TEST RESULTS:

Table 36: Statistical Results for preliminary tests.

Total Aggregations															
	Inishowen			All of Ireland			Parameter Settings								
Submodel	ME	RMSE	MAE	ME	RMSE	MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return-season
Food/Social	0.33	0.40	0.35	0.32	0.37	0.32	50	20	3E+12	10	9	5	14	20
Food/Social	0.35	0.42	0.36	0.33	0.39	0.34	50	20	3E+12	20	9	5	14	20
Food/Social	0.26	0.37	0.28	0.24	0.36	0.28	10	10	1.00E+11	10	8	5	14	20
Food/Social	0.19	0.30	0.22	0.18	0.29	0.21	10	10	1.00E+11	10	9	5	4	20
Food/Social	0.13	0.21	0.16	0.11	0.20	0.14	17	17	3E+12	10	9	5	14	20
Food/Social	0.14	0.22	0.17	0.12	0.21	0.15	10	10	3.00E+12	10	9	5	14	20
Food	0.32	0.38	0.33	0.30	0.36	0.31	50	20	3E+12	10	9	5	14	20
Food	0.31	0.38	0.33	0.30	0.35	0.31	50	20	3E+12	20	9	5	14	20
Food	0.19	0.30	0.22	0.17	0.29	0.21	10	10	1.00E+11	10	8	5	14	20
Food	0.16	0.25	0.19	0.14	0.24	0.18	10	10	1.00E+11	10	9	5	4	20
Food	0.28	0.35	0.29	0.26	0.34	0.27	17	17	3E+12	10	9	5	14	20
Food	0.28	0.36	0.29	0.26	0.35	0.28	10	10	3.00E+12	10	9	5	14	20

Each test was run for ten trials and contained a total of 100 sharks. Note that Submodels Random and Friends were not run for this test, due to the statical results in Table 12, which indicated low correlation with IBSG/IWDG data. Total Aggregations compare groups of two or more sharks. The highlighted results are the same settings used for Test A.

Table 37 Statistical Results for Pseudo-Sighting Reports for Preliminary Tests

Pseudo-Sighting Reports														
	Inishowen			All of Ireland			Parameter Settings							
Submodel	ME	RMSE	MAE	ME	RMSE	MAE	Cal	Otherzp	Threshold ZP	Sense Distance	Swim Speed	Friend Min	No Eat	Return
Food/Social	0.08	0.17	0.12	0.06	0.16	0.11	17	17	3.E+12	10	9	5	14	20
Food/Social	0.08	0.17	0.12	0.06	0.16	0.11	10	10	3.E+12	10	9	5	14	20
Food	0.12	0.20	0.15	0.10	0.18	0.14	17	17	3.E+12	10	9	5	14	20
Food	0.10	0.20	0.14	0.08	0.18	0.12	10	10	1.E+11	10	8	5	14	20
Food/Social	0.11	0.21	0.15	0.09	0.20	0.14	10	10	1.E+11	10	8	5	14	20
Food	0.16	0.27	0.19	0.14	0.26	0.18	10	10	1.E+11	10	9	5	4	20
Food/Social	0.16	0.28	0.20	0.14	0.26	0.18	10	10	1.E+11	10	9	5	4	20
Food	0.19	0.28	0.22	0.17	0.27	0.20	10	10	3.E+12	10	9	5	14	20
Food/Social	0.24	0.32	0.27	0.22	0.30	0.24	50	20	3.E+12	10	9	5	14	20
Food/Social	0.30	0.38	0.32	0.28	0.36	0.30	50	20	3.E+12	20	9	5	14	20
Food	0.30	0.38	0.32	0.28	0.36	0.30	50	20	3.E+12	10	9	5	14	20
Food	0.32	0.41	0.35	0.30	0.39	0.32	50	20	3.E+12	20	9	5	14	20

Each test was run for ten trials and contained a total of 100 sharks. Note that Submodels Random and Friends were not run for this test, due to the statical results in Table 12, which indicated low correlation with IBSG/IWDG data. Pseudo-Sighting compare any sighting (1+) of sharks. The highlighted results are the same settings used for Test A.

B.3. RESULTS FOR TEST A: 100 SHARKS

The results of 50 trials per submodel were averaged together. Tests were conducted with a maximum of 100 sharks and 200 sharks within the model.

B.3.i. Average Size of Aggregations Per Month

Table 38 Comparison of Average Aggregation Size Per Month (Total Aggregations; 100 sharks) — Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.15	0.23	0.17	0.14	0.22	0.16
Food	0.25	0.33	0.27	0.24	0.31	0.25
Social	0.38	0.48	0.39	0.36	0.45	0.36
Random	0.34	0.46	0.36	0.32	0.43	0.33

Total aggregations (average across 50 trials) compared to IBSG/IWDG sightings. Data was normalized via min-max normalization. Total Aggregations count groups of two or more sharks. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

Table 39 Comparison of Average Aggregation Size Per Month (Pseudo-Sighting Reports; 100 sharks) — Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.14	0.22	0.17	0.12	0.21	0.15
Food	0.19	0.27	0.21	0.16	0.25	0.19
Social	0.27	0.32	0.29	0.25	0.30	0.27
Random	0.28	0.33	0.29	0.25	0.30	0.27

Pseudo-Sighting Reports (averaged across 50 trials) compared to IBSG/IWDG sightings. 20 random patches are sampled per day, and all shark sightings (including single sharks) are reported. Data was normalized via min-max normalization. Results were compared to IBSG/IWDG data from the model area (Inishowen) and all of the IBSG/IWDG data (All of Ireland).

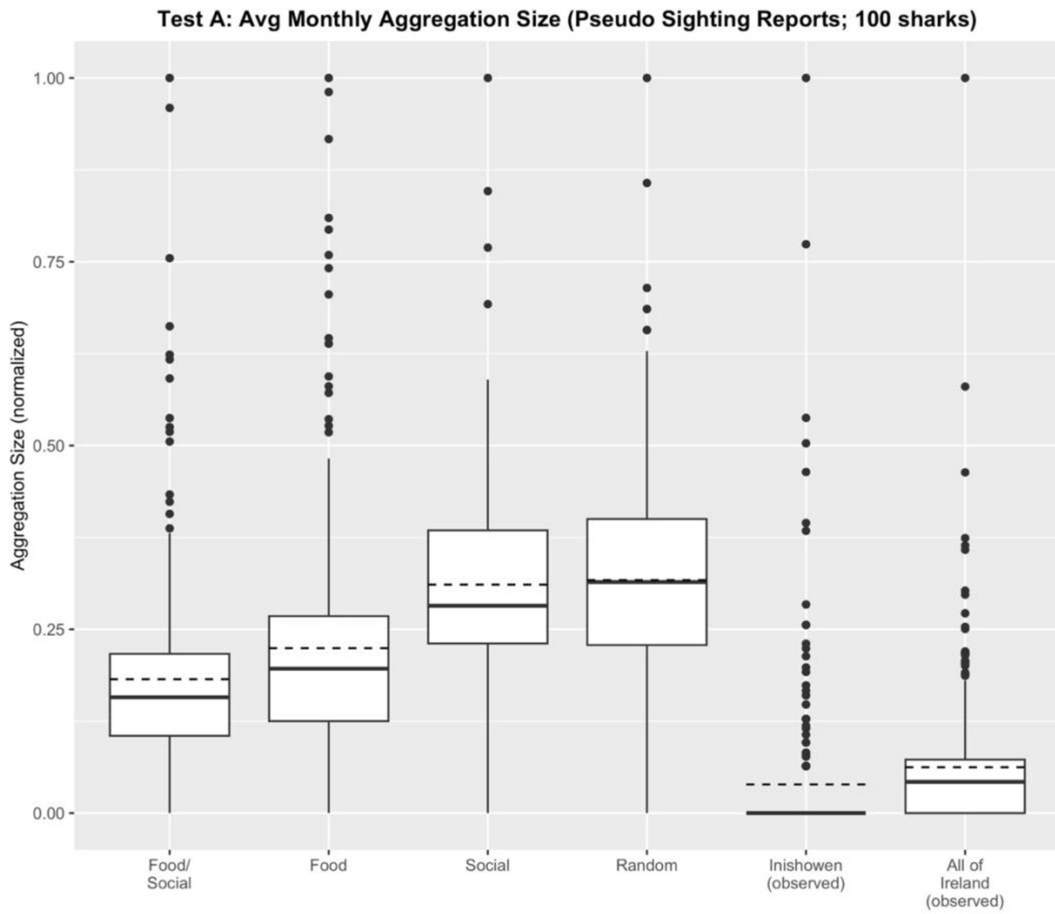
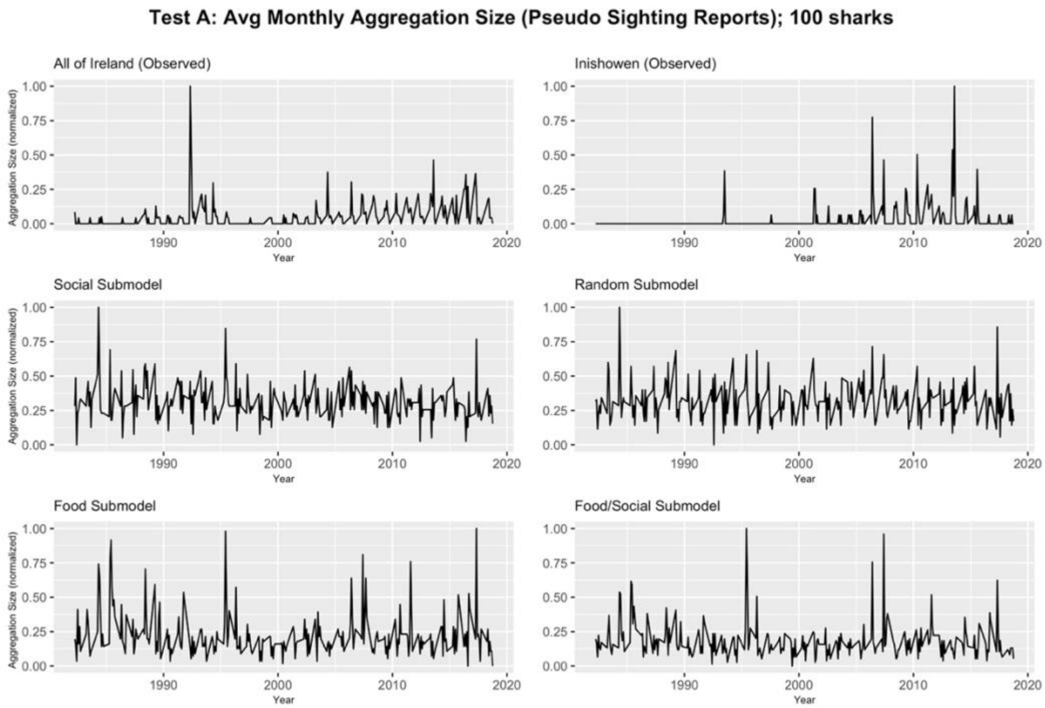
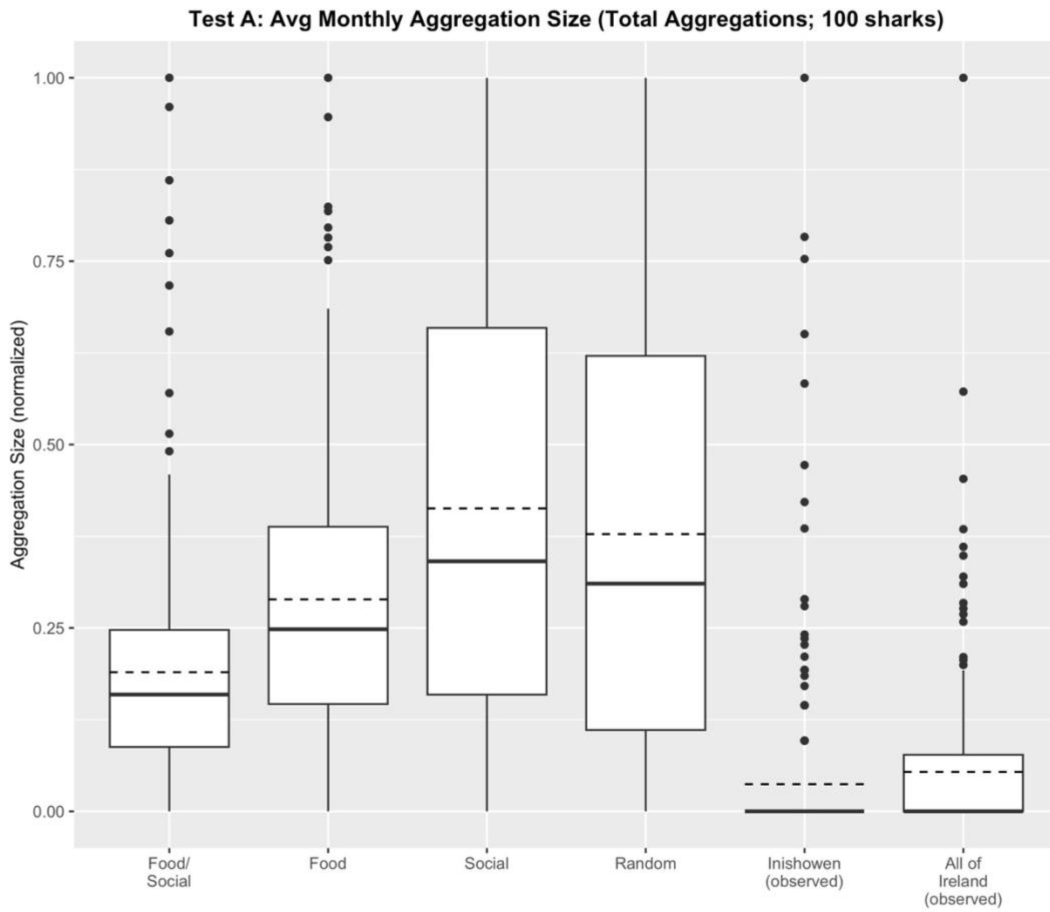

Test A: Avg Monthly Aggregation Size (Pseudo Sighting Reports; 100 sharks)
Aggregation Size (normalized)
1.00
0.75
0.50
0.25
0.00
Food/ Social
Food
Social
Random
Inishowen (observed)
All of Ireland (observed)

Figure 23



Test A: Avg Monthly Aggregation Size (Pseudo Sighting Reports); 100 sharks
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Aggregation Size (normalized)
Year

Figure 24



Test A: Avg Monthly Aggregation Size (Total Aggregations; 100 sharks)
Aggregation Size (normalized)
1.00
0.75
0.50
0.25
0.00
Food/ Social
Food
Social
Random
Inishowen (observed)
All of Ireland (observed)

Figure 25

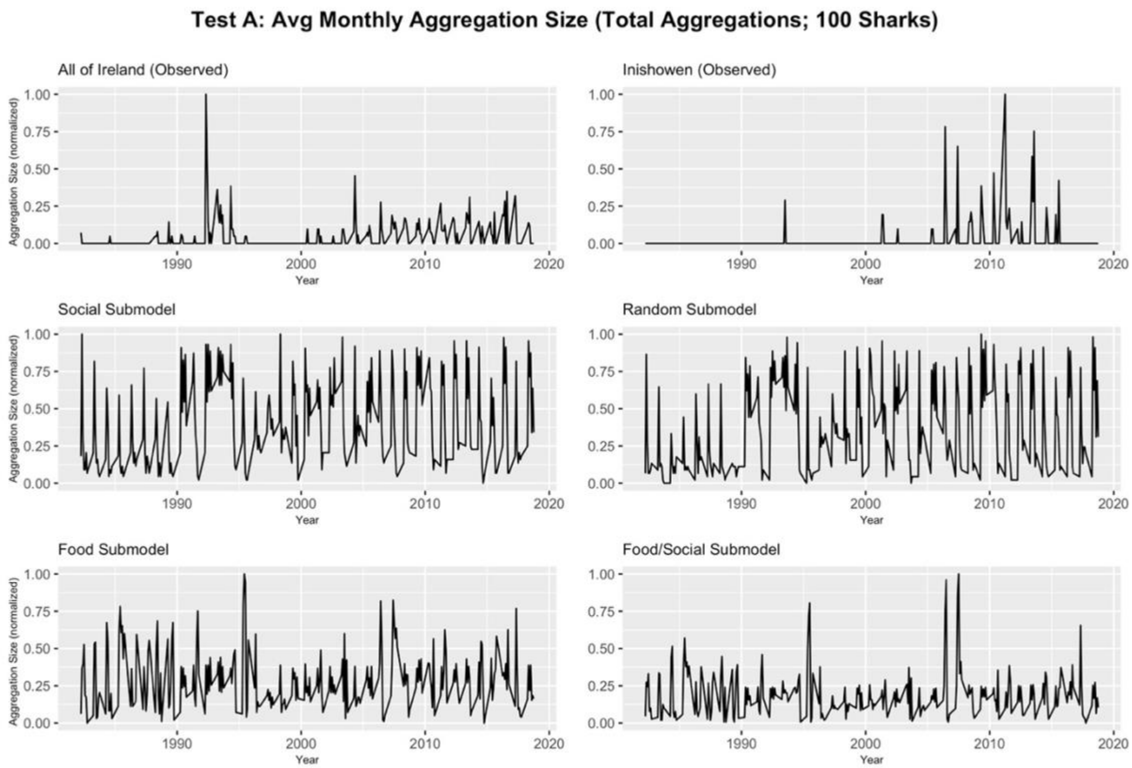

Test A: Avg Monthly Aggregation Size (Total Aggregations; 100 Sharks)
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Aggregation Size (normalized)
Year

Figure 26

B.3.ii Average Number of Aggregations Per Month:

Table 40: Total Aggregations; 100 sharks — Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.01	0.14	0.04	-0.02	0.15	0.06
Food	0.01	0.14	0.04	-0.02	0.15	0.06
Social	0.26	0.37	0.27	0.23	0.34	0.25
Random	0.15	0.22	0.16	0.12	0.20	0.15

Table 41: Pseudo-Sighting Reports; 100 sharks— Test A

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.14	0.21	0.16	0.09	0.21	0.15
Food	0.11	0.19	0.13	0.07	0.20	0.13
Social	0.17	0.22	0.19	0.13	0.22	0.17
Random	0.21	0.25	0.22	0.17	0.24	0.20

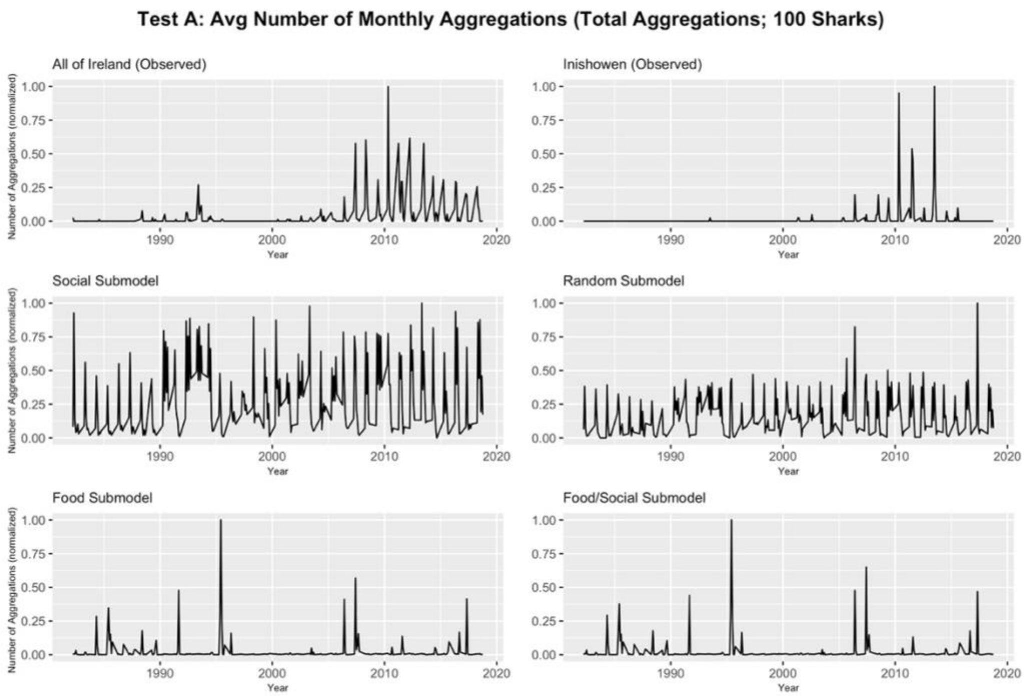

Test A: Avg Number of Monthly Aggregations (Total Aggregations; 100 Sharks)
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Number of Aggregations (normalized)
Year

Figure 27

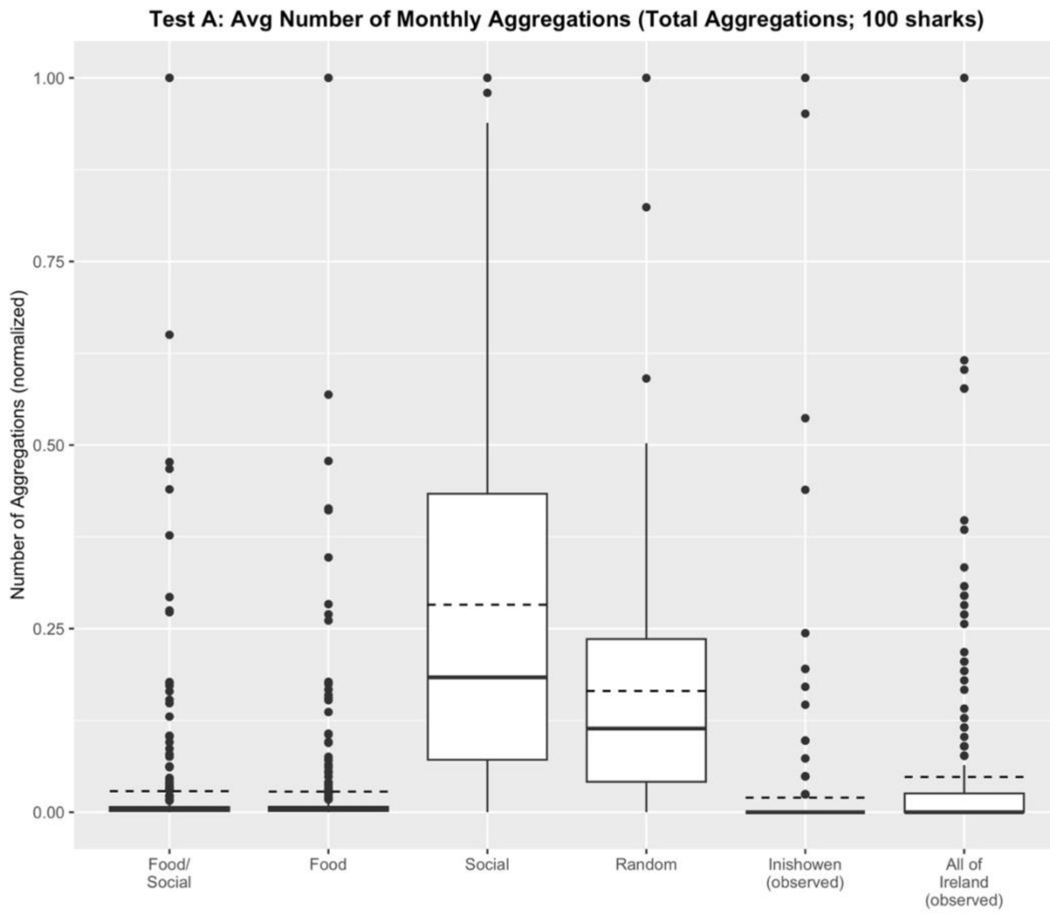

Test A: Avg Number of Monthly Aggregations (Total Aggregations; 100 sharks)
Number of Aggregations (normalized)
1.00
0.75
0.50
0.25
0.00
Food/
Social
Food
Social
Random
Inishowen
(observed)
All of
Ireland
(observed)

Figure 28

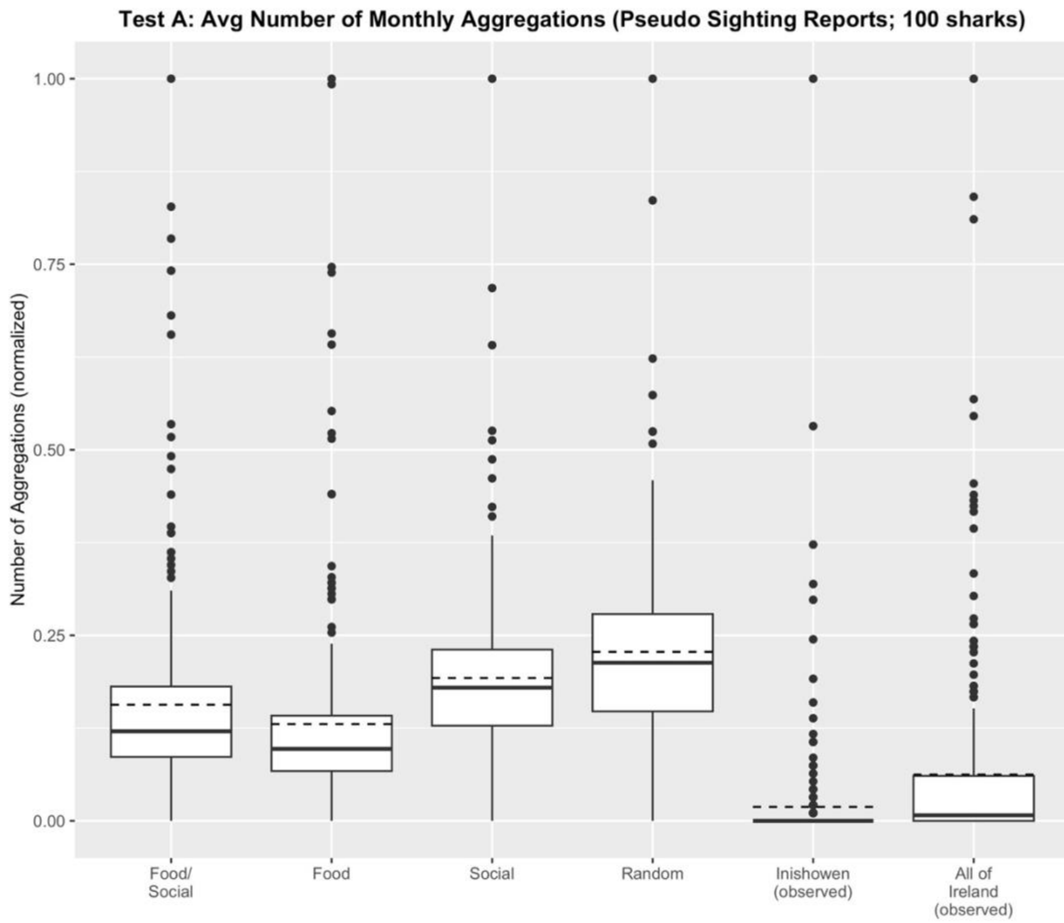

Test A: Avg Number of Monthly Aggregations (Pseudo Sighting Reports; 100 sharks)
Number of Aggregations (normalized)
1.00
0.75
0.50
0.25
0.00
Food/
Social
Food
Social
Random
Inishowen
(observed)
All of
Ireland
(observed)

Figure 29

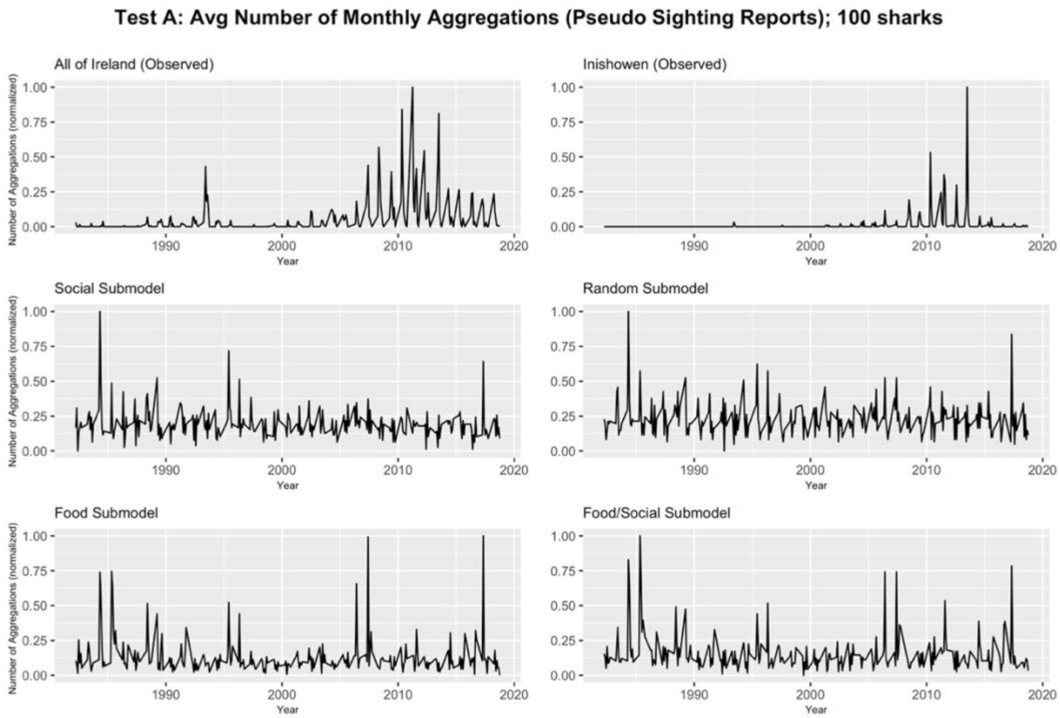

Test A: Avg Number of Monthly Aggregations (Pseudo Sighting Reports); 100 sharks
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Number of Aggregations (normalized)
Year
1.00
0.75
0.50
0.25
0.00
1990
2000
2010
2020

Figure 30

B.4. RESULTS FOR TEST B

50 trials per submodel were averaged together. Tests were conducted with a maximum of 100 sharks and 200 sharks.

Table 42: Settings for Test B

threshold_zp	3E+12
sense-distance	20
swim-speed	9
Cal_%	50
other_zp_%	20
friend_min	5
No_eat_min	14
return-season	20

B.4.i Average Size of Aggregations Per Month

Table 43: Average Number of Aggregations (50 trials) — Test B

	Total Aggregations		Pseudo-Sighting Reports	
Submodel	100 sharks	200 sharks	100 sharks	200 sharks
Food/Social	281	1044	81	160
Food	271	998	78	168
Social	230	911	82	162
Random	236	931	81	161

Total number of aggregations throughout the entirety of the model run (1982—2018). Pseudo-Sighting Reports include any shark "sighted" during a random sample of 20 patches, including single sharks, while Total Aggregations only count groups of two or more sharks, but count all aggregations in the model each day.

Table 44: Kolmogorov-Smirnov Test Between Trials (% different) — Test B

	Total Aggregations		Pseudo-Sighting Reports	
Submodel	100 sharks	200 sharks	100 sharks	200 sharks
Food/Social	18.86	19.10	0.00	0.00
Food	0.24	0.00	0.00	0.00
Social	0.00	0.00	0.00	0.00
Random	0.00	0.00	0.00	0.00

Table 45: Total Aggregations; 100 sharks— Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.28	0.34	0.30	0.27	0.31	0.27
Food	0.28	0.34	0.30	0.26	0.31	0.27
Social	0.54	0.60	0.55	0.52	0.57	0.52
Random	0.53	0.61	0.54	0.51	0.58	0.51

Table 46: Pseudo-Sighting Reports; 100 sharks— Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.35	0.42	0.37	0.33	0.39	0.34
Food	0.30	0.35	0.32	0.28	0.32	0.29
Social	0.33	0.40	0.35	0.30	0.37	0.32
Random	0.35	0.41	0.36	0.33	0.38	0.34

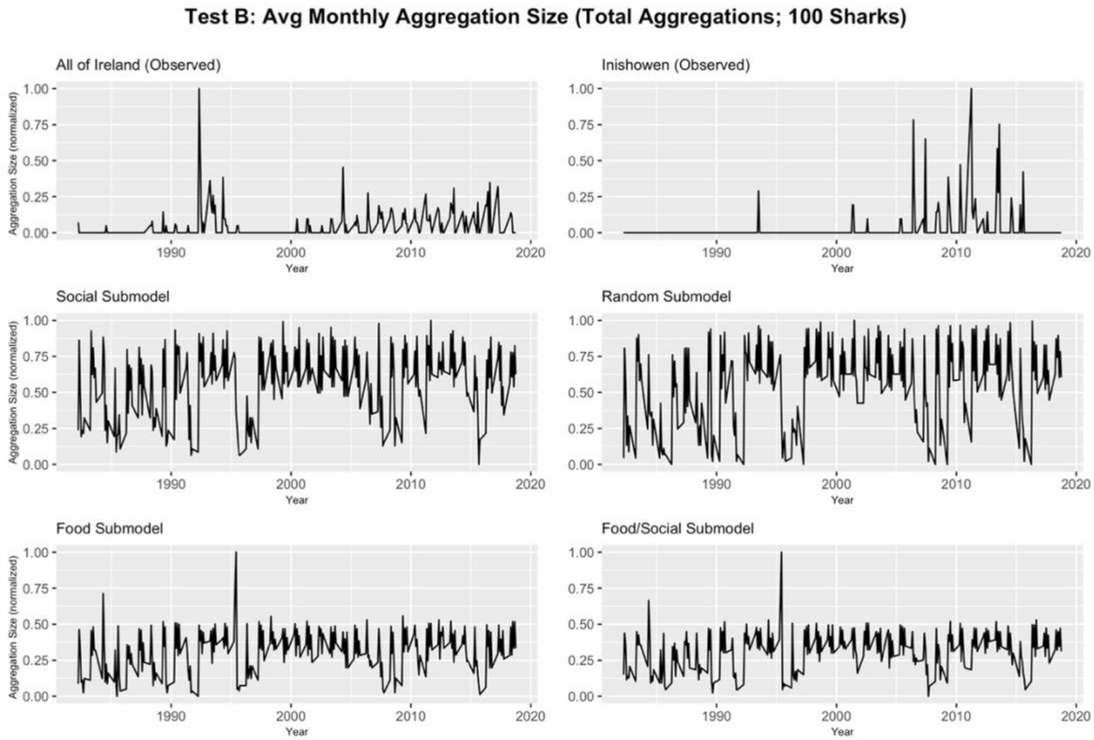

Test B: Avg Monthly Aggregation Size (Total Aggregations; 100 Sharks)
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Aggregation Size (normalized)
Year
1.00
0.75
0.50
0.25
0.00
1990
2000
2010
2020

Figure 31

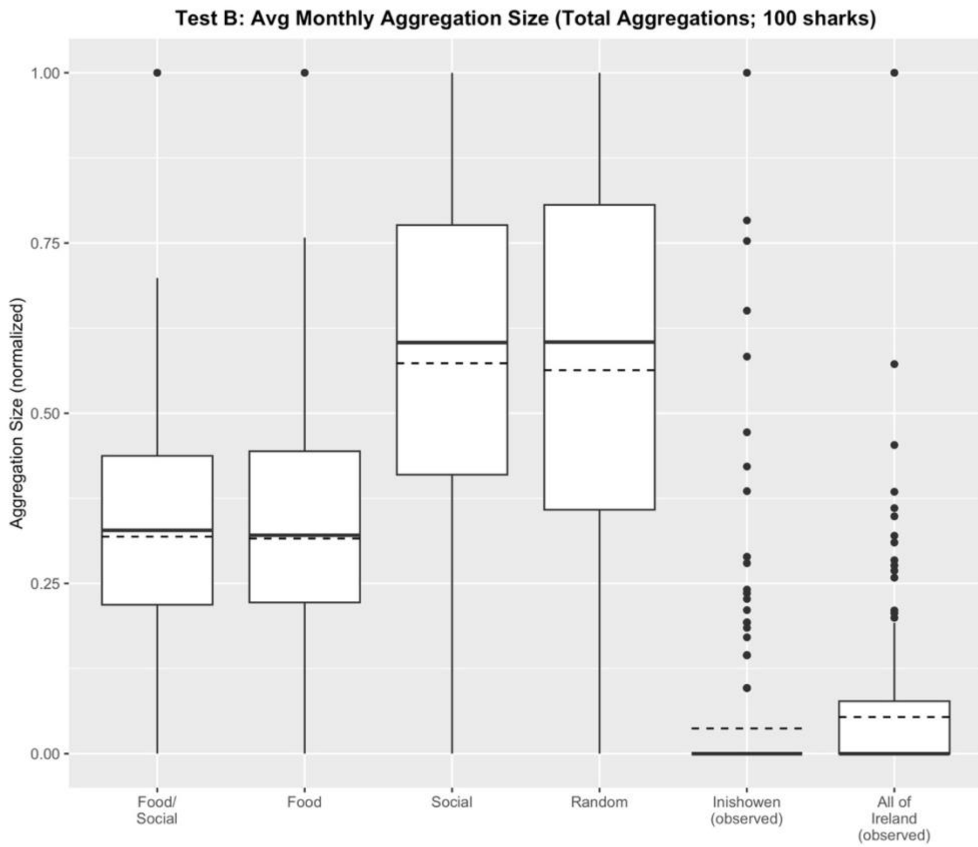

Test B: Avg Monthly Aggregation Size (Total Aggregations; 100 sharks)
Aggregation Size (normalized)
1.00
0.75
0.50
0.25
0.00
Food/
Social
Food
Social
Random
Inishowen
(observed)
All of
Ireland
(observed)

Figure 32

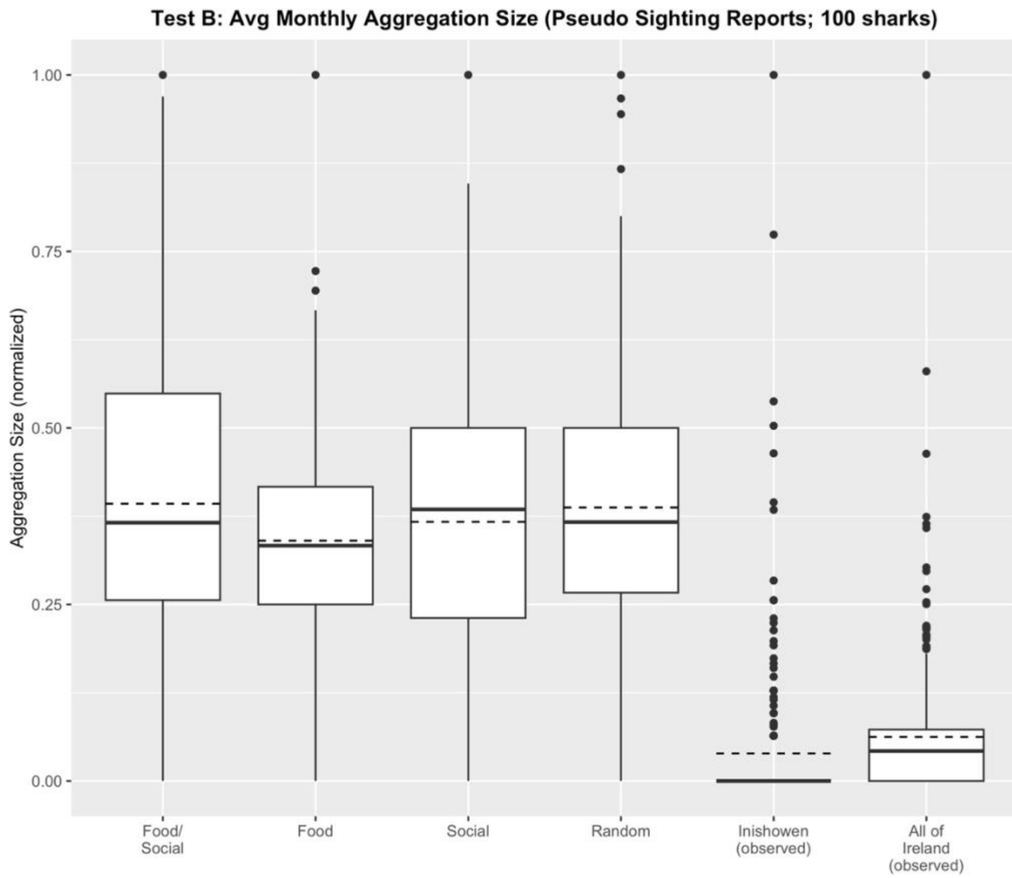

Test B: Avg Monthly Aggregation Size (Pseudo Sighting Reports; 100 sharks)
Aggregation Size (normalized)
1.00
0.75
0.50
0.25
0.00
Food/
Social
Food
Social
Random
Inishowen
(observed)
All of
Ireland
(observed)

Figure 33

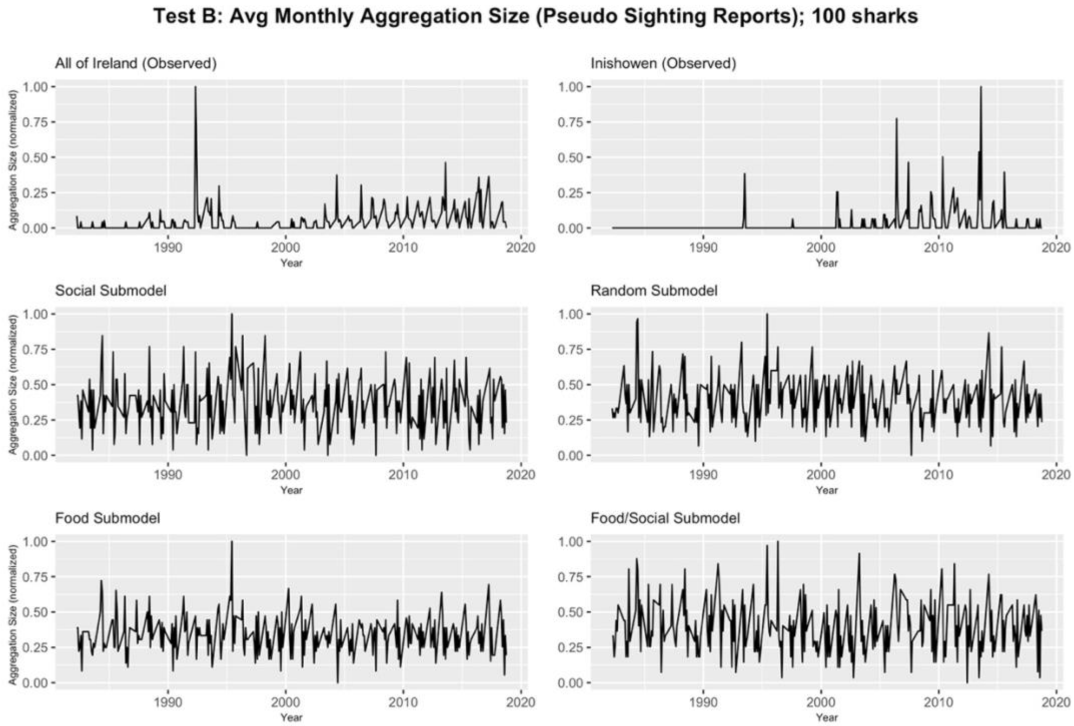

Test B: Avg Monthly Aggregation Size (Pseudo Sighting Reports); 100 sharks
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Aggregation Size (normalized)
Year

Figure 34

B.4.ii Average Number of Aggregations per month

Table 47: Total Aggregations; 100 sharks — Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.01	0.12	0.05	-0.01	0.14	0.06
Food	0.02	0.12	0.05	-0.01	0.14	0.06
Social	0.44	0.52	0.44	0.41	0.50	0.42
Random	0.31	0.38	0.32	0.28	0.36	0.30

Table 48: Test B: Pseudo-Sighting Reports; 100 sharks — Test B

	Inishowen			All of Ireland		
Submodel	ME	RMSE	MAE	ME	RMSE	MAE
Food/Social	0.26	0.32	0.27	0.22	0.30	0.25
Food	0.28	0.33	0.29	0.23	0.30	0.26
Social	0.23	0.28	0.24	0.19	0.27	0.23
Random	0.23	0.28	0.24	0.18	0.26	0.22

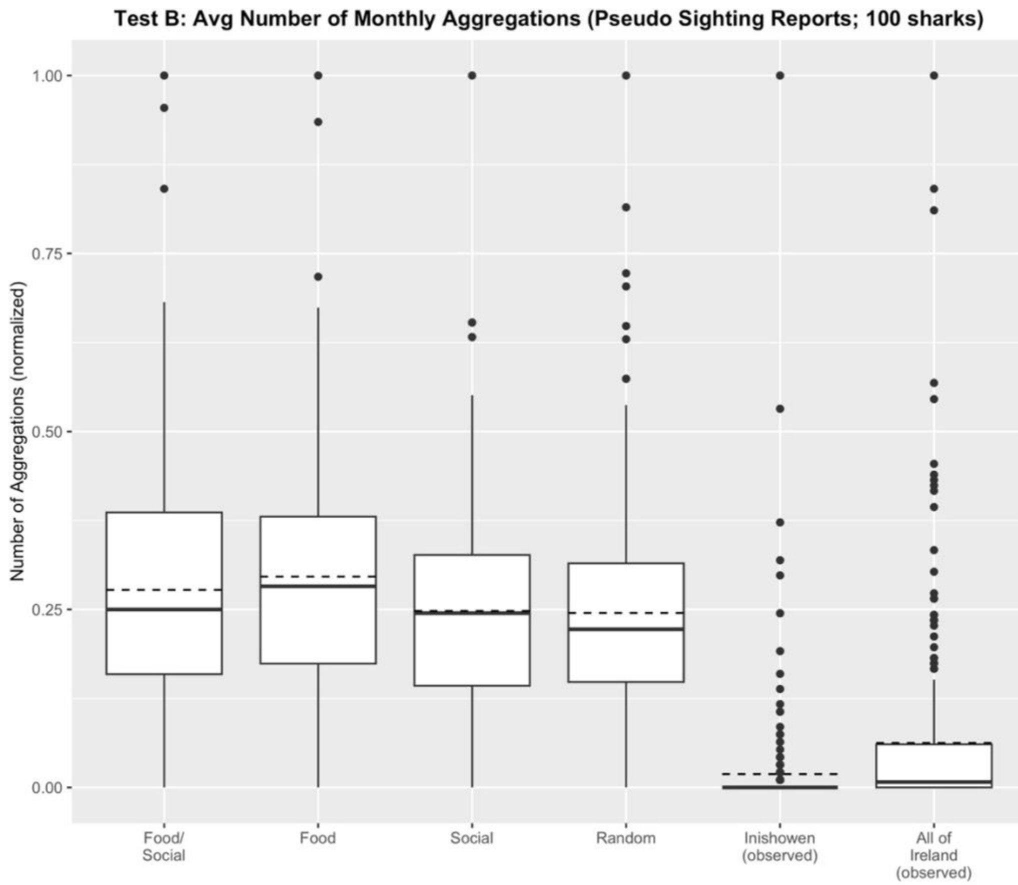

Test B: Avg Number of Monthly Aggregations (Pseudo Sighting Reports; 100 sharks)
Number of Aggregations (normalized)
1.00
0.75
0.50
0.25
0.00
Food/
Social
Food
Social
Random
Inishowen
(observed)
All of
Ireland
(observed)

Figure 35

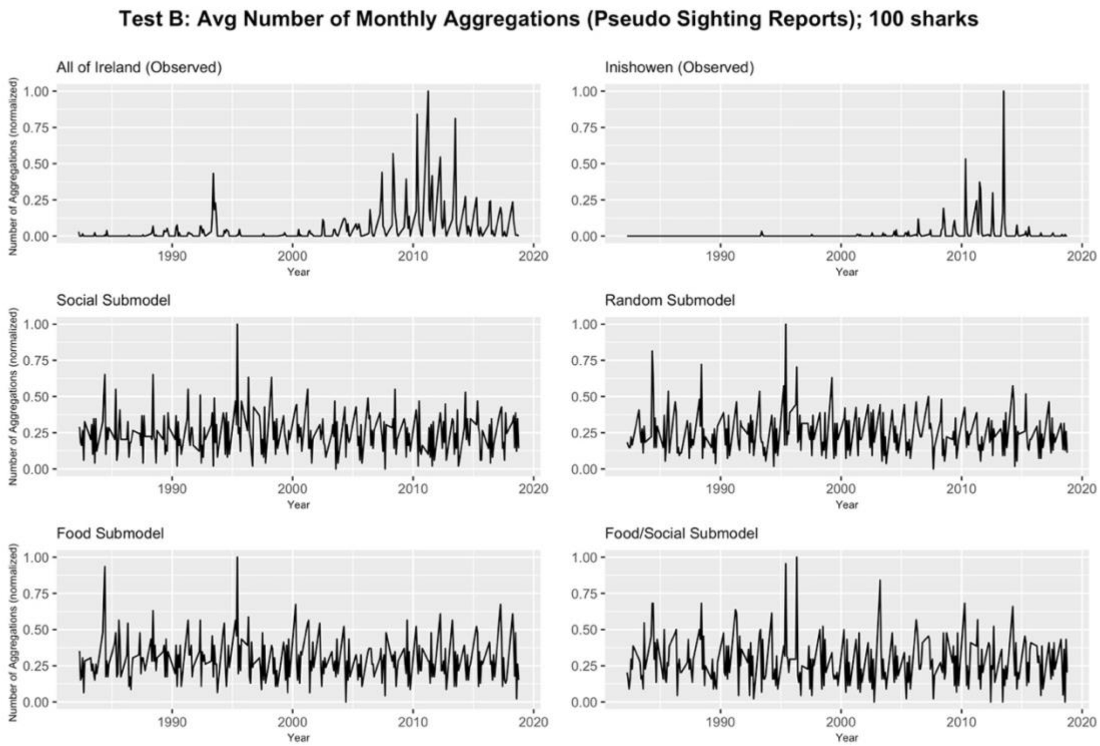

Test B: Avg Number of Monthly Aggregations (Pseudo Sighting Reports); 100 sharks
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Number of Aggregations (normalized)
Year
1.00
0.75
0.50
0.25
0.00
1990
2000
2010
2020

Figure 36

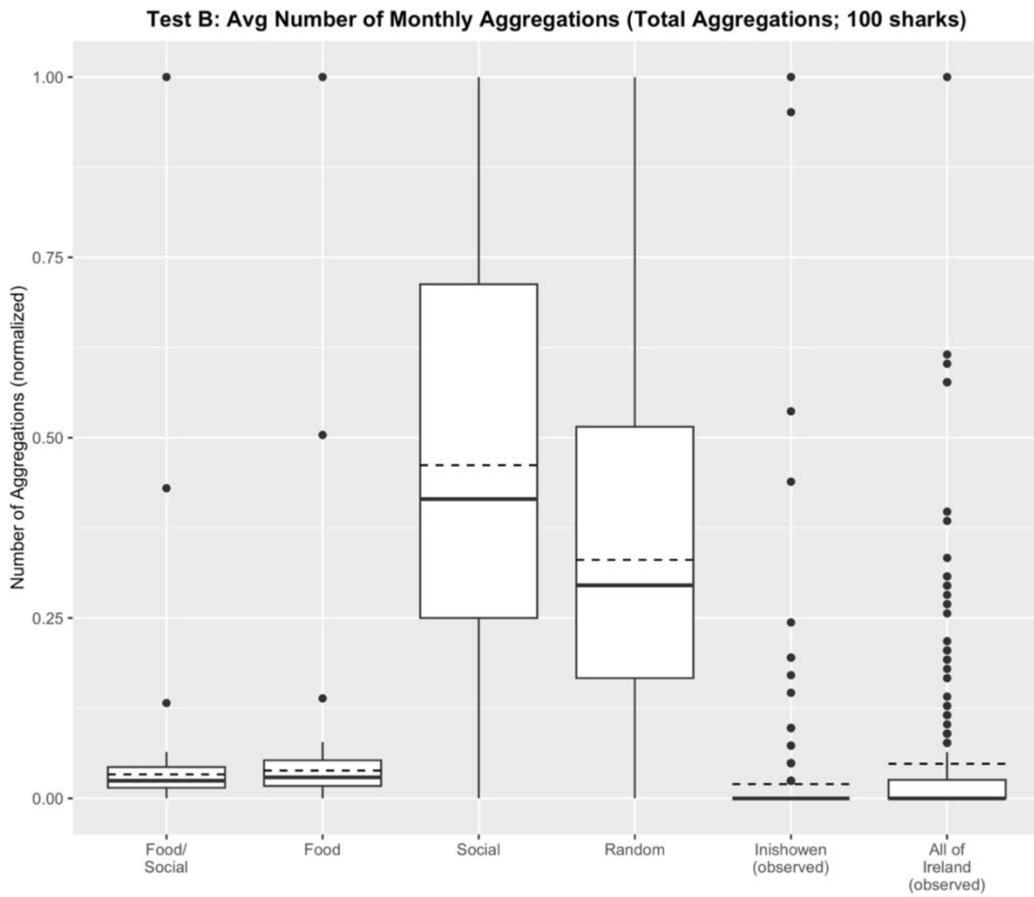

Test B: Avg Number of Monthly Aggregations (Total Aggregations; 100 sharks)
Number of Aggregations (normalized)
1.00
0.75
0.50
0.25
0.00
Food/
Social
Food
Social
Random
Inishowen
(observed)
All of
Ireland
(observed)

Figure 37

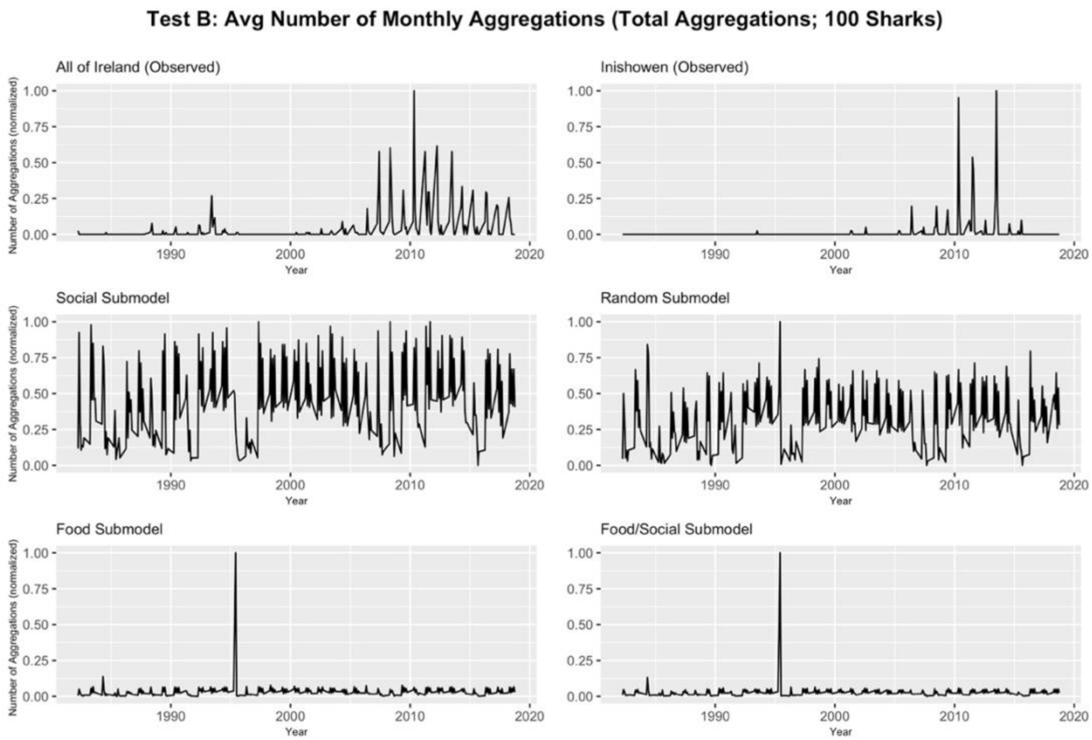

Test B: Avg Number of Monthly Aggregations (Total Aggregations; 100 Sharks)
All of Ireland (Observed)
Inishowen (Observed)
Social Submodel
Random Submodel
Food Submodel
Food/Social Submodel
Number of Aggregations (normalized)
Year
1990
2000
2010
2020
0.00
0.25
0.50
0.75
1.00

Figure 38

B.4.iii Daily Comparison to SST and Zooplankton

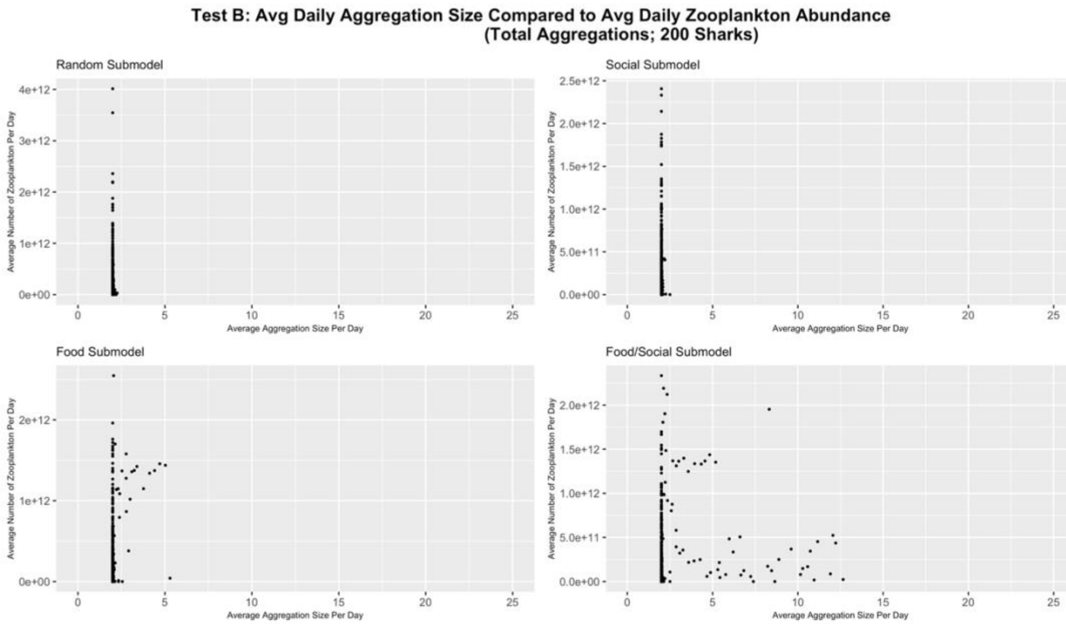


Figure 39

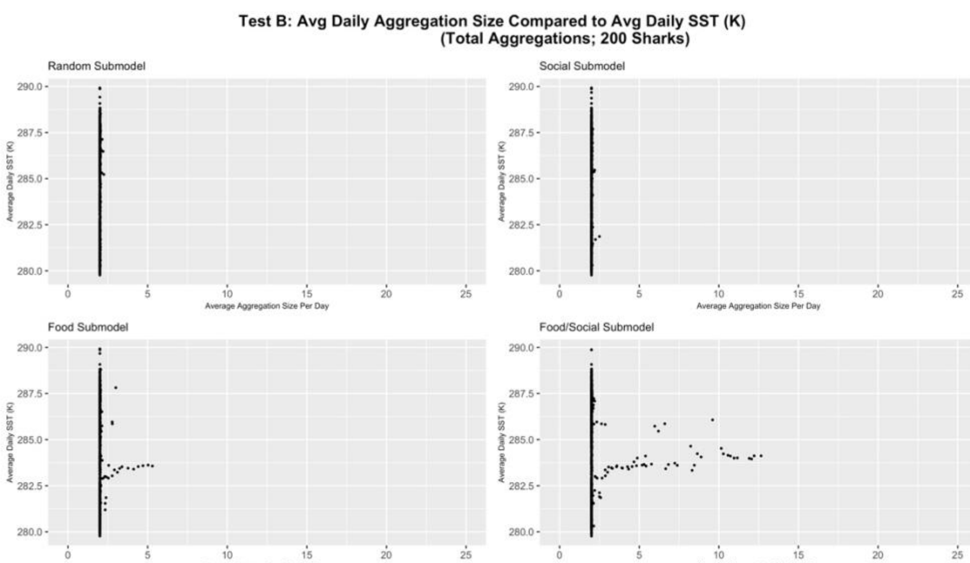
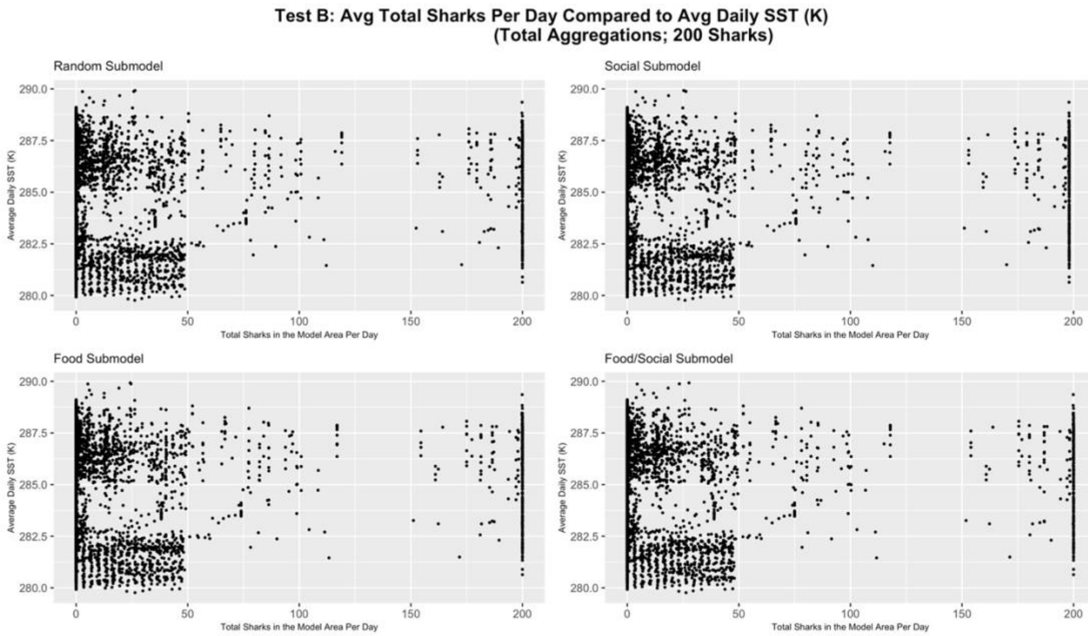


Figure 40



Test B: Avg Total Sharks Per Day Compared to Avg Daily SST (K)
(Total Aggregations; 200 Sharks)
Random Submodel
Social Submodel
Food Submodel
Food/Social Submodel
Average Daily SST (K)
Total Sharks in the Model Area Per Day

Figure 41

APPENDIX C: CASE STUDY INFORMATION

The interview methods were approved by George Mason's Human Subjects Review Board.

C.1 Case Study Protocol

A. Overview of Case Study

1. This research will seek understand the following views of the policymaker(s) or policy developer(s): (1) their current policy theory, (2) the perception they hold regarding scientists, (3) trust in the model, (4) understanding of the model results, (5) understanding of model's purpose and, (6) their understanding if the model influences policy in any way.
2. Theoretical Framework
    a. Multiple Streams Theory
    b. Grounded theory will be used to develop hypothesis post interviews using theoretical coding (Auerbach & Silverstein, 2003).
    c. There will be no assumed theoretical framework followed by interviewed policymakers. Instead, the framework that the subjects follow will be identified to avoid bias (Mayan, 2016).
    d. Manifest content analysis will be used to identify common ideas (i.e. number of times policymakers express confusion around research) and

latent content analysis will be used to delve more deeply into these common themes (Mayan, 2016).

3. The role of this protocol is to guide the researcher, to ensure consistent interview practices throughout each interview.

B. Data Collection Procedures

1. Field Work Contact: Members of the Irish Basking Shark Group will be initial contacts for snowball sampling.
2. Data Collection Plan: Snowball Sampling
    a. Names of potential interview subjects & and their organizations. Will reach out to and schedule 1—hour interviews.
        i. Sources will initially be provided by Irish Basking Shark Group Members, and then snowball sampling will be used to find subsequent interview subjects.
    b. Policy relevant documents published by the organization, meeting minutes, PR statements, and other potential mentions of evidence used to inform policy will be reviewed *prior* to interviews.
    c. Interviews (approx. 1 hour)
        i. Semi-structured.
        ii. Recorded and transcribed on zoom.
        iii. Data analysis conducted using the autogenerated caption, edited for accuracy.
3. Expected preparation prior to fieldwork.

a. Complete the One-pager.

b. Identify relevant organizations & people and create a one-page summary of their organization and types of evidence used to inform policy (if possible).

    i. If not possible, prepare questions to ask in the interview to gather this basic information.

C. Data Collection Questions

1. Background questions on evidence used in the organization [if needed]

    a. What kind of evidence is used to inform policy in this agency/group?

        i. Source: Published policy documents, meeting minutes, published statements, interviews

2. Collaboration in policymaking comes across many sectors, in a non-organized fashion. It involves scientists, the public, NGOs, governmental agencies, and representatives and their staffs. Environmental policy is partially informed by scientific research, including models. This research seeks to understand why some evidence is used over others.

    a. Where does the evidence come from?

        i. Source: Published policy documents, interviews, Press releases

3. Cognitive interviews that assess accurate understanding of the model

    a. Source: Interviews *(Understanding of IBMs)*

4. Are models used to inform policy?

    a. If yes, how?

        i. Source: Interviews

5. Are models trusted?

   a. Source: Interviews *(Trust in Model & Evidence Selection (Methods))*

6. Are models assessed for reliability?

   a. If so, how?

      i. Source: Interviews *(Trust in Model & Evidence Selection (Methods))*

7. If interviewees are expected to communicate the sample basking shark model to higher up (likely along with other evidence) how will they communicate the results?

   a. Source: Interviews *(Model Use in Policy (Communication))*

   b. This will provide information for both accuracy of understanding and use of model results in policy

8. What is the interviewees' perspective on evidence use in policy/policy development?

   a. Source: Interviews *(Trust in Model & Evidence Selection (Methods))*

9. Do they feel that evidence matters?

   a. Source: Interviews *(Trust in Model & Evidence Selection (Methods))*

10. What is the interviewees' perspective on scientists and science?

   a. Are they compelling, when compared to other sources of information (e.g., constituent pressure, managerial pressures?)

   b. Are they trusted?

   c. Source: Interviews *(Wholistic interpretation of interview)*

D. Guide for Case Study Report

1. Audience of the report: Other modelers, to inform communication strategies and advocacy for model use in policy
2. Types of models preferred for "evidence-based" policy.
3. Summary of themes in how evidence is found (e.g., scientific advocacy, relying on lobbyists)
4. Summary of how/if models are used to inform policy
    a. Will include information on the types of models
    b. Will include information on the knowledge that interviewees had of models and model development
5. Summary of if/how models/evidence are assessed for reliability and applicability
6. Summary of mental and cultural frameworks, and how it may impact policymaker decision-making process (e.g., How much do the policymakers trust the science or the scientists?).
7. End result: Outline (similar to TRACE or ODD) to guide modelers in how to make a communication plan.

C.2 Criteria for Interviewing

- Must be involved in policy development in some tangible way, such as…
    - Writing policy recommendations (e.g., from an NGO)
    - Lobbying
    - Assistant to an elected representative
    - An elected representative

    - Agency that makes management policies (e.g., EPA)

- May be a scientist and can have modeling expertise.
- Cannot be: Solely an academic or researcher at academic institution

APPENDIX D: INTERVIEW QUESTIONS

D.1 GENERAL OVERVIEW:

D.1.1 Research Questions/Objectives

4. What is the policy theory held by the policymaker or developer
    a. Does the interviewee feel that evidence matters when it comes to policy development, and/or how does evidence influence policy *in their perspective*?
        i. This will not be a direct question, but assessed using a wholistic understanding of the interview using Manifest Content Analysis
5. What is the perception of scientists held by policymaker or developer?
6. What is the perception or value of basking shark (or related marine) conservation to the policymakers?
7. Does the one-pager impact the policymakers understanding and perception of the issue of basking shark conservation?

D.1.2 Interview Questions

- Tell me a little about your professional path. How did you get here? *[ice breaker]*
- Tell me a bit about your work
    - Ask for more detail on something they mention
- May ask clarifying questions about documents/materials found online and reviewed prior to the interview. These documents/materials will be relevant to the specific agency or organization that the interviewee is a member of and will relate to types of scientific evidence used to inform policy.

D.2 UNDERSTANDING OF IBMS

D.2.1 Research Questions/Objectives

8. What is the level of understanding of the model results held by policymaker or developer?
9. What is the level of understanding of model's purpose held by policymaker or developer?

D.2.2 Interview Questions/Objectives

- Are you familiar with what a model is? Can you define it for me?
- Did you review the one-pager?
    - [if yes] Can you summarize it for me?
    - [if no] is that format something you see often?

D.3 TRUST IN MODEL & EVIDENCE SELECTION (METHODS)

D.3.1 Research Questions/Objectives

10. What is the level of trust in the model held by policymaker or developer
11. How are scientific models (to be used as 'scientific evidence') chosen for policy?
12. Are models assessed for reliability, applicability, or appropriateness for use in policy?

D.3.2 Interview Questions

- What do you understand about the term evidence-based policymaking? How important or accepted is it currently, and to give examples of what constitutes evidence?
- Are you familiar with modeling methods?
- When it comes to models, do you have a preferred method you trust? Do you assess the model methods?
    a. [if they get evidence from someone] are you more willing to trust evidence from that person?

    b. Could I, for example, present this one pager to you and argue convincingly for a policy viewpoint or its inclusion in appropriate documents?

- When you are reviewing evidence, do you take notes?
- Do you ever print things out, and/or stamp them or mark them?
- What factors disqualify evidence? Do you track evidence that's been disqualified?
- How do you find evidence? Do you do that yourself, or do people bring it to your attention?

D.4 MODEL USE IN POLICY (COMMUNICATION)

D.4.1 Research Questions/Objectives

13. Will policymakers indicate that the model has influenced their own policy in any way? What would be the preferred way of model communication/advocacy?
14. Would the interviewee be expected to communicate the scientific evidence (sample model) to higher ups?

D.4.2 Interview Questions

- Do you trust this one pager? Why or why not?
    - Would there be a better way to present this information?
- You had to communicate the model to higher ups how will they communicate the results?
    - Would you also include other research?
        - How would that other research be decided?

APPENDIX E: INTERVIEW QUOTES

E.1. UNIQUE NGO

Tadgh: It's very clear who does what work and what the steps are that we go through. So, it's not like kind of we're some kind of advisors and go to meetings, fancy meetings, or something. No, this really all about doing the work and getting the work done. It's not about lobbying, or it's just about the evidence, and it's very restrictive, and it's very kind of ethical, transparent. It's not lobbying or something like that…. We just present the evidence. But, of course, the evidence in this case goes beyond a single project, or a single region or something. The evidence is often based on a global review and knowledge synthesis that is out there. So, we don't really come up with very specific policy recommendations. It's more like: "Here's the evidence, and how it could be used by policy." It's not so much like: "Here's the evidence, and you should do this." So that's, I think, a little bit different. We make knowledge available. We make it available in an understandable way. We have a list of things that where we see gaps where we see, maybe research needs or policy needs. But then it is at the end, up to the policymaker to use that evidence.

E.2. EVIDENCE BASED POLICY

Laoise: When I hear that term [evidence based policy], or what I would associate with, it is that were [the agency] to take on any policy, or if *any government body is to take on any policy, then they need to know that there's actual concrete evidence in place to say that it will give the proven benefits, or that if it's not benefits, [then] they have concrete evidence in place to kind of back up the reasoning for doing [a policy].*

***

Mack: for us in [agency] to create any policy, we have to go off the best available evidence. Usually we have our go-to sources. So, if it's information about a particular species or a habitat, we will use the likes of Marlin, which is collection of peer-reviewed data sources. So, for us, we have to stand over everything that we decide on. The fishing industry really holds us to account on that because anything they don't like, they really stress the fact that: "What evidence did you use to come up with this decision? On what evidence?" And they seem to think that we are making decisions on a single point of evidence whenever we try and get as broad of a spectrum as possible. So yeah, for us, it is definitely: How many sources we can find? But It's not just the number of sources, it's reliable sources. Or is it peer reviewed [or] has a Q. A. [quality assessment]? Is it from a company or a source that we have used before? And can [we] stand over their data. And we always have to have that evidence trail backing up any decisions we make.

***

Jason: Well, I think it's certainly a term we would use ourselves [in my agency] that it's based on. In our case, we'd say scientific data or measurements. Not based on anecdote or hearsay. That it can be backed up. That it is possible to be published, and possibly in grey literature or and, hopefully, [in a] peer-review journal. And then it's transparent… so *that a bias is removed from the data set and the analysis and what you're seeing is a true account of the data, and it's reporting.*

***

Interviewer: Especially when it comes to things like basking sharks where the science is really rapidly moving rapidly developing- How do you assess the reliability of evidence when there's so much coming in? Also when there's so much developing on the policies [in that area] so rapidly.

Colm: Well, I guess beyond whether or not information have been published. In the peer-reviewed literature, I think the integrity of the scientists involved is important. You know the experience [or] the sort of pedigree of the laboratory or the university, or a combination of universities and collaborators— All of that is important [and] it feeds into the overall picture....I think there's— there's merit in processes that have different stages. They have the technical stage, and they have the policy consideration stage, and sometimes it goes back to the technical stage to, you know, provide better information to the policymakers. But I think drawing from international collaboration can be really important, particularly for mobile species. Because the scales [at] which individuals are operating are huge, and your window on their actual ecology is tiny, really, compared to their day to day lives throughout the year and everything. So, I think there's a combination of different features. I think that you want to know that you can rely on the information.

E.3. MODELS

Mack: I think I've heard a hundred times, but [that] all models are wrong, but some are useful. So, to me a model is our best guess. I've predicted something that we have a little bit of information on, so I know the better information we put in there, be it volume of data or quality of data, the better results we're going to get out. But yeah, a model's a way of getting an idea of something that we don't know anything about. But there are confidence issues with it, so the better the model the better the data. The more confidence you can have in the predictability of the outcomes. But they're never going to be exact. They [are] only at best an estimate.

***

Colm: I suppose a [model is] simulation of a set of circumstances, using samples of information… Basic statistical modeling would have been would have been part of my work in the past. But yeah, I'm familiar with various different modeling techniques. I wouldn't implement them now in in my day-to-day work um, but in my doctoral and post-doctoral years it would have done.

***

Interviewer: That's an interesting perspective to have, especially the legal component at the species level, because obviously so much of the legislation impacts the research. So, I'm curious. Do you think that this need for a population level, or at least a bias towards kind of a

population level in a policy-based determination, biases towards specific modeling methods?

Colm: To be honest, I don't really know. [That would be my] would be the answer to that. I think I'm probably not up to speed sufficiently on the technical side of models and what they can do [in order] to really give you a very, very definitive answer on that. But I think from a decision-making point of view… what tools do we have? I think the responsibility is on us as policymakers to use the best tools that we have. And if the only tools that we have for some things are individual-based models rather than population level models, because we have access to this cohort of individuals from a North Atlantic population, that God only knows where the rest of them are most of the time— Well, then… [if] the only thing we could work on is that sample [even] when it's… it's not a statistically sound sample. But you've got to work with something. So, I think it's sort of an assessment of what tools we have to call on…. What evidence do we have to call on? What are the science outputs that we can call on to develop a policy position? They'll all be important, you know. It's a matter of what we have first.

***

Briain: Well, it [a model] can be lots of things, but I guess in the context here it's where you infer from a small set of data, what's happening on a larger area.

***

Jason: Well, I would see it as an approach to understanding and presenting the data…. and using that to define potential patterns into the *future. And possibly even just to explore what we've been presenting in different ways and in terms of currency [i.e., current]. So that we'd be able to say: "Well, yes, it fits a model," or "it's a good fit to the model. So, therefore it's telling us about the performance of a stock or the performance of a fishery." Or, in general, the performance of maybe certain interactions as well.*

***

Peadar: I take a very broad view of models. So model is essentially a representation of the world in some way, and it's almost necessarily a simplified representation of the world. So, the kinds of classical models that we think of in my field of study would be a mathematical representation of the system. [A mathematical model is] stripped down to the aspects of that system to the components that we're interested in and kind of ignoring things that we're not interested in. Or a computer simulation model that essentially code that replicates the system in a sort of simplified form... I think, about almost any representation of the world as being a model. I mean, we're all modeling right now, as we talk, using words, and with pictures. I don't see every aspect of what's going on, [while] I'm interacting with you. I'm modeling this region of the world, essentially taking out parts of it that don't mean anything in the context of this, focusing on something that I can get my head around essentially. And that's, I think, what most of modeling, if not all, of modeling, is. It's [a] tool for clarifying thought. Be it a mathematical tool. We had a meaningful type of verbal model. We could sit and say: "Okay, well, you know, suppose this species is increasing, and you have another species moving in. The interaction is mediated by a predator." We can talk about what happens, and that would be a type of model. Usually, we try to make models formal and rigorous in the sense that we know exactly what it is *we're defining, and exactly the logical consequences of those definitions and in in those systems.*

E.3.i. Inertia

Mack: At my last job where we created the habitat stability models. I ran a workshop based on just models, and I was looking [for] the best type of model to use for the work we did. Because there was something like six or eight different partners in the project, and I thought it would be great if we all could see a model so that we could share results, share bits of code. We're all working off the same environmental data. The only thing that would change between my model and some of these model in [country] would be the species data.

So we have this workshop [and] look at the pros and cons of the different type of species distribution models that were right there in literature. And as part of that, I asked, you know, different speakers to take a model, go and do some research, and present the pros and cons of it. And then at the end of the day… we discussed: "Okay, based on the data that we're all using which model might be best suited for our needs in this project."… And sometimes you come up with people who have used a certain model before and [they'll] be like, "Oh, no! This model is really good." And it's not that it's really good. It's just [that] they're familiar with it, and they don't want to change [to] the new one.

I came... from a point of view— I had never done species distribution model, so all of it was new to me, so I didn't have a preference. I was able to look at it and go: "Okay, based on this bunch of papers and this bunch of papers—" and...I conclude[d] that a maximum attribute model is the best for my data. So yeah, it is something that we almost have to work with each other, because of the multi partner projects for everyone *because… We're very rarely work[ing] in isolation here. [If] I was working on something and I was the MPA team representative, I may have to go to the range strategy team or the main policy team, or the even the... the bird team, and if we're all working in some sort of MPA wide model, I still have to consult with all of them, because all their individual data points would feed into the model. So, we all have to be on the same page.*

E.4. RESPONSE TO ONE-PAGER

Jason: I suppose it's a key point that they can understand the— the knob of the arguments and speak to them and be reasonably confident that they're articulating the view of the policy, I suppose, if the person is representing an agency and promoting this protection, they can point to the 50 page document that supports the decision or whatever. But I think oftentimes the nuances of a document are lost, and I think if they're presented in a coherent, logical, easy to assimilate way. It may be much easier for a manager to support.

***

Interviewer: How useful was the policy recommendation part for you? Is that something that you thought was beneficial? Or is that something you [feel] like, "No, I'd rather read it and come up with my own policy recommendations"?

Berni: I would definitely use what you said there. I would probably also back it up with other scientific literature within that space…what you're doing. It shows that you actually, have evidence to show as well. So, a lot of the times I will be emailed by somebody who has like a big idea of *what they want to do, or has an idea for a project, and it helps me to see that [you]'ve actually got evidence, or have got a picture there of who you are and what your aims are. And yeah, it's a good way to introduce people to you and the work that you do and get them interested in that. I want to read more, if that makes sense.*

***

Mack: Usually [I get documents with] more details. Now it's usually not just one page. But what people will give us [is] their overview. You're taught this from your academic point of view, that you have to provide a background on most policy. People will look at the over-all project, and then we'll skip down to the recommendations. And then, if there's anything that stands out as consensus, or that might cause a bit of issues, if I were to implement that. Then we go back and go higher [up the document].... So it's almost like a you start from the back and you work forward. The way people present work to us is almost like a small thesis, where they would have their overview, what they did, and then what their main findings are, with the recommendation.

***

Vince: We would, I think, have to be fairly comfortable [with the research], so that may just involve [saying]: "Okay, send us what you got," and if we need a bit more, like a template that you shared, that would be a starting point. Is this kind of data that we could use to justify that? And if it's not. We go back to them [the researcher who sent information] and say, "Have you got more?"

***

Colm: How much of a response I gave would depend on how important the paper and your communication to me would be in the context of what the main priorities are underway [in my agency] at the moment. Then I would, at a minimum, keep the communication... If I had time to read it, I'd sweep through it. Certainly one page would be very quick to read [but] whether I got to read that one page or no would depend on how hectic it was, how busy it was on the day. But normally, I would if I get an attachment from someone I preview it to see: is this big, small, medium? Can I go through this quickly? If I could scoot through quickly, I would, which I would for one page, and then, you know, I might follow up then with [the sender] and say: "Look, I'll be back to you on this. This is really interesting."

***

Jason: I do think I've often said this: the managers are busy. People are dealing with staff and lots of different situations. I think they probably need to be able to assimilate the information. They can drill down more if they wish. And having a short summaries like that, are probably very, very useful,

***

Briain: It [his job] does take a lot of time. It's not something I have a lot of… it's [the one pager] short. That's really good. It's to the point. It tells me exactly what [I need]. I go straight to the bottom of the page, and I say: "What are you looking for?" Then I see:… "Does that make sense, what you're saying? Do you have some evidence that support[s] it?" It's [the one-pager is] direct, there's no filler in it, it's just the information *that we need, and it's a one-pager. I can communicate that quickly… I would consider the recommendations…[but] very honestly, we are so short of resources, not financially, but personnel…I have to prioritize [other work] that is the big priority for the moment. And if I got this, I would respond and say, "Thank you for the information, and we will continue it, and I will be keeping a file in this, and we will be acting in the future."*

***

Interviewee (anonymized): I think that maybe [it] may make sense that Malin Head could be a good [area for a protected site]. Always when I'm looking at these things, I'm thinking about what it means for me. [The] basking shark is going to come within my remit. So, I haven't really put a lot of effort into thinking about protected areas for basking shark… Maybe this is going off topic here now, but this could be a location that is suitable. Certainly, there's been a lot of effort put into that location. I know that, and I know that [name] has been working very hard up there in that particular location. And I know as well that [the] basking shark does have, kind of, hotspots. And it's interesting that, as reproduction seems to be the driver in this location, as opposed to just feeding resources, which would be the first thing we start thinking about when it comes to basking shark.

E.5. SUMMARY OF ONE-PAGER

Vince did not do a summary, but instead dove right into talking about the use of the one pager. This was due to time constraints and the nature of the conversation.

Laoise: I know that the preface was kind of around basking sharks [and] that they're recently protected…. There's [better] understanding now *that you've got that Wildlife act in the Republic… and [now you're] actually doing a little bit more research to understand how they're [basking sharks are] using [the] waters [around Ireland]. And [the] measure management measures, specific management measures [to] put in place to protect those species. And then…that there's a little bit of [new] research [in the one-pager]. And there's policy recommendations which…. If we don't have a lot of time to go into the nitty-gritty details of the research, [me and other people who work in policy] will tend to just go straight to those… And those specific management measures [were] relating… to marine protected areas. What will you need to put in place and the like? How will the Government go about getting those [things done]?*

***

Mack: Some of the key points are that historically basking sharks were common and they're not anymore. And there's a need for them to be protected. [The one-pager[Suggested that Ireland is an important spot for breeding and feeding [of basking sharks and] that they're seasonal. [Pause] [Basking shark is] occupancy due to food being available—That there potentially could be a tourist market for them. [Pause]

So, you use[d] an individual-based model, to look at aggregations with potential courtship suggested. Oh, another method used [was] continuous plankton recorder [data]. So, you assessed food availability. Made note to other observations from Irish basking sharks, probably [researcher]'s work. Then summarize why they're seasonal… In summary, you have looked at observations and food availability compared that to some sort of temporal scale to suggest seasonality, and then proposed why these animals are here seasonally. So, food *production, reproduction status, habitat need and then [proposed protections], based off of your um assumptions, because based on this, you don't actually have the data to practically test that any of these are actually the reason why they [basking sharks] are there. But based on your assumptions you're putting forward four policy recommendations and potential designations.*

***

Colm: Okay, key points are [that] basking shark research in Ireland indicates [Ireland contains] areas of importance. [That] basking sharks have an important ecological position. [That] at least one core area within Irish waters seems to be of key importance in relation to food foraging, but also reproductive behavior. And there's an argument that protected areas for basking shark, and not least including this Malin area, are justifiable based on research. So, far more work needs to be done. More funding needs to be put into research, particularly in in relation to climate influences now and into the future.

APPENDIX F: WEB OF SCIENCE ARTICLES

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Abesamis, R. A., Stockwell, B. L., Bernardo, L. P. C., Villanoy, C. L.,; Russ, G. R. (2016). Predicting reef fish connectivity from biogeographic patterns and larval dispersal modelling to inform the development of marine reserve networks. Ecological Indicators, 66, 534–544. https://doi.org/10.1016/j.ecolind.2016.02.032	Developing networks of no-take marine reserves is often hindered by uncertainty in the extent to which local marine populations are connected to one another through larval dispersal and recruitment (connectivity). While patterns of connectivity can be predicted by larval dispersal models and validated by empirical methods, biogeographic approaches have rarely been used to investigate connectivity at spatial scales relevant to reserve networks (10's—100's of km). Here, species assemblage patterns in coral reef fish were used together with an individual-based model of dispersal of reef fish larvae to infer patterns of connectivity in a similar to 300 km wide region in the	Y	Developing networks of no-take marine reserves is	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Philippines that included the Bohol Sea and adjacent bodies of water. A dominant current flows through the study region, which may facilitate connectivity among >100 no-take reserves. Connectivity was first investigated by analysing data on the presence/absence of 216 species of reef fish and habitat variables across 61 sites. Hierarchical clustering of sites reflecting species assemblage patterns distinguished a major group of sites in the Bohol Sea (Bray-Curtis similarity >70%) from sites situated in adjacent bodies of water (bays, channels between islands and a local sea). The grouping of sites could be partly explained by a combination of degree of embayment, % cover of sand and % cover of rubble (Spearman rank correlation, rho(w) = 0.42). The individual-based model simulated dispersal of reef fish larvae monthly for three consecutive years in the region. The results of simulations, using a range of pelagic larval durations (15—45 days), were consistent with the species assemblage patterns. Sites in the model that showed strongest potential connectivity corresponded to the majority of sites that								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	comprised the Bohol Sea group suggested by hierarchical clustering. Most sites in the model that exhibited weak connectivity were groups of sites which had fish assemblages that were least similar to those in the Bohol Sea group. Concurrent findings from the two approaches suggest a strong influence of local oceanography and geography on broad spatial patterns of connectivity. The predictions can be used as an initial basis to organise existing reserves to form ecologically meaningful networks. This study showed that species assemblage patterns could be a viable supplementary indicator of connectivity if used together with predictions from a larval dispersal model and if the potential effect of habitat on the structuring of species assemblages is taken into consideration.								
Al—Rabai'ah HA, Koh HL, DeAngelis D, Lee HL. Modeling fish community dynamics in the Florida Everglades: role of temperature variation. Water Sci Technol. 2002;46(9):71—8. PMID: 12448454.	Temperature variation is an important factor in Everglade wetlands ecology. A temperature fluctuation from 17degreesC to 32degreesC recorded in the Everglades may have significant impact on fish dynamics. The short life cycles of some of Everglade fishes has rendered this	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	temperature variation to have even more impacts on the ecosystem. Fish population dynamic models, which do not explicitly consider seasonal oscillations in temperature, may fail to describe the details of such a population. Hence, a model for fish in freshwater marshes of the Florida Everglades that explicitly incorporates seasonal temperature variations is developed. The model's main objective is to assess the temporal pattern of fish population and densities through time subject to temperature variations. Fish population is divided into 2 functional groups (FGs) consisting of small fishes; each group is subdivided into 5-day age classes during their life cycles. Many governing sub-modules are set directly or indirectly to be temperature dependent. Growth, fecundity, prey availability, consumption rates and mortality are examples. Several mortality sub-modules are introduced in the model, of which starvation mortality is set to be proportional to the ratio of prey needed to prey available at that particular time step. As part of the calibration process, the model is run for 50								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	years to ensure that fish densities do not go to extinction, while the simulation period is about 8 years.The model shows that the temperature dependent starvation mortality is an important factor that influences fish population densities. It also shows high fish population densities at some temperature ranges when this consumption need is minimum. Several sensitivity analyses involving variations in temperature terms, food resources and water levels are conducted to ascertain the relative importance of temperature dependence terms.								
Alonzo, Suzanne; Mangel, Marc. (2005). Sex—change rules, stock dynamics, and the performance of spawning-per-recruit measures in protogynous stocks. Fishery Bulletin. 103.	Predicting and understanding the dynamics of a population requires knowledge of vital rates such as survival, growth, and reproduction. However, these variables are influenced by individual behavior, and when managing exploited populations, it is now generally realized that knowledge of a species' behavior and life history strategies is required. However, predicting and understanding a response to novel conditions-such as increased fishing-induced mortality, changes in environmental	Y	predicting and understanding a response to novel conditions-such as increased fishing-induced mortality, changes in environmental conditions, or specific management strategies	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	conditions, or specific management strategies—also require knowing the endogenous or exogenous cues that induce phenotypic changes and knowing whether these behaviors and life history patterns are plastic. Although a wide variety of patterns of sex change have been observed in the wild, it is not known how the specific sex—change rule and cues that induce sex change affect stock dynamics. Using an individual based model, we examined the effect of the sex—change rule on the predicted stock dynamics, the effect of mating group size, and the performance of traditional spawning-per-recruit (SPR) measures in a protogynous stock. We considered four different patterns of sex change in which the probability of sex change is determined by 1) the absolute size of the individual, 2) the relative length of individuals at the mating site, 3) the frequency of smaller individuals at the mating site, and 4) expected reproductive success. All four patterns of sex change have distinct stock dynamics. Although each sex—change rule leads to the prediction that the stock will be sensitive to the size-selective fishing pattern and may crash if too many reproductive size								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	classes are fished, the performance of traditional spawning-per-recruit measures, the fishing pattern that leads to the greatest yield, and the effect of mating group size all differ distinctly for the four sex—change rules. These results indicate that the management of individual species requires knowledge of whether sex change occurs, as well as an understanding of the endogenous or exogenous cues that induce sex change.								
Aumann, C. A., Eby, L. A.,; Fagan, W. F. (2006). How Transient Patches Affect Population Dynamics: The Case Of Hypoxia And Blue Crabs. Ecological Monographs, 76(3), 415–438. https://doi.org/10.1890/0012—9615(2006)076[0415:HTPAPD]2.0.CO;2	Transient low-oxygen patches may have important consequences for the population dynamics of estuarine species. We investigated whether these transient hypoxic patches altered population dynamics of the commercially important blue crab (Callinectes sapidus) and assessed two alternative hypotheses for the causal mechanism. One hypothesis is that temporary reductions in habitat due to hypoxia increase cannibalism. The second hypothesis is that crab population dynamics result from food limitation caused by hypoxia—induced mortality of the benthos. We developed a spatially explicit individual-based model of blue crabs in a hierarchical framework to connect	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	the autoecology of crabs with the spatial and temporal dynamics of their physical and biological environments. Three primary scenarios were run to examine the interactive effects of (1) hypoxic extent vs. static and transient patches, (2) hypoxic extent vs. prey abundance, and (3) hypoxic extent vs. cannibalism potential. Static patches resulted in populations limited by egg production and recruitment whereas transient patches led to populations limited by the effects of cannibalism and patch interactions. Crab survivorship was greatest for simulations with the largest hypoxic patches which also had the lowest prey abundance and lowest crab densities. In these simulations, nearly all crab mortality was accounted for by aggression, not starvation. In addition, increased prey abundance had little influence on crab abundance and dynamics, and massive reductions in prey abundance (> 50%) were necessary to decrease crab abundance, survival, and egg production. Our analyses suggest that cannibalism coupled with decreased egg production determined key aspects of crab demography.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Specifically, decreased cannibalism potential resulted in a food-limited crab population with long development times and high adult crab densities whereas increased cannibalism potential led to low adult crab densities with higher individual egg production rates. Our analyses identified several key knowledge gaps, including the nature of crab—crab cannibalism and the role of refuges from predation. Several experiments are suggested to test model predictions and to improve understanding of ecosystem—population linkages for this estuarine species.								
BABCOCK, R.; EGLI, D; ATTWOOD, C. (2012). Incorporating behavioural variation in individual-based simulation models of marine reserve effectiveness. Environmental Conservation, 39(3), 282—294. doi:10.1017/S0376892912000148	Effective spatial management of marine species requires informed planning, as well as ongoing assessment. For mobile species such as fish, knowledge of the scale and variation in movement is central to key planning decisions, such as the size and shape of marine reserves and the interpretation of the response of protected populations. For example, populations of species that require large areas of habitat may not show increases in abundance inside small reserves, but	Y	On balance, while marine reserves with sizes similar to Leigh and Tawharanui (c. 5 km(2)) can achieve significant levels of protection for snapper, they are too small to fully protect resident reserve snapper populations.	Y	SNAPPER (SNA1) MANAGEMENT PLAN: Prepared by the SNA1 Strategy Group with assistance from the Ministry for Primary Industries. (2016). SNA1 Strategy Group.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	calculating optimal reserve size is complicated by individual variations in behaviour. Fish movements can be used to quantitatively inform marine reserve planning and assessment. An individual based numerical simulation model including acoustic telemetry and census data was used to simulate changes in populations of snapper Pagrus auratus in north-eastern New Zealand. Four behavioural categories and offshore migration were used to represent the observed variability in movement. Age-structures of modelled fish populations in fully exploited areas, marine reserves and virgin populations differed substantially. However, the population structure within reserves resembled a fully fished population more closely than an unfished population. Due to the range of movement types shown by snapper, fish were not 'locked up' by reserves, and fish with centres of activity based in reserves were predicted to have a relatively high chance of being caught outside these reserves. Furthermore, the model showed that the response of fish populations within marine reserves was dependent on levels of								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	exploitation in fished areas. For snapper in coastal reef areas, reserves c. 40 km(2) or more may be required to achieve abundances > 50% of the unfished stock. On balance, while marine reserves with sizes similar to Leigh and Tawharanui (c. 5 km(2)) can achieve significant levels of protection for snapper, they are too small to fully protect resident reserve snapper populations.								
Barros, C., Palmer, S. C. F., Bocedi, G.,; Travis, J. M. J. (2016). Spread rates on fragmented landscapes: The interacting roles of demography, dispersal and habitat availability. Diversity and Distributions, 22(12), 1266–1275. https://doi.org/10.1111/ddi.12487	AimWe still lack a comprehensive understanding of the relative importance of demographic, dispersal and landscape characteristics on species' rates of range expansion (RRE) and on how these factors interact. Here, we provide an analysis of these effects for passive dispersers, by investigating how habitat characteristics, such as habitat quality, availability and fragmentation, interplay with species' dispersal characteristics in determining species' RRE. In addition, we assessed the predictability of RRE in cases where we have the knowledge of a species' demography, dispersal and habitat availability.Methods Using the newly available individual-based modelling	Y	Main conclusionsSimulation-based approaches provide important insights into the drivers of RRE that are relevant for conservation planning.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	platform, RangeShifter we simulated the range expansion of species with different dispersal abilities, by varying mean dispersal distance and number of emigrants, on various landscapes. Landscapes varied in habitat quality (in terms of carrying capacity and species' growth rates) and in habitat availability (in terms of the proportion of suitable habitat and its degree of fragmentation).ResultsOur results show that 55% of the total variation in RRE was explained by our six main effects, being considerably faster in landscapes with more suitable habitat, but only slightly affected by the degree of habitat fragmentation. Also, synergies between the amount of suitable habitat and species dispersal characteristics had significant positive effects on range expansion. Notably, however, 33% of variation in RRE was not explained by any of the tested factors or interactions between them and can be considered inherent and irreducible uncertainty.Main conclusionsSimulation-based approaches provide important insights into the drivers of RRE that are relevant for conservation planning. For instance, our results								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	indicate when it is likely to be better to allocate resources to improve existing habitat rather than creating new habitat, and vice versa. Additionally, our results emphasize that there will often be substantial uncertainty in the RRE, which needs to be taken into account for ecological management.								
Bastardie, Francois; Nielsen, J Rasmus; Eigaard, Ole; Fock, Heino; Jonsson, P.; Bartolino, Valerio. (2014). Competition for marine space: Modelling the Baltic Sea fisheries and effort displacement under spatial restrictions. ICES Journal of Marine Science: Journal du Conseil. 72. 10.1093/icesjms/fsu215.	Maritime spatial planning (MSP) and fishery management may generate extra costs for fisheries by constraining fishers activity with conservation areas and new utilizations of the sea. More energy-efficient fisheries are also likely to alter existing fishing patterns, which already vary from fishery to fishery and from vessel to vessel. The impact assessment of new spatial plans involving fisheries should be based on quantitative bioeconomic analyses that take into account individual vessel decisions, and trade-offs in cross-sector conflicting interests. We use a vessel-oriented decision-support tool (the DISPLACE model) to combine stochastic variations in spatial fishing activities with harvested resource dynamics in scenario projections. The assessment computes	Y	Maritime spatial planning (MSP) and fishery management may generate extra costs for fisheries by constraining fishers activity with conservation areas and new utilizations of the sea.	Y	European Commission, Directorate—General for Maritime Affairs and Fisheries, Fiorentino, F., Calleja, D., Colloca, F., et al., Marine protected areas : network(s) for enhancement of sustainable fisheries in EU Mediterranean waters : MANTIS : Marine protected Areas Network Towards Sustainable fisheries in the Central Mediterranean, Publications Office, 2020, https://data.	Boschetti, S., Piroddi, C., Druon, J. and Palialexis, A., Marine Strategy Framework Directive – Review and analysis of Member States' 2018 reports – Descriptor 4: Food webs, EUR 30652 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978—	Y,N	Y,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	economic and stock status indicators by modelling the activity of Danish, Swedish, and German vessels (> 12 m) in the international western Baltic Sea commercial fishery, together with the underlying size-based distribution dynamics of the main fishery resources of sprat, herring, and cod. The outcomes of alternative scenarios for spatial effort displacement are exemplified by evaluating the fishers's abilities to adapt to spatial plans under various constraints. Interlinked spatial, technical, and biological dynamics of vessels and stocks in the scenarios result in stable profits, which compensate for the additional costs from effort displacement and release pressure on the fish stocks. The effort is further redirected away from sensitive benthic habitats, enhancing the ecological positive effects. The energy efficiency of some of the vessels, however, is strongly reduced with the new zonation, and some of the vessels suffer decreased profits. The DISPLACE model serves as a spatially explicit bioeconomic benchmark tool for management strategy evaluations for capturing tactical decision-making in reaction to MSP.				europa.eu/doi/10.2771/33931	92—76—32461—4, doi:10.2760/990099, JRC124263.			

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Beatty, W. S., Kesler, D. C., Webb, E. B., Naylor, L. W., Raedeke, A. H., Humburg, D. D., Coluccy, J. M.,; Soulliere, G. J. (2017). How will predicted land-use change affect waterfowl spring stopover ecology? Inferences from an individual-based model. Journal of Applied Ecology, 54(3), 926–934. https://doi.org/10.1111/1365—2664.12788	1. Habitat loss, habitat fragmentation, overexploitation and climate change pose familiar and new challenges to conserving natural populations throughout the world. One approach conservation planners may use to evaluate the effects of these challenges on wildlife populations is scenario planning.2. We developed an individual-based model to evaluate the effects of future land use and land cover changes on spring-migrating dabbling ducks in North America. We assessed the effects of three Intergovernmental Panel on Climate Change emission scenarios (A1B, A2 and B1) on dabbling duck stopover duration, movement distances and mortality. We specifically focused on migration stopover duration because previous research has demonstrated that individuals arriving earlier on the nesting grounds exhibit increased reproductive fitness.3. Compared to present conditions, all three scenarios increased stopover duration and movement distances of agent ducks.4. Although all three scenarios presented migrating ducks with increased amounts of wetland habitat, scenarios also contained	Y	Thus, conservation planners will have to address population-level energetic implications of shifting agricultural food resources and increased uncertainty in yearly precipitation patterns within the next 50 years.	Y	Connecting People, Waterfowl, and Wetlands: North American Waterfowl Ma—gement Plan (-wMP) Update. (2018). U.S. Fish & Wildlife Service.	—	N	N	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	substantially less cropland, which decreased overall carrying capacity of the study area.5. Synthesis and applications. Land-use change may increase waterfowl spring migration stopover duration in the midcontinent region of North America due to reduced landscape energetic carrying capacity. Climate change will alter spatial patterns of crop distributions with corn and rice production areas shifting to different regions. Thus, conservation planners will have to address population-level energetic implications of shifting agricultural food resources and increased uncertainty in yearly precipitation patterns within the next 50 years.								
Benjamin, C. S., Punongbayan, A. T., dela Cruz, D. W., Villanueva, R. D., Baria, M. V. B.,; Yap, H. T. (2017). Use of Bayesian analysis with individual-based modeling to project outcomes of coral restoration: Modeling outcomes of coral restoration. Restoration Ecology, 25(1), 112–122. https://doi.org/10.1111/rec.12395	Various approaches to coral restoration have been developed to help increase rate of reef recovery from perturbations, among the most common of which is coral transplantation. Success is often evaluated based on short-term observations that capture only the initial phase of space colonization by coral transplants. Here, an individual-based model is developed to quantify uncertainty in future trajectories	Y	Here, an individual-based model is developed to quantify uncertainty in future trajectories in experimental plots given past observations.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	in experimental plots given past observations. Empirical data were used to estimate probabilistic growth, survival, and fission rates of Acropora pulchra and A. intermedia (order Scleractinia) in a sandy reef flat (Bolinao, Philippines). Simulations were initialized with different densities (25 or 50 transplants per species per 16m(2)) to forecast possible coral cover trajectories over a 5-year period. Given current conditions, there is risk of local extinction which is higher in low-density plots for both species, and higher for A. intermedia compared to A. pulchra regardless of density. While total coral cover is projected to increase, species composition in the future is more likely to be highly uneven. The model was used to quantify effect on recovery rate of protection from pulse anthropogenic disturbances, given different initial transplantation densities. When monitoring data are limited in time, stochastic models may be used to assess whether the restoration trajectory is heading toward the desired state and at what rate, and foresee system response to various adaptive interventions.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Bennett, V. J., Fernández—Juricic, E., Zollner, P. A., Beard, M. J., Westphal, L.,; Fisher, C. L. L. (2011). Modelling the responses of wildlife to human disturbance: An evaluation of alternative management scenarios for black—crowned night-herons. Ecological Modelling, 222(15), 2770–2779. https://doi.org/10.1016/j.ecolmodel.2011.04.025	The impact of anthropogenic disturbance on wildlife is increasing becoming a source of concern as the popularity of outdoor recreation rises. There is now more pressure on site managers to simultaneously ensure the continued persistence of wildlife and provide recreational opportunities. Using 'Simulation of Disturbance Activities', a model designed to investigate the impact of recreational disturbance on wildlife, we demonstrate how a simulation modelling approach can effectively inform such management decisions. As an example, we explored the implications of various design and management options for a proposed recreational area containing a historic breeding bird colony. By manipulating the proximity, orientation and intensity of recreation, we were able to evaluate the impact of recreational activities on the behaviour of black—crowned night-heron nestlings (Nycticorax nycticorax). Using a classification and regression tree (CART) procedure to analyse simulation output, we explored the dynamics of multiple strategies in concert. Our analysis revealed that there are inherent advantages	Y	Furthermore, such models potentially have broad application in understanding human-wildlife interactions (e.g. exploring the implications of roads on wildlife, probability of bird strikes around airports, etc.). They therefore represent a valuable decision-making tool in the ecological design of urban infrastructures.	Y	Wyoming State Wildlife Action Plan: Black—crowned Night-Heron. (2017). Wyoming Game and Fish Department.	—	N	N	N

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	in implementing multiple strategies as opposed to any single strategy. Nestlings were not disturbed by recreation when bird-watching facility placement (proximity and orientation) and type were considered in combination. In comparison, proximity alone only led to a <10% reduction in disturbance. Thus we demonstrate how simulation models based on customised empirical data can bridge the gap between field studies and active management, enabling users to test novel management scenarios that are otherwise logistically difficult. Furthermore, such models potentially have broad application in understanding human-wildlife interactions (e.g. exploring the implications of roads on wildlife, probability of bird strikes around airports, etc.). They therefore represent a valuable decision-making tool in the ecological design of urban infrastructures.								
Boschetti, Fabio; Vanderklift, Mat. (2015). How the movement characteristics of large marine predators influence estimates of their abundance. Ecological Modelling. 313. 223—236.	Understanding animal movement provides information that helps design effective conservation initiatives. We intuitively understand that the way animals move at large scales	Y	Understanding animal movement provides information that helps design effective conservation initiatives.	Y	SEDAR. 2020. SEDAR 65 Atlantic Blacktip Shark Stock Assessment Report. SEDAR,	Hall—Arber, M., Murray, S., Aylesworth, L., Carr, M., Field, J.,	N,N	N,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
10.1016/j.ecolmodel.2015.06.035.	determines the extent of their home range and their migratory patterns — and we know that these features are relevant to decisions about the location, size and distribution of protected areas. It is less intuitively obvious that knowledge of movement characteristics at finer scales can also have conservation implications. By modelling the small to intermediate scale movement (1—10(3) m) of a large marine predator in a shallow coastal environment, we show how different assumptions about movement patterns influence estimates of species abundance derived from field observations. Foraging behaviour, statistical properties of the swimming path and average speed exert the greatest impact, suggesting that these should be the focus of further experimental work. Better data would inform our understanding and considerably reduce the uncertainty in abundance estimation, improving conservation-related decision making.				North Charleston SC. 438 pp. available online at: http://sedarweb.org/sedar-65	Gorud—Colvert, K., Martone, R., Nickols, K., Saarman, E., Wertz, S. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust, June 2021			
Bowgen, Katharine; Stillman, Richard; Herbert, R.. (2015). Predicting the effect of invertebrate regime shifts on wading birds: Insights	Regime shifts in benthic invertebrates within coastal ecosystems threaten the survival of wading birds (Charadrii).	Y	Predicting how invertebrate regime shifts will affect wading birds allows conservation	Y	Eaton, M., & Noble, D. (2021). England biodiversity indicators	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
from Poole Harbour, UK. Biological Conservation. 186. 10.1016/j.biocon.2015.02.032.	Predicting how invertebrate regime shifts will affect wading birds allows conservation management and mitigation measures to be implemented, including protection of terrestrial feeding areas. An individual-based model was used to investigate the impact of regime shifts on wading birds through their prey (marine worms and bivalves) in the estuarine system Poole Harbour, (UK). The model predicted the number of curlew (Numenius arquata), oystercatcher (Haematopus ostralegus), black—tailed godwit (Limosa limosa), redshank (Tringa totanus) and dunlin (Calidris alpina) supported in the Harbour during the non-breeding season (autumn and winter months). The most dramatic declines in bird numbers were for regime shifts that reduced the abundance of the largest invertebrates, particularly marine worms. The least adaptable bird species (those with the most restrictive diets) were unable to compensate by consuming other prey. Generally, as birds adapt to changes by switching to alternative prey species and size classes, changes in invertebrate size and species distribution do not necessarily affect the number of		management and mitigation measures to be implemented…Our predictions reveal a weakness in using birds as indicators of site health and invertebrate regime shifts. Differences in bird populations would not necessarily be detected by standard survey methods until extreme changes in invertebrate communities had occurred, potentially beyond the point at which these changes could be reversed. Therefore, population size of wading birds should not be used in isolation when assessing the conservation status of coastal sites.		(Technical Background Document: The Wild Bird Indicator for England). https://www.gov.uk/government/statistics/england-biodiversity-indicators				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	birds that the Harbour can support. Our predictions reveal a weakness in using birds as indicators of site health and invertebrate regime shifts. Differences in bird populations would not necessarily be detected by standard survey methods until extreme changes in invertebrate communities had occurred, potentially beyond the point at which these changes could be reversed. Therefore, population size of wading birds should not be used in isolation when assessing the conservation status of coastal sites.								
Brigolin, Daniele; Cavraro, Francesco; Zanatta, Vanessa; Pastres, Roberto; Malavasi, Stefano. (2016). The influence of habitat structure on energy allocation tactics in an estuarine batch spawner. Estuarine, Coastal and Shelf Science. 172. 10.1016/j.ecss.2016.01.038.	Trade-off between fecundity and survival was tested in a batch spawner, the Mediterranean killifish Aphanius fasciatus, using an integrated modelling-data approach based on previously collected empirical data. Two sites of the lagoon of Venice (Northern Adriatic sea, Italy) were selected in order to compare the energy allocation between growth and reproduction in two contrasting habitats. These were characterised by high and comparable level of richness in basal resources, but showed two different mortality schedules: an open natural salt	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	marsh, exposed to high level of predation, and a confined artificial site protected from piscivorous predation. By means of a bioenergetic Scope for Growth model, developed and calibrated for the specific goals of this work, we compared the average individual life history between the two habitats. The average individual life history is characterised by a higher number of spawning events and lower per-spawning investment in the confined site exposed to lower predation risk, compared to the site connected with the open lagoon. Thus, model predictions suggest that habitat structure with different extrinsic mortality schedules may shape the life history strategy in modulating the pattern of energy allocation. Model application highlights the central role of energy partitioning through batch spawning, in determining the life history strategy. The particular ovary structure of a batch spawner seems therefore to allow the fish to modulate timing and investment of spawning events, shaping the optimal life history in relation to the environmental conditions.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Brigolin, Daniele; Pastres, Roberto; Tomassetti, Paolo; Porrello, Salvatore. (2010). Modelling the biomass yield and the impact of seabream mariculture in the Adriatic and Tyrrhenian Seas (Italy). Aquaculture International. 18. 149—163. 10.1007/s10499—008—9232—4.	An individual-based model for Sparus aurata was developed, taking into account the effects on the growth rate of water temperature, food availability and diet composition. The model was identified on the basis of the recent literature regarding the physiological ecology of this species. It was subsequently calibrated and validated by using original field data collected at two Italian fish farms located, respectively, in the Adriatic and Tyrrhenian Seas. The mass budget of uneaten food and faeces was computed using the model at each farm: the optimal ingestion rate of a fish was computed based on its wet weight and the temperature of the water, while the faeces estimation considered the different digestibility of lipids, carbohydrates and proteins in the diet. From an applied perspective, the future use of this growth model in relation to mariculture site selection and monitoring might typically be to estimate both the yield and the amount of uneaten food and faeces discharged from a fish cage. This second output represents a useful input for deposition models which are routinely used in the field of mariculture	Y	The integration of growth and deposition models in a single system could provide a useful tool for the site-selection and monitoring of finfish mariculture operations in Mediterranean environments.	Y	UNEP-MAP-RAC/SPA. 2014. Status and Conservation of Fisheries in the Adriatic Sea. By H. Farrugio & Alen Soldo. Draft internal report for the purposes of the Mediterranean Regional Workshop to Facilitate the Description of Ecologically or Biologically Significant Marine Areas, Malaga, Spain, 7—11 April 2014.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	monitoring by different EU countries. The integration of growth and deposition models in a single system could provide a useful tool for the site-selection and monitoring of finfish mariculture operations in Mediterranean environments.								
Bromaghin, Jeffrey; Nielson, Ryan; Hard, Jeffrey. (2011). A Model Of Chinook Salmon Population Dynamics Incorporating Size-selective Exploitation And Inheritance Of Polygenic Correlated Traits. Natural Resource Modeling. 24. 1 — 47. 10.1111/j.1939—7445.2010.00077.x.	P>Concern regarding the potential for selective fisheries to degrade desirable characteristics of exploited fish populations is growing worldwide. Although the occurrence of fishery-induced evolution in a wild population has not been irrefutably documented, considerable theoretical and empirical evidence for that possibility exists. Environmental conditions influence survival and growth in many species and may mask comparatively subtle trends induced by selective exploitation, especially given the evolutionarily short time series of data available from many fisheries. Modeling may be the most efficient investigative tool under such conditions. Motivated by public concern that large-mesh gillnet fisheries may be altering Chinook salmon in western Alaska, we constructed a	Y	Use of this model has potential to improve our ability to investigate the consequences of selective exploitation and aid development of improved management strategies to more effectively sustain fish and fisheries into the future.	Y	Title : 2016 5-year Review : Summary & Evaluation of Puget Sound Chinook Salmon Hood Canal Summer-run Chum Salmon Puget Sound Steelhead Published Date : 2017 URL : https://repository.library.noaa.gov/view/noaa/17015	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	stochastic model of the population dynamics of Chinook salmon. The model contained several individually based components and incorporated size-selective exploitation, assortative mating, size-dependent female fecundity, density-dependent survival, and the heritability of size and age. Substantial reductions in mean size and age were observed under all scenarios. Concurrently reducing directional selection and increasing spawning abundance was most effective in stimulating population recovery. Use of this model has potential to improve our ability to investigate the consequences of selective exploitation and aid development of improved management strategies to more effectively sustain fish and fisheries into the future.								
Butler, Mark. (2003). Incorporating ecological process and environmental change into spiny lobster population models using a spatially-explicit, individual-based approach. Fisheries Research. 65. 63—79. 10.1016/j.fishres.2003.09.007.	Marine fisheries and the ecosystems that sustain them are increasingly beset by environmental deterioration, yet traditional fishery models used for stock prediction typically handle these dynamics poorly if at all. To do so requires the integration of spatio-temporal change in	Y	Marine fisheries and the ecosystems that sustain them are increasingly beset by environmental deterioration, yet traditional fishery models used for stock prediction typically handle these dynamics poorly if at all...Although not applicable in all	Y	John S. Burke, W. Judson Kenworthy, T. Shay Viehman, Vanessa L. McDonough, and Brian Degan. 2011. Biodiversity and Ecosystem function of	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	environmental quality and its subsequent effects on habitat suitability and life history dynamics. Spatially-explicit, individual-based simulation models are particularly well suited to this task and, although they are seeing increased use in fisheries ecology and management, this approach has seen limited application in crustacean fisheries. In 1993. we began development of a spatially-explicit individual-based model (IBM) describing the recruitment of Caribbean spiny lobster (Panulirus argus) in the Florida Keys, Florida (USA) to investigate the impact of regional changes in environmental quality, habitat structure and postlarval supply on lobster recruitment. The shallow coastal waters of the Florida Keys ecosystem have experienced an unprecedented series of environmental perturbations over the past decade. Seagrass die-offs, cyanobacteria blooms, sponge die-offs and dramatic changes in salinity have occurred and these potentially impact the recruitment of spiny lobsters in the region via both direct and indirect means. Here I provide an overview of the unique approach that we have		situations, spatially-explicit IBMs should see wider use in crustacean fishery applications because of both the ecological insight they yield and their ability to integrate data across hierarchical scales of organization.		Shallow Bank Systems within Florida Keys National Marine Sanctuary (FKNMS. Marine Sanctuaries Conservation Series ONMS—12—03. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 45 pp.				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	used to examine these dynamics, an approach that links environmental events that occur on large scales (e.g. changes in habitat structure and salinity) with their population-level consequences for lobsters via impacts that operate on the individual-level. Although not applicable in all situations, spatially-explicit IBMs should see wider use in crustacean fishery applications because of both the ecological insight they yield and their ability to integrate data across hierarchical scales of organization.								
Cabral, Reniel; Geronimo, Rollan; Lim, May; Aliño, Porfirio. (2010). Effect of variable fishing strategy on fisheries under changing effort and pressure: An agent-based model application. Ecological Modelling. 362—369. 10.1016/j.ecolmodel.2009.09.019.	An agent-based model was used to evaluate the response of a two-species fish community to fishing boat exploration strategies, namely: boats following high-yield boats (Cartesian); boats fishing at random sites (stochast-random); and boats fishing at least exploited sites (stochast-pressure). At low fishing pressure, the stochast-random mode yielded a high average catch per boat while sustaining fish biomass. At high fishing pressure, the Cartesian mode was more effective. For the Cartesian strategy, fish biomass exhibited four distinct behaviors with	Y	An agent-based model was used to evaluate the response of a two-species fish community to fishing boat exploration strategies, namely: boats following high-yield boats (Cartesian); boats fishing at random sites (stochast-random); and boats fishing at least exploited sites (stochast-pressure).	Y	Stelzenmüller, V. et al., 2020, Research for PECH Committee – Impact of the use of offshore wind and other marine renewables on European fisheries. European Parliament, Policy Department for Structural and Cohesion Policies, Brussels	—	Y	Y	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	increasing number of boats. In the first phase, the fish biomass dropped with increasing number of boats due to a corresponding rise in biomass extraction. Rapid exploitation occurred in the second phase, when two or more boats occupied the same initial area, that led to the faster abandonment of those sites which then underwent biomass recovery. in the third phase, adding more boats resulted in a fluctuating stock biomass, where the combined effects of initial spatial distribution of boats and rapid localization led to either full stock recovery when boats were eventually confined to a single location due to spillovers, or stock extirpation when the entire area became fully occupied. Beyond the third phase, stock extirpation was assured. in order to break the pattern of localization (bandwagon effect), we introduced stochast-random intruders in a Cartesian-dominated fishery. Adding a single intruder changed the patchy-structured stock biomass pattern of a purely Cartesian fishery to a uniformly explored stock biomass pattern because of the additional spatial information provided by the intruder.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Consequently, the average catch per boat increased but at the expense of a disproportionate decline in equilibrium biomass.								
Cavallo, Catherine; Dempster, Tim; Kearney, Michael; Kelly, Ella; Booth, David; Hadden, Kate; Jessop, Tim. (2014). Predicting climate warming effects on green turtle hatchling viability and dispersal performance. Functional Ecology. 29. 10.1111/1365—2435.12389.	1. Ectotherms are taxa considered highly sensitive to rapid climate warming. This is because body temperature profoundly governs their performance, fitness and life history. Yet, while several modelling approaches currently predict thermal effects on some aspects of life history and demography, they do not consider how temperature simultaneously affects developmental success and offspring phenotypic performance, two additional key attributes that are needed to comprehensively understand species responses to climate warming.2. Here, we developed a stepwise, individual-level modelling approach linking biophysical and developmental models with empirically derived performance functions to predict the effects of temperature—induced changes to offspring viability, phenotype and performance, using green sea turtle hatchlings as an ectotherm model. Climate warming is	Y	Such advances could better serve ecologists to highlight the most vulnerable species and populations, encouraging prioritization of conservation effort to the most threatened systems.	Y	Mitigation strategies to reduce the impact of climate change on nesting beaches (CIT-CC12—2015—Tec.10). (2015). Inter-American Convention for the Protection and Conservation of Sea Turtles.	Recovery Plan for Marine Turtles in Australia, Commonwealth of Australia 2017. (2017). Australian Government | Department of the Environment and Energy.	N,N	N,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	expected to particularly threaten sea turtles, as their life—history traits may preclude them from rapid adaptation.3. Under conservative and extreme warming, our model predicted large effects on performance attributes key to dispersal, as well as a reduction in offspring viability. Forecast sand temperatures produced smaller, weaker hatchlings, which were up to 40% slower than at present, albeit with increased energy stores. Conversely, increases in sea surface temperatures aided swimming performance.4. Our exploratory study points to the need for further development of integrative individual-based modelling frameworks to better understand the complex outcomes of climate change for ectotherm species. Such advances could better serve ecologists to highlight the most vulnerable species and populations, encouraging prioritization of conservation effort to the most threatened systems.								
Chion, C., Cantin, G., Dionne, S., Dubeau, B., Lamontagne, P., Landry, J.—A., Marceau, D., Martins, C. C. A., Ménard, N., Michaud, R., Parrott, L.,; Turgeon, S.	Anticipating the impacts of a new policy before implementation on a complex social-ecological system is a challenging task for	Y	The ABM, called the Marine Mammal and Maritime Traffic Simulator (3MTSim), represents the	Y	Williams, R., Lacy, R. C., Ashe, E., Hall, A., Lehoux, C., Lesage, V., McQuinn,	—	N	Y	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
(2013). Spatiotemporal modelling for policy analysis: Application to sustainable management of whale-watching activities. Marine Policy, 38, 151–162. https://doi.org/10.1016/j.marpol.2012.05.031	managers and policymakers. This paper reports on the development and use of an agent-based model (ABM) dedicated to support marine park managers in their effort to devise policies to sustainably manage whale-watching activities. The ABM, called the Marine Mammal and Maritime Traffic Simulator (3MTSim), represents the spatiotemporal dynamics of marine mammals and navigation activities in and around the Saguenay-St. Lawrence Marine Park in Canada. In the context of updating the current regulations on whale-watching in the Marine Park, 3MTSim was run to evaluate the merits of a proposed set of rules compared to the current regulations. To do so, a set of variables related to policies' impacts on the three spheres of sustainable development, namely the impact on whales (Environment), on whale-watching companies (Economy), and tourist experience (Society) was analysed. 3MTSim's simulations highlighted that the proposed rules are expected to improve the situation regarding whale conservation and tourist experience with only marginal		spatiotemporal dynamics of marine mammals and navigation activities in and around the Saguenay-St. Lawrence Marine Park in Canada….ABMs developed in close relationship with end-users are unarguably a tool of choice to manage complex social-ecological systems since they provide insight into phenomena hard or impossible to measure in the real system. Despite the labour intensive nature of their implementation, this investment is worth the effort.		I., & Plourde, S. (2017). Predicting responses of St. Lawrence beluga to environmental change and anthropogenic threats to orient effective management actions. Fisheries and Oceans Canada: Canadian Science Advisory Secretariat. https://waves—vagues.dfo-mpo.gc.ca/Library/40605772.pdf				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	impact on the whale-watching industry. In the proposed regulations, one rule is expected to be very influential on whale-watching activities. This rule limits to 10 the number of whale-watching boats allowed to stand within 926 m of any boat in observation mode. Assuming efficient law enforcement, 3MTSim predicts a significant decrease in overall boat concentration around whales in the Marine Park, which is one of the management objectives benefiting both whales and tourists. Interestingly, 3MTSim reveals that this rule could indirectly force some boats to observe second—choice whales present in higher abundance rather than some more attractive species scarcer in the region. This highlights the following management tradeoffs: Reducing boat exposure for the humpback whale and endangered blue whale is likely to increase it for the more abundant fin whale listed as of special concern (Canada's Species at Risk Act) and minke whale. This work demonstrates the utility of ABMs to support policy analysis in the context of sustainable management in a Marine Park. ABMs developed in close								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	relationship with end-users are unarguably a tool of choice to manage complex social-ecological systems since they provide insight into phenomena hard or impossible to measure in the real system. Despite the labour intensive nature of their implementation, this investment is worth the effort.								
Chion, Clément; Lagrois, Dominic; Dupras, Jérôme; Turgeon, Samuel; McQuinn, Ian; Michaud, Robert; Ménard, Nadia; Parrott, Lael. (2017). Underwater acoustic impacts of shipping management measures: Results from a social-ecological model of boat and whale movements in the St. Lawrence River Estuary (Canada). Ecological Modelling. 354. 72—87. 10.1016/j.ecolmodel.2017.03.014.	The recovery of whale species at risk requires the implementation of protection measures designed to mitigate the risks posed by various stressors. In the St. Lawrence Estuary (Canada), several whale species are threatened by navigation activities in various ways. Since 2013, seasonal voluntary ship strike mitigation measures, including a speed reduction area (SRA) and a no—go area, were implemented annually and largely adopted by the maritime industry to reduce the risks of lethal collisions with four species of baleen whales. While the endangered St. Lawrence beluga population is unlikely to be subject to collisions with large merchant ships, it is known to be negatively affected by vessel—generated underwater noise. To assess how these protection measures modify the beluga's	Y	Although refinements are required to improve the modelling of noise sources and propagation for finer scale projections in this complex nearshore environment, this agent -based modelling paradigm of 3MTSim proved informative for underwater acoustic impact assessments.	Y	Government of Canada, F. and O. C. (2018). Review of the Effectiveness of Recovery Measures for St. Lawrence Estuary Beluga.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	soundscape throughout their critical habitat, we implemented an underwater acoustic module within an existing agent-based model (3MTSim) of ship-whale movements and interactions in the St. Lawrence Estuary. We ran multiple simulations for two scenarios 1) without and 2) with the protection measures to compare the level of noise received by belugas before and after 2013. Overall, the simulations showed a statistically-significant 1.6% decrease in the total amount of noise received by belugas in their critical habitat following the implementation of the protection measures. Although slowing down ships reduces instantaneous radiated noise, it also increases the total amount of acoustic energy released in the environment by extending the time spent in the SRA. Accordingly, our simulations showed a 2.4% increase in the cumulative noise from shipping received by beluga in the SRA. Conversely, belugas located in the Upper Estuary, mostly females and calves, i.e., the most valuable individuals experienced a 5.4% reduction in the cumulative received level of shipping noise. Although refinements are								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	required to improve the modelling of noise sources and propagation for finer scale projections in this complex nearshore environment, this agent -based modelling paradigm of 3MTSim proved informative for underwater acoustic impact assessments.								
Datta, Samik; Delius, Gustav; Law, Richard. (2010). A Jump-Growth Model for Predator–Prey Dynamics: Derivation and Application to Marine Ecosystems. Bulletin of mathematical biology. 72. 1361—82. 10.1007/s11538—009—9496—5.	This paper investigates the dynamics of biomass in a marine ecosystem. A stochastic process is defined in which organisms undergo jumps in body size as they catch and eat smaller organisms. Using a systematic expansion of the master equation, we derive a deterministic equation for the macroscopic dynamics, which we call the deterministic jump-growth equation, and a linear Fokker-Planck equation for the stochastic fluctuations. The McKendrick—von Foerster equation, used in previous studies, is shown to be a first-order approximation, appropriate in equilibrium systems where predators are much larger than their prey. The model has a power-law steady state consistent with the approximate constancy of mass density in logarithmic intervals of body mass	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	often observed in marine ecosystems. The behaviours of the stochastic process, the deterministic jump-growth equation, and the McKendrick—von Foerster equation are compared using numerical methods. The numerical analysis shows two classes of attractors: steady states and travelling waves.								
Davidson, Keith. (2014). The Challenges of Incorporating Realistic Simulations of Marine Protists in Biogeochemically Based Mathematical Models. Acta protozoologica. 53. 129—138. 10.4467/16890027AP.14.012.1449.	Protists are key components of marine microbial communities and hence of the biogeochemical mathematical models that are used to study the interaction between organisms, and the associated cycling of carbon and other nutrients. With increased computing power, models of microbial communities have markedly increased in complexity in the last 20 years, from relatively simple single nutrient currency, nutrient-phytoplankton-zooplankton-detritus (NPZD) models to plankton functional type (PFT) or trait based models of multiple organisms, or individual based models (IBMs) of specific organisms. However, our recognition, if not parameterisation, of the physiological processes that underpin both autotrophic and heterotrophic protist	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	nutrition and growth arguably have increased faster than our modelling capability, generating a wealth of new modelling challenges. This paper therefore reviews historical development, current capability, and the future directions and challenges in protist based mathematical modelling.								
Dorman, Jeffrey; Sydeman, William; Bograd, Steven; Powell, Thomas. (2015). An individual-based model of the krill Euphausia pacifica in the California Current. Progress in Oceanography. 138. 10.1016/j.pocean.2015.02.006.	Euphausia pacifica is an abundant and important prey resource for numerous predators of the California Current and elsewhere in the North Pacific. We developed an individual-based model (IBM) for E. pacifica to study its bioenergetics (growth, stage development, reproduction, and mortality) under constant/ideal conditions as well as under varying ocean conditions and food resources. To model E. pacifica under varying conditions, we coupled the IBM to an oceanographic-ecosystem model over the period 2000—2008 (9 years). Model results under constant/ideal food conditions compare favorably with experimental studies conducted under food unlimited conditions. Under more realistic variable oceanographic conditions, mean	Y	enhance an ecosystem approach to fisheries and wildlife management in this region	Y	Final Performance Progress Report. (2016). Cooperative Institute for Marine Ecosystems and Climate.	—	Y	Y	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	growth rates over the continental shelf were positive only when individuals migrated diurnally to the depth of maximum phytoplankton layer during nighttime feeding. Our model only used phytoplankton as prey and coastal growth rates were lower than expected (0.01 mm d(—1)), suggesting that a diverse prey base (zooplankton, protists, marine snow) may be required to facilitate growth and survival of modeled E. pacifica in the coastal environment. This coupled IBM—ROMS modeling framework and its parameters provides a tool for understanding the biology and ecology of E. pacifica and could be developed to further the understanding of climatic effects on this key prey species and enhance an ecosystem approach to fisheries and wildlife management in this region.								
Dorman, Jeffrey; Sydeman, William; García-reyes, Marisol; Zeno, Ramona; Santora, Jarrod. (2015). Modeling krill aggregations in the central—northern California Current. Marine Ecology Progress Series. 528. 10.3354/meps11253.	In the California Current ecosystem, krill availability is a well—known influence on the demography of commercially and ecologically valuable fish, seabirds, and marine mammals. Modeling factors that enhance or inhibit krill aggregations, or 'hotspots', will benefit management of marine predators of	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	conservation concern and contribute to ecosystem approaches to fisheries. Here, we link an oceanographic model (ROMS) and an individual-based model (IBM) parameterized for the krill species Euphausia pacifica to test the hypothesis that occurrences of krill hotspots are disassociated from centers of upwelling along the central—northern California coast due to strong advective currents that transport zooplankton away from the productive continental shelf environment. We compare the distribution of modeled to observed hotspots derived from hydroacoustic surveys from 2000 to 2008. Both acoustic data and modeled hotspots show the greater Gulf of the Farallones and Monterey Canyon as areas of persistent krill hotspots. In this large retention zone, we found no clear relationships between krill hotspots and proxies of upwelling. In contrast, modeled hotspots were associated with reduced upwelling (warmer sea surface temperature [SST] and lower alongshore currents) to the north of Pt. Reyes, and with enhanced upwelling (cooler SST and greater alongshore currents) south of Pt. Sur. Our model								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	highlights the role spatial variability of physical forcing plays in determining the likelihood of krill hotspots forming in particular regions. Notably, our model reproduced the spatial organization of krill hotspots using only simple oceanographic forcing mechanisms and diurnal vertical migration behavior.								
Douglas, Adam; Christensen, Andreas; Hofmann, Rebecca; Steimanis, Ivo; Vollan, Björn. (2017). Influence of sea level rise on discounting, resource use and migration in small—island communities: an agent-based modelling approach. Environmental Conservation. 44. 1—8. 10.1017/S0376892917000339.	Time discounting — the degree to which individuals value current more than future resources — is an important component of natural resource conservation. As a response to climate change impacts in island communities, such as sea level rise, discounting the future can be a rational response due to increased stress on natural resources and uncertainty about whether future generations will have the same access to the same resources. By incorporating systematic responses of discount rates into models of resource conservation, realistic expectations of future human responses to climate change and associated resource stress may be developed. This paper illustrates the importance of time discounting through a theoretical agent-based model of resource use in island communities. A	Y	The negative impacts of climate change are therefore likely to be underestimated if changes in discount rates and emerging migration patterns are not taken into account.	Y	Oppenheimer, M., B.C. Glavovic , J. Hinkel, R. van de Wal, A.K. Magnan, A. Abd-elgawad, R. Cai, M. Cifuentes—Jara, R.M. DeConto, T. Ghosh, J. Hay, F. Isla, B. Marzeion, B. Meyssignac, and Z. Sebesvari, 2019: Sea Level Rise and Implications for Low-lying Islands, Coasts and Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-o.	—	N	Y	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	discount rate change can dramatically change projections about future migration and community-based conservation efforts. Our simulation results show that an increase in discount rates due to a credible information shock about future climate change impacts is likely to speed resource depletion. The negative impacts of climate change are therefore likely to be underestimated if changes in discount rates and emerging migration patterns are not taken into account.				Pörtner, D.C. Roberts, V. Masson-delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. (2022) Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 321—445. https://doi.org/10.1017/9781009157964.006				
Dudley, Peter. (2018). A salmonid individual-based model as a proposed decision support tool for management of a large regulated river. Ecosphere. 9. 10.1002/ecs2.2074.	Large regulated rivers often require fisheries and water managers to make management decisions involving resident fish population dynamics that have many ecological drivers. Because of the large scale of the system and often competing interests and demands for water, there is a critical need for decision support tools (DSTs) that allow examination of alternative management scenarios while considering key ecological	Y	The proposed DTS results compare favorably with the predictive power of a general additive model, while providing a much fuller and richer data set that could significantly aid and inform management decisions.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	interactions. Spatially explicit individual-based models (IBMs) can serve as effective DSTs by providing information on fish population dynamics while accounting for, and providing extensive, spatially explicit information on, the numerous ecological drivers. Spatially explicit IBMs are often difficult to implement owing to the numerous and often complex inputs the models require. Here, I demonstrate how a suite of free, graphical user interface equipped programs, along with three custom-built and publicly available plugins, can streamline the modeling process and serve as a IBM-based DST for fisheries management on large regulated rivers. The main program is a spatially explicit IBM of juvenile salmonid dynamics, inSALMO, with two other programs that generate the key input data in the required spatially explicit formats. I then use this proposed DST to simulate a Chinook salmon population on a portion of California's Sacramento River to determine whether an IBM-based DST is appropriate to evaluate management impacts on a large regulated river. The Sacramento is a large river of major concern in California and is								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	representative of many rivers in the United States and worldwide in that it is dammed, has a resident fish population, and is heavily used for water supply. The proposed DTS results compare favorably with the predictive power of a general additive model, while providing a much fuller and richer data set that could significantly aid and inform management decisions.								
Durell, Sarah; Stillman, Richard; Triplet, Patrick; Desprez, Michel; Fagot, Cédric; Loquet, Nicolas; Sueur, François; Goss—Custard, John. (2008). Using an individual-based model to inform estuary management in the Baie de Somme, France. Oryx. 42. 265 — 277. 10.1017/S003060530800625X.	Conservation managers need to be able to assess and prioritize issues that may affect their target habitats and species. In the Baie de Somme, France, conservation issues affecting overwintering shorebirds include hunting pressure, cockle fishing, recreational disturbance, Spartina encroachment, and changing sediment levels. We used an individual-based model to predict the effect of these issues on the survival of three shorebird species: dunlin Calidris alpina, oystercatcher Haematopus ostralegus and curlew Numenius arquata. In the model, removing hunting from the mudflats in the eastern part of the estuary had the greatest positive	Y	Conservation managers need to be able to assess and prioritize issues that may affect their target habitats and species.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	effect on shorebird survival. Oystercatcher survival decreased markedly when stocks of large cockles were reduced to < 250 m(—2) or numbers of fishermen per day were doubled. Short-term disturbance events, such as walkers, had more effect on shorebird survival than long-term events, such as fishermen. Dunlin, as a protected species, were able to feed outside the Reserve Naturelle and were unaffected by disturbance within the Reserve. Oystercatcher survival decreased when the number of disturbance events within the Reserve exceeded one h(—1), and curlew survival when disturbance events exceeded six h(—1). Spartina encroachment caused dunlin survival to decline steadily as feeding habitat was lost. Dunlin were also the species most affected by changes in sediment levels, likely to occur through either sedimentation or sea level rise.								
Edwards, Helen J.; Elliott, Ian A.; Eakin, C. Mark; Irikawa, Akiyuki; Madin, Joshua S.; McField, Melanie; Morgan, Jessica A.; van Woesik, Robert; Mumby, Peter J. (2010). How much time can herbivore protection buy for coral reefs under realistic	Coral reefs have been more severely impacted by recent climate instability than any other ecosystem on Earth. Corals tolerate a narrow range of physical environmental stress, and increases in sea	Y	Recognizing where such management interventions will either help or fail is an important step towards both achieving sustainable use of coral-reef resources and	Y	Knowles, J., Green, A., Dahlgren, C., Arnett, F., & Knowles, L. (2017). Expanding The Bahamas	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
regimes of hurricanes and coral bleaching?. Global Change Biology. 17. 2033 — 2048. 10.1111/j.1365—2486.2010.02366.x.	temperature of just 1 degrees C over several weeks can result in mass coral mortality, often exceeding 95% of individuals over hundreds of square kilometres. Even conservative climate models predict that mass coral bleaching events could occur annually by 2050. Unfortunately, managers of coral-reef resources have few options available to meet this challenge. Here, we investigate the role that fisheries conservation tools, including the designation of marine reserves, can play in altering future trajectories of Caribbean coral reefs. We use an individual-based model of the ecological dynamics to test the influence of spatially realistic regimes of disturbance on coral populations. Two major sources of disturbance, hurricanes and coral bleaching, are simulated in contrasting regions of the Caribbean: Belize, Bonaire, and the Bahamas. Simulations are extended to 2099 using the HadGEM1 climate model. We find that coral populations can maintain themselves under all levels of hurricane disturbance providing that grazing levels are high. Regional differences in hurricane frequency are found		maximizing resource management investments.		Marine Protected Area Network to Protect 20% of the Marine and Coastal Environment by 2020: A Gap Analysis. The Nature Conservancy & Bahamas National Trust.				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	to cause strikingly different spatial patterns of reef health with greater patchiness occurring in Belize, which has less frequent disturbance, than the Bahamas. The addition of coral bleaching led to a much more homogenous reef state over the seascape. Moreover, in the presence of bleaching, all reefs exhibited a decline in health over time, though with substantial variation among regions. Although the protection of herbivores does not prevent reef degradation it does delay rates of coral loss even under the most severe thermal and hurricane regimes. Thus, we can estimate the degree to which local conservation can help buy time for reefs with values ranging between 18 years in the Bahamas and over 50 years in Bonaire, compared with heavily fished systems. Ultimately, we demonstrate that local conservation measures can benefit reef ecosystem services but that their impact will vary spatially and temporally. Recognizing where such management interventions will either help or fail is an important step towards both achieving sustainable use of coral-reef								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	resources and maximizing resource management investments.								
Charlotte E. Davies, Andrew F. Johnson, Emma C. Wootton, Spencer J. Greenwood, K. Fraser Clark, Claire L. Vogan, Andrew F. Rowley, Effects of population density and body size on disease ecology of the European lobster in a temperate marine conservation zone, ICES Journal of Marine Science, Volume 72, Issue suppl_1, July 2015, Pages i128–i138, https://doi.org/10.1093/icesjms/fsu237	Marine conservation zones (MCZs) are a form of spatial marine management, increasingly popular since the move towards ecosystem-based fisheries management. Implementation, however, is somewhat contentious and as a result of their short history, their effects are still widely unknown and understudied. Here, we investigate the population and health of the European lobster (Homarus gammarus) in the Lundy Island Marine Conservation Zone, Bristol Channel, UK. Using the fished refuge zone (RZ) as a control area, catch per unit effort was calculated for both the no-take zone (NTZ) and RZ and binomial logistic regression models were used to examine the effects of site, sex, landing size, and loss of chelae on the probability of shell disease and injury presence in individuals. Lobsters were also tested for the causative agent of gaffkaemia, Aerococcus viridans var. homari, and white spot syndrome virus (WSSV). The analysis revealed a higher lobster density and larger lobsters in the NTZ compared with	Y	Marine conservation zones (MCZs) are a form of spatial marine management, increasingly popular since the move towards ecosystem-based fisheries management.	Y	Lundy Management Forum. 2017. Lundy Marine Management Plan 2017. Written by Rebecca MacDonald and revised by Robert Irving. Produced for Natural England by the Landmark Trust, Lundy Island.	—	N	N	N

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	the RZ. Shell disease was present in 24% of lobsters and the probability of shell disease occurrence increased notably for individuals over the minimum landing size (MLS) of 90 mm carapace length. Shell disease was also more prevalent in lobsters displaying injury, and in males. Injury was present in 33% of lobsters sampled and prevalence was higher in lobsters in the NTZ compared with the RZ, and in lobsters. MLS. Aerococcus viridans var. homari was detected in,1% of individuals, but WSSV was absent from all sampled lobsters. Overall, the study demonstrates both positive and potentially negative effects of NTZs, methods for effective non-lethal sampling of disease agents, and highlights the need for more comprehensive, long-term monitoring within highly protected MCZs, both before and after implementation.								
El Saadi, Nadjia; Bah, Alassane. (2006). On phytoplankton aggregation: a view from an IBM approach. Comptes rendus biologies. 329. 669—78. 10.1016/j.crvi.2006.05.004.	In this paper, we build up an individual - based model (IBM) that describes the aggregative behavior in phytoplankton. The processes in play at the individual level (an individual = a phytoplankton cell) are: a random dispersal, a displacement due to the net effect of cells present in a suitable	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	neighborhood (spatial interactions) and a branching (cell division and death). The IBM model provides a virtual world where phytoplankton cells appear to form clusters. Using this model, we explore the spatial structure of phytoplankton and present some numerical simulations that help the understanding of the aggregation phenomenon.								
Elderd, Bret; Nott, M.. (2007). Hydrology, habitat change and population demography: An individual-based model for the endangered Cape Sable seaside sparrow Ammodramus maritimus mirabilis. Journal of Applied Ecology. 45. 258 — 268. 10.1111/j.1365—2664.2007.01369.x.	1. Habitat destruction and fragmentation have led to precipitous declines in a number of species of concern. For these species, traditional models that group individuals into age or stage cohorts may not accurately capture the stochasticity associated with small populations. Additionally, traditional models do not explicitly incorporate landscape-level structure, which becomes increasingly important at small population sizes. Thus, for declining species, spatially explicit individual-based models (SEIBM) can be used to understand both population demography and the impacts of habitat destruction, and to guide management practices to increase the chances of species survival.2. To gauge	Y	to guide management practices to increase the chances of species survival.	Y	Virzi, T., S.P. Murphy, and M.J. Davis. 2018. Recovery of Cape Sable seaside sparrow – subpopulation A. Report to the United States Fish and Wildlife Service (South Florida Ecological Services Field Office), Vero Beach, Florida, USA and National Park Service (Everglades National Park), Homestead, Florida	Emergency management action plan for the endangered Cape Sable Seaside Sparrow. U. S. Fish and Wildlife Service, Vero Beach, FL. Slater, G. L., R. L. Boulton, C. N. Jenkins, J. L. Lockwood, S. L. Pimm. 2009.	N,N	N,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	the impacts of changes in habitat and also demographic rates on a US endangered species, we constructed an SEIBM for the Cape Sable seaside sparrow (Ammodramus maritimus mirabilis Howell) of the South Florida Everglades. The model simulates temporal and spatial dynamics of individual sparrows using local GIS-based topography, vegetation and hydrology along with behavioural and demographic rates derived from field studies.3. When adult mortality and, to a lesser extent, juvenile mortality were increased in model simulations, there was an increase in extinction risk and a decrease in population size, whereas changes in number of clutches or female mating range had little impact. In contrast to the effects of simulating changes in mortality rates, simulated landscape-level changes (increasing water levels or decreasing habitat availability) were associated with dramatic population declines and increases in extinction risk. The sparrow appears to be particularly sensitive to the loss of higher-elevation breeding habitat. These results highlight the importance of proper water- and land-use management in assuring the species'								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	survival.4. Synthesis and applications. Although changes in demographic rates affect population growth and are often the focus of conservation efforts, changes in habitat structure can also dramatically alter population viability. When both landscape-level and demographic data are available, spatially explicit models are particularly advantageous. Not only do they allow researchers and resource managers to prioritize areas for habitat restoration and species management, but they can also be used to help focus future research efforts.								
Etterson, Matthew; Ellis—Felege, Susan; Evers, David; Gauthier, Gilles; Grzybowski, Joseph; Mattsson, Brady; Nagy, Laura; Olsen, Brian; Pease, Craig; Post van der Burg, Max; Potvien, Aaron. (2011). Modeling fecundity in birds: Conceptual overview, current models, and considerations for future developments. Ecological Modelling — ECOL MODEL. 222. 2178—2190. 10.1016/j.ecolmodel.2010.10.013.	Fecundity is fundamental to the fitness, population dynamics, conservation, and management of birds. For all the efforts made to measure fecundity or its surrogates over the past century of avian research, it is still mismeasured, misrepresented, and misunderstood. Fundamentally, these problems arise because of partial observability of underlying processes such as renesting, multiple brooding, and temporary emigration. Over the last several decades, various analytical approaches have been	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	developed to estimate fecundity from incomplete and biased data. These, include scalar arithmetic formulae, partial differential equations, individual-based simulations, and Markov chain methodology. In this paper, we: (1) identify component processes of avian reproduction; (2) review existing methods for modeling fecundity; (3) place these diverse models under a common conceptual framework; (4) describe the parameterization, validation, and limitations of such models; and (5) point out future considerations and challenges in the application of fecundity models. We hope this synthesis of existing literature will help direct researchers toward the most appropriate methods to assess avian reproductive success for answering questions in evolutionary ecology, natural history, population dynamics, reproductive toxicology, and management. Published by Elsevier B.V.								
Garavelli, Livia; Grüss, Arnaud; Grote, Britta; Chang, Nicolette; SMITH, M.; Verley, Philippe; Stenevik, Erling; Kaplan, David; Lett, Christophe. (2012). Modeling the dispersal of	The two Cape hake species of the southern Benguela ecosystem, the shallow-water and deep-water hakes Merluccius capensis and M. paradoxus, are	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Cape hake ichthyoplankton. Journal of Plankton Research. 34. 10.1093/plankt/fbs039.	economically the most important marine resources in South Africa. Recruitment is a key process in the dynamics of marine organisms, yet very little is known about the early life history of Cape hakes, especially the location of spawning grounds and transport of eggs and larvae. For each species, ichthyoplankton dispersal off South Africa is simulated by coupling oceanographic simulations to an individual-based model in order to track virtual individuals. Results indicate that the most favorable spawning areas for transport to nursery areas are located off the south-western coast and the eastern Agulhas Bank, and highlight partly different drift routes followed by the two ichthyoplankton species off Cape Columbine. Transport from spawning to nursery areas is the highest in austral winter for a spawning depth ranging between 0 and 100 m. These modeling results are in broad agreement with available knowledge on the ecology of Cape hakes. The present work on Cape hakes complements previous modeling studies on anchovy and sardine in the same area. Taken together, these studies underline the								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	correspondence between cross-shore (for hakes) or alongshore (for anchovy and sardine) transport mechanisms and the spawning strategies used by these key species of the southern Benguela ecosystem.								
Giacomini, Henrique; Deangelis, Donald; Trexler, Joel; Petrere, Miguel. (2013). Trait contributions to fish community assembly emerge from trophic interactions in an individual-based model. Ecological Modelling. 251. 32—43. 10.1016/j.ecolmodel.2012.12.003.	Community ecology seeks to understand and predict the characteristics of communities that can develop under different environmental conditions, but most theory has been built on analytical models that are limited in the diversity of species traits that can be considered simultaneously. We address that limitation with an individual-based model to simulate assembly of fish communities characterized by life history and trophic interactions with multiple physiological tradeoffs as constraints on species performance. Simulation experiments were carried out to evaluate the distribution of 6 life history and 4 feeding traits along gradients of resource productivity and prey accessibility. These experiments revealed that traits differ greatly in importance for species sorting along the gradients. Body growth rate emerged as a key	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	factor distinguishing community types and defining patterns of community stability and coexistence, followed by egg size and maximum body size. Dominance by fast-growing, relatively large, and fecund species occurred more frequently in cases where functional responses were saturated (i.e. high productivity and/or prey accessibility). Such dominance was associated with large biomass fluctuations and priority effects, which prevented richness from increasing with productivity and may have limited selection on secondary traits, such as spawning strategies and relative size at maturation. Our results illustrate that the distribution of species traits and the consequences for community dynamics are intimately linked and strictly dependent on how the benefits and costs of these traits are balanced across different conditions.								
Godley, Brendan; Barbosa, Clarita; Bruford, Michael; Broderick, Annette; Catry, Paulo; Coyne, Michael; Formia, Angela; Hays, Graeme; Witt, Matthew. (2010). Unravelling migratory connectivity in marine turtles using multiple methods. Journal of Applied Ecology. 47. 769	P>1. Comprehensive knowledge of the fundamental spatial ecology of marine species is critical to allow the identification of key habitats and the likely sources of anthropogenic threats, thus informing effective conservation strategies.2. Research	Y	Comprehensive knowledge of the fundamental spatial ecology of marine species is critical to allow the identification of key habitats and the likely sources of anthropogenic threats, thus informing effective	Y	The State of the World's Sea Turtle: Special Feature South America. (2016). Oceanic Society.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
— 778. 10.1111/j.1365—2664.2010.01817.x.	on migratory marine vertebrates has lagged behind many similar terrestrial animal groups, but studies using electronic tagging systems and molecular techniques offer great insights.3. Marine turtles have complex life history patterns, spanning wide spatio-temporal scales. As a result of this multidimensional complexity, and despite extensive effort, there are no populations for which a truly holistic understanding of the spatial aspects of the life history has been attained. There is a particular lack of information regarding the distribution and habitats utilized during the first few years of life.4. We used satellite tracking technology to track individual turtles following nesting at the green turtle Chelonia mydas nesting colony at Poilao Island, Guinea Bissau; the largest breeding aggregation in the eastern Atlantic.5. We further contextualize these data with pan-Atlantic molecular data and oceanographic current modelling to gain insights into likely dispersal patterns of hatchlings and small pelagic juveniles.6. All adult turtles remained in the waters of West Africa, with strong connectivity demonstrated with Banc D'Arguin, Mauritania.7. Despite		conservation strategie						

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	shortcomings in current molecular markers, we demonstrate evidence for profound sub-structuring of marine turtle stocks across the Atlantic; with a high likelihood based on oceanographic modelling that most turtles from Guinea-bissau are found in the eastern Atlantic.8. Synthesis and applications. There is an increased need for a better understanding of spatial distribution of marine vertebrates demonstrating life histories with spatio-temporal complexity. We propose the synergistic use of the technologies and modelling used here as a working framework for the future rapid elucidation of the range and likely key habitats used by the different life stages from such species.								
Goodwin, R. Andrew; Politano, Marcela; Garvin, Justin W.; Nestler, John M.; Hay, Duncan; Anderson, James J.; Weber, Larry J.; Dimperio, Eric; Smith, David L.; Timko, Mark (2014). Fish navigation of large dams emerges from their modulation of flow field experience. Proceedings of the National Academy of Sciences of the United States of America. 111. 10.1073/pnas.1311874111.	Navigating obstacles is innate to fish in rivers, but fragmentation of the world's rivers by more than 50,000 large dams threatens many of the fish migrations these waterways support. One limitation to mitigating the impacts of dams on fish is that we have a poor understanding of why some fish enter routes engineered for their safe travel around the dam but others pass through more dangerous routes. To	Y	One limitation to mitigating the impacts of dams on fish...emphasize the role of experience and perception in the decision making of animals that can inform opportunities and limitations in living resources management and engineering design.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	understand fish movement through hydropower dam environments, we combine a computational fluid dynamics model of the flow field at a dam and a behavioral model in which simulated fish adjust swim orientation and speed to modulate their experience to water acceleration and pressure (depth). We fit the model to data on the passage of juvenile Pacific salmonids (Oncorhynchus spp.) at seven dams in the Columbia/Snake River system. Our findings from reproducing observed fish movement and passage patterns across 47 flow field conditions sampled over 14 y emphasize the role of experience and perception in the decision making of animals that can inform opportunities and limitations in living resources management and engineering design.								
Goss—Custard, John; Burton, Niall; Clark, Nigel; Ferns, Peter; McGrorty, Selwyn; Reading, Chris; Rehfisch, Mark; Stillman, Richard; Townend, Ian; West, Andrew; Worrall, David. (2007). Test of a behavior-based individual-based model: Response of shorebird mortality to habitat loss. Ecological applications : a publication of the Ecological Society of	In behavior-based individual-based models (IBMs), demographic functions are emergent properties of the model and are not built into the model structure itself, as is the case with the more widely used demography-based IBMs. Our behavior-based IBM represents the physiology and behavioral decision	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
America. 16. 2215—22. 10.1890/1051—0761	making of individual animals and, from that, predicts how many survive the winter nonbreeding season, an important component of fitness.This paper provides the first test of such a model by predicting the change in winter mortality of a charadriid shorebird following removal of intertidal feeding habitat, the main effect of which was to increase bird density. After adjusting one calibration parameter to the level required to replicate the observed mortality rate before habitat loss, the model predicted that mortality would increase by 3.65%, which compares well with the observed increase of 3.17%. The implication that mortality was density-dependent was confirmed by predicting mortality over a range of bird densities. Further simulations showed that the density dependence was due to an increase in both interference and depletion competition as bird density increased.Other simulations suggested that an additional area of mudflat, equivalent to only 10% of the area that had been lost, would be needed by way of mitigation to return mortality to its original level. Being situated at a high shore level with the flow of water in and out impeded by inlet pipes, the								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	mitigating mudflat would be accessible to birds when all mudflats in the estuary were covered at high tide, thus providing the birds with extra feeding time and not just a small replacement mudflat.Apart from providing the first, and confidence—raising, test of a behavior-based IBM, the results suggest (1) that the chosen calibration procedure was effective; (2) that where no new fieldwork is required, and despite being parameter rich, a behavior-based IBM can be parameterized quickly (few weeks), and thus cheaply, because so many of the parameter values can be obtained from the literature and are embedded in the model; and (3) that behavior-based IBMs can be used to explore system behavior (e.g., the role of depletion competition and interference competition in density-dependent mortality).								
Groeneveld, Jürgen; Johst, Karin; Meyer, Bettina; Teschke, Mathias; Grimm, Volker. (2015). How biological clocks and changing environmental conditions determine local population growth and species distribution in Antarctic krill (Euphausia superba): A conceptual model. Ecological Modelling.	The Southern Ocean ecosystem is characterized by extreme seasonal changes in environmental factors such as day length, sea ice extent and food availability. The key species Antarctic krill (Euphausia superba) has evolved metabolic and behavioural seasonal	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
303. 10.1016/j.ecolmodel.2015.02.009.	rhythms to cope with these seasonal changes. We investigate the switch between a physiological less active and active period for adult krill, a rhythm which seems to be controlled by internal biological clocks. These biological clocks can be synchronized by environmental triggers such as day length and food availability. They have evolved for particular environmental regimes to synchronize predictable seasonal environmental changes with important life cycle functions of the species. In a changing environment the time when krill is metabolically active and the time of peak food availability may not overlap if krill's seasonal activity is solely determined by photoperiod (day length). This is especially true for the Atlantic sector of the Southern Ocean where the spatio-temporal ice cover dynamics are changing substantially with rising average temperatures. We developed an individual-based model for krill to explore the impact of photoperiod and food availability on the growth and demographics of krill. We simulated dynamics of local krill								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	populations (with no movement of krill assumed) along a south-north gradient for different triggers of metabolic activity and different levels of food availability below the ice. We also observed the fate of larval krill which cannot switch to low metabolism and therefore are likely to overwinter under ice. Krill could only occupy the southern end of the gradient, where algae bloom only lasts for a short time, when alternative food supply under the ice was high and metabolic activity was triggered by photoperiod. The northern distribution was limited by lack of overwintering habitat for krill larvae due to short duration of sea ice cover even for high food content under the ice. The variability of the krill's length-frequency distributions varied for different triggers of metabolic activity, but did not depend on the sea ice extent. Our findings suggest a southward shift of krill populations due to reduction in the spatial sea ice extent, which is consistent with field observations. Overall, our results highlight the importance of the explicit consideration of spatio-temporal sea ice dynamics especially for larval krill together with temporal synchronization								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	through internal clocks, triggered by environmental factors (photoperiod and food) in adult krill for the population modelling of krill. d.								
Grünbaum, Daniel; Chan, Karen; Tobin, Elizabeth; Nishizaki, Michael. (2008). Non-linear advection–diffusion equations approximate swarming but not schooling populations. Mathematical biosciences. 214. 38—48. 10.1016/j.mbs.2008.06.002.	Advection-diffusion equations (ADEs) are concise and tractable mathematical descriptions of population distributions used widely to address spatial problems in applied and theoretical ecology. We assessed the potential of non-linear ADEs to approximate over very large time and space scales the spatial distributions resulting from social behaviors such as swarming and schooling, in which populations are subdivided into many groups of variable size, velocity and directional persistence. We developed a simple numerical scheme to estimate coefficients in non-linear ADEs from individual-based model (IBM) simulations. Alignment responses between neighbors within groups quantitatively and qualitatively affected how populations moved. Asocial and swarming populations, and schooling populations with weak alignment tendencies, were well approximated by non-linear ADEs. For these behaviors,	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	numerical estimates such as ours could enhance realism and efficiency in ecosystem models of social organisms. Schooling populations with strong alignment were poorly approximated, because (in contradiction to assumptions underlying the ADE approach) effective diffusion and advection were not uniquely defined functions of local density. PDE forms other than ADEs are apparently required to approximate strongly aligning populations.								
Hellweger, Ferdi; Sebille, Erik; Fredrick, Neil. (2014). Biogeographic patterns in ocean microbes emerge in a neutral agent-based model. Science (New York, N.Y.). 345. 1346—9. 10.1126/science.1254421.	A key question in ecology and evolution is the relative role of natural selection and neutral evolution in producing biogeographic patterns. We quantify the role of neutral processes by simulating division, mutation, and death of 100,000 individual marine bacteria cells with full 1 million-base-pair genomes in a global surface ocean circulation model. The model is run for up to 100,000 years and output is analyzed using BLAST (Basic Local Alignment Search Tool) alignment and metagenomics fragment recruitment. Simulations show the production and maintenance of biogeographic patterns,	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	characterized by distinct provinces subject to mixing and periodic takeovers by neighbors (coalescence), after which neutral evolution reestablishes the province and the patterns reorganize. The emergent patterns are substantial (e. g., down to 99.5% DNA identity between North and Central Pacific provinces) and suggest that microbes evolve faster than ocean currents can disperse them. This approach can also be used to explore environmental selection.								
Hill, Nicole; Foster, Scott; Duhamel, Guy; Welsford, Dirk; Koubbi, Philippe; Johnson, Craig. (2017). Model-based mapping of assemblages for ecology and conservation management: A case study of demersal fish on the Kerguelen Plateau. Diversity and Distributions. 23. 1216—1230. 10.1111/ddi.12613.	Aim: Quantifying biological assemblages and their environment is a fundamental, yet statistically challenging task in conservation ecology. Here, we use a recently developed approach called Regions of Common Profile (RCP) to quantify and map the distribution of demersal fish assemblages in an ecologically significant region of the Southern Ocean to (1) gain ecological and management insights and (2) evaluate the utility of the new method for ecoregionalization.Location: Northern Kerguelen Plateau, Subantarctic Islands, Southern Ocean.Methods: The	Y	Main conclusions: The RCP is a valuable tool for classifying biological regions with a range of ecological and conservation management applications. Our results extend current ecological and biogeographic knowledge for the northern Kerguelen Plateau, and maps of the distribution of assemblages will be useful for ongoing spatial management.	Y	Ashley A. Rowden, Carolyn J. Lundquist, Judi E. Hewitt, Fabrice Stephenson, Mark A. Morrison. (2018). Review of New Zealand's coastal and marine habitat and ecosystem classification. National Institute of Water & Atmospheric Research.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	RCP approach is a multispecies, model-based approach that can overcome many limitations of traditional distance-based approaches. It simultaneously groups sites with a similar composition of species and describes the patterns of variation in assemblages using environmental data, allowing the prediction of assemblages across the study region. We apply RCP to a unique dataset of demersal fish occurrences across the northern Kerguelen Plateau to model and map the distribution of assemblages and examine the representativeness of the Heard Island and McDonald Island marine reserve.Results: We demonstrate that the RCP approach allows a direct and quantitative interpretation of the composition of assemblages as well as their environment. Further, the model reasonably predicts the occurrence of individual species across the plateau as well as the species composition of sites. We distinguish and map seven assemblages defined by depth, surface temperature and chlorophyll a. Shallow-water assemblages contain a high proportion of endemic species, while deep-water								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	assemblages contain more cosmopolitan species. With the exception of one deep-water assemblage, — assemblages were well represented within the current Heard and McDonald Islands marine reserve. Main conclusions: The RCP is a valuable tool for classifying biological regions with a range of ecological and conservation management applications. Our results extend current ecological and biogeographic knowledge for the northern Kerguelen Plateau, and maps of the distribution of assemblages will be useful for ongoing spatial management.								
Hill, Simeon; Watters, George; Punt, André; McAllister, Murdoch; Le Quéré, Corinne; Turner, John. (2007). Model Uncertainty in the Ecosystem Approach to Fisheries. Fish and Fisheries. 8. 315 — 336. 10.1111/j.1467—2979.2007.00257.x.	Fisheries scientists habitually consider uncertainty in parameter values, but often neglect uncertainty about model structure, an issue of increasing importance as ecosystem models are devised to support the move to an ecosystem approach to fisheries (EAF). This paper sets out pragmatic approaches with which to account for uncertainties in model structure and we review current ways of dealing with this issue in fisheries and other disciplines. All involve considering a set of alternative models representing	Y	Practical implementation of an EAF should therefore be based on management approaches that acknowledge the uncertainty inherent in model predictions and are robust to it.	Y	FAO Fisheries Technical Guidelines for Responsible Fisheries. No. 4, Suppl. 2, Add. 1. Rome, FAO. 2008. 78p.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	different structural assumptions, but differ in how those models are used. The models can be asked to identify bounds on possible outcomes, find management actions that will perform adequately irrespective of the true model, find management actions that best achieve one or more objectives given weights assigned to each model, or formalize hypotheses for evaluation through experimentation. Data availability is likely to limit the use of approaches that involve weighting alternative models in an ecosystem setting, and the cost of experimentation is likely to limit its use. Practical implementation of an EAF should therefore be based on management approaches that acknowledge the uncertainty inherent in model predictions and are robust to it. Model results must be presented in ways that represent the risks and trade-offs associated with alternative actions and the degree of uncertainty in predictions. This presentation should not disguise the fact that, in many cases, estimates of model uncertainty may be based on subjective criteria. The problem of model uncertainty is far from unique to fisheries, and a dialogue among								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	fisheries modellers and modellers from other scientific communities will therefore be helpful.								
Holland, Dan; Schnier, Kurt. (2006). Individual Habitat Quotas for Fisheries. Journal of Environmental Economics and Management. 51. 72—92. 10.1016/j.jeem.2005.04.005.	Fishery managers in the US are required to identify and limit adverse consequences of fishing on essential fish habitat. We propose an individual habitat quota (IHQ) system for habitat conservation that would utilize economic incentives to achieve habitat conservation goals cost-effectively. Individual quotas of habitat impact units (HIU) would be distributed to fishers with an aggregate quota set to maintain a target habitat stock. HIU use would be based on a proxy for marginal habitat damage. We use a dynamic, explicitly spatial fishery and habitat simulation model to explore the cost-effectiveness of achieving specified habitat conservation targets with our IHQ system versus fixed or rotating marine protected areas (MPAs). We find that the IHQ system can be considerably more cost-effective than MPAs, but that the relative advantage decreases as fish diffusion rates and uncertainty about fish distribution increases.	Y	We propose an individual habitat quota (IHQ) system for habitat conservation that would utilize economic incentives to achieve habitat conservation goals cost-effectively.	Y	Squires, D., Maunder, M., Vestergaard, N., Restrepo, V., Metzner, R., Herrick, S., Hannesson, R., del Valle, I. & Andersen, P. 2014. Effort rights in fisheries management: general principles and case studies from around the world, 17–20 September 2012, Bilbao, Spain. FAO Fisheries and Aquaculture Proceedings No. 34. Rome, FAO. 260pp.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Holt, R. D., Barfield, M.,; Gomulkiewicz, R. (2004). Temporal Variation Can Facilitate Niche Evolution in Harsh Sink Environments. The American Naturalist, 164(2), 187–200. https://doi.org/10.1086/422343	We examine the impact of temporal variation on adaptive evolution in sink environments, where a species encounters conditions outside its niche. Sink populations persist because of recurrent immigration from sources. Prior studies have highlighted the importance of demographic constraints on adaptive evolution in sinks and revealed that adaptation is less likely in harsher sinks. We examine two complementary models of population and evolutionary dynamics in sinks: a continuous-state quantitative—genetics model and an individual-based model. In the former, genetic variance is fixed; in the latter, genetic variance varies because of mutation, drift, and sampling. In both models, a population in a constant harsh sink environment can exist in alternative states: local maladaptation (phenotype comparable to immigrants from the source) or adaptation (phenotype near the local optimum). Temporal variation permits transitions between these states. We show that moderate amounts of temporal variation can facilitate adaptive evolution in sinks, permitting niche evolution, particularly for slow or	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	autocorrelated variation. Such patterns of temporal variation may particularly pertain to sinks caused by biotic interactions (e. g., predation). Our results are relevant to the evolutionary dynamics of species' ranges, the fate of exotic invasive species, and the evolutionary emergence of infectious diseases into novel hosts.								
Hovel, Kevin; Regan, Helen. (2008). Using an individual-based model to examine the roles of habitat fragmentation and behavior on predator–prey relationships in seagrass landscapes. Landscape Ecology. 23. 75—89. 10.1007/s10980—007—9148—9.	Seagrasses, which form critical subtidal habitats for marine organisms worldwide, are fragmented via natural processes but are increasingly being fragmented and degraded by boating, fishing, and coastal development. We constructed an individual-based model to test how habitat fragmentation and loss influenced predator-prey interactions and cohort size for a group of settling juvenile blue crabs (Callinectes sapidus Rathbun) in seagrass landscapes. Using results from field studies suggesting that strong top-down processes influence the relationship between cannibalistic blue crab populations and seagrass landscape structure, we constructed a model in which prey (juvenile blue crabs) are eaten by mesopredators (larger	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	blue crabs) which in turn are eaten by top-level predators (e.g., large fishes). In our model, we varied the following parameters within four increasingly fragmented seagrass landscapes to test for their relative effects on cohort size: juvenile blue crab (prey) predator avoidance response, hunting ability of mesopredators and predators, the presence of a top-level predator, and prey settlement routines. Generally, prey cohort size was maximized in the presence of top-level predators and when mesopredators and predators exhibited random searching behavior vs. directed hunting. Cohort size for stationary (tethered) prey was maximized in fragmented landscapes, which corresponds to results from field experiments, whereas mobile prey able to detect and avoid predators had higher survival in continuous landscapes. Prey settlement patterns had relatively small influences on cohort size. We conclude that the effects of seagrass fragmentation and loss on organisms such as blue crabs will depend heavily on behaviors of prey and predatory organisms and how these behaviors change								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	with landscape structure.								
Hovestadt, Thomas; Poethke, Hans. (2006). The control of emigration and its consequences for the survival of populations. Ecological Modelling. 190. 443—453. 10.1016/j.ecolmodel.2005.03.023.	Dispersal is the key process enhancing the long-term persistence of metapopulations in heterogeneous and dynamic landscapes. However, any individual emigrating from a occupied patch also increases the risk of local population extinction. The consequences of this increase for metapopulation persistence likely depend on the control of emigration. In this paper, we present results of individual-based simulations to compare the consequences of density-independent (DIE) and density-dependent (DDE) emigration on the extinction risk of local populations and a two—patch metapopulation. (1) For completely isolated patches extinction risk increases linearly with realised emigration rates in the DEE scenario. (2) For the DDE scenario extinction risk is nearly insensitive to emigration as longs as emigration probabilities remain below approximate to 0.2. Survival chances are up to half an order of magnitude larger than for populations with DIE. (3) For low dispersal mortality both modes of emigration increase	Y	significantly affect our conclusions concerning the conservation status of species.	Y	Roughan & O'Donovan Dursey Island Cable Car and Visitor Centre Consulting Engineers. (2019). Dursey Island Cable Car and Visitor Centre: Environmental Impact Assessment Report. Cork County Council.*	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	survival of a metapopulation by ca. one order of magnitude. (4) For high dispersal mortality only DDE can improve the global survival chances of the metapopulation. (5) With DDE individuals are only removed from a population at high population density and the risk of extinction due to demographic stochasticity is thus much smaller compared to the DIE scenario. With density-dependent emigration prospects of metapopulations survival may thus be much higher compared to a system with density-independent emigration. Consequently, the knowledge about the factors driving emigration may significantly affect our conclusions concerning the conservation status of species.								
Hufnagl, Marc; Peck, Myron. (2011). Physiological-based modelling of larval Atlantic herring (Clupea harengus) foraging and growth: Insights on climate-driven life history scheduling. ICES Journal of Marine Science. 68. 1170—1188. 10.1093/icesjms/fsr078.	A physiological individual-based model for the foraging and growth of Atlantic herring (Clupea harengus) larvae was constructed, validated using laboratory and field data, tested for parameter sensitivity, and used to examine climate-driven constraints on life—history scheduling. Model scenarios	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	examined how natural (phenological and magnitude) changes in key environmental factors (temperature, prey, and photoperiod/daylength) affected the estimates of survival and growth of spring- and autumn-spawned larvae. The most suitable hatching seasons agreed well with the periods of larval abundance in Northeast Atlantic waters. Modelled survival is unlikely in June, July, and November. Mean annual temperature, prey concentration, and composition significantly influenced larval growth of both autumn and spring spawners. The model suggested that climate-driven changes in bottom-up factors will affect spring- and autumn-spawned larvae in different ways. It is unlikely that autumn-spawning herring will be able to avoid unfavourable conditions by delaying their spawning time or by utilizing more northern spawning grounds because of limitations in daylength to larval growth and survival. Conversely, earlier spawning in spring, or later, midsummer spawning will be tightly constrained by match mismatch dynamics between larvae and zooplankton production.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Hunter, Elizabeth. (2017). How will sea-level rise affect threats to nesting success for Seaside Sparrows?. The Condor. 119. 459—468. 10.1650/CONDOR-17—11.1.	Sea-level rise (SLR) threatens the nesting success of salt marsh breeding birds, including Seaside Sparrows (Ammodramus maritimus), by increasing the magnitude and frequency of extreme high tides that flood nests. However, the threat to nesting success from tidal flooding is intertwined with that of predation because the threats are connected through a trade-off along a nest height gradient. Therefore, to understand the risk to nesting success from SLR, it is necessary to consider predation threats simultaneously. I used an individual-based model of Seaside Sparrow nesting behavior, calibrated using empirical data on nest success rates and nest-site selection behaviors, to project the effects of SLR conditions on the relative importance of predation and flooding threats in affecting nesting success, and to investigate whether nest-site selection along a gradient of nest height can modulate the risk of SLR. Outputs from the model revealed that present-day levels of predation risk pose as great a risk to nesting success as tidal flooding under simulated SLR conditions with extreme flooding	Y	Therefore, management actions to reduce the risk of excessive failures from predation could reduce the risk of failures from both threats—a potentially useful management strategy, given that controlling predation is more tractable than controlling increased flooding from SLR at a local level.	Y	U.S. Fish and Wildlife Service. 2018. Species status assessment report for the MacGillivray's seaside sparrow (Ammodramus maritimus macgillivraii), Version 1.3. May 2018. Atlanta, GA.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	risks. Nest success rates could become very low under extreme SLR scenarios, especially when predation risk is very high. The risks of failure from either threat are linked through nest-site selection behaviors: In high-predation-risk seasons, failure probability from flooding is greater than it would be under lower predation risk, due to the predation avoidance behavior of nesting closer to the ground. Therefore, management actions to reduce the risk of excessive failures from predation could reduce the risk of failures from both threats—a potentially useful management strategy, given that controlling predation is more tractable than controlling increased flooding from SLR at a local level.								
Jager, Henriette. (2005). Genetic and demographic implications of aquaculture in white sturgeon (Acipenser transmontanus) conservation. Canadian Journal of Fisheries and Aquatic Sciences. 62. 1733—1745. 10.1139/f05—106.	This study uses a genetic individual-based model of white sturgeon (Acipenser transmontanus) populations in a river to examine the genetic and demographic trade-offs associated with operating a conservation hatchery. Simulation experiments evaluated three management practices: (i) setting quotas to equalize family contributions in an effort to prevent genetic swamping, (ii) an adaptive	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	management scheme that interrupts stocking when introgression exceeds a specified threshold, and (iii) alternative broodstock selection strategies that influence domestication. The first set of simulations, designed to evaluate equalizing the genetic contribution of families, did not show the genetic benefits expected. The second set of simulations showed that simulated adaptive management was not successful in controlling introgression over the long term, especially with uncertain feedback. The third set of simulations compared the effects of three alternative broodstock selection strategies on domestication for hypothetical traits controlling early density-dependent survival. Simulated aquaculture selected for a density-tolerant phenotype when broodstock were taken from a genetically connected population. Using broodstock from an isolated population (i.e., above an upstream barrier or in a different watershed) was more effective at preventing domestication than using wild broodstock from a connected population.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Kerbiriou, Christian; Le Viol, Isabelle; Robert, Alexandre; Porcher, Emmanuelle; Gourmelon, Françoise; Julliard, Romain. (2009). Tourism in protected areas can threaten wild populations: From individual response to population viability of the chough Pyrrhocorax pyrrhocorax. Journal of Applied Ecology. 46. 657—665. 10.1111/j.1365—2664.2009.01646.x.	Many protected areas are now faced with increasing pressure from visitors and tourism development. There is thus an urgent need for conservation biologists to evaluate the full impact of human disturbance not only on individual responses, but also on the viability of protected populations, so that relevant management measures can be proposed.We studied the impact of tourism on the rare and endangered chough Pyrrhocorax pyrrhocorax on a protected French island to assess the relationship between visitor pressure, bird individual behaviour and fitness, and population viability. During 8 years, we monitored foraging behaviour and estimated monthly juvenile survival using mark-recapture data. Population viability was examined under different tourism scenarios, using a stochastic individual-based model that incorporated the impact of visitor numbers on juvenile survival.In summer, the foraging probability of choughs was negatively correlated with the number of visitors. As a result, the time allocated to foraging during peak tourist season, adjusted to day length and prey availability,	Y	This suggests that the full impact of tourism in protected areas may be overlooked, and has direct consequences for the assessment of sustainable levels of human disturbance and the design of quantitative management options compatible with tourist activities in protected areas. We specifically emphasize the need for more integrative approaches combining research at individual and population levels.	Y	Roughan & O'Donovan Dursey Island Cable Car and Visitor Centre Consulting Engineers. (2019). Dursey Island Cable Car and Visitor Centre: Environmental Impact Assessment Report. Cork County Council.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	was 50% lower than expected.Juvenile survival rates were lowest in August, the peak tourist season, and varied significantly across years. August survival rate and therefore annual survival were negatively correlated with the number of visitors on the island in August and, except for a minor negative effect of rainfall, were not influenced by other environmental variables.Stochastic simulations predicted a low probability of extinction of the protected population if the number of visitors remains constant in the future. However, short-term viability would be dramatically reduced if the current rate of increase in visitor numbers is maintained.Synthesis and applications. We show that a relatively minor human-induced disturbance (e.g. scaring individuals away) has dramatic effects on population viability in a protected area, even when breeding individuals are not directly affected. This suggests that the full impact of tourism in protected areas may be overlooked, and has direct consequences for the assessment of sustainable levels of human disturbance and the design of quantitative management options compatible with tourist activities in								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	protected areas. We specifically emphasize the need for more integrative approaches combining research at individual and population levels.								
Koeck, Barbara; Gerigny, Olivia; Durieux, Eric; Coudray, Sylvain; Garsi, Laure—Hélène; Bisgambiglia, Paul—Antoine; Galgani, François; Agostini, Sylvia. (2015). Connectivity patterns of coastal fishes following different dispersal scenarios across a transboundary marine protected area (Bonifacio strait, NW Mediterranean). Estuarine Coastal and Shelf Science. 154. 234—247. 10.1016/j.ecss.2015.01.010.	The Strait of Bonifacio constitutes one of the rare transboundary Marine Protected Areas (MPA) of the Mediterranean Sea (between Sardinia, Italy and Corsica, France). Based on the hypothesis that no-take zones will produce more fish larvae, compared to adjacent fished areas, we modeled the outcome of larvae released by coastal fishes inside the no-take zones of the MPA in order to: (1) characterize the dispersal patterns across the Strait of Bonifacio; (2) identify the main potential settlement areas; (3) quantify the connectivity and the larval supply from the MPAs to the surrounding areas. A high resolution hydrodynamic model (MARS 3D, Corse 400 m) combined to an individual based model (Ichthyop software) was used to model the larval dispersal of fish following various scenarios (Pelagic Larval Duration PLD and release depth) over the main spawning period (i.e. between April and	Y	Biotic and abiotic parameters affecting the dispersal dynamic of fish larvae within the Strait of Bonifacio were identified and synthesis maps were established as a tool for conservation planning.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	September). Dispersal model outputs were then compared with those obtained from an ichthyoplankton sampling cruise performed in August 2012. There was a significant influence of PLD to the connectivity between coastal areas. The synchronization between spawning and hydrodynamic conditions appeared to be determinant in the larval transport success. Biotic and abiotic parameters affecting the dispersal dynamic of fish larvae within the Strait of Bonifacio were identified and synthesis maps were established as a tool for conservation planning.								
Koizumi, Itsuro; Shimatani, Kenichiro. (2016). Socially induced reproductive synchrony in a salmonid: An approximate Bayesian computation approach. Behavioral Ecology. 27. arw056. 10.1093/beheco/arw056.	Reproductive synchrony is a widespread phenomenon found in many taxa, including plants and corals. However, compared with synchrony caused by environmental cues, knowledge of socially induced reproductive synchrony is limited, partly due to the difficulty of experimentally manipulating and/or making detailed behavioral observations of populations in the wild. In this study, we developed a novel modeling framework combining an individual-based model, a hierarchical	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Bayesian model, and an approximate Bayesian computation (ABC) to elucidate socially induced reproductive synchrony. This method was applied to time-series redd (i.e., spawning nests) count data in 30 wild populations of stream-dwelling Dolly Varden charr. The model with reproductive synchrony explained all the redd count data, whereas the null model, which did not include the synchrony, failed to reproduce the observed data in several populations. In addition, our models suggest that Dolly Varden should be able to adjust spawning by up to a week following other females to produce synchrony. No significant correlation was observed between reproductive timing and environmental factors, suggesting that the major cue for the synchrony was social rather than environmental. The presence of reproductive synchrony within but not among local populations suggests that predator satiation is not the main driver of the synchrony; rather, other mechanisms must exist in the Dolly Varden, such as induced monogamy or polygamy, or avoidance of nest superimposition. This								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	study has demonstrated the effectiveness of using individual-based and hierarchical modeling together with an ABC parameter estimation method in behavioral ecological studies.								
Kristiansen, Trond; Lough, R.; Werner, Francisco; Broughton, Elisabeth; Buckley, Larry. (2009). Individual-based modeling of feeding ecology and prey selection of larval cod on Georges Bank. Marine Ecology Progress Series. 376. 227—243. 10.3354/meps07796.	Understanding larval fish survival dynamics is essential to determining variability in future adult population structure. Realistic modeling of larval fish feeding ecology depends on incorporating both the biotic and abiotic conditions that affect predator-prey interactions. We used an individual-based model (IBM) to test which variables drive Atlantic larval cod Gadus morhua feeding preferences. The IBM included a bioenergetics component that incorporated metabolic parameters and growth and a mechanistic prey selection component that depended on larval development and behavior, prey size and behavior, depth, light, and physical oceanographic conditions. We applied our model to Georges Bank and incorporated high-resolution field data on environmental conditions and prey abundance to analyze larval cod feeding ecology. Based on simulated selectivity	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	indices, we found that cod prey selection was determined by differential encounter of prey due to the abundance of suitably sized prey, their visibility, and larval cod ability to capture these prey items. The model suggested that Pseudocalanus spp. were the dominant prey species for larval cod because of their abundance in the water column and their large image area. Centropages spp. were also modeled to be an important part of larval diet, but no copepodite stages of this taxon were found in gut samples. Lack of Centropages spp. in the gut samples indicated that they are more elusive in their behavior than Pseudocalanus spp. Overall our results suggest larval cod feeding ecology on Georges Bank is a consequence of the physical and biological conditions rather than active prey selection.								
Kristiansen, Trond; Vollset, Knut; Sundby, Svein; Vikebø, Frode. (2014). Turbulence enhances feeding of larval cod at low prey densities. ICES Journal of Marine Science. 71. 10.1093/icesjms/fsu051.	The ability of larval fish to find food successfully after hatching is critical for their growth and survival during the early life stages. However, the feeding ecology of larval fish is strongly dependent on prevailing physical and biological conditions. Small changes in the prey distribution, turbulence, light, and	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	ocean temperature can affect larval survival probabilities. This study combined physical and biological observations collected from Atlantic cod (Gadus morhua) spawning grounds from Lofoten, Norway, during the years 1991—1992 with an individual-based model (IBM) that is able to simulate behaviour, feeding, and growth. Observational data on the vertical distribution of larval cod revealed that they congregated at 10—25m during the day, although the highest abundance of prey was generally in the upper 10 m. Using the behavioural component of the IBM, we analysed the mechanistic interactions between larval bioenergetics and the physical-biological environment and compared modelled with observed vertical larval cod distribution. During periods of both low and high prey densities, turbulence had a significant impact on larval cod feeding and growth rates as well as on larval vertical distribution. At low prey abundance (<5 nauplii l(—1)), turbulence enhanced encounter rates were very important for sustaining ingestion and growth rates for first-feeding larval								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	cod. Our results suggest that turbulence allowed larval cod to sustain high ingestion rates even deeper in the water column, where prey densities are usually lower.								
Little, L.; Punt, André; Mapstone, Bruce; Begg, Gavin; Goldman, Barry; Williams, Ashley. (2013). An Agent-based Model for Simulating Trading of Multi-Species Fisheries Quota. Ecological Modelling. 3404—3412. 10.1016/j.ecolmodel.2009.08.004.	Individual transferable quotas (ITQs) are increasingly seen as a way to make fisheries more profitable and halt over-capitalisation. ITQs allocate to users of a resource a share of a total allowable catch (TAC) which they are free to use, lease, or sell. We outline an approach to modelling the effect of an ITQ system in a multi-species, multi-sector fishery and apply it to the Coral Reef Fin Fish Fishery (CRFFF) in Queensland, Australia. An ITQ model, based on the assumption that operators seek to maximize profits, simulates the use of tradeable quota units by operators in the fishery, taking account of the initial quota allocation to operators, seasonal fish prices and individual operator variable costs, their fishing efficiency and experience, and constraints on vessel movements. Rationalization of the fishery is predicted to occur under an ITQ system for the CRFFF, which will	Y	Individual transferable quotas (ITQs) are increasingly seen as a way to make fisheries more profitable and halt over-capitalisation. ITQs allocate to users of a resource a share of a total allowable catch (TAC) which they are free to use, lease, or sell. We outline an approach to modelling the effect of an ITQ system in a multi-species, multi-sector fishery and apply it to the Coral Reef Fin Fish Fishery (CRFFF) in Queensland, Australia.	Y	Bunnefeld, N., Redpath, S. & Irvine, J. 2015. A review of approaches to adaptive management. Scottish Natural Heritage Commissioned Report No. 795.	Kritzer, J.P., Hicks, C.C., Mapstone, B.D., Pina—Amargós, F., Peter, F., & Sale (2013). 1 Ecosystem-based management of coral reefs and interconnected nearshore tropical habitats.	Y,Y	N,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	lead to reductions in effort, increases in profits, and changes over time in quota prices. The ecological consequences of transferable quota in the multi-species fishery are seen in the catch and discard levels of the less profitable species, even though a TAC was set. This had flow-on effects on biomass. For example, simulations showed that the TAC for the primary target species, coral trout, was used more fully than that for a less valuable target species, red throat emperor, and that this was achieved through increased discarding of red throat emperor. Catches of both coral trout and red throat emperor that were derived from the model were higher than those recently observed in the fishery. The effort predicted by the model, however, closely approximated the actual effort observed in the fishery following implementation of ITQ management.								
Lovvorn, James; Cruz, Susan; Takekawa, John; Shaskey, Laura; Richman, Samantha. (2013). Niche overlap, threshold food densities, and limits to prey depletion for a diving duck assemblage in an estuarine bay. Marine Ecology Progress Series.	Planning for marine conservation often requires estimates of the amount of habitat needed to support assemblages of interacting species. During winter in subtidal San Pablo Bay, California, the 3 main diving duck species are lesser	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
476. 251—268. 10.3354/meps10104.	scaup Aythya affinis (LESC), greater scaup A. marila (GRSC), and surf scoter Melanitta perspicillata (SUSC), which all feed almost entirely on the bivalve Corbula amurensis. Decreased body mass and fat, increased foraging effort, and major departures of these birds appeared to result from food limitation. Broad overlap in prey size, water depth, and location suggested that the 3 species responded similarly to availability of the same prey. However, an energetics model that accounts for differing body size, locomotor mode, and dive behavior indicated that each species will become limited at different stages of prey depletion in the order SUSC, then GRSC, then LESC. Depending on year, 35 to 66% of the energy in Corbula standing stocks was below estimated threshold densities for profitable foraging. Ectothermic predators, especially flounders and sturgeons, could reduce excess carrying capacity for different duck species by 4 to 10%. A substantial quantity of prey above profitability thresholds was not exploited before most ducks left San Pablo Bay. Such pre-depletion departure has been attributed in								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	other taxa to foraging aggression. However, in these diving ducks that showed no overt aggression, this pattern may result from high costs of locating all adequate prey patches, resulting reliance on existing flocks to find food, and propensity to stay near dense flocks to avoid avian predation. For interacting species assemblages, modeling profitability thresholds can indicate the species most vulnerable to food declines. However, estimates of total habitat needed require better understanding of factors affecting the amount of prey above thresholds that is not depleted before the predators move elsewhere.								
Mark J. Butler IV. (2005). Benthic fisheries ecology in a changing environment: Unraveling process to achieve prediction. Aquatic Living Resources, 18(3), 301–311. https://doi.org/10.1051/alr:2005034	Marine fisheries and the ecosystems that sustain them are increasingly beset by environmental deterioration, and the problem is particularly acute in coastal zones where human Populations are increasing. In the best of circumstances, fishery managers are faced with the multiple, often conflicting, demands of resource users, politicians, and scientists when considering strategies for resource management. A further challenge is that management	Y	Although not applicable for all resource management situations, our experiences provide all example of the potential use of spatially-explicit, individual-based modeling and targeted empirical science in predicting resource conditions in a dynamic environment.	Y	John S. Burke, W. Judson Kenworthy, T. Shay Viehman, Vanessa L. McDonough, and Brian Degan. 2011. Biodiversity and Ecosystem function of Shallow Bank Systems within Florida Keys National Marine Sanctuary	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	decisions must be made against a backdrop of a deteriorating environment and the shifting status of coastal ecosystem integrity. Traditional tools for single-species management may be inadequate in these settings. Furthermore. the necessary empirical data to appropriately parameterize models with vital rates representative of all altered environment are often lacking. Thus, we need approaches that better approximate the complicated dynamics between environmental conditions, fishery impacts, and multi-species interactions. Spatially-explicit, indivickial-based simulation modeling potentially permits this kind of integration, but it has seen limited use in marine resource management. especially with respect to benthic resources. My colleagues and I have used this approach, combined with targeted experimental work, to explore the impacts of nursery habitat deterioration, coastal freshwater management. and fishery activities oil Caribbean spiny lobster populations and sponge community structure in the Florida Keys, Florida (USA). Although not applicable for all				(FKNMS. Marine Sanctuaries Conservation Series ONMS—12—03. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 45 pp.				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	resource management situations, our experiences provide all example of the potential use of spatially-explicit, individual-based modeling and targeted empirical science in predicting resource conditions in a dynamic environment.								
Martin, Benjamin; Zimmer, Elke; Grimm, Volker; Jager, Tjalling. (2012). Dynamic Energy Budget theory meets individual-based modelling: A generic and accessible implementation. Methods in Ecology and Evolution. 3. 10.1111/j.2041—210X.2011.00168.x.	1. Dynamic Energy Budget (DEB) theory was designed to understand the dynamics of biological systems from cells to populations and ecosystems via a mass balance approach of individuals. However, most work so far has focused on the level of the individual. To encourage further use of DEB theory in a population context, we developed DEB—IBM, a generic individual-based model (IBM) that is based on DEB theory. 2. The generic IBM is implemented as a computer program using NetLogo, a free software platformthat is accessible to biologists with little programming background. The IBMuses DEB to represent assimilation, maintenance, growth and reproduction of individuals. The model description follows the overview, design and details (ODD) protocol, a generic format for describing IBMs, and	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	thereby provides a novel and accessible introduction to DEB theory and how it works in a population context. 3. Dynamic Energy Budget-individual— based model can be used to explore properties of both individual life—history traits and population dynamics, which emerge from the set of DEB parameters of a species, and their interaction with environmental variables such as food density. Furthermore, DEB— IBM can be adapted to address specific research questions, for example by including spatial effects. A user manual explains how this can be done. 4. Dynamic Energy Budget- individual—based model is designed to both facilitate use and testing DEB theory in a population context and to advance individual— based modelling by basing the representation of individuals on well—tested physiological principles.								
Matsinos, Yiannis; Wolff, Wilfried; Moustakas, Aristides. (2012). Adapting foraging to habitat heterogeneity and climate change: an individual-based model for wading birds. Ethology Ecology; Evolution.	In an effort to assess the role of adaptive foraging behaviour to the spatial and temporal heterogeneity as a factor determining the success of the colony, we used single—colony individual-based spatial models for a visual foraging, the Great Blue Heron	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	and a tactile foraging bird, the Wood Stork. The model followed simultaneously daily activities of individuals, their spatial movements, foraging efficiency, bioenergetics and growth of the nestlings during a nesting season. For each colony we used two scenarios; in the first, that depicted a normal nesting season, the extent and distribution of feeding sites led to successful reproduction for both species. In the second, we simulated increased precipitation regimes resulting in reversals in water depth (i.e. increases in depth during the dry season when water levels are normally falling). The results reveal that Wood Storks were significantly more adversely affected than Great Blue Herons by the prey dilution caused by the reversals in water depth. In the latter scenario where resources became scarce, resource predictability decreased. The foraging birds that foraged in groups exhibited low foraging success, resulting in poor reproductive performance. This result was more pronounced in the case of storks that foraged in groups than for herons foraging in groups. Concluding, increased variance in precipitation regimes								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	is more likely to affect tactile rather than visual foraging bird species. Further, in harsh climatic conditions (increased precipitation and water level regimes) solitary foraging was more beneficial for wading birds than group foraging.								
Mazaris, Antonios; Broder, Breckling; Matsinos, Yiannis. (2006). An individual based model of a sea turtle population to analyze effects of age dependent mortality. Ecological Modelling. 198. 174—182. 10.1016/j.ecolmodel.2006.04.012.	Effective conservation of wildlife species relies on our ability to recognize interactions among critical life stages, leading to the design of the appropriate protection measures. We developed an individual based model to analyze the variability of extinction probabilities as a result of interacting mortalities at different life stages of a sea turtle population. We conducted several simulation with different combinations of mortality rates for both terrestrial stages (i.e. egg and hatchling), and also for all marine stages of the species. To test and assess the implication of the numerous simulation sets produced by the fluctuating survival rates, counter plots were employed. The results of the simulation analysis show that the pelagic stage has a significant effect on population persistence. It is also apparent that	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	increased survival of the first year cohort could to some extent be beneficial for the population. The need for additional demographic data and a better understanding of the behavioral and biological processes is highlighted.								
Mazaris, Antonios; Matsinos, Yiannis; Pantis, John. (2009). Evaluating the impacts of coastal squeeze on sea turtle nesting. Ocean; Coastal Management. 52. 139—145. 10.1016/j.ocecoaman.2008.10.005.	Recent studies have provided theoretical and empirical evidence about the importance of hatchling production for sea turtle population dynamics. Therefore, understanding the effect of nesting habitat loss as a factor leading to hatchling reduction is essential in order to establish conservation plans for the recovery of sea turtle populations. In the present study, we developed a method to quantify habitat loss and link it with hatchling production. We used data for loggerhead sea turtles (Caretta caretta) collected at Sekania nesting beach, western Greece, to describe biological and behavioral attributes of nesting individuals. Spatial characteristics of the nesting site were analyzed and alternative scenarios of habitat loss were examined. We then used circle-packing technique to evaluate the impact of an increasingly reduced available nesting area on the spatial	Y	Our results clearly demonstrated the need to apply direct and efficient conservation measures at Sekania nesting site to minimize further habitat loss from human-related processes and a rising sea level,	Y	Mitigation strategies to reduce the impact of climate change on nesting beaches (CIT-CC12—2015—Tec.10). (2015). Inter-American Convention for the Protection and Conservation of Sea Turtles.*	Recovery Plan for Marine Turtles in Australia, Commonwealth of Australia 2017. (2017). Australian Government | Department of the Environment and Energy.*	N,N	N,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	distribution of nests. An increased number of nests within the study site resulted in density-dependent processes regulating hatchling production. Under the different scenarios, we evaluated the risk of the laying nests exceeding the estimated carrying capacity of the nesting beach. Our results clearly demonstrated the need to apply direct and efficient conservation measures at Sekania nesting site to minimize further habitat loss from human-related processes and a rising sea level, The approach developed evaluates the effect of habitat loss upon nesting by linking it with quantifiable processes (density dependence), providing a conservation tool to guide planning decisions towards the conservation of the sea turtle population.								
McDonald, A.; Little, L.; Gray, Randall; Fulton, Elizabeth; Sainsbury, Keith; Lyne, Vincent. (2008). An Agent-based Modelling Approach to Evaluation of Multiple-use Management Strategies for Coastal Marine Ecosystems. Mathematics and Computers in Simulation. 78. 401—411. 10.1016/j.matcom.2008.01.039.	The general objective of the multiple-use management strategy evaluation (MSE) framework is to develop and demonstrate practical science-based methods that support, under existing statutory arrangements, integrated regional planning and management of coastal and marine ecosystems. In the	Y	The example explores the implications of a change in management strategy that not only has a direct impact on the targeted sectors, but also indirect impacts, not all of which are to be expected.	Y	Kritzer, J.P., Hicks, C.C., Mapstone, B.D., Pina—Amargós, F., Peter, F., & Sale (2013). 1 Ecosystem-based management of coral reefs and interconnected	Bindoff, N.L., W.W.L. Cheung, J.G. Kairo, J. Aristegui, V.A. Guinder, R. Hallberg, N. Hilmi, N. Jiao, M.S. Karim, L. Levin,	N,N	Y,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	present paper multiple-use MSE is focused on four sectors: oil and gas, conservation, fisheries, and urban and industrial development. A selection of cross-sectoral development scenarios, management strategies and computer representations, provided by the relevant interest groups, is represented. These include prospective future sectoral activities and their impacts, and the sectoral response to alternative management policies and strategies. The agent-based modelling software InVitro is well placed for analysing prospective social and ecological impacts of multiple-use management strategies in a risk—assessment framework such as MSE. An illustrative example is provided to demonstrate the tradeoffs that can be recognised and quantified using the MSE framework. The example explores the implications of a change in management strategy that not only has a direct impact on the targeted sectors, but also indirect impacts, not all of which are to be expected.				nearshore tropical habitats.*	S. O'Donoghue, S.R. Purca Cuicapusa, B. Rinkevich, T. Suga, A. Tagliabue, and P. Williamson, 2019: Changing Ocean, Marine Ecosystems, and Dependent Communities. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-o. Pörtner, D.C. Roberts, V. Masson-delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer			

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
						(eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 447–587. https://doi.org/10.1017/9781009157964.007.			
Miller, Brian; Breckheimer, Ian; McCleary, Amy; Guzmán-Ramirez, Liza; Caplow, Susan; Jones-smith, Jessica; Walsh, Stephen. (2010). Using stylized agent-based models for population-environment research: A case study from the Galápagos Islands. Population and environment. 75. 279—287. 10.1007/s11111—010—0110—4.	Agent-based models (ABMs) are powerful tools for population-environment research but are subject to trade-offs between model complexity and abstraction. This study strikes a compromise between abstract and highly specified ABMs by designing a spatially explicit, stylized ABM and using it to explore policy scenarios in a setting that is facing substantial conservation and development challenges. Specifically, we present an ABM that reflects key Land Use/Land Cover dynamics and livelihood decisions on Isabela Island in the Galapagos Archipelago of Ecuador. We implement the model using the NetLogo software platform, a free program that requires relatively	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	little programming experience. The landscape is composed of a satellite-derived distribution of a problematic invasive species (common guava) and a stylized representation of the Galapagos National Park, the community of Puerto Villamil, the agricultural zone, and the marine area. The agent module is based on publicly available data and household interviews and represents the primary livelihoods of the population in the Galapagos Islands-tourism, fisheries, and agriculture. We use the model to enact hypothetical agricultural subsidy scenarios aimed at controlling invasive guava and assess the resulting population and land cover dynamics. Findings suggest that spatially explicit, stylized ABMs have considerable utility, particularly during preliminary stages of research, as platforms for (1) sharpening conceptualizations of population-environment systems, (2) testing alternative scenarios, and (3) uncovering critical data gaps.								
Miller, Matt; Ringelman, Kevin; Schank, Jeffrey; Eadie, John. (2013). SWAMP: An agent-based model for wetland and waterfowl conservation	The management of North American waterfowl is widely recognized as a premier example of a successful conservation	Y	While there is growing recognition of the potential utility of agent-based models in conservation	Y	Matchett, E.L., Fleskes, J.P., Young, C.A., and Purkey,	Sustaining and Improving Waterfowl Conserv	Y,N	N,N	Y,N

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
management. Simulation. 90. 10.1177/0037549713511864.	program. Conservation managers on the wintering grounds typically use simple estimates of food availability and population-wide cumulative energy demand to determine how many birds can be supported on a given landscape. When attempting to plan for future needs due to land reallocation, climate change, and other large-scale environmental changes, simple bioenergetic models may not capture important impacts on individual behavior, such as changes in metabolic costs due to increased travel—time and reduced food accessibility leading to non-linear declines in forager success. We describe the development of an agent-based model of foraging waterfowl that uses explicit individual behavior to generate more detailed and potentially more accurate insights into the impact of environmental changes on forager success and survival. While there is growing recognition of the potential utility of agent-based models in conservation planning, there has yet to be an attempt to formulate, validate, and communicate such a model for use as a decision support tool to guide habitat		planning, there has yet to be an attempt to formulate, validate, and communicate such a model for use as a decision support tool to guide habitat management conservation for wetlands in North America. Our model seeks to provide the foundational framework for such an effort. We predict that this model will be a useful tool for stakeholders making conservation management decisions.		D.R., 2015, A framework for modeling anthropogenic impacts on waterbird habits—Addressing future uncertainty in conservation planning: U.S. Geological Survey Open-File Report 2015—1017, 40 p., http://dx.doi.org/10.3133/ofr20151017.	ation in Canada: Final Summary. (2020). McGraw Center for Conservation Leadership.			

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	management conservation for wetlands in North America. Our model seeks to provide the foundational framework for such an effort. We predict that this model will be a useful tool for stakeholders making conservation management decisions.								
Mohd, Mohd Hafiz; Murray, Rua; Plank, Michael; Godsoe, William. (2016). Effects of dispersal and stochasticity on the presence–absence of multiple species. Ecological Modelling. 342. 10.1016/j.ecolmodel.2016.09.026.	A key problem in ecology is to predict the presence absence of species across a geographical region. Dispersal is thought to have an important influence on the range limits of species, and understanding this problem in a multi-species community with priority effects (i.e. initial abundances determine the presence absence of species) is a challenging task because dispersal interacts with biotic and abiotic factors as well as demographic stochasticity. By using stochastic individual-based models (IBM) and deterministic models consisting of biotic interactions and environmental gradients, we investigate the joint effects of dispersal and stochasticity on the occurrence of priority effects that can shape the presence absence of multiple species. Our analysis shows the conditions under	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	which priority effects occur and disappear as dispersal intensity changes. Without dispersal, priority effects emerge in the presence of intense biotic interactions; only one species surviving at any given location, with no overlap in their ranges. Inclusion of dispersal first reduces the prevalence of priority effects (i.e. for weak dispersal), and then leads to their increase (i.e. for moderate dispersal); consequently, dispersal enhances the possibility for species ranges to overlap. Increasing dispersal strength above a threshold value leads to the disappearance of priority effects and causes extinction of some species. We also demonstrate contrasting observations of stochasticity on priority effects: while this phenomenon is more prevalent in the stochastic IBM than in the deterministic models for large populations, we observe fewer occurrences of priority effects in IBM for small populations; in particular, our IBM results show that priority effects are eliminated by weaker values of dispersal when population sizes are small than when they are large. This situation can induce an uncertainty in the predictions of species presence absence.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Overall, our results demonstrate how the interplay of dispersal and stochasticity can combine to result in the (dis—)appearance of priority effects that strongly determine the presence absence of species.								
Mooij, Wolf; Bennetts, Robert; Kitchens, Wiley; Deangelis, Donald. (2002). Exploring the effect of drought extent and interval on the Florida Snail Kite: interplay between spatial and temporal scales. Ecological Modelling. 149. 25—39. 10.1016/S0304—3800(01)00512—9.	The paper aims at exploring the viability of the Florida snail kite population under various drought regimes in its wetland habitat. The population dynamics of snail kites are strongly linked with the hydrology of the system due to the dependence of this bird species on one exclusive prey species. the apple snail, which is negatively affected by a drying out of habitat. Based on empirical evidence, it has been hypothesised that the viability of the snail kite population critically depends not only on the time interval between droughts, but also on the spatial extent of these droughts. A system wide drought is likely to result in reduced reproduction and increased mortality, whereas the birds can respond to local droughts by moving to sites where conditions are still favourable. This paper explores the implications of this hypothesis by means of a spatially-explicit individual-based	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	model. The specific aim of the model is to study in a factorial design the dynamics of the kite population in relation to two scale parameters, the temporal interval between droughts and the spatial correlation between droughts. In the model high drought frequencies led to reduced numbers of kites. Also, habitat degradation due to prolonged periods of inundation led to lower predicted numbers of kites. Another main result was that when the spatial correlation between droughts was low, the model showed little variability in the predicted numbers of kites. But when droughts occurred mostly on a system wide level, environmental stochasticity strongly increased the stochasticity in kite numbers and in the worst case the viability of the kite population was seriously threatened.								
Moustakas, Aristides; Silvert, William. (2011). Spatial and temporal effects on the efficacy of marine protected areas: Implications from an individual based model. Stochastic Environmental Research and Risk Assessment. 25. 403—413. 10.1007/s00477—010—0411—2.	We have developed a spatially explicit model that simulates the interaction between fish and fishers based on past fish location, abundance and fish dispersal. We have examined four scenarios for the design and management of Marine Protected	Y	Our results suggest that it is not per se the perimeter to surface ratio that matters, but the trade-off between edge effects and maximised MPA surface in the predominant dispersal direction. Our results also have implications	Y	Hall—Arber, M., Murray, S., Aylesworth, L., Carr, M., Field, J., Grorud—Colvert, K., Martone, R., Nickols, K., Saarman, E., Wertz,	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Areas (MPA) and for each we simulated fish biomass and fish catches: (1) No MPA. (2) A single MPA located at a feeding area. (3) A single MPA designed to maximise its overlap with the predominant route of fish dispersal. (4) The use of two MPAs. Each scenario was replicated with two scenarios regarding the time that fish remains within the MPA and two grid map scenarios to account for time-space effects and map/coastline characteristics. Results showed that overall closing an area increased fish biomass. However, an MPA located in the open sea for a limited time may have adverse effects on fish biomass. MPAs increased fish catches when a single large MPA or two small MPAs were located in the open sea for a limited time. The effects of time that fish remains protected in closed areas vary in combination with the spatial design: When examining time effects on the efficacy of MPAs within each scenario with an MPA located in the open sea, fish biomass was always higher in the case where fish was protected for more calendar days during each year. When comparing between different spatial designs, proximity to the coast was a more predominant factor in		for the design of terrestrial reserves.		S. Scientific Guidance for California's MPA Decadal Reviews: A Report by the Ocean Protection Council Science Advisory Team Working Group and California Ocean Science Trust, June 2021*				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	the efficacy of MPAs rather than time that fish was protected. The scenario that gave the highest total fish biomass was the one that covered the largest part of the migration route, despite increased edge effects. Our results suggest that it is not per se the perimeter to surface ratio that matters, but the trade-off between edge effects and maximised MPA surface in the predominant dispersal direction. Our results also have implications for the design of terrestrial reserves.								
Nabe—Nielsen, J., Sibly, R. M., Tougaard, J., Teilmann, J.,; Sveegaard, S. (2014). Effects of noise and by-catch on a Danish harbour porpoise population. Ecological Modelling, 272, 242–251. https://doi.org/10.1016/j.ecolmodel.2013.09.025	Ships and wind turbines generate noise, which can have a negative impact on marine mammal populations by scaring animals away. Effective modelling of how this affects the populations has to take account of the location and timing of disturbances. Here we construct an individual-based model of harbour porpoises in the Inner Danish Waters. Individuals have their own energy budgets constructed using established principles of physiological ecology. Data are lacking on the spatial distribution of food which is instead inferred from knowledge of time—varying porpoise distributions. The model produces	Y	This suggests that conservation efforts should be more focused on reducing by-catch in commercial gillnet fisheries than on limiting the amount of anthropogenic noise. Individual-based models are unique in their ability to take account of the location and timing of disturbances and to show their likely effects on populations.	Y	Russell Leaper and Susannah Calderan (2018). Review of methods used to reduce risks of cetacean bycatch and entanglements. UNEP/CMS Secretariat, Bonn, Germa01. 76 pages. CMS Technical Series No. 38	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	plausible patterns of population dynamics and matches well the age distribution of porpoises caught in by-catch. It estimates the effect of existing wind farms as a 10% reduction in population size when food recovers fast (after two days). Proposed new wind farms and ships do not result in further population declines. The population is however sensitive to variations in mortality resulting from by-catch and to the speed at which food recovers after being depleted. If food recovers slowly the effect of wind turbines becomes negligible, whereas ships are estimated to have a significant negative impact on the population. Annual by-catch rates >10% lead to monotonously decreasing populations and to extinction, and even the estimated by-catch rate from the adjacent area (approximately 4.1%) has a strong impact on the population. This suggests that conservation efforts should be more focused on reducing by-catch in commercial gillnet fisheries than on limiting the amount of anthropogenic noise. Individual-based models are unique in their ability to take account of the location and timing of disturbances and to								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	show their likely effects on populations. The models also identify deficiencies in the existing database and can be used to set priorities for future field research.								
Neuheimer, A. B., Gentleman, W. C., Pepin, P.; Head, E. J. H. (2010). How to build and use individual-based models (IBMs) as hypothesis testing tools. Journal of Marine Systems, 81(1–2), 122–133. https://doi.org/10.1016/j.jmarsys.2009.12.009	Traditional plankton models do not simulate the life history, physiology or phenology of mesozooplankton with sufficient realism to represent their ecological roles and associated environmental dependencies. In contrast, individual-based models (IBMs) have proven utility in characterizing fish population dynamics as they bridge the gap between the level at which environmental impacts occur (individuals) and the level at which observations are made (populations). IBMs are under-utilized in zooplankton ecology, possibly because of their apparent complexity, reliance on uncertain parameters, and/or computational expense. Here, we show that such limitations are not inherent, and in fact, IBMs can offer considerable power for quantitative hypothesis testing. We present a	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	conceptually and programmatically simple approach for building a stochastic stage-based IBM for copepods (abundant mesozooplankters). Our model incorporates physiological rates that vary with environmental conditions, and includes stochasticity via a Fitness parameter, which characterizes individual variability, and may be prescribed a priori (e.g. genetic), or solved dynamically based on individual history, condition, environment, etc. We demonstrate how this Fitness allows for easy evaluation of the relative importance of forcing factors (e.g. temperature vs. food) on modelled rates and abundances as well as statistical comparison to observations. The latter is a powerful feature of our modelling approach, which we exploit to test hypotheses regarding the seasonal dynamics of the copepod Calanus finmarchicus in the northwest Atlantic as a case study. The result is a model description (including flow chart and code) that can be adapted for a wide range of species and novel applications in a quantitative manner.								
Neuswanger, Jason; Wipfli, Mark; Rosenberger, Amanda;	Drift-feeding fish are challenged to discriminate between	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Hughes, Nicholas. (2014). Mechanisms of drift-feeding behavior in juvenile Chinook salmon and the role of inedible debris in a clear-water Alaskan stream. Environmental Biology of Fishes. 97. 10.1007/s10641—014—0227—x.	prey and similar-sized particles of debris, which are ubiquitous even in clear-water streams. Spending time and energy pursuing debris mistaken as prey could affect fish growth and the fitness potential of different foraging strategies. Our goal was to determine the extent to which debris influences drift-feeding fish in clear water under low—flow conditions when the distracting effect of debris should be at a minimum. We used high-definition video to measure the reactions of drift-feeding juvenile Chinook salmon (Oncorhynchus tshawytscha) to natural debris and prey in situ in the Chena River, Alaska. Among all potential food items fish pursued, 52 % were captured and quickly expelled from the mouth, 39 % were visually inspected but not captured, and only 9 % were ingested. Foraging attempt rate was only moderately correlated with ingestion rate (Kendall's tau = 0.55), raising concerns about the common use of foraging attempts as a presumed index of foraging success. The total time fish spent handling debris increased linearly with foraging attempt rate and ranged between 4 and 25 % of total foraging time among observed								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	groups. Our results help motivate a revised theoretical view of drift feeding that emphasizes prey detection and discrimination, incorporating ideas from signal detection theory and the study of visual attention in cognitive ecology. We discuss how these ideas could lead to better explanations and predictions of the spatial behavior, prey selection, and energy intake of drift-feeding fish.								
Nicholson, Arwen; Wilkinson, David; Williams, Hywel; Lenton, Timothy. (2016). Multiple states of environmental regulation in well-mixed model biospheres. Journal of Theoretical Biology. 414. 10.1016/j.jtbi.2016.11.019.	The Gaia hypothesis postulates that life influences Earth's feedback mechanisms to form a self regulating system. This provokes the question: how can global self-regulation evolve? Most models demonstrating environmental regulation involving life have relied on alignment between local selection and global regulation. In these models environment-improving individuals or communities spread to outcompete environment degrading individuals/communities, leading to global regulation, but this depends on local differences in environmental conditions. In contrast, well-mixed components of the Earth system, such as the atmosphere, lack local environmental	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	differentiation. These previous models do not explain how global regulation can emerge in a system with no well defined local environment, or where the local environment is overwhelmed by global effects. We present a model of self-regulation by 'microbes' in an environment with no spatial structure. These microbes affect an abiotic 'temperature' as a byproduct of metabolism. We demonstrate that global self regulation can arise in the absence of spatial structure in a diverse ecosystem without localised environmental effects. We find that systems can exhibit nutrient limitation and two temperature limitation regimes where the temperature is maintained at a near constant value. During temperature regulation, the total temperature change caused by the microbes is kept near constant by the total population expanding or contracting to absorb the impacts of new mutants on the average affect on the temperature per microbe. Dramatic shifts between low temperature regulation and high temperature regulation can occur when a mutant arises that causes the sign of the temperature effect to change. This result								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	implies that self-regulating feedback loops can arise without the need for spatial structure, weakening criticisms of the Gaia hypothesis that state that with just one Earth, global regulation has no mechanism for developing because natural selection requires selection between multiple entities.								
O'Farrell, Shay; Salguero—Gómez, Roberto; van Rooij, Jules; Mumby, Peter. (2015). Disentangling trait-based mortality in species with decoupled size and age. The Journal of animal ecology. 84. 10.1111/1365—2656.12399.	Size and age are fundamental organismal traits, and typically, both are good predictors of mortality. For many species, however, size and age predict mortality in ontogenetically opposing directions. Specifically, mortality due to predation is often more intense on smaller individuals whereas mortality due to senescence impacts, by definition, on older individuals. When size-based and age-based mortality are independent in this manner, modelling mortality in both traits is often necessary. Classical approaches, such as Leslie or Lefkovitch matrices, usually require the model to infer the state of one trait from the state of the other, for example by assuming that explicitly modelled age (or stage) class structure provides implicit information	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	on underlying size—class structure, as is the case in many species. However, the assumption that one trait informs on the other is challenged when size and age are decoupled, as often occurs in invertebrates, amphibians, fish, reptiles and plants. In these cases, age-structured models may perform poorly at capturing size-based mortality, and vice versa. We offer a solution to this dilemma, relaxing the assumption that class structure in one trait is inferable from class structure in another trait. Using empirical data from a reef fish, Sparisoma viride (Scaridae), we demonstrate how an individual-based model (IBM) can be implemented to model mortality as explicit, independent and simultaneous functions of individual size and age — an approach that mimics the effects of mortality in many wild populations. By validating this multitrait IBM' against three independent lines of empirical data, we determine that the approach produces more convincing predictions of size—class structure, longevity and post-settlement mortality for S.viride than do the trait-independent or single—trait mortality models								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	tested. Multitrait IBMs also allow trait-based mortality to be modelled either additively or multiplicatively, and individual variability in growth rates can be accommodated. Consequently, we propose that the approach may be useful in fields that may benefit from disentangling, or investigating interactions among, size-based and age-based demographic processes, including comparative demography (e.g. life—history consequences of resource patchiness) and conservation biology (e.g. impacts of invasive predators on size structure but not life span of natives).								
Pais, Miguel; Cabral, Henrique. (2017). Fish behaviour effects on the accuracy and precision of underwater visual census surveys. A virtual ecologist approach using an individual-based model. Ecological Modelling. 346. 58—69. 10.1016/j.ecolmodel.2016.12.011.	Underwater visual census (UVC) methods are used worldwide to monitor shallow marine and freshwater habitats and support management and conservation decisions. However, several sources of bias still undermine the ability of these methods to accurately estimate abundances of some species.The present study introduces FishCensus, a spatially-explicit individual-based model that simulates underwater visual census of fish populations. The	Y	The model can be used as a tool for planning and optimization of monitoring programs or to calculate conversion factors for past or ongoing surveys, assuming behavioural patterns are well replicated.	Y	Przeslawski R, Foster S [Eds.]. (2020). Field Manuals for Marine Sampling to Monitor Australian Waters, Version 2. Report to the National Environmental Science Program, Marine Biodiversity Hub. Geoscience Australia and CSIRO.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	model features small temporal and spatial scales and uses a movement algorithm which can be shaped to reflect complex behaviours and effects of diver presence. Four different types of fish were used in the model, featuring typically problematic behavioural traits, namely schooling behaviour, cryptic habits, shyness and boldness. Corresponding control types were also modelled, lacking only the key behavioural traits. Sampling was conducted by a virtual diver using four true fish densities and employing two distinct methods: strip transects and stationary point counts.Comparisons with control fish have shown that schooling and bold behaviours induce positive bias and reduce precision, while cryptic and shy behaviours induce negative bias and increase precision, although shy behaviour did not have a significant effect on precision in transects. By looking at deviations from true density, however, schooling, shy and bold fish densities were strongly overestimated by both methods, while cryptic fish were slightly underestimated. Schooling and bold fish had the lowest precision overall,				http:dx.doi.org/10.11636/9781925848755				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	followed by shy fish. Fish rarity decreased precision, but had no effect on bias. Stationary points had less precision than transects for all fish types, and led to much higher counts, resulting in greater overestimation of density overall.By modelling complex behaviour, it was possible to separate the contributions of detectability and non-instantaneous sampling on bias, and gain a deeper understanding of the effect of behavioural traits on UVC estimates. The model can be used as a tool for planning and optimization of monitoring programs or to calculate conversion factors for past or ongoing surveys, assuming behavioural patterns are well replicated.								
Parrott, Lael; Chion, Clément; Gonzal,; s, Rodolphe; Latombe, Guillaume. (2012). Agents, Individuals, and Networks: Modeling Methods to Inform Natural Resource Management in Regional Landscapes. Ecology and Society. 17. 10.5751/es—04936—170332.	Landscapes are complex systems. Landscape dynamics are the result of multiple interacting biophysical and socioeconomic processes that are linked across a broad range of spatial, temporal, and organizational scales. Understanding and describing landscape dynamics poses enormous challenges and demands the use of new multiscale approaches to modeling. In this synthesis article, we present three regional	Y	This model is being used to inform decision-makers on how to mitigate the impacts of maritime traffic on whales in the Saint Lawrence Estuary in eastern Canada.	Y	The paper itself, as it includes a discussion of model implementation	—	Y	Y	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	systems—i.e., a forest system, a marine system, and an agricultural system and describe how hybrid, bottom-up modeling of these systems can be used to represent linkages across scales and between subsystems. Through the use of these three examples, we describe how modeling can be used to simulate emergent system responses to different conservation policy and management scenarios from the bottom up, thereby increasing our understanding of important drivers and feedback loops within a landscape. The first case study involves the use of an individual-based modeling approach to simulate the effects of forest harvesting on the movement patterns of large mammals in Canada's boreal forest and the resulting emergent population dynamics. This model is being used to inform forest harvesting and management guidelines. The second case study combines individual and agent-based approaches to simulate the dynamics of individual boats and whales in a marine park. This model is being used to inform decision-makers on how to mitigate the impacts of maritime traffic on whales in the Saint Lawrence Estuary in								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	eastern Canada. The third example is a case study of biodiversity conservation efforts on the Eyre Peninsula, South Australia. In this example, the social-ecological system is represented as a complex network of interacting components. Methods of network analysis can be used to explore the emergent responses of the system to changes in the network structure or configuration, thus informing managers about the resilience of the system. These three examples illustrate how bottom-up modeling approaches may contribute to a new landscape science based on scenario building, to find solutions that meet the multiple objectives of integrated resource management in social-ecological systems.								
Peck, Myron; Daewel, Ute. (2007). Physiologically based limits to food consumption, and individual-based modeling of foraging and growth of larval fishes. Marine Ecology-progress Series — MAR ECOL—PROGR SER. 347. 171—183. 10.3354/meps06976.	Larval fish individual-based models (IBMs) that include foraging subroutines to depict prey encounter, capture and ingestion often include static parameters (e.g. a maximum feeding rate, C-mAX) to prevent 'overfeeding' and unrealistically high growth rates. We formulated 2 physiologically based approaches to limit food consumption rate (C) based on gut	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	capacity and evacuation rate (GER) and feeding rate-dependent changes in assimilation efficiency (AE). Parameterizations were based on data reported for a variety of marine and freshwater teleost larvae. The effects of the 3 approaches (C-mAX, GER and AE) on feeding and growth were compared in IBM simulations of 12 mm larval sprat Sprattus sprattus L. foraging within homogenous and patchy prey fields. Prey concentrations for maximum growth were between 5 and 10 copepodites l(—1), similar to thresholds determined for successful foraging by larvae of other marine fish species in laboratory studies. The AE limit allowed larvae to exploit prey patches (to consume prey at higher rates but at lower AEs). In simulations using prey concentrations observed in productive areas of the southern North Sea (e. g. 21.0 copepodites l(—1)), larvae benefited little (benefited much) from adopting this patch feeding strategy when patch prey concentrations were <= 2—fold (>= 5—fold) those outside of the patches. At <= 10 copepodites l(—1), foraging model predictions of C were close to limits imposed by C-mAX,								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	GER and AE methods. In patches (20 to 40 copepodites l(—1)), foraging model estimates of C were 2— to 4—fold greater than the highest (AE-based) limit. Physiological-based limits to C are recommended for larval fish IBMs and will be necessary to adequately assess the impacts of prey patchiness on survival and growth of marine fish larvae.								
Pirotta, Enrico; Harwood, John; Thompson, Paul; New, Leslie; Cheney, Barbara; Arso Civil, Monica; Hammond, Philip; Donovan, Carl; Lusseau, David. (2015). Predicting the effects of human developments on individual dolphins to understand potential long-term population consequences. Proceedings of the Royal Society B: Biological Sciences. 282. 20152109. 10.1098/rspb.2015.2109.	Human activities that impact wildlife do not necessarily remove individuals from populations. They may also change individual behaviour in ways that have sublethal effects. This has driven interest in developing analytical tools that predict the population consequences of short-term behavioural responses. In this study, we incorporate empirical information on the ecology of a population of bottlenose dolphins into an individual-based model that predicts how individuals' behavioural dynamics arise from their underlying motivational states, as well as their interaction with boat traffic and dredging activities. We simulate the potential effects of proposed coastal developments on this population and	Y	Our work can be used to guide management decisions, accelerate the consenting process for coastal and offshore developments and design targeted monitoring.	Y	Conservation and Management Advice: MORAY FIRTH SAC. (2021). NatureScot.	—	N	N	N

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	predict that the operational phase may affect animals' motivational states. For such results to be relevant for management, the effects on individuals' vital rates also need to be quantified. We investigate whether the relationship between an individual's exposure and the survival of its calves can be directly estimated using a Bayesian multi-stage model for calf survival. The results suggest that any effect on calf survival is probably small and that a significant relationship could only be detected in large, closely studied populations. Our work can be used to guide management decisions, accelerate the consenting process for coastal and offshore developments and design targeted monitoring.								
Ramirez, Francisco; Afán, Isabel; Hobson, Keith; Bertellotti, Marcelo; Blanco, Guillermo; Forero, Manuela. (2014). Natural and anthropogenic factors affecting the feeding ecology of a top marine predator, the Magellanic penguin. Ecosphere. 5. 38. 10.1890/ES13—00297.1.	Understanding how top predators respond to natural and anthropogenically induced changes in their environment is a major conservation challenge especially in marine environments. We used a multidisciplinary approach to explore the mechanisms through which a typical central—place forager, the Magellanic penguin (Spheniscus	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	magellanicus) from the Chubut province of Argentina, responds to variations in oceanic conditions and prey resources. We combined habitat and species distribution modeling with isotopic dietary reconstructions based on blood delta 13C and delta 15N values to quantify the role of bathymetry, sea-surface temperature and chlorophyll-a concentration, abundance of conspecifics, and extent of fisheries activities in explaining the foraging and feeding ecology of individuals breeding at different colonies. The at-sea distribution of penguins was tightly coupled with the spatial distribution of their staple prey species, anchovies (Engraulis anchoita), especially in areas over the continental shelf (>200 m depth), with relatively warm water (from 16 degrees to 21 degrees C), and moderate abundances of conspecifics (from 50 to 250 individuals). Competition with conspecifics and human fisheries were also identified as important factors explaining penguin diet with decreasing relative contributions of anchovies with increasing abundance of conspecifics and fishing activity. Our multifactorial approach allowed us to simultaneously								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	explore different physical, biological and anthropogenic features likely affecting marine resource availability, and, consequently, driving the feeding and foraging ecology of this central—place forager. Our approach can be extended to a large suite of central—place foragers, thus providing important advances in the way we investigate how to effectively conserve and manage these species.								
Richards, P. M., Mooij, W. M.,; DeAngelis, D. L. (2004). Evaluating the effect of salinity on a simulated American crocodile (Crocodylus acutus) population with applications to conservation and Everglades restoration. Ecological Modelling, 180(2–3), 371–394. https://doi.org/10.1016/j.ecolmodel.2004.04.038	Everglades restoration will alter the hydrology of South Florida, affecting both water depth and salinity levels in the southern fringes of the Everglades, the habitat of the endangered American crocodile (Crocodylus acutus). A key question is what the effects of these hydrologic changes will be on the crocodile population. Reliable predictions of the viability of endangered species under a variety of management scenarios are of vital importance in conservation ecology. Juvenile American crocodiles are thought to be sensitive to high salinity levels, suffering reduced mass, and potentially reduced survivorship and recruitment. This could negatively	Y	Everglades restoration will alter the hydrology of South Florida, affecting both water depth and salinity levels in the southern fringes of the Everglades, the habitat of the endangered American crocodile (Crocodylus acutus)...we conclude that conservation priority should be placed on reducing anthropogenic sources of mortality on large individuals, such as road mortality. Finally, research should focus on estimates of annual survivorship for large individuals.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	impact the population recovery. We addressed the management issue of how the crocodile population will respond to alterations in hydrology with a spatially explicit individual-based model. The model is designed to relate water levels, salinities, and dominant vegetation to crocodile distribution, abundance, population growth, individual growth, survival, nesting effort, and nesting success. Our analysis shows that Everglades restoration, through its effects on water flow to estuaries, may benefit crocodile populations if increased freshwater flow reduces the chance that regional salinity levels exceed levels where small individuals lose mass. In addition, we conclude that conservation priority should be placed on reducing anthropogenic sources of mortality on large individuals, such as road mortality. Finally, research should focus on estimates of annual survivorship for large individuals.								
Rougier, Thibaud; Drouineau, Hilaire; Dumoulin, Nicolas; Faure, Thierry; Deffuant, Guillaume; Rochard, Eric; Lambert, Patrick. (2014). The GR3D	Within the context of ongoing environmental changes, the life history of diadromous fish represents a real potential for	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
model, a tool to explore the Global Repositioning Dynamics of Diadromous fish Distribution. Ecological Modelling. 283. 31–44. 10.1016/j.ecolmodel.2014.03.019.	exploring and colonizing new environments due to high potential dispersal abilities. The use of dynamic approaches to assess how these species will respond to climate change is a challenging issue and mechanistic models able to incorporate biological and evolutionary processes are a promising tool. To this end we developed an individual-based model, called GR3D (Global Repositioning Dynamics for Diadromous fish Distribution), combining climatic requirements and population dynamics with an explicit dispersal process to evaluate potential evolution of their distribution area in the context of climatic change. This paper describes thoroughly the model structure and presents an exploratory test case where the repositioning of a virtual allis shad (Alosa alosa L.) population between two river catchments under a scenario of temperature increase was assessed. The global sensitivity analysis showed that landscape structure and parameters related to sea lifespan and to survival at sea were crucial to determine the success of colonization. These results were consistent with the								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	ecology of this species. The integration of climatic factors directly into the processes and the explicit dispersal process make GR3D an original and relevant tool to assess the repositioning dynamics and persistence of diadromous fish facing climate change.								
Soler, German; Thomson, Russell; Stuart-Smith, Rick; Smith, ADM; Edgar, GJ. (2016). The contributions of body size, habitat and taxonomy to predictions of temperate Australian fish diets. Marine Ecology Progress Series. 545. 10.3354/meps11584.	Using k—nearest neighbour procedures to predict prey type and linear models to predict mean prey size, we developed a 2-step dietary model based on the stomach contents of fish of known species, size and location from Western Port, Victoria (Australia). The model, nicknamed 'Consume', was used to assess the relative extent to which fish diet varied with body size, species identity, season, and location. Both prey type (mean overlap between predicted and actual prey types = 77%) and mean prey size (r(2) between predicted and observed mean prey size = 93%) were predicted with reasonable accuracy when species identity and length of consumer fish were known. The most important predictor for prey type was the size of the individual consumer, while the most important predictor for mean	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	prey size was the consumer's taxonomic identity. Predictors were individually removed from both k—nearest neighbour and linear models to assess their relative contributions to the model. Little loss of accuracy (1%) was evident when family rather than species identity was used for both prey type and mean prey size. Environmental information associated with the time and location of fish sampling (habitat, site and season) contributed only marginally to predictions of prey type. Use of the Consume model will allow for an improved understanding of community-level trophic pathways through the integration of prey type and size predictions for consumer fishes.								
Souissi, Sami; Seuront, Laurent; Schmitt, Francois; Ginot, Vincent. (2005). Describing space—time patterns in aquatic ecology using IBMs and scaling and multi-scaling approaches. Nonlinear Analysis-real World Applications — NONLINEAR ANAL-reAL WORLD APP. 6. 705—730. 10.1016/j.nonrwa.2004.12.013.	In this paper a new simulation platform, Mobidyc, dedicated to non-computer expert end-users, is used to illustrate the advantages of such platforms for simulating population dynamics in space and time. Using dedicated and open-source platforms probably represents a necessary step to guarantee the readability and comparison between models and/or scenarios. The Mobidye platform is	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	specifically dedicated to population dynamics with 2D-discrete spatial representation. We show first how to build easily stage-structured population dynamics models, on the basis of an experimental parameterization of the population dynamic of the copepod Eurytemora affinis, the most dominant species in estuaries of the Northern hemisphere. We subsequently focus on the role of spatial representation and the possible sources of heterogeneities in copepod populations. The sources generating patterns in our examples are strictly endogenous to the population and individual characteristics. They are generated by the random walk of individual at local scale and the demographic processes (birth, metamorphosis and mortality) at the population scale in the absence of any externally imposed pattern. The large spatio-temporal data sets of abundances of total population are analysed statistically. Spatial and temporal patterns are investigated using models and data analysis techniques initially developed in the fields of turbulence and nonlinear physics (e.g. scaling and								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	multi-scaling approaches for data analysis and stochastic simulation). Finally, the role of simulation tools for theoretical studies is discussed in this paper.								
Spies, Ingrid; Punt, André. (2015). The utility of genetics in marine fisheries management: A simulation study based on Pacific cod off Alaska. Canadian Journal of Fisheries and Aquatic Sciences. 72. 150525143455003. 10.1139/cjfas—2014—0050.	Information on genetic population structure has been documented in many marine fish species, but it is not always incorporated into management plans. This study examines how conservation status and yield change when management units are established using genetic data versus treating the entire area as a single management unit. Simulations use a spatially structured, individual-based model that combines multilocus microsatellite genotypes and a traditional fish population dynamics model that establishes abundance—at-age by cohort. Results are considered in terms of marine fish species in general, and parameters in the model are based on Pacific cod (Gadus macrocephalus) in the Bering Sea and Aleutian Islands region of Alaska. Population dynamics are projected under several management strategies, some of which establish management units based on the results of	Y	Population dynamics are projected under several management strategies, some of which establish management units based on the results of genetic testing and some that do not.	N	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	genetic testing and some that do not. Simulations incorporate annual stock assessments and fishing for 100 years. Results show that managed fishing can result in a reduction in stock sizes below target reference points when distinct populations are not managed based on the results of genetic testing. However, stock size is maintained at target levels and catches may increase when stocks identified using genetics are managed separately, even given error rates inherent to genetic testing.								
Stillman, R.; Moore, Jon; Woolmer, Andrew; Murphy, M.; Walker, P.; Vanstaen, Karen; Palmer, D.; Sanderson, William. (2010). Assessing waterbird conservation objectives: An example for the Burry Inlet, UK. Biological Conservation — BIOL CONSERV. 143. 2617—2630. 10.1016/j.biocon.2010.07.004.	We use an individual-based model to assess the conservation objectives for knot Calidris canutus L and oystercatcher Haematopus ostralegus L on the Burry Inlet Special Protection Area (SPA), UK. Population monitoring has identified a decline in oystercatcher numbers, but cannot determine whether this is due to a decline in site quality. Long term data on cockle stocks show that the biomass of the large-sized cockles consumed by oystercatcher declined after 2004, whereas a similar decline was not observed in the smaller cockles	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	consumed by knot. The model postdicts that during the winters of 2005/2006 to 2008/2009 the site was unable to support the number of oystercatcher present at the time it was designated (i.e. the SPA population). Large cockle biomass remained low during 2009/2010, but increases in mussel biomass meant that the model postdicted that the site could support the SPA population of oystercatcher. Knot food supplies remained high during most years, except 2008/2009 during which the model postdicted that the SPA population could not be supported. The model postdicted that the stock reserved for oystercatchers after shellfishing needed to be 2—4 times the amount consumed by the birds in order to support the bird population. We recommend that where necessary, the conservation objectives of waterbirds should be assessed using a combination of thorough population size and behaviour monitoring to identify sites with population declines, and individual-based modelling on these sites to determine whether reduction in site quality may contribute to the site-specific population decline.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Stillman, RA; Goss—Custard, John; West, AD; Durell, Sarah; Caldow, R.; McGrorty, S.; Clarke, Ralph. (2001). Predicting mortality in novel environments: Tests and sensitivity of a behaviour-based model. Journal of Applied Ecology. 37. 564 — 588. 10.1046/j.1365—2664.2000.00506.x.	1. In order to assess the future impact of a proposed development or evaluate the cost effectiveness of proposed mitigating measures, ecologists must be able to provide accurate predictions under new environmental conditions. The difficulty with predicting to new circumstances is that often there is no way of knowing whether the empirical relationships upon which models are based will hold under the new conditions, and so predictions are of uncertain accuracy.2. We present a model, based on the optimality approach of behavioural ecology, that is designed to overcome this problem. The model's central assumption is that each individual within a population always behaves in order to maximize its fitness. The model follows the optimal decisions of each individual within a population and predicts population mortality rate from the survival consequences of these decisions. Such behaviour-based models should provide a reliable means of predicting to new circumstances because, even if conditions change greatly, the basis of predictions — fitness maximization — will not.3. The model was	Y	In order to assess the future impact of a proposed development or evaluate the cost effectiveness of proposed mitigating measures, ecologists must be able to provide accurate predictions under new environmental conditions.	Y	Florida Fish and Wildlife Conservation Commission. 2013. A species action plan for four imperiled species of beach-nesting birds. Tallahassee, Florida.	Biological Status Review Report for the American Oystercatcher (Haematopus palliatus). (2011). Florida Fish and Wildlife Conservation Commission.	N,N	N,N	Y,N

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	parameterized and tested for a shorebird, the oystercatcher Haematopus ostralegus. Development aimed to minimize the difference between predicted and observed overwinter starvation rates of juveniles, immatures and adults during the model calibration years of 1976—80. The model was tested by comparing its predicted starvation rates with the observed rates for another sample of years during 1980—91, when the oystercatcher population was larger than in the model calibration years. It predicted the observed density-dependent increase in mortality rate in these years, outside the conditions for which it was parameterized.4. The predicted overwinter mortality rate was based on generally realistic behaviour of oystercatchers within the model population. The two submodels that predicted the interference—free intake rates and the numbers and densities of birds on the different mussel Mytilus edulis beds at low water did so with good precision. The model also predicted reasonably well (i) the stage of the winter at which the birds starved; (ii) the relative mass of birds using different feeding methods; (iii)								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	the number of minutes birds spent feeding on mussels at low water during both the night and day; and (iv) the dates at which birds supplemented their low tide intake of mussels by also feeding on supplementary prey in fields while mussel beds were unavailable over the high water period.5. A sensitivity analysis showed that the model's predictive ability depended on virtually all of its parameters. However, the importance of different parameters varied considerably. In particular, variation in gross energetic parameters had a greater influence on predictions than variations in behavioural parameters. In accord with this, much of the model's predictive power was retained when a detailed foraging submodel was replaced with a simple functional response relating intake rate to mussel biomass. The behavioural parameters were not irrelevant, however, as these were the basis of predictions.6. Although we applied the model to oystercatchers, the general principle on which it is based applies widely. We list the key parameters that need to be measured in order to apply the model to other systems, estimate the time scales involved and								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	describe the types of environmental changes that can be modelled. For example, in the case of estuaries, the model can be used to predict the impact of habitat loss, changes in the intensity or method of shellfishing, or changes in the frequency of human disturbance.7. We conclude that behaviour-based models provide a good basis for predicting how demographic parameters, and thus population size, would be affected by novel environments. The key reason for this is that, by being based on optimal decision rules, animals in these models are likely to respond to environmental changes in the same way as real ones would.								
Stillman, RA; West, AD; Goss—Custard, John; McGrorty, S; Frost, NJ; Morrisey, Donald; Kenny, Andrew; Drewitt, Allan. (2005). Predicting Site Quality for Shorebird Communities: a Case Study on the Humber Estuary, UK. Marine Ecology-progress Series — MAR ECOL—PROGR SER. 305. 203—217. 10.3354/meps305203.	The conservation importance of estuaries is often measured by bird numbers, but monitoring numbers is not necessarily a reliable way of assessing changes in site quality. We used an individual-based model, comprised of fitness-maximising individuals, to assess the quality of the Humber estuary, UK, for 9 shorebirds; dunlin Calidris alpina, common ringed plover Charadrius	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	hiaticula, red knot Calidris canutus, common redshank Tringa totanus, grey plover Pluvialis squatarola, blacktailed godwit Limosa limosa, bar-tailed godwit L. lapponica, Eurasian oystercatcher Haematopus ostralegus and Eurasian curlew Numenius arquata. We measured site quality as predicted overwinter survival. The model accurately predicted the observed shorebird distribution (if non-starving birds were assumed to feed on any prey or patch on which intake rate equalled or exceeded their requirements), and the diets of most species. Predicted survival rates were highest in dunlin and common ringed plovers, the smallest species, and in Eurasian oystercatchers, which consumed larger prey than the other species. Shorebird survival was most strongly influenced by the biomass densities of annelid worms, and the bivalve molluscs Cerastoderma edule and Macoma balthica. A 2 to 8 % reduction in intertidal area (the magnitude expected through sea level rise and industrial developments) decreased predicted survival rates of all species except the dunlin, common ringed plover, red knot and Eurasian								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	oystercatcher. This paper shows how an individual-based model can assess present-day site quality and predict how site quality may change in the future. The model was developed using existing data from intertidal invertebrate and bird monitoring schemes plus new intertidal invertebrate data collected over 2 winters. We believe that individual-based models are useful tools for assessing estuarine site quality.								
Stillman, Richard; Goss—Custard, John. (2009). Individual-based Ecology of Coastal Birds. Biological reviews of the Cambridge Philosophical Society. 85. 413—34. 10.1111/j.1469—185X.2009.00106.x.	Conservation objectives for non-breeding coastal birds (shorebirds and wildfowl) are determined from their population size at coastal sites. To advise coastal managers, models must predict quantitatively the effects of environmental change on population size or the demographic rates (mortality and reproduction) that determine it. As habitat association models and depletion models are not able to do this, we developed an approach that has produced such predictions thereby enabling policymakers to make evidence-based decisions. Our conceptual framework is individual-based ecology, in which populations are	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	viewed as having properties (e.g. size) that arise from the traits (e.g. behaviour, physiology) and interactions of their constituent individuals. The link between individuals and populations is made through individual-based models (IBMs) that follow the fitness-maximising decisions of individuals and predict population-level consequences (e.g. mortality rate) from the fates of these individuals. Our first IBM was for oystercatchers Haematopus ostralegus and accurately predicted their density-dependent mortality. Subsequently, IBMs were developed for several shorebird and wildfowl species at several European sites, and were shown to predict accurately overwinter mortality, and the foraging behaviour from which predictions are derived. They have been used to predict the effect on survival in coastal birds of sea level rise, habitat loss, wind farm development, shellfishing and human disturbance. This review emphasises the wider applicability of the approach, and identifies other systems to which it could be applied. We view the IBM approach as a very useful contribution to the general problem								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	of how to advance ecology to the point where we can routinely make meaningful predictions of how populations respond to environmental change.								
Stillman, Richard; Wood, Kevin; Gilkerson, Whelan; Elkinton, Elizabeth; Black, Jeffrey; Ward, David; Petrie, Mark. (2015). Predicting effects of environmental change on a migratory herbivore. Ecosphere. 6. 10.1890/ES14—00455.1.	Changes in climate, food abundance and disturbance from humans threaten the ability of species to successfully use stopover sites and migrate between non-breeding and breeding areas. To devise successful conservation strategies for migratory species we need to be able to predict how such changes will affect both individuals and populations. Such predictions should ideally be process-based, focusing on the mechanisms through which changes alter individual physiological state and behavior. In this study we use a process-based model to evaluate how Black Brant (Branta bernicla nigricans) foraging on common eelgrass (Zostera marina) at a stopover site (Humboldt Bay, USA), may be affected by changes in sea level, food abundance and disturbance. The model is individual-based, with empirically based parameters, and incorporates the immigration of birds	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	into the site, tidal changes in availability of eelgrass, seasonal and depth-related changes in eelgrass biomass, foraging behavior and energetics of the birds, and their mass-dependent decisions to emigrate. The model is validated by comparing predictions to observations across a range of system properties including the time birds spent foraging, probability of birds emigrating, mean stopover duration, peak bird numbers, rates of mass gain and distribution of birds within the site: all 11 predictions were within 35% of the observed value, and 8 within 20%. The model predicted that the eelgrass within the site could potentially support up to five times as many birds as currently use the site. Future predictions indicated that the rate of mass gain and mean stopover duration were relatively insensitive to sea level rise over the next 100 years, primarily because eelgrass habitat could redistribute shoreward into intertidal mudflats within the site to compensate for higher sea levels. In contrast, the rate of mass gain and mean stopover duration were sensitive to changes in total eelgrass biomass and the percentage of time for which birds								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	were disturbed. We discuss the consequences of these predictions for Black Brant conservation. A wide range of migratory species responses are expected in response to environmental change. Process-based models are potential tools to predict such responses and understand the mechanisms which underpin them.								
Sundelof, Andreas; Grimm, Volker; Ulmestrand, Mats; Fiksen, Øyvind. (2014). Modelling harvesting strategies for the lobster fishery in northern Europe: the importance of protecting egg-bearing females. Population Ecology. 57. 237—251. 10.1007/s10144—014—0460—3.	European lobster populations in Norway and Sweden are severely reduced as a result of intense harvesting over a long time. Various alternative management options have been proposed or endorsed to both facilitate recovery and increase yield. Accordingly, Minimum Landing Size (MLS) regulations are widely used for the European lobster. We developed an individual-based population model which integrates biological knowledge about lobsters' population dynamics to explore how available harvesting strategies and management options influence abundance and yield. The model reproduced basic features of a real lobster population in Sweden. Even for a relatively large MLS high fishing effort may still be	Y	Minimum Landing Size (MLS) regulations are widely used for the European lobster...A smaller MLS enables the harvest of many individuals but is very sensitive to increase in effort which easily promotes overfishing.	Y	OSPAR Marine Litter Regional Action Plan. (2020). OSPAR scoping study on best practices for the design and recycling of fishing gear as a means to reduce quantities of fishing gear found as marine litter in the North-East Atlantic. OSPAR Commission.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	detrimental to the long term production of the stock, while increasing the MLS further prevents this recruitment overfishing. A moratorium on berried females, in combination with the MLS appears to stabilize population fluctuations and yield, leading to higher yield for all MLS's considered. The female moratorium harvesting strategy also performed better than a maximum size limit. Yield per recruit calculations gave similar quantitative results, and also shows that a larger MLS reduce the risk of growth overfishing. A smaller MLS enables the harvest of many individuals but is very sensitive to increase in effort which easily promotes overfishing.								
Taylor, Caz; Lank, David; Pomeroy, Andrea; Ydenberg, Ronald. (2007). Relationship Between Stopover Site Choice of Migrating Sandpipers, Their Population Status, and Environmental Stressors. Israel Journal of Ecology and Evolution. 53. 245—261. 10.1560/IJEE.53.3.245.	Measures of animal behavior can be used in a variety of situations to make inferences about the environment and population status. Work by our research group shows that migratory shorebirds adjust their usage of, and behavior at, stopover sites in response to environmental conditions. Motivated by this, we built an individual-based model of migrating shorebirds moving through a sequence of alternating small and	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	large stopover sites. Birds at larger sites are safer from predators, but we assumed that less food is available than at small sites. In the model, both predation risk and food intake are density-dependent, and the behavior of migrants is controlled by two rules: one that determines whether a bird will depart a stopover site, and one that controls the individual's foraging versus vigilance intensity. The optimal behavior is calculated by maximizing a payoff function that depends on arrival date and arrival energy stores at the final site. We used this model to predict mass gain, foraging intensity, and usage by migrants of small and large sites under various conditions. We examined the effects of a flyway-wide reduction in the amount of food, a flyway-wide increase in predation danger, and the effects of lowering the overall population size. The mass action of many individuals, each optimizing its migration timing and routing, leads to the emergence of distinctive patterns of behavior and site choice under these differing environmental conditions. When food availability is reduced throughout the flyway, Our model predicts that								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	foraging intensity increases at every stopover site, thereby forcing birds to accept greater danger to maintain the fitness benefit of a timely arrival to the breeding area. A flyway-wide increase in predation danger results in fewer migrants choosing (and/or migrants staying a shorter time at) small stopover sites, balanced by a higher usage of large sites. These effects contrast with what is observed under true population declines, when the usage of both small and large sites declines.								
Thomas, Christopher; Bridge, Tom; Figueiredo, Joana; Deleersnijder, Eric; Hanert, Emmanuel. (2015). Connectivity between submerged and near-sea-surface coral reefs: Can submerged reef populations act as refuges?. Diversity and Distributions. 21. 1254—1266. 10.1111/ddi.12360.	AimConnectivity is a key determinant of coral reef resilience. However, connectivity models rarely account for deep or submerged reefs, despite their widespread occurrence in many coral reef provinces. Here, we model coral larval connectivity among submerged and near-sea-surface (NSS) reefs, investigate differences in dispersal potential for coral larvae from these differing reef morphologies and estimate the potential for deeper reef habitats (>10m) to provide a source of larvae to shallower reef habitats (<10m).LocationGreat Barrier Reef, Australia.MethodsWe	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	used two newly developed, high-resolution models to identify the location and spatial extent of submerged and NSS reefs and to simulate oceanographic currents (SLIM') affecting larval dispersal. Dispersal patterns for five depth-generalist coral species with differing life histories and dispersal potential were modelled using an individual-based model (IBM).ResultsNear-sea-surface reefs were the largest source of larvae successfully settling, but submerged reefs exported a greater proportion of larvae per unit area to other reefs. Larvae originating from submerged reefs also dispersed greater distances. Recruits on shallow-water reef habitats primarily originated from other shallow areas, but two-way connectivity did occur between deep and shallow habitats. Empirical data indicate that long-term coral cover has declined most steeply on the shallow habitats predicted by our model to be highly dependent on other shallow habitats for recruits.Main conclusionsSubmerged reefs may contribute significantly to larval production and should therefore be considered in connectivity analyses. The hydrodynamic environment on								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	submerged reefs results in larvae dispersing greater distances, potentially increasing their importance as source reefs following disturbances. Deep reef habitats are generally less exposed to disturbances and could therefore constitute an important larval source to some shallow habitats following disturbances. Given the importance of connectivity to coral reef resilience, greater attention should be afforded to identifying and protecting submerged reefs and other deeper habitats.								
Tomas Chaigneau, Tim M. Daw, Individual and village-level effects on community support for Marine Protected Areas (MPAs) in the Philippines, Marine Policy, Volume 51, 2015, Pages 499—506, ISSN 0308—597X, https://doi.org/10.1016/j.marpol.2014.08.007.	A crucial factor in the success of protected areas and conservation efforts in general is the support amongst the adjacent community. It is thought to be especially crucial for the success of small MPAs. Whilst the importance of community support has been highlighted in a number of studies, it has not yet been clearly defined or explicitly studied. Questionnaires were carried out (N=166) at three different villages within the Visayas region of the Philippines to determine individuals' support towards adjacent MPAs and individual	Y	This study highlights the importance in distinguishing between attitudes and actions of individuals and suggests specific individual characteristics can be vital in influencing support towards MPAs.	Y	Post, K. (2018). Increasing the Resilience of Marine Ecosystems : Creating and Managing Marine Protected Areas in the Philippines. Marine Conservation Philippines.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	characteristics that have previously been hypothesised to influence support. Multiple regressions analysis determined: (1) Which individual-level factors predict attitude towards MPAs, (2) whether attitudes of individuals are related to actions that benefit the adjacent MPA and (3) whether individual or community-level factors are better predictors of individual support for local community-based MPAs. Knowledge of MPA objectives, perceived participation in decision making, trust towards other fishers and differences between villages all significantly predicted attitudes towards MPAs. Weak relationships were found between attitudes and certain MPA related actions due to contextual factors. Village was not the only significant predictor of both attitudes and MPA related actions; individual characteristics irrespective of differences between villages, were also important in predicting support for the MPA. This study highlights the importance in distinguishing between attitudes and actions of individuals and suggests specific individual characteristics can be vital in influencing								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	support towards MPAs.								
Travers—Trolet, Morgane; Shin, Yunne—Jai; Jennings, Simon; Machu, Eric; Huggett, Jenny; Field, John; Cury, Philippe. (2009). Two-way coupling versus one-way forcing of plankton and fish models to predict ecosystem changes in the Benguela. Ecological Modelling. 220. 3089—3099. 10.1016/j.ecolmodel.2009.08.016.	End-to-end' models have been adopted in an attempt to capture more of the processes that influence the ecology of marine ecosystems and to make system wide predictions of the effects of fishing and climate change. Here, we develop an end-to-end model by coupling existing models that describe the dynamics of low (ROMS—N(2)P(2)Z(2)D(2)) and high trophic levels(OSMOSE). ROMS—N(2)P(2)Z(2)D(2) is a biogeochemical model representing phytoplankton and zooplankton seasonal dynamics forced by hydrodynamics in the Benguela upwelling ecosystem. OSMOSE is an individual-based	Y	and food web function and emphasise the need to critically examine the consequences of different model architectures when seeking to predict the effects of fishing and climate change.	Y	Kelleher, K., & Japp, D. (2013). Preparation of the Horse Mackerel (T. trecae) Management Plan for Angola. COFREPECHE.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	model representing the dynamics of several species of fish, linked through opportunistic and size-based trophic interactions. The models are coupled through a two-way size-based predation process. Plankton provides prey for fish, and the effects of predation by fish on the plankton are described by a plankton mortality term that is variable in space and time. Using the end-to-end model, we compare the effects of two-way coupling versus one-way forcing of the fish model with the plankton biomass field. The fish-induced mortality on plankton is temporally variable, in part explained by seasonal changes in fish biomass. Inclusion of two-way feedback affects the seasonal dynamics of plankton groups and usually reduces the amplitude of variation in abundance (top-down effect). Forcing and coupling lead to different predicted food web structures owing to changes in the dominant food chain which is supported by plankton (bottom-up effect). Our comparisons of one-way forcing and two-way coupling show how feedbacks may affect abundance, food web structure and food web function and emphasise the need to critically examine the								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	consequences of different model architectures when seeking to predict the effects of fishing and climate change.								
Uchmanski, Janusz. (2000). Individual variability and population regulation: An individual-based model. Oikos. 90. 10.1034/j.1600—0706.2000.900312.x.	To study the influence of individual variability on population dynamics an individual-based model of the dynamics of a single population consisting of different individuals is constructed. The model is based on differences in individual assimilation rates due to intraspecific competition and variability of initial weights. The model exhibits imperfect regulation, i.e., the number of individuals in the population oscillates and sooner or later the population becomes extinct. When individual variability is included, the model produces longer population extinction times than without individual variability. The average extinction time is not however a monotonic function of the degree of individual variability.	N	—	—	—	—	—	—	—
Uttieri, Marco; Cianelli, Daniela; Zambianchi, Enrico. (2013). Behaviour-dependent predation risk in swimming zooplankters. Zoological studies. 52.	Background: The survival of zooplanktonic organisms is determined by their capability of moving in a fluid environment, trading	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
10.1186/1810—522X—52—32.	off between the necessities of finding prey and avoiding predators. In previous numerical experiments, we concentrated on the relationship between natatorial modality and encounter success of a virtual copepod swimming in the presence of prey distributed either in patches or uniformly in the environment.Results: In this contribution, we extend this simulation framework to the encounter with chaetognaths, the primary copepod predators, considering different motion rules as a proxy of different swimming strategies and looking at the influence of the concentration of predators and the size of their detection radius in posing a risk on copepod survival. The outcomes of our simulations indicate that more convoluted trajectories are more vulnerable to predator encounter while straighter motions reduce predation risk.Conclusions: Our results are then complemented with those obtained in our previous studies to perform a general cost-benefit analysis of zooplankton motion.								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
van Beest, Floris; Kindt-Larsen, Lotte; Bastardie, Francois; Bartolino, Valerio; Nabe—Nielsen, Jacob. (2017). Predicting the population-level impact of mitigating harbor porpoise bycatch with pingers and time-area fishing closures. Ecosphere. 8. 10.1002/ecs2.1785.	Unintentional mortality of higher trophic-level species in commercial fisheries (bycatch) represents a major conservation concern as it may influence the long-term persistence of populations. An increasingly common strategy to mitigate bycatch of harbor porpoises (Phocoena phocoena), a small and protected marine top predator, involves the use of pingers (acoustic alarms that emit underwater noise) and time—area fishing closures. Although these mitigation measures can reduce harbor porpoise bycatch in gillnet fisheries considerably, inference about the long-term population-level consequences is currently lacking. We developed a spatially explicit individual-based simulation model (IBM) with the aim to evaluate the effectiveness of these two bycatch mitigation measures. We quantified both the direct positive effects (i.e., reduced bycatch) and any indirect negative effects (i.e., reduced foraging efficiency) on the population size using the inner Danish waters as a biological system. The model incorporated empirical data on gillnet fishing effort and noise avoidance behavior by free—ranging harbor porpoises exposed to randomized high-	Y	Unintentional mortality of higher trophic-level species in commercial fisheries (bycatch) represents a major conservation concern... offer an efficient and dynamic framework to evaluate the impact of human activities on the long-term survival of marine populations and can serve as a basis to design adaptive management strategies that satisfy both ecological and socioeconomic demands on marine ecosystems.	Y	Scientific, Technical and Economic Committee for Fisheries (STECF) – Review of the implementation of the EU regulation on the incidental catches of cetaceans (STECF—19—07). Publications Office of the European Union, Luxembourg, 2019, ISBN 978—92—76—11228—0, doi:10.2760/64091 JRC117515	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	frequency (20— to 160—kHz) pinger signals. The IBM simulations revealed a synergistic relationship between the implementation of time—area fishing closures and pinger deployment. Time—area fishing closures reduced bycatch rates substantially but not completely. In contrast, widespread pinger deployment resulted in total mitigation of bycatch but frequent and recurrent noise avoidance behavior in high-quality foraging habitat negatively affected individual survival and the total population size. When both bycatch mitigation measures were implemented simultaneously, the negative impact of pinger noise—induced sub-lethal behavioral effects on the population was largely eliminated with a positive effect on the population size that was larger than when the mitigation measures were used independently. Our study highlights that conservationists and policymakers need to consider and balance both the direct and indirect effects of harbor porpoise bycatch mitigation measures before enforcing their widespread implementation. Individual-based simulation models, such as the one presented here, offer an efficient and								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	dynamic framework to evaluate the impact of human activities on the long-term survival of marine populations and can serve as a basis to design adaptive management strategies that satisfy both ecological and socioeconomic demands on marine ecosystems.								
van de Koppel, Johan; Gascoigne, Joanna; Theraulaz, Guy; Rietkerk, Max; Mooij, Wolf; Herman, Peter. (2008). Experimental Evidence for Spatial Self-organization and Its Emergent Effects in Mussel Bed Ecosystems. Science (New York, N.Y.). 322. 739—42. 10.1126/science.1163952.	Spatial self—organization is the main theoretical explanation for the global occurrence of regular or otherwise coherent spatial patterns in ecosystems. Using mussel beds as a model ecosystem, we provide an experimental demonstration of spatial self—organization. Under homogeneous laboratory conditions, mussels developed regular patterns, similar to those in the field. An individual—based model derived from our experiments showed that interactions between individuals explained the observed patterns. Furthermore, a field study showed that pattern formation	Y	Our results imply that spatial self—organization is an important determinant of the structure and functioning of ecosystems, and it needs to be considered in their conservation.	Y	Feature: HORSE MUSSEL BEDS. (2019). [PRIORITY MARINE FEATURE (PMF) — FISHERIES MANAGEMENT REVIEW]. Scottish Government consultations. https://consult.gov.scot/marine-scotland/priority-marine—features/supporting_documents/Review%20of%20PMFs	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	affected ecosystem—level processes in terms of improved growth and resistance to wave action. Our results imply that spatial self—organization is an important determinant of the structure and functioning of ecosystems, and it needs to be considered in their conservation.				%20outside%20the%20Scottish%20MPA%20network%20%20FINAL%20%20Horse%20mussel%20beds.pdf				
Van Oosterhout, Cock; Potter, R; Wright, H; Cable, Jo. (2008). Gyro-scope: An individual-based computer model to forecast gyrodactylid infections on fish hosts. International journal for parasitology. 38. 541—8. 10.1016/j.ijpara.2007.09.016.	Individual-based computer models (IBM) feature prominently in current theoretical ecology but have only been applied in a small number of parasitological studies. Here we designed an IBM to simulate the infection dynamics of gyrodactylid parasites and immune defence of naive hosts (i.e. fish previously not exposed to these parasites). We compared the results of the model with empirical data from guppies (Poecilia reticulata) infected with Gyrodactylus parasites. The laboratory experiments on guppies showed that larger fish acquired a heavier parasite load at the peak of the infection. The survival probability declined with increased body size and no fish survived a parasite load of 80 or more worms in this experiment (i.e. lethal	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	load). The model was a good predictor of the Gyrodactylus infection dynamics of guppies and the model output was congruent with previously published data on Gyrodactylus salaris infections of salmon (Salmo salar). Computer simulations indicated that the infections persisted longer on larger hosts and that the parasite load increased exponentially with the body size of the host. Simulations furthermore predicted that the parasite load of fish with a standard length in excess of 17 mm (i.e. the size of adult guppies) reached a lethal load. This suggests that in the conditions of the experiment, the immune defence of naive guppies can offer moderate protection against gyrodactylid infections to juveniles, but not to naive adult guppies. The model is a useful tool to forecast the development of gyrodactylid infections on single hosts and make predictions about optimal life history strategies of parasites.								
Vanderklift, Mat; Boschetti, Fabio; Roubertie, Clovis; RD, Pillans; Haywood, Michael; Babcock, R.. (2014). Density of reef sharks estimated by applying an agent-based model to video surveys.	Policies on harvesting and conservation are developed in response to information about trends in the abundance of species, so making accurate estimates of abundance is	Y	Policies on harvesting and conservation are developed in response to information about trends in the abundance of species, so making	Y	SEDAR. 2020. SEDAR 65 Atlantic Blacktip Shark Stock Assessment Report. SEDAR,	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Marine Ecology Progress Series. 508. 201—209. 10.3354/meps10813.	important. However, estimating the abundance of sparsely distributed species is challenging, especially where direct observations are difficult. We collected observations of blacktip reef sharks Carcharhinus melanopterus by using remote underwater video cameras, and developed an agent-based model to generate estimates of the density of sharks from the frequency of observations made using the video. We augmented these observations with diel patterns in detections in different habitats of C. melanopterus with surgically implanted acoustic transmitters. Median estimates of density ranged from 2—9 ind. km(—2) at noon to 20—90 ind. km(—2) at dusk, depending on whether modelled movement paths were random or directional. These estimates suggest that individuals might exhibit diel patterns in movement, with directional movement to the reef flat during dusk. Data from tagged individuals supported this hypothesis, with more detections recorded from reef flat habitat during early evening and early morning than at other times of day. Estimates of density were among the highest reported for C. melanopterus. The agent-based		accurate estimates of abundance is important		North Charleston SC. 438 pp. available online at: http://sedarweb.org/sedar-65*				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	model approach is flexible, and can be extended to simulate a range of behaviours and other types of observations.								
Walsh, Stephen; Mena, Carlos. (2016). Interactions of social, terrestrial, and marine sub-systems in the Galapagos Islands, Ecuador. Proceedings of the National Academy of Sciences. 113. 201604990. 10.1073/pnas.1604990113.	Galapagos is often cited as an example of the conflicts that are emerging between resource conservation and economic development in island ecosystems, as the pressures associated with tourism threaten nature, including the iconic and emblematic species, unique terrestrial landscapes, and special marine environments. In this paper, two projects are described that rely upon dynamic systems models and agent-based models to examine human-environment interactions. We use a theoretical context rooted in complexity theory to guide the development of our models that are linked to social-ecological dynamics. The goal of this paper is to describe key elements, relationships, and processes to inform and enhance our understanding of human-environment interactions in the Galapagos Islands of Ecuador. By formalizing our knowledge of how systems operate and the manner in which key elements are linked in coupled human-natural	Y	have practical applications in that they emphasize how political policies generate different human responses and model outcomes, many detrimental to the social-ecological sustainability of the Galapagos Islands.	Y	State of Conservation Report: Galápagos Islands. (2018). UNESCO World Heritage Centre.	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	systems, we specify rules, relationships, and rates of exchange between social and ecological features derived through statistical functions and/or functions specified in theory or practice. The processes described in our models also have practical applications in that they emphasize how political policies generate different human responses and model outcomes, many detrimental to the social-ecological sustainability of the Galapagos Islands.								
Watkins, Katherine; Rose, Kenneth. (2017). Simulating individual-based movement in dynamic environments. Ecological Modelling. 356. 59—72. 10.1016/j.ecolmodel.2017.03.025.	The accuracy of spatially-explicit individual-based models (IBMs) often depends on the realistic simulation of the movement of organisms, which is especially challenging when movement cues (e.g., environmental conditions; prey and predator abundances) vary in time and space. A number of approaches or sub-models have been developed for simulating movement in IBMs. We evaluated four movement sub-models (restricted—area search, kinesis, event-based, and run and tumble) in a spatially explicit cohort IBM in which the prey and predators were both dynamic (varying across cells and over time) and responsive to the	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	dynamics of the cohort individuals. Movement, growth, and mortality were simulated every 25 min for 30 12—h days (single generation) on a 2.7 x 2.7 km(2) grid with 625 m(2) cells, and egg production was calculated based on weight and survival of individuals at the end of 30 days. We based the cohort model on small pelagic coastal fish, and the prey was based on zooplankton and the predators based on a typical piscivorous fish. Movement sub-models were calibrated with a genetic algorithm in dynamic and static versions of the prey and predator-defined environments. Prey and predator fields were fixed in the static environment; in the dynamic environment, prey density was reduced based on consumption and predators actively sought out cohort individuals. Static—trained sub-models were then tested in the dynamic environments and vice versa. The four movement sub-models were successfully trained and performed reasonably well in terms of egg production (a measure of individual fitness) when trained and tested in the same type of environment. However, the type of environment affected calibration success,								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	and static—trained models did not perform well when tested in dynamic environments because cohort individuals moved in response to both prey and predator cues rather than primarily avoiding fixed—in-space high mortality cells. Use of movement sub-models in IBMs should carefully consider how the conditions assumed for calibration relates to the dynamic conditions the model will be used to address.								
West, Andrew; Stillman, Richard; Drewitt, Allan; Frost, Natalie; Mander, Matt; Miles, Chris; Langston, R.; Sanderson, William; Willis, Jay. (2010). WaderMORPH – a user-friendly individual-based model to advise shorebird policy and management. Methods in Ecology and Evolution. 2. 95 — 98. 10.1111/j.2041—210X.2010.00049.x.	1. Conservation objectives for non-breeding shorebirds (waders) are determined from their population size. Individual-based models (IBMs) have accurately predicted mortality rate (a determinant of population size) of these species, and are a tool for advising coastal management and policy. However, due to their complexity, the use of these IBMs has been restricted to specialist modellers in the scientific community, whereas, ideally, they should be accessible to non-specialists with a direct interest in coastal issues.2. We describe how this limitation has been addressed by the development of WaderMORPH, a user-friendly interface	Y	Conservation objectives for non-breeding shorebirds (waders) are determined from their population size.	Y	Aonghais S.C.P. Cook, David J. Turner, Niall H.K. Burton & Lucy J. Wright. (2016). Tracking Curlew and Redshank on the Humber Estuary. The British Trust for Ornithology.	—	Y	Y	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	to a shorebird IBM, MORPH, that runs within Microsoft Windows. WaderMORPH hides technical and mathematical details of parameterisation from the user and allows models to be parameterised in a series of simple steps. We provide an overview of WaderMORPH and its range of applications. WaderMORPH, its user guide and an example data set can be downloaded from http://individualecology.bournemouth.ac.uk.								
West, Andrew; Yates, Michael; McGrorty, Selwyn; Stillman, Richard. (2007). Predicting Site Quality for Shorebird Communities: A Case Study on the Wash Embayment, UK. Ecological Modelling. 202. 527—539. 10.1016/j.ecolmodel.2006.11.026.	Conservation managers responsible for estuaries are often required to monitor their site to ensure that the conservation status of any bird species for which the site is considered important is not affected by deterioration of their habitat or by disturbance of the birds themselves. Here, we use an individuals-based model to predict the quality of the Wash embayment, UK, defined in this case as overwinter survival rate, for eight shorebird species. We use the model to predict how site quality would be affected by changes in the types of prey available, prey density, mudflat area and the rate at which	Y	Conservation managers responsible for estuaries are often required to monitor their site to ensure that the conservation status of any bird species for which the site is considered important is not affected by deterioration of their habitat or by disturbance of the birds themselves. Here, we use an individuals-based model to predict the quality of the Wash embayment...They also show such models can be used to set maximum disturbance rates for each species by predicting how disturbance rates influence shorebird survival.	Y	"Plagányi, É.E. Models for an ecosystem approach to fisheries. FAO Fisheries Technical Paper. No. 477. Rome, FAO. 2007. 108p."	Austin, G.E., Cook, A.S.C.P., Maclean, I.M.D., Mitchell, P.I., Rehfisch M.M. & Wright, L.J. 2010. Healthy & Biologically Diverse Seas Evidence Group Technical Report Series: Evaluation and gap analysis of current and	N,N	Y,N	Y,Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	birds are disturbed. The results suggested that Macoma, Hydrobia and Corophium had relatively little influence on site quality for any species modelled except black—tailed godwit, despite being the preferred prey for some bird species. Arenicola Marina, other annelids and Cerastoderma edule were found to be important. influences on site quality. Birds began to starve, when autumn, estuary-wide food biomass density was below about 5 g AFDM m(—2) and survival rates fell below 90% at 4g AFDM m(—2). One possible conservation objective for the Wash estuary would be to monitor whether the 99% confidence limit of biomass density falls below one of these limits, to determine whether site quality is being maintained. The system as a whole was predicted to be relatively insensitive to habitat loss. Black—tailed godwits were the most sensitive species, but their survival was not affected until 40% of the feeding grounds were removed. The survival of all species in the model remained high at fewer than 20 disturbances/hour. Although disturbance rates on the Wash were not measured during this study it is unlikely that present-day rates of					potential indicators for Seabirds & Waterbirds.			

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	disturbance on the Wash represent a threat to the survival of the bird species modelled. our results show how an individuals-based model can assess present-day site quality and how it may change in the future. The model predicted prey biomasses below which survival rate decreased, which shorebird species were most vulnerable to changes in site quality, and that prey density was a more important factor in shorebird survival than habitat area on the Wash. They also show such models can be used to set maximum disturbance rates for each species by predicting how disturbance rates influence shorebird survival.								
Wildhaber, Mark; Lamberson, Peter. (2004). Importance of habitat choice behavior when modeling the effects of food and temperature on fish populations. Ecological Modelling. 175. 395—409. 10.1016/j.ecolmodel.2003.08.022.	Various mechanisms of habitat choice in fishes based on food and/or temperature have been proposed: optimal foraging for food alone; behavioral thermoregulation for temperature alone; and behavioral energetics and discounted matching for food and temperature combined. Along with development of habitat choice mechanisms, there has been a major push to develop and apply to fish populations	Y	Hence, resource managers who use modeling results to predict fish population trends should be very aware of and understand the underlying patch choice mechanisms used in their models to assure that those mechanisms correctly represent the fish populations being modeled.	Y	Barange, M., Bahri, T., Beveridge, M.C.M., Cochrane, K.L., Funge-smith, S. & Poulain, F., eds. 2018. Impacts of climate change on fisheries and aquaculture : synthesis of current knowledge, adaptation and	—	N	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	individual-based models that incorporate various forms of these mechanisms. However, it is not known how the wide variation in observed and hypothesized mechanisms of fish habitat choice could alter fish population predictions (e.g. growth, size distributions, etc.). We used spatially explicit, individual-based modeling to compare predicted fish populations using different submodels of patch choice behavior under various food and temperature distributions. We compared predicted growth, temperature experience, food consumption, and final spatial distribution using the different models. Our results demonstrated that the habitat choice mechanism assumed in fish population modeling simulations was critical to predictions of fish distribution and growth rates. Hence, resource managers who use modeling results to predict fish population trends should be very aware of and understand the underlying patch choice mechanisms used in their models to assure that those mechanisms correctly represent the fish populations being modeled.				mitigation options. FAO Fisheries and Aquaculture Technical Paper No. 627. Rome, FAO. 628 pp.				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Xue, Huijie; Incze, Lewis; Xu, Danya; Wolff, Nicholas; Pettigrew, Neal. (2008). Connectivity of lobster populations in the coastal Gulf of Maine: Part I: Circulation and larval transport potential. Ecological Modelling. 210. 193–211. 10.1016/j.ecolmodel.2007.07.024.	The remarkable increase of Homarus Americanus (lobster) abundance in recent years has resulted in record landings throughout the states and provinces along the perimeter of the Gulf of Maine. A considerable amount of data on various life stages of lobsters has been collected for research, management and conservation purposes over the past 15 years. We have used these data sets to develop models that simulate lobster populations from newly hatched larval stage through settlement and recruitment to the fishery. This paper presents a part of the synthesis study that focuses on the early life history of lobsters.A coupled biophysical individual based model was developed that considers patterns of egg production (abundance, distribution and timing of hatch), temperature-dependent larval growth, stage-explicit vertical distributions of larvae, and mortality. The biophysical model was embedded in the realistic simulations of the physical environment (current and temperature) from the Gulf of Maine Nowcast/Forecast System. The predominant direction of larval movement	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	follows the cyclonic Gulf of Maine Coastal Current (GMCC). Results show relatively low accumulation of planktonic stages along the eastern Maine coast and high accumulation along the western Maine coast. In years when the eastern branch of the GMCC turns offshore southeast of Penobscot Bay, more particles accumulate downstream of the branch point. Interannual variability is also apparent in development times that vary as a function of year-to-year water temperature variation. The larval stages tend to remain relatively near shore, but the final planktonic stage (the postlarva) resides near the sea surface, and the prevailing southwesterly winds in summer cause eastward and offshore drift of postlarvae. Thus, more settlement might take place earlier in the potentially long postlarval stage, and the timing and strength of the southwesterly winds are important in determining the population of potential settlers.								
Yemane, Dawit; Shin, Yunne—Jai; Field, John. (2008). Exploring the effect of Marine Protected Areas on the dynamics of fish communities in the	Marine Protected Areas (MPAs) have been suggested as a tool that can achieve some of the goals of an Ecosystem Approach to Fisheries	Y	simultaneous introduction of the MPAs affected varying proportions of the distribution of the modelled species	Y	Sowman, Merle & Cardoso, Paula. (2010). Small-scale fisheries	—	N	N	N

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
southern Benguela: an individual-based modelling approach. Ices Journal of Marine Science — ICES J MAR SCI. 66. 378—387. 10.1093/icesjms/fsn171.	(EAF), e.g. prevention of overexploitation, biodiversity conservation, recovery of overexploited population, but the consequences of their establishment on the dynamics of protected components are often unclear. Spatial and multispecies models can be used to investigate the effects of their introduction. An individual-based, spatially explicit, size-structured, multispecies model (known as OSMOSE) is used to investigate the likely consequences of the introduction of three MPAs off the coast of South Africa, individually or in combination. The simultaneous introduction of the MPAs affected varying proportions of the distribution of the modelled species (5—17%) and 12% of the distribution of the whole community. In general, the introduction of the MPAs in the different scenarios resulted in a relative increase in the biomass of large predatory fish and a decrease in the biomass of small pelagic fish. The simulation demonstrates that consideration of trophic interactions is necessary when introducing MPAs, with indirect effects that may be detrimental to some		(5—17%) and 12% of the distribution of the whole community. In general, the introduction of the MPAs in the different scenarios resulted in a relative increase in the biomass of large predatory fish and a decrease in the biomass of small pelagic fish.		and food security strategies in countries in the Benguela Current Large Marine Ecosystem (BCLME) region: Angola, Namibia and South Africa. Marine Policy. 34. 1163—1170. 10.1016/j. marpol.2010.03.016.				

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	(mainly smaller prey) species.								
Zador, Stephani; Piatt, John; Punt, André. (2006). Balancing predation and egg harvest in a colonial seabird: A simulation model. Ecological Modelling — ECOL MODEL. 195. 318—326. 10.1016/j.ecolmodel.2005.11.002.	We developed an individual-based model to study the effects of different regimes of harvesting eggs and natural predation on reproductive success in a colony of the glaucous-winged gull (Larus glaucescens) in Glacier Bay National Park, Alaska. The model incorporates the sequence of egg laying, relaying, and incubation to hatching for individual nests and calculates hatching success, incubation length, and the total number of eggs laid (as a result of re—nesting and relaying) in all nests in the colony. Stochasticity is incorporated in the distribution of nest lay dates, predation rates, and nests attacked during predation and harvest events. We estimated parameter values by fitting the model to data collected at a small colony during 1999 and 2000 using maximum likelihood. We then simulated harvests and analyzed model predictions. Model outputs indicate that harvesting early, and at one time, provides a predictable take of eggs with the least impact to gulls.	Y	Model outputs indicate that harvesting early, and at one time, provides a predictable take of eggs with the least impact to gulls.	Y	Lewis, T., & Moss, M. B. (n.d.). Glaucous-winged Gull Monitoring and Egg Harvest in Glacier Bay, Alaska. National Park Service. https://www.nps.gov/articles/aps—v14—i2—c6.htm	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications ?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
Zhang, Hua; Gorelick, Steven. (2014). Coupled impacts of sea-level rise and tidal marsh restoration on endangered California clapper rail. Biological Conservation. 172. 89–100. 10.1016/j.biocon.2014.02.016.	We develop a predictive multi-process framework to quantitatively assess the spatially variable, inter-linked dynamics of sea-level rise, wetland transition, habitat suitability and connectivity, and shorebird distribution and abundance. Bird behavior is represented in a spatially explicit agent-based model that tracks responses of individuals to predicted changes in local habitat quantity and quality. We apply this framework to the endangered California clapper rail (Rallus longirostris obsoletus) in the San Francisco Estuary, US, under a range of sea-level rise and conservation scenarios aimed at clapper rail recovery. The framework enables quantification of the relationship between critical habitat destruction and clapper rail population decline. The most influential factors that characterize the quality of tidal marsh habitat are salinity, which is a proxy for higher quality nesting environment and abundance of macroinvertebrates, and tidal conditions, which affect flood and predation threats. Results suggest that clapper rail viability should remain at the present level for moderate sea level rise. However, for a rise of 1.66 m,	Y	Should sea level rise to the predicted maximum, proposed conservation efforts are likely to be ineffective in preventing California clapper rail extinction by 2100.	Y	SFEI. 2021. Ecotone Levees and Wildlife Connectivity: A Technical Update to the Adaptation Atlas. Publication #1037, San Francisco Estuary Institute, Richmond, CA.	—	Y	N	Y

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	extinction risk increases from 0.01 to 0.36. The framework enables quantitative evaluation of proposed conservation efforts, and should complement existing theory and empirical inferences. Compared with sub-regional efforts, estuary-wide conservation is more effective in improving reproduction and dispersal success and accommodates a sea-level rise of an additional 10 cm before population falls below criticality. Should sea level rise to the predicted maximum, proposed conservation efforts are likely to be ineffective in preventing California clapper rail extinction by 2100.								
Zhang, Jingjing; Dennis, Todd; Landers, Todd; Bell, Elizabeth; Perry, George. (2017). Linking individual-based and statistical inferential models in movement ecology: A case study with black petrels (Procellaria parkinsoni). Ecological Modelling. 360. 425—436. 10.1016/j.ecolmodel.2017.07.017.	Individual-based models (IBMs) are increasingly used to explore ecological systems and, in particular, the emergent outcomes of individual-level processes. A major challenge in developing IBMs to investigate the movement ecology of animals is that such models must represent and parameterise unobserved behaviours occurring at multiple hierarchical levels.	N	—	—	—	—	—	—	—

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	Approaches based on approximate Bayesian computation (ABC) methods have been used to support the parameterisation, calibration and evaluation of IBMs. However, a key component of the ABC approach is the use of multiple quantitative patterns derived from empirical data to exclude model structures and parameterisations that generate atypical or implausible patterns. We propose a modelling framework that integrates information derived from statistical inferential models, which are now widely used to describe the behaviour of moving animals, with ABC methodologies for the parameterisation and analysis of IBMs. To demonstrate its application, we apply this framework to high-resolution movement trajectories of the foraging trips of black petrels (Procellaria parkinsoni), an endangered seabird endemic to New Zealand. The outcomes of our study show that the use of inferential statistical models to summarise movement data can aid model selection and parameterisation procedures via ABC, and yield valuable insights into the modelling in								

WoS Article Citation	WoS Abstract	WoS Article Claims Policy/ Conservation Implications?	Policy/ Conservation Implication from Abstract	Able to locate a policy paper?	Policy Paper #1	Policy Paper #2	Policy Paper Cites the listed IBM?	Policy Paper Cites a different IBM?	Policy Paper Cites a Different Model Method?
	movement ecology of animals.								

Caption: Result of WoS search (N=108). 55% (59 papers) argued in the abstract that the research had policy/management implications (relevant line from the abstract highlighted in Column 4). 52 relevant policy documents were located. Of those 52 documents, only 17 (29%) cited the IBM, with an additional eight citing separate IBMs not identified by the WoS search. 83% (43) of the policy documents cited a different, non-IBM model method.
Y= Yes, N= No. A * indicates duplicate (duplicates are not marked on first appearance).

REFERENCES

Akerlof, K. (2022). Beyond the sheltering academic silo: Norms for scientists' participation in policy. In *Progress in Molecular Biology and Translational Science* (Vol. 188, pp. 29–44). Elsevier. https://doi.org/10.1016/bs.pmbts.2021.11.007

Akerlof, K., Bromser-Kloeden, T., Timm, K., Rowan, K. E., Olds, J. L., Clarke, C., Rohring, E. B., Cloyd, E. T., Curran, K., Duesterhoeft, E. C., Farooque, M., Goldman, E., Gring-Pemble, L., Hampton, S. E., Kim, S. C., Kotcher, J., Milligan, D., Muñoz Brenes, C. L., Sandoval, C.,... Zhao, X. (2021). Categorizing Professionals' Perspectives on Environmental Communication with Implications for Graduate Education. *Environmental Communication*, *15*(4), 447–464. https://doi.org/10.1080/17524032.2020.1862890

Akerlof, K., Lemos, M., Cloyd, E., Heath, E., Nelson, S., Hathaway, J., & Timm, K. (2018, August 6). *Barriers in communicating science for policy in Congress. Association for Education in Journalism and Mass Communication*. Association for Education in Journalism and Mass Communication, 2018 Annual Conference, Washington, DC.

Akerlof, K., Rowan, K. E., Fitzgerald, D., & Cedeno, A. Y. (2012). Communication of climate projections in US media amid politicization of model science. *Nature Climate Change*, *2*(9), 648–654. https://www.nature.com/articles/nclimate1542

Allen, R. E., & Wiles, J. L. (2016). A rose by any other name: Participants choosing research pseudonyms. *Qualitative Research in Psychology*, *13*(2), 149–165. https://doi.org/10.1080/14780887.2015.1133746

Anderson, R. M., Jackson, H. C., May, R. M., & Smith, A. M. (1981). Population dynamics of fox rabies in Europe. *Nature*, *289*(5800), Article 5800. https://doi.org/10.1038/289765a0

Auerbach, C. F., & Silverstein, L. B. (2003). *Qualitative data an introduction to coding and analysis*. University Press.

Austin, R. A., Hawkes, L. A., Doherty, P. D., Henderson, S. M., Inger, R., Johnson, L., Pikesley, S. K., Solandt, J.-L., Speedie, C., & Witt, M. J. (2019). Predicting habitat suitability for basking sharks (Cetorhinus maximus) in UK waters using ensemble ecological niche modelling. *Journal of Sea Research*, *153*, 101767. https://doi.org/10.1016/j.seares.2019.101767

Béland, D., & Howlett, M. (2016). The Role and Impact of the Multiple-Streams Approach in Comparative Policy Analysis. *Journal of Comparative Policy Analysis: Research and Practice*, *18*(3), 221–227. https://doi.org/10.1080/13876988.2016.1174410

Berrow, S., & Heardman, C. (1994). The Basking Shark *Cetorhinus maximus* (Gunnerus) in Irish Waters: Patterns of Distribution and Abundance. *Biology and Environment: Proceedings of the Royal Irish Academy*, *94B*, 101–107.

Bonnet, D., Richardson, A., Harris, R., Hirst, A., Beaugrand, G., Edwards, M., Ceballos, S., Diekman, R., López-Urrutia, A., Valdes, L., Carlotti, F., Molinero, J. C., Weikert, H., Greve, W., Lucic, D., Albaina, A., Yahia, N. D., Umani, S. F., Miranda, A.,... Fernandez de Puelles, M. L. (2005). An overview of <i>Calanus helgolandicus<i> ecology in European waters. *Progress in Oceanography*, *65*(1), 1–53. https://doi.org/10.1016/j.pocean.2005.02.002

Braun, C. D., Skomal, G. B., & Thorrold, S. R. (2018). Integrating Archival Tag Data and a High-Resolution Oceanographic Model to Estimate Basking Shark (Cetorhinus maximus) Movements in the Western Atlantic. *Frontiers in Marine Science*, *5*. https://doi.org/10.3389/fmars.2018.00025

Bresnan, E., Cook, K. B., Hughes, S. L., Hay, S. J., Smith, K., Walsham, P., & Webster, L. (2015). Seasonality of the plankton community at an east and west coast monitoring site in Scottish waters. *Journal of Sea Research*, *105*, 16–29. https://doi.org/10.1016/j.seares.2015.06.009

Bruce, E., & Gershenson, C. (2015). Modelling Complexity for Policy: Opportunities and Challenges. In *Handbook on Complexity and Public Policy, edited by Robert Geyer and Paul Cairney* (pp. 190–204). Cheltenham, UK: Edward Elgar.

Cairney, P. (2016a). Conclusion: How to Respond to the Limits of EBPM. In P. Cairney (Ed.), *The Politics of Evidence-Based Policy Making* (pp. 119–133). Palgrave Macmillan UK. https://doi.org/10.1057/978-1-137-51781-4_5

Cairney, P. (2016b). Evidence in Environmental Policy: Learning Lessons from Health? In P. Cairney (Ed.), *The Politics of Evidence-Based Policy Making* (pp. 85–118). Palgrave Macmillan UK. https://doi.org/10.1057/978-1-137-51781-4_4

Cairney, P. (2016c). Health and Advocacy: What Are the Barriers to the Use of Evidence in Policy? In P. Cairney (Ed.), *The Politics of Evidence-Based Policy Making* (pp. 51–84). Palgrave Macmillan UK. https://doi.org/10.1057/978-1-137-51781-4_3

Cairney, P. (2016d). The Role of Evidence in Theories of the Policy Process. In P. Cairney, *The Politics of Evidence-Based Policy Making*. Palgrave Macmillan UK. https://link.springer.com/chapter/10.1057/978-1-137-51781-4_2#citeas

Cairney, P. (2016e). The Science of Policymaking. In P. Cairney, *The Politics of Evidence-Based Policy Making*. Palgrave Macmillan UK. https://doi.org/10.1057/978-1-137-51781-4_1

Cairney, P. (2017). Evidence-based best practice is more political than it looks: A case study of the "Scottish Approach." *Evidence & Policy*, *13*(3), 499–515. https://bristoluniversitypressdigital.com/view/journals/evp/13/3/article-p499.xml

Cairney, P. (2019). Evidence and policy making. In A. Boaz, H. T. O. Davies, A. Fraser, & S. M. Nutley (Eds.), *What works now?: Evidence-informed policy and practice*. Policy Press.

Cairney, P., & Kwiatkowski, R. (2017). How to communicate effectively with policymakers: Combine insights from psychology and policy studies. *Palgrave Communications*, *3*(1), Article 1. https://doi.org/10.1057/s41599-017-0046-8

Cairney, P., & Oliver, K. (2017). Evidence-based policymaking is not like evidence-based medicine, so how far should you go to bridge the divide between evidence and policy? *Health Research Policy and Systems*, *15*. https://health-policy-systems.biomedcentral.com/articles/10.1186/s12961-017-0192-x

Cartwright, S. J., Bowgen, K. M., Collop, C., Hyder, K., Nabe-Nielsen, J., Stafford, R., Stillman, R. A., Thorpe, R. B., & Sibly, R. M. (2016). Communicating complex ecological models to non-scientist end users. *Ecological Modelling*, *338*, 51–59. https://doi.org/10.1016/j.ecolmodel.2016.07.012

Case Studies. (n.d.). *Bournemouth University Individual Ecology*. Retrieved March 30, 2023, from https://www.individualecology.com/case-studies/

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences*, *100*(14), 8086–8091. https://doi.org/10.1073/pnas.1231332100

CDC. (2010). *Community Health Assessment and Group Evaluation (CHANGE) Action Guide: Building a Foundation of Knowledge to Prioritize Community Needs.* Centers for Disease Control and Prevention.

Chang, M., Thellufsen, J. Z., Zakeri, B., Pickering, B., Pfenninger, S., Lund, H., & Østergaard, P. A. (2021). Trends in tools and approaches for modelling the energy transition. *Applied Energy*, *290*, 116731. https://doi.org/10.1016/j.apenergy.2021.116731

Cheruvelil, K. S., Soranno, P. A., Weathers, K. C., Hanson, P. C., Goring, S. J., Filstrup, C. T., & Read, E. K. (2014). Creating and maintaining high-performing collaborative research teams: The importance of diversity and interpersonal skills. *Frontiers in Ecology and the Environment*, *12*(1), 31–38. https://doi.org/10.1890/130001

Childress, M. J. (2014, October 15). Going with the flow: Forecasting the impact of climate change on blue crabs. *Proceedings of the 2014South Carolina Water Resources Conference*. Proceedings of the 2014South Carolina Water Resources Conference. https://core.ac.uk/display/268629091?utm_source=pdf&utm_medium=banner&utm_campaign=pdf-decoration-v1

Chow, A. (2014). Understanding Policy Change: Multiple Streams and National Education Curriculum Policy in Hong Kong. *Journal of Public Administration and Governance*, *4*(2), Article 2. https://doi.org/10.5296/jpag.v4i2.5184

Christensen, V., & Walters, C. J. (2004). Ecopath with Ecosim: Methods, capabilities and limitations. *Ecological Modelling*, *172*(2), 109–139. https://doi.org/10.1016/j.ecolmodel.2003.09.003

Cockrell, M., Dubickas, K., Hepner, M., Ilich, A., & McCarthy, M. (2018). Embracing Advocacy in Science. *Fisheries*, *43*(4), 179–182. https://doi.org/10.1002/fsh.10055

Codling, E. A. (2008). Individual-based movement behaviour in a simple marine reserve-fishery system: Why predictive models should be handled with care. *Hydrobiologia*, *606*(1), 55–61. https://link.springer.com/chapter/10.1007/978-1-4020-8808-7_5

Cognitive Interviewing. (2008). In *Encyclopedia of Survey Research Methods*. Sage Publications, Inc. https://doi.org/10.4135/9781412963947.n73

Coll, M., Akoglu, E., Arreguín-sánchez, F., Fulton, E. A., Gascuel, D., Heymans, J. J., Libralato, S., Mackinson, S., Palomera, I., Piroddi, C., Shannon, L. J., Steenbeek, J., Villasante, S., & Christensen, V. (2015). Modelling dynamic ecosystems: Venturing beyond boundaries with the Ecopath approach. *Reviews in Fish Biology and Fisheries*, *25*(2), 413–424. http://dx.doi.org/10.1007/s11160-015-9386-x

Collin, S. P. (2012). The Neuroecology of Cartilaginous Fishes: Sensory Strategies for Survival. *Brain, Behavior and Evolution*, *80*(2), 80–96. https://doi.org/10.1159/000339870

Comfort, S. E., & Park, Y. E. (2018). On the Field of Environmental Communication: A Systematic Review of the Peer-Reviewed Literature. *Environmental Communication*, *12*(7), 862–875. https://doi.org/10.1080/17524032.2018.1514315

Conover, R. J. (1988). Comparative life histories in the genera Calanus and Neocalanus in high latitudes of the northern hemisphere. *Hydrobiologia*, *167*(1), 127–142. https://doi.org/10.1007/BF00026299

Cook, C. N., Mascia, M. B., Schwartz, M. W., Possingham, H. P., & Fuller, R. A. (2013). Achieving Conservation Science that Bridges the Knowledge–Action Boundary. *Conservation Biology*, *27*(4), 669–678. https://doi.org/10.1111/cobi.12050

Corden, A., & Sainsbury, R. (2006). Using Verbatim Quotations in Reporting Qualitative Social Research: The views of research users. *University of. York: York: Social Policy Research Unit*.

Cotton, P., Sims, D. W., Fanshawe, S., & Chadwick, M. (2005). The effects of climate variability on zooplankton and basking shark (*Cetorhinus maximus*) relative abundance off southwest Britain. *Fisheries Oceanography*, *14*(2), 151–155. https://doi.org/10.1111/j.1365-2419.2005.00331.x

Crowe, L. M., O'Brien, O., Curtis, T. H., Leiter, S. M., Kenney, R. D., Duley, P., & Kraus, S. D. (2018). Characterization of large basking shark Cetorhinus maximus aggregations in the western North Atlantic Ocean. *Journal of Fish Biology*, *92*(5), 1371–1384. https://doi.org/10.1111/jfb.13592

DeAngelis, D. L., & Grimm, V. (2014). Individual-based models in ecology after four decades. *F1000Prime Reports*, *6*. https://doi.org/10.12703/P6-39

Department for Environment, Food & Rural Affairs. (2012). *Marine Strategy Framework Directive Consultation: Summary of Responses*. Department for Environment, Food & Rural Affairs. https://www.gov.uk/government/consultations/marine-strategy-framework-directive-consultation-uk-initial-assessment-and-proposals-for-good-environmental-status

Deterding, N. M., & Waters, M. C. (2021). Flexible Coding of In-depth Interviews: A Twenty-first-century Approach. *Sociological Methods & Research*, *50*(2), 708–739. https://doi.org/10.1177/0049124118799377

Doherty, P. D. (2017). *Basking shark movement ecology in the North-East Atlantic* [ProQuest Dissertations Publishing]. http://search.proquest.com/docview/2188989313/?pq-origsite=primo

Doherty, P. D., Baxter, J. M., Gell, F. R., Godley, B. J., Graham, R. T., Hall, G., Hall, J., Hawkes, L. A., Henderson, S. M., Johnson, L., Speedie, C. D., & Witt, M. J. (2017). Long-term satellite tracking reveals variable seasonal migration strategies of basking sharks in the north-east Atlantic. *Scientific Reports (Nature Publisher Group); London*, *7*, 42837. http://dx.doi.org/10.1038/srep42837

Doherty, P. D., Baxter, J. M., Godley, B. J., Graham, R. T., Hall, G., Hall, J., Hawkes, L. A., Henderson, S. M., Johnson, L., Speedie, C., & Witt, M. J. (2017). Testing the boundaries: Seasonal residency and inter-annual site fidelity of basking sharks in a proposed Marine Protected Area. *Biological Conservation*, *209*, 68–75. https://doi.org/10.1016/j.biocon.2017.01.018

Dove, A. D. M., & Pierce, S. J. (2021). *Whale Sharks: Biology, Ecology, and Conservation*. CRC Press.

Durán, J. M. (2020). What is a Simulation Model? *Minds and Machines*, *30*(3), 301–323. https://doi.org/10.1007/s11023-020-09520-z

Edmonds, B. (2017). Different Modelling Purposes. In B. Edmonds & R. Meyer (Eds.), *Simulating Social Complexity: A Handbook* (pp. 39–58). Springer International Publishing. https://doi.org/10.1007/978-3-319-66948-9_4

Eisinger, D., Thulke, H.-H., Selhorst, T., & Müller, T. (2005). Emergency vaccination of rabies under limited resources – combating or containing? *BMC Infectious Diseases*, *5*(1), 10. https://doi.org/10.1186/1471-2334-5-10

Epstein, G., Bennett, A., Gruby, R., Acton, L., & Nenadovic, M. (2014). Studying Power with the Social-Ecological System Framework. In M. J. Manfredo, J. J. Vaske, A. Rechkemmer, & E. A. Duke (Eds.), *Understanding Society and Natural Resources: Forging New Strands of Integration Across the Social Sciences* (pp. 111–135). Springer Netherlands. https://doi.org/10.1007/978-94-017-8959-2_6

European Commission, Directorate-General for Maritime Affairs and Fisheries, Fiorentino, F., Calleja, D., Colloca, F., Perez, M., Prato, G., Russo, T., Sabatella, R., Scarcella, G., Solidoro, C., & Vrgoč, N. (2020). *Marine protected areas: Network(s) for enhancement of sustainable fisheries in EU Mediterranean waters: MANTIS : Marine protected Areas Network Towards Sustainable fisheries in the Central Mediterranean*. Publications Office. https://doi.org/10.2771/33931

European Union-Copernicus Marine Service. (2015). *Baltic Sea- Sea Surface Temperature Reprocessed* [dataset]. Mercator Ocean International. https://doi.org/10.48670/MOI-00156

Everett, J. D., Baird, M. E., Buchanan, P., Bulman, C., Davies, C., Downie, R., Griffiths, C., Heneghan, R., Kloser, R. J., Laiolo, L., Lara-Lopez, A., Lozano-Montes, H., Matear, R. J., McEnnulty, F., Robson, B., Rochester, W., Skerratt, J., Smith, J. A., Strzelecki, J.,... Richardson, A. J. (2017). Modeling What We Sample and Sampling What We Model: Challenges for Zooplankton Model Assessment. *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00077

Fayet, A. L. (2020). Exploration and refinement of migratory routes in long-lived birds. *Journal of Animal Ecology*, *89*(1), 16–19. https://doi.org/10.1111/1365-2656.13162

Finucci, B., Duffy, C. A. J., Brough, T., Francis, M. P., Milardi, M., Pinkerton, M. H., Petersen, G., & Stephenson, F. (2021). Drivers of Spatial Distributions of Basking Shark (Cetorhinus maximus) in the Southwest Pacific. *Frontiers in Marine Science, 8*. https://www.frontiersin.org/articles/10.3389/fmars.2021.665337

Foley, G., Timonen, V., Conlon, C., & O'Dare, C. E. (2021). Interviewing as a Vehicle for Theoretical Sampling in Grounded Theory. *International Journal of Qualitative Methods, 20,* 1609406920980957. https://doi.org/10.1177/1609406920980957

Fuller, R. A., Lee, J. R., & Watson, J. E. M. (2014). Achieving Open Access to Conservation Science. *Conservation Biology*, *28*(6), 1550–1557. https://doi.org/10.1111/cobi.12346

García-Asorey, M. I., Escati-Peñaloza, G., Parma, A. M., & Pascual, M. A. (2011). Conflicting objectives in trophy trout recreational fisheries: Evaluating trade-offs using an individual-based model. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*(11), 1892.

GEBCO Bathymetric Compilation Group. (2020). *The GEBCO_2020 Grid—A continuous terrain model of the global oceans and land.* (Version 1) [Network Common Data Form]. British Oceanographic Data Centre, National Oceanography Centre, NERC, UK. https://doi.org/10.5285/A29C5465-B138-234D-E053-6C86ABC040B9

Gojovic, M. Z., Sander, B., Fisman, D., Krahn, M. D., & Bauch, C. T. (2009). Modelling mitigation strategies for pandemic (H1N1) 2009. *CMAJ : Canadian Medical Association Journal*, *181*(10), 673–680. https://doi.org/10.1503/cmaj.091641

Gordon, H. S. (1954). The Economic Theory of a Common-Property Resource: The Fishery. *Journal of Political Economy*, *62*(2), 124–142. https://doi.org/10.1086/257497

Gore, M., Abels, L., Wasik, S., Saddler, L., & Ormond, R. (2018). Are close-following and breaching behaviours by basking sharks at aggregation sites related to courtship? *Journal of the Marine Biological Association of the United Kingdom*, 1–13. https://doi.org/10.1017/S0025315418000383

Gray, C., Peters-Burton, E., Smith, C., & Parsons, E. C. M. (2022). Basking shark tourism in Donegal, Ireland – a case-study of public interest and support for shark conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *32*(3), 537–550. https://doi.org/10.1002/aqc.3774

Greenhalgh, T., & Russell, J. (2009). Evidence-Based Policymaking: A critique. *Perspectives in Biology and Medicine*, *52*(2), 304–318.

Gregory, B., Christophe, L., & Martin, E. (2009). Rapid biogeographical plankton shifts in the North Atlantic Ocean. *Global Change Biology*, *15*(7), 1790–1803. https://doi.org/10.1111/j.1365-2486.2009.01848.x

Grimm, V., Augusiak, J., Focks, A., Frank, B. M., Gabsi, F., Johnston, A. S., Liu, C., Martin, B. T., Meli, M., Radchuk, V., Thorbek, P., & Railsback, S. F. (2014). Towards better modelling and decision support: Documenting model development, testing, and analysis using TRACE. *Ecological Modelling*, *280*, 129–139. https://doi.org/10.1016/j.ecolmodel.2014.01.018

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S. K., Huse, G., Huth, A., Jepsen, J. U., Jørgensen, C., Mooij, W. M., Müller, B., Pe'er, G., Piou, C., Railsback, S. F., Robbins, A. M.,... DeAngelis, D. L. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, *198*(1), 115–126. https://doi.org/10.1016/j.ecolmodel.2006.04.023

Grimm, V., Johnston, A. S. A., Thulke, H.-H., Forbes, V. E., & Thorbek, P. (2020). Three questions to ask before using model outputs for decision support. *Nature Communications*, *11*(1), Article 1. https://doi.org/10.1038/s41467-020-17785-2

Grimm, V., & Railsback, S. (2005a). *Individual-based Modeling and Ecology*. Princeton University Press.

Grimm, V., & Railsback, S. (2005b). Introduction. In *Individual-based Modeling and Ecology:* (STU-Student edition, pp. 3–21). Princeton University Press; JSTOR. https://www.jstor.org/stable/j.ctt5hhnk8.5

Guilford, T., Freeman, R., Boyle, D., Dean, B., Kirk, H., Phillips, R., & Perrins, C. (2011). A Dispersive Migration in the Atlantic Puffin and Its Implications for Migratory Navigation. *PLOS ONE*, *6*(7), e21336. https://doi.org/10.1371/journal.pone.0021336

Häfker, N. S., Teschke, M., Last, K. S., Pond, D. W., Hüppe, L., & Meyer, B. (2018). *Calanus finmarchicus* seasonal cycle and diapause in relation to gene expression, physiology, and endogenous clocks. *Limnology and Oceanography*, *63*(6), 2815–2838. https://doi.org/10.1002/lno.11011

Hall, A. J., McConnell, B. J., Rowles, T. K., Aguilar, A., Borrell, A., Schwacke, L., Reijnders, P. J. H., & Wells, R. S. (2006). Individual-Based Model Framework to Assess Population Consequences of Polychlorinated Biphenyl Exposure in Bottlenose Dolphins. *Environmental Health Perspectives*, *114*(Suppl 1), 60–64. https://doi.org/10.1289/ehp.8053

Harvey-Clark, C. J., Stobo, W. T., Helle, E., & Mattson, M. (1999). Putative Mating Behavior in Basking Sharks off the Nova Scotia Coast. *Copeia*, *1999*(3), 780. https://doi.org/10.2307/1447614

Hayes, A., Slater, M., & Snyder, L. (2008). *The SAGE Sourcebook of Advanced Data Analysis Methods for Communication Research*. Sage Publications, Inc. https://doi.org/10.4135/9781452272054

Hays, G. C., Bailey, H., Bograd, S. J., Bowen, W. D., Campagna, C., Carmichael, R. H., Casale, P., Chiaradia, A., Costa, D. P., Cuevas, E., Nico de Bruyn, P. J., Dias, M. P., Duarte, C. M., Dunn, D. C., Dutton, P. H., Esteban, N., Friedlaender, A., Goetz, K. T., Godley, B. J.,... Sequeira, A. M. M. (2019). Translating Marine Animal Tracking Data into Conservation Policy and Management. *Trends in Ecology & Evolution*, *34*(5), 459–473. https://doi.org/10.1016/j.tree.2019.01.009

Hoelzel, R., Shivji, M., Magnussen, J., & Francis, M. (2006). Low worldwide genetic diversity in the basking shark (*Cetorhinus maximus*). *Biology Letters*, *2*(4), 639–642. https://doi.org/10.1098/rsbl.2006.0513

Holland, D. (2010). *Management Strategy Evaluation and Management Procedures: Tools for Rebuilding and Sustaining Fisheries* (OECD Food, Agriculture and Fisheries Papers 25; OECD Food, Agriculture and Fisheries Papers, Vol. 25). https://doi.org/10.1787/5kmd77jhvkjf-en

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.*

Islam, M. N., & Jørgensen, S. E. (Eds.). (2017). *Environmental Management of Marine Ecosystems*. CRC Press. https://doi.org/10.4324/9781315153933

Izumi, B. T., Schulz, A. J., Israel, B. A., Reyes, A. G., Martin, J., Lichtenstein, R. L., Wilson, C., & Sand, S. L. (2010). The One-Pager: A Practical Policy Advocacy Tool for Translating Community-Based Participatory Research Into Action.

Progress in Community Health Partnerships : Research, Education, and Action, *4*(2), 141–147. https://doi.org/10.1353/cpr.0.0114

Jeffers, V. F., & Godley, B. J. (2016). Satellite tracking in sea turtles: How do we find our way to the conservation dividends? *Biological Conservation*, *199*, 172–184. https://doi.org/10.1016/j.biocon.2016.04.032

Johns, D. (2020). *CPR_SelectzooUK* [dataset]. The Archive for Marine Species and Habitats Data (DASSH). https://doi.org/10.17031/64D23CC3A1069

Johnson, J. M. (2001). In-Depth Interviewing. In J. Gubrium & J. Holstein, *Handbook of Interview Research* (pp. 103–119). SAGE Publications, Inc. https://doi.org/10.4135/9781412973588.n8

Johnston, E. M., Halsey, L. G., Payne, N. L., Kock, A. A., Iosilevskii, G., Whelan, B., & Houghton, J. D. R. (2018). Latent power of basking sharks revealed by exceptional breaching events. *Biology Letters*, *14*(9), 20180537. https://doi.org/10.1098/rsbl.2018.0537

Johnston, E. M., Mayo, P. A., Mensink, P. J., Savetsky, E., & Houghton, J. D. R. (2019). Serendipitous re-sighting of a basking shark *Cetorhinus maximus* reveals inter-annual connectivity between American and European coastal hotspots. *Journal of Fish Biology*, *95*(6), 1530–1534. https://doi.org/10.1111/jfb.14163

Kaplan, I. C., Gaichas, S. K., Stawitz, C. C., Lynch, P. D., Marshall, K. N., Deroba, J. J., Masi, M., Brodziak, J. K. T., Aydin, K. Y., Holsman, K., Townsend, H., Tommasi, D., Smith, J. A., Koenigstein, S., Weijerman, M., & Link, J. (2021). Management Strategy Evaluation: Allowing the Light on the Hill to Illuminate

More Than One Species. *Frontiers in Marine Science*, *8*, 624355. https://doi.org/10.3389/fmars.2021.624355

Kingdon, J. W. (1984). *Agendas, alternatives, and public policies*. Little, Brown and Company.

Knafl, K., Deatrick, J., Gallo, A., Holcombe, G., Bakitas, M., Dixon, J., & Grey, M. (2007). The analysis and interpretation of cognitive interviews for instrument development. *Research in Nursing & Health*, *30*(2), 224–234. https://doi.org/10.1002/nur.20195

Koehler, L., & Lowther, J. (2022). Policy making for sharks and the role and contribution of non-governmental organisations in the fulfilment of international legal obligations. *Marine Policy*, *144*, 105228. https://doi.org/10.1016/j.marpol.2022.105228

Kolkman, D. A., Campo, P., Balke-Visser, T., & Gilbert, N. (2016). How to build models for government: Criteria driving model acceptance in policymaking. *Policy Sciences*, *49*(4), 489–504. https://doi.org/10.1007/s11077-016-9250-4

Leith, P., Warman, R., Harwood, A., Bosomworth, K., & Wallis, P. (2018). An operation on ‘the neglected heart of science policy’: Reconciling supply and demand for climate change adaptation research. *Environmental Science & Policy*, *82*, 117–125. https://doi.org/10.1016/j.envsci.2018.01.015

Lemos, M. C., Kirchhoff, C. J., Kalafatis, S. E., Scavia, D., & Rood, R. B. (2014). Moving Climate Information off the Shelf: Boundary Chains and the Role of

RISAs as Adaptive Organizations. *Weather, Climate, and Society*, *6*(2), 273–285. https://doi.org/10.1175/WCAS-D-13-00044.1

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climate Change*, *2*(11), 789–794. https://www.nature.com/articles/nclimate1614

Lieber, L., Hall, G., Hall, J., Berrow, S., Johnston, E., Gubili, C., Sarginson, J., Francis, M., Duffy, C., Wintner, S. P., Doherty, P. D., Godley, B. J., Hawkes, L. A., Witt, M. J., Henderson, S. M., de Sabata, E., Shivji, M. S., Dawson, D. A., Sims, D. W.,... Noble, L. R. (2020). Spatio-temporal genetic tagging of a cosmopolitan planktivorous shark provides insight to gene flow, temporal variation and site-specific re-encounters. *Scientific Reports*, *10*(1), Article 1. https://doi.org/10.1038/s41598-020-58086-4

Lorig, F., Johansson, E., & Davidsson, P. (2021). Agent-Based Social Simulation of the Covid-19 Pandemic: A Systematic Review. *Journal of Artificial Societies and Social Simulation*, *24*(3), 5.

MacKenzie, D. (1998). The Certainty Trough. In R. Williams, W. Faulkner, & J. Fleck (Eds.), *Exploring Expertise: Issues and Perspectives* (pp. 325–329). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-13693-3_15

Maeda, E. E., Haapasaari, P., Helle, I., Lehikoinen, A., Voinov, A., & Kuikka, S. (2021). Black Boxes and the Role of Modeling in Environmental Policy Making. *Frontiers in Environmental Science*, *9*. https://www.frontiersin.org/articles/10.3389/fenvs.2021.629336

Marine Protected Area Advisory Group. (2020). *Expanding Ireland's Marine Protected Area Network*. Department of Housing, Local Government and Heritage. https://www.gov.ie/en/publication/135a8-expanding-irelands-marine-protected-area-network/

Marine science (Ninth Report of Session 2012–13). (2013). House of Commons Science and Technology Committee. https://publications.parliament.uk/pa/cm201213/cmselect/cmsctech/727/727.pdf

Marine Scotland. (2020). *Designation of four Marine Protected Areas in Scottish waters: Consultation analysis*. Minister for Rural Affairs and the Natural Environment. https://www.gov.scot/publications/consultation-proposals-designate-four-marine-protected-areas-scottish-waters-consultation-analysis-report/

Mayan, M. J. (2016). *Essentials of qualitative inquiry*. Routledge.

McBryde, E. S., Meehan, M. T., Adegboye, O. A., Adekunle, A. I., Caldwell, J. M., Pak, A., Rojas, D. P., Williams, B. M., & Trauer, J. M. (2020). Role of modelling in COVID-19 policy development. *Paediatric Respiratory Reviews*, *35*, 57–60. https://doi.org/10.1016/j.prrv.2020.06.013

McConnell, A., & Hart, P. (2019). Inaction and public policy: Understanding why policymakers 'do nothing.' *Policy Sciences*, *52*(4), 645–661. https://doi.org/10.1007/s11077-019-09362-2

Mcintosh, B., Giupponi, C., Voinov, A., Smith, C., Matthews, K., Monticino, M., Kolkman, M., Crossman, N., Ittersum, M. van, Haase, D., Haase, A., Mysiak, J., Groot, J., Sieber, S., Verweij, P., Quinn, N., Waeger, P., Gaber, N., Hepting, D.,...

Assaf, H. (2008). Bridging the Gaps between Design and Use: Developing Tools to Support Environmental Management and Policy. *U.S. Environmental Protection Agency Papers*. https://digitalcommons.unl.edu/usepapapers/71

McInturf, A. G., Bowman, J., Schulte, J. M., Newton, K. C., Vigil, B., Honig, M., Pelletier, S., Cox, N., Lester, O., Cantor, M., & Chapple, T. K. (2023). A unified paradigm for defining elasmobranch aggregations. *ICES Journal of Marine Science*, fsad099. https://doi.org/10.1093/icesjms/fsad099

McInturf, A. G., Muhling, B., Bizzarro, J. J., Fangue, N. A., Ebert, D. A., Caillaud, D., & Dewar, H. (2022). Spatial Distribution, Temporal Changes, and Knowledge Gaps in Basking Shark (Cetorhinus maximus) Sightings in the California Current Ecosystem. *Frontiers in Marine Science, 9*. https://www.frontiersin.org/articles/10.3389/fmars.2022.818670

Melle, W., Runge, J., Head, E., Plourde, S., Castellani, C., Licandro, P., Pierson, J., Jonasdottir, S., Johnson, C., Broms, C., Debes, H., Falkenhaug, T., Gaard, E., Gislason, A., Heath, M., Niehoff, B., Nielsen, T. G., Pepin, P., Stenevik, E. K., & Chust, G. (2014). The North Atlantic Ocean as habitat for *Calanus finmarchicus*: Environmental factors and life history traits. *Progress in Oceanography*, *129*, 244–284. https://doi.org/10.1016/j.pocean.2014.04.026

Mika, A. M., & Newman, J. A. (2010). Climate change scenarios and models yield conflicting predictions about the future risk of an invasive species in North America. *Agricultural and Forest Entomology*, *12*(3), 213–221. https://doi.org/10.1111/j.1461-9563.2009.00464.x

Miller, P. I., Scales, K. L., Ingram, S. N., Southall, E. J., & Sims, D. W. (2015). Basking sharks and oceanographic fronts: Quantifying associations in the north-east Atlantic. *Functional Ecology*, *29*(8), 1099–1109. https://doi.org/10.1111/1365-2435.12423

Milne, G. J., Kelso, J. K., Kelly, H. A., Huband, S. T., & McVernon, J. (2008). A Small Community Model for the Transmission of Infectious Diseases: Comparison of School Closure as an Intervention in Individual-Based Models of an Influenza Pandemic. *PLoS One*, *3*(12), e4005. https://doi.org/10.1371/journal.pone.0004005

Mintrom, M., & Norman, P. (2009). Policy Entrepreneurship and Policy Change. *Policy Studies Journal*, *37*(4), 649–667. https://doi.org/10.1111/j.1541-0072.2009.00329.x

MORPH. (n.d.). *Bournemouth University Individual Ecology*. Retrieved March 30, 2023, from https://www.individualecology.com/morph/

Murphy, K. J., Ciuti, S., & Kane, A. (2020). An introduction to agent-based models as an accessible surrogate to field-based research and teaching. *Ecology and Evolution*, *10*(22), 12482–12498. https://doi.org/10.1002/ece3.6848

Natugonza, V., Ainsworth, C., Sturludóttir, E., Musinguzi, L., Ogutu-Ohwayo, R., Tomasson, T., Nyamweya, C., & Stefansson, G. (2020). Ecosystem modelling of data-limited fisheries: How reliable are Ecopath with Ecosim models without historical time series fitting? *Journal of Great Lakes Research*, *46*(2), 414–428. https://doi.org/10.1016/j.jglr.2020.01.001

Nature Scot. (2020). *NatureScot has today welcomed the designation of 12 Special Protection Areas (SPAs) and four Marine Protected Areas (MPAs) in Scotland's seas*. https://www.nature.scot/iconic-species-protected-marine-designations

Nelson, M. P., & Vucetich, J. A. (2009). On Advocacy by Environmental Scientists: What, Whether, Why, and How. *Conservation Biology*, *23*(5), 1090–1101. https://doi.org/10.1111/j.1523-1739.2009.01250.x

Nutley, S., Huw, D., & Hughes, J. (2019). Assessing and Labelling Evidence. In A. Boaz, H. T. O. Davies, A. Fraser, & S. M. Nutley (Eds.), *What works now?: Evidence-informed policy and practice*. Policy Press.

Ortiz, M., & Jordán, F. (2021). *Marine coastal ecosystems modelling and conservation: Latin american experiences* (1st ed. 2021.). Springer. https://doi.org/10.1007/978-3-030-58211-1

OSPAR Commission. (2015). *Background Document for Basking Shark Cetorhinus maximus*. Convention for the Protection of the Marine Environment of the North-East Atlantic.

Paolisso, M., Trombley, J., Hood, R. R., & Sellner, K. G. (2015). Environmental Models and Public Stakeholders in the Chesapeake Bay Watershed. *Estuaries and Coasts*, *38*(1), 97–113. https://doi.org/10.1007/s12237-013-9650-z

Parsons, E. C. M. (2016). Why IUCN Should Replace "Data Deficient" Conservation Status with a Precautionary "Assume Threatened" Status—A Cetacean Case Study. *Frontiers in Marine Science*, *3*. https://www.frontiersin.org/articles/10.3389/fmars.2016.00193

Parsons, E. C. M., DellaSala, D. A., & Wright, A. J. (2015). Is Marine Conservation Science Becoming Irrelevant to Policy Makers? *Frontiers in Marine Science*, *2*. https://doi.org/10.3389/fmars.2015.00102

Perl, A., Howlett, M., & Ramesh, M. (2018). Policy-making and truthiness: Can existing policy models cope with politicized evidence and willful ignorance in a "post-fact" world? *Policy Sciences*, *51*(4), 581–600. https://link.springer.com/article/10.1007/s11077-018-9334-4

Pilkey, O. H. (2007). *Useless arithmetic: Why environmental scientists can't predict the future*. Columbia University Press.

Planque, B., Aarflot, J. M., Buttay, L., Carroll, J., Fransner, F., Hansen, C., Husson, B., Langangen, Ø., Lindstrøm, U., Pedersen, T., Primicerio, R., Sivel, E., Skogen, M. D., Strombom, E., Stige, L. C., Varpe, Ø., & Yoccoz, N. G. (2022). A standard protocol for describing the evaluation of ecological models. *Ecological Modelling*, *471*, 110059. https://doi.org/10.1016/j.ecolmodel.2022.110059

Powell, K. (2016). Does it take too long to publish research? *Nature*, *530*(7589), Article 7589. https://doi.org/10.1038/530148a

Pullin, A. S., & Knight, T. M. (2003). Support for decision making in conservation practice: An evidence-based approach. *Journal for Nature Conservation*, *11*(2), 83–90. https://doi.org/10.1078/1617-1381-00040

Pullin, A. S., & Knight, T. M. (2005). Assessing Conservation Management's Evidence Base: A Survey of Management-Plan Compilers in the United Kingdom and

Australia. *Conservation Biology*, *19*(6), 1989–1996. https://doi.org/10.1111/j.1523-1739.2005.00287.x

Radaelli, C. M. (2004). The diffusion of regulatory impact analysis – Best practice or lesson-drawing? *European Journal of Political Research*, *43*(5), 723–747. https://doi.org/10.1111/j.0304-4130.2004.00172.x

Railsback, S., Ayllón, D., & Harvey, B. C. (2021). InSTREAM 7: Instream flow assessment and management model for stream trout. *River Research and Applications*. https://doi.org/10.1002/rra.3845

Railsback, S., & Grimm, V. (2011). *Agent-Based and Individual-Based Modeling: A Practical Introduction*. Princeton University Press.

Railsback, S., & Grimm, V. (2019). *Agent-Based and Individual-Based Modeling* (2nd ed.). https://press.princeton.edu/books/hardcover/9780691190822/agent-based-and-individual-based-modeling

Reed, M., & Meagher, L. (2019). Using evidence in environmental and sustainability issues. In A. Boaz, H. T. O. Davies, A. Fraser, & S. M. Nutley (Eds.), *What works now?: Evidence-informed policy and practice*. Policy Press.

Richardson, A. J., Walne, A. W., John, A. W. G., Jonas, T. D., Lindley, J. A., Sims, D. W., Stevens, D., & Witt, M. (2006). Using continuous plankton recorder data. *Progress in Oceanography*, *68*(1), 27–74. https://doi.org/10.1016/j.pocean.2005.09.011

Rose, D. (2015). The case for policy-relevant conservation science. *Conservation Biology*, *29*(3), 748–754. https://doi.org/10.1111/cobi.12444

Rose, N., & Parsons, E. C. M. (2015). “Back off, man, I’m a scientist!” When marine conservation science meets policy. *Ocean & Coastal Management*, *115*, 71–76. https://doi.org/10.1016/j.ocecoaman.2015.04.016

Rudd, J. L., Exeter, O. M., Hall, J., Hall, G., Henderson, S. M., Kerry, C., Witt, M. J., & Hawkes, L. A. (2021). High resolution biologging of breaching by the world’s second largest shark species. *Scientific Reports*, *11*(1), Article 1. https://doi.org/10.1038/s41598-021-84670-3

Ryan, K., Gannon-Slater, N., & Culbertson, M. J. (2012). Improving Survey Methods With Cognitive Interviews in Small- and Medium-Scale Evaluations. *American Journal of Evaluation*, *33*(3), 414–430. https://doi.org/10.1177/1098214012441499

Salajan, A., Tsolova, S., Massimo Ciotti, & Suk, J. E. (2020). To what extent does evidence support decision making during infectious disease outbreaks? A scoping literature review. *Evidence & Policy: A Journal of Research, Debate and Practice*, *16*(3), 453–475. https://doi.org/10.1332/174426420X15808913064302

Sarewitz, D., & Pielke, R. A. (2007). The neglected heart of science policy: Reconciling supply of and demand for science. *Environmental Science & Policy*, *10*(1), 5–16. https://doi.org/10.1016/j.envsci.2006.10.001

Schmolke, A., Thorbek, P., DeAngelis, D. L., & Grimm, V. (2010). Ecological models supporting environmental decision making: A strategy for the future. *Trends in Ecology & Evolution*, *25*(8), 479–486. https://doi.org/10.1016/j.tree.2010.05.001

Serra, H., & Godoy, W. A. C. (2011). Using Ecological Modeling to Enhance Instruction in Population Dynamics and to Stimulate Scientific Thinking. *Creative Education*, *2*(2), Article 2. https://doi.org/10.4236/ce.2011.22012

Setterfield, M. (2018). Can monetary policy survive policy model mis-specification? Model uncertainty and the perils of "policy model complacency." *Metroeconomica*, *69*(1), 2–15. https://doi.org/10.1111/meca.12163

Shiffman, D. S., Macdonald, C. C., Wallace, S. S., & Dulvy, N. K. (2021). The role and value of science in shark conservation advocacy. *Scientific Reports*, *11*(1), Article 1. https://doi.org/10.1038/s41598-021-96020-4

Silverman, E. (2018). *Methodological Investigations in Agent-Based Modelling: With Applications for the Social Sciences*. Springer International Publishing. https://doi.org/10.1007/978-3-319-72408-9

Sims, D. W. (2000). Filter-feeding and cruising swimming speeds of basking sharks compared with optimal models: They filter-feed slower than predicted for their size. *Journal of Experimental Marine Biology and Ecology*, *249*(1), 65–76. https://doi.org/10.1016/S0022-0981(00)00183-0

Sims, D. W. (2008). Chapter 3 Sieving a Living. In *Advances in Marine Biology* (Vol. 54, pp. 171–220). Elsevier. https://doi.org/10.1016/S0065-2881(08)00003-5

Sims, D. W., Berrow, S. D., O'Sullivan, K. M., Pfeiffer, N. J., Collins, R., Smith, K. L., Pfeiffer, B. M., Connery, P., Wasik, S., Flounders, L., Queiroz, N., Humphries, N. E., Womersley, F. C., & Southall, E. J. (2022). Circles in the sea: Annual courtship "torus" behaviour of basking sharks Cetorhinus maximus identified in the eastern North Atlantic Ocean. *Journal of Fish Biology*, 1–22. https://doi.org/10.1111/jfb.15187

Sims, D. W., & Merrett, D. A. (1997). Determination of zooplankton characteristics in the presence of surface feeding basking sharks *Cetorhinus maximus*. *Marine Ecology Progress Series*, *158*, 297–302.

Sims, D. W., & Quayle, V. A. (1998). Selective foraging behaviour of basking sharks on zooplankton in a small-scale front. *Nature*, *393*(6684), 460–464. https://doi.org/10.1038/30959

Sims, D. W., & Reid, P. C. (2002). Congruent trends in long-term zooplankton decline in the north-east Atlantic and basking shark (*Cetorhinus maximus*) fishery catches off west Ireland. *Fisheries Oceanography*, *11*(1), 59–63. https://doi.org/10.1046/j.1365-2419.2002.00189.x

Sims, D. W., Southall, E. J., Quayle, V. A., & Fox, A. M. (2000). Annual social behaviour of basking sharks associated with coastal front areas. *Proceedings of the Royal Society B: Biological Sciences*, *267*(1455), 1897–1904. https://doi.org/10.1098/rspb.2000.1227

Skomal, G., Zeeman, S., Chisholm, J., Summers, E., Walsh, H., McMahon, K., & Thorrold, S. (2009). Transequatorial Migrations by Basking Sharks in the Western Atlantic Ocean. *Current Biology*, *19*(12), 1019–1022. https://doi.org/10.1016/j.cub.2009.04.019

Snyder, M. N., Schumaker, N. H., Ebersole, J. L., Dunham, J. B., Comeleo, R. L., Keefer, M. L., Leinenbach, P., Brookes, A., Cope, B., Wu, J., Palmer, J., & Keenan, D.

(2019). Individual based modeling of fish migration in a 2-D river system: Model description and case study. *Landscape Ecology*, *34*(4), 737–754. https://link.springer.com/article/10.1007/s10980-019-00804-z

Speedie, C. D., Johnson, L. A., & Witt, M. J. (2009). *Basking Shark Hotspots on the West Coast of Scotland: Key sites, threats and implications for conservation of the species* (Commissioned Report No.339).

Squazzoni, F., & Boero, R. (2010). Complexity-Friendly Policy Modelling. In *Innovation in Complex Social Systems, edited by Petra Ahrweiler* (pp. 290–299). New York: Routledge.

Stamatakis, K. A., McBride, T. D., & Brownson, R. C. (2010). Communicating Prevention Messages to Policy Makers: The Role of Stories in Promoting Physical Activity. *Journal of Physical Activity & Health*, *7*(0 1), S99-107.

Steel, B., List, P., Lach, D., & Shindler, B. (2004). The role of scientists in the environmental policy process: A case study from the American west. *Environmental Science & Policy*, *7*(1), 1–13. https://doi.org/10.1016/j.envsci.2003.10.004

Sterling, E. J., Betley, E., Sigouin, A., Gomez, A., Toomey, A., Cullman, G., Malone, C., Pekor, A., Arengo, F., Blair, M., Filardi, C., Landrigan, K., & Porzecanski, A. L. (2017). Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biological Conservation*, *209*, 159–171. https://doi.org/10.1016/j.biocon.2017.02.008

Stringer, L. C., & Dougill, A. J. (2013). Channelling science into policy: Enabling best practices from research on land degradation and sustainable land management in dryland Africa. *Journal of Environmental Management*, *114*(15), 328–335. https://doi.org/10.1016/j.jenvman.2012.10.025

Suhay, E., & Cloyd, E. T. (2018, December 10). *Incentives, Opportunities, and Success? AAAS Members' Experiences Communicating with Policymakers*. AGU Fall Meeting 2018. https://agu.confex.com/agu/fm18/meetingapp.cgi/Paper/394004

Süsser, D., Ceglarz, A., Gaschnig, H., Stavrakas, V., Flamos, A., Giannakidis, G., & Lilliestam, J. (2021). Model-based policymaking or policy-based modelling? How energy models and energy policy interact. *Energy Research & Social Science*, *75*, 101984. https://doi.org/10.1016/j.erss.2021.101984

Syme, G., Bennett, D., Macpherson, D., & Thomas, J. (2011, December 12). Guidelines for policy modellers – 30 years on: New tricks or old dogs? *Chan, F., Marinova, D. and Anderssen, R.S. (Eds) MODSIM2011, 19th International Congress on Modelling and Simulation.* 19th International Congress on Modelling and Simulation. https://doi.org/10.36334/modsim.2011.G6.syme

Thorne, S. (2020). On the use and abuse of verbatim quotations in qualitative research reports. *Nurse Author & Editor*, *30*(3), 4–6. https://doi.org/10.1111/nae2.2

Thornhill, J. L. (2014). *Bridging the Gap between Research and Decision-Making: Empirical Evidence from a Case Study of Gray Wolf (Canis lupus) Management in the U.S.* [Ph.D., George Mason University].

http://search.proquest.com/docview/1556432405/abstract/28C4434EE9FB4EFFPQ/1

Toomey, A. H., Knight, A. T., & Barlow, J. (2017). Navigating the Space between Research and Implementation in Conservation. *Conservation Letters*, *10*(5), 619–625. https://doi.org/10.1111/conl.12315

Tuinstra, W. (2022). Air Pollution, Science, Policy, and International Negotiations. *Oxford Research Encyclopedia of Environmental Science*. https://doi.org/10.1093/acrefore/9780199389414.013.730

Tuinstra, W., Hordijk, L., Mol, A. P. J., Hisschemoeller, M., & Berk, M. (2002). *Climate OptiOns for the Long term (COOL). Synthesis Report*. https://www.osti.gov/etdeweb/biblio/20309687

Turnhout, E., Stuiver, M., Klostermann, J., Harms, B., & Leeuwis, C. (2013). New roles of science in society: Different repertoires of knowledge brokering. *Science and Public Policy*, *40*(3), 354–365. https://doi.org/10.1093/scipol/scs114

Turnpenny, J., Radaelli, C. M., Jordan, A., & Jacob, K. (2009). The Policy and Politics of Policy Appraisal: Emerging Trends and New Directions. *Journal of European Public Policy*, *16*(4), 640–653. https://doi.org/10.1080/13501760902872783

Uchmański, J., & Grimm, V. (1996). Individual-based modelling in ecology: What makes the difference? *Trends in Ecology & Evolution*, *11*(10), 437–441. https://doi.org/10.1016/0169-5347(96)20091-6

Walsh, J. C., Dicks, L. V., & Sutherland, W. J. (2015). The effect of scientific evidence on conservation practitioners' management decisions. *Conservation Biology, 29*(1), 88–98. https://doi.org/10.1111/cobi.12370

Weiner, S. (2011). How information literacy becomes policy: An analysis using the Multiple Streams Framework. *Library Trends*. https://doi.org/10.1353/lib.2011.0037

Wilhelm-Rechmann, A., & Cowling, R. M. (2011). Framing biodiversity conservation for decision makers: Insights from four South African municipalities. *Conservation Letters*, *4*(1), 73–80. https://doi.org/10.1111/j.1755-263X.2010.00149.x

Will, M., Dressler, G., Kreuer, D., Thulke, H., Grêt-Regamey, A., & Müller, B. (2021). How to make socio-environmental modelling more useful to support policy and management? *People and Nature*, *3*(3), 560–572. https://doi.org/10.1002/pan3.10207

Williams, R., Lacy, R. C., Ashe, E., Hall, A., Lehoux, C., Lesage, V., McQuinn, I., & Plourde, S. (2017). *Predicting responses of St. Lawrence beluga to environmental change and anthropogenic threats to orient effective management actions*. Fisheries and Oceans Canada: Canadian Science Advisory Secretariat. https://waves-vagues.dfo-mpo.gc.ca/Library/40605772.pdf

Wilson, R. J., Heath, M. R., & Speirs, D. C. (2016). Spatial Modeling of Calanus finmarchicus and Calanus helgolandicus: Parameter Differences Explain Differences in Biogeography. *Frontiers in Marine Science, 3*. https://doi.org/10.3389/fmars.2016.00157

Yin, R. K. (2014). *Case Study Research Design and Methods (5th ed.)*. SAGE Publications, Inc.

BIOGRAPHY

Chelsea Gray earned a Master of Science (George Mason University, Department of Environmental Science and Policy) in 2019, researching support for basking shark conservation and interest in shark tourism. She was Secretary (2017—2019), Vice president (2020) and president (2021) of the Conservation Marketing and Engagement Working Group (Society for Conservation Biology). She was an outreach assistant for the Potomac Environmental Research and Education Center from 2016—2023 and has produced numerous educational articles and videos. She is currently a researcher and science communicator with the Irish Basking Shark Group. Chelsea is dedicated to scientific outreach, education, behavior change, and has a deep love of interdisciplinary research. She is also a strong advocate of women in science and an Irish language speaker.