Application for SCOR Working Groups 2019

Marine Species Distribution Modelling

in the global ocean (MSDM-GO)

Abstract

Understanding the drivers that control the distribution of species and habitats is a fundamental requirement for conservation and management, particularly when predicting their response to anthropogenic stressors including climate change. Over the last decade, the use of species distribution modelling (SDM) in the marine environment has proliferated, driven largely by 1) an increased accessibility of distributional data, 2) global datasets of environmental predictors, 3) a diversity of modelling tools and 4) increased demands by managers and conservationists to be better informed about the distribution of species now and into the future. SDMs typically build a statistical understanding of the relationship between species occurrences and/or their biological responses and environmental drivers (e.g., temperature, depth, food supplies), requiring a multidisciplinary understanding that bridges statistics, biology and physical oceanography. With a lower barrier to entry, SDMs are being used by increasing numbers of researchers. However, without robust guidance and benchmarking standards, the quality of studies generated by increased SDM use varies widely, reducing confidence and uptake by stakeholders. This SCOR WG will develop community-driven best-practice guidance that will enable the development of next-generation marine distributional models that will drive policy and practice globally. Given the international effort to map the global seabed at high-resolution by 2030 (Nippon Foundation-GEBCO), the 2021 launch of the UN Decade of Ocean Science for Sustainable Development, and an ever-increasing amount and quality of available observation and environmental data, it is important that these guidelines are established in order to maximize the scientific and societal impact of marine SDMs.

Scientific Background and Rationale

Many marine environments are under intense and increasing anthropogenic pressure, both from climate change and direct impact from sources such as commercial fishing, oil and gas exploration, and aggregate or mineral extraction activities (e.g., Davies et al. 2007). This pressure is especially problematic given that much of the global ocean remains unmapped, uncharacterized and under-explored, particularly with respect to biodiversity (Ramirez-Llodra et al. 2010). Consequently, scientists and stakeholders face unique challenges and urgency in the study and management of most ocean ecosystems (e.g., Auster et al. 2011). Recent technological advancements in ocean data collection have greatly advanced our ability to explore, observe and ultimately exploit ocean ecosystems (Danovaro et al. 2014). Coupled with improved access to data through open access initiatives, global scale environmental datasets and the emergence of spatially and taxonomically comprehensive databases, these advances have the potential to enable the marine scientific community to better understand the ocean environment and the organisms that reside within. However, success is contingent on engagement across the broader community of marine scientists, policy makers and managers. SCOR and its partners have the means to achieve this, providing access and influence beyond a single national project and will draw global attention to our outputs which are tailored to support near- and long-term management and policy decisions.

Our current knowledge of marine systems is spatially variable, biased towards locations near well developed countries and shallow, continental shelf depths (Robinson et al. 2011; Vierod et al. 2014; Robinson et al. 2017). However, the wider ocean, particularly areas that lie beyond national jurisdiction where anthropogenic impacts nonetheless occur and are likely to increase, remains largely data poor (e.g. Southern Ocean, South Pacific). This general paucity of information, and ever-expanding footprint of anthropogenic activity, leads to an urgent need for the development of scientific methods that accurately describe the distribution of species and biodiversity in the marine environment.

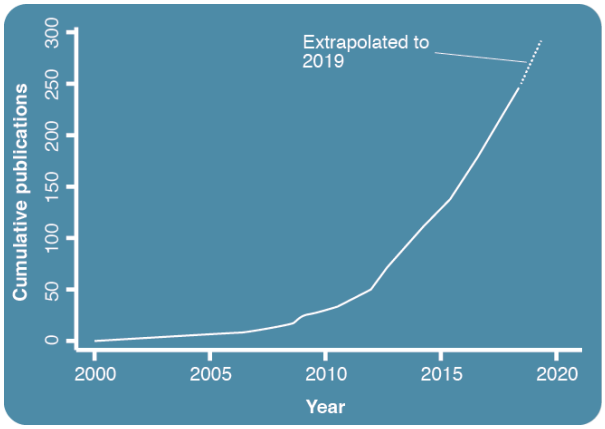

Fig 1: Cumulative number of publications from Scopus (Mar 2019) for the search term: (Ocean AND ("species distribution model" OR "habitat suitability model")).

Application of SDM in marine systems

One tool that can address gaps in our knowledge and has seen rapid adoption in a variety of marine ecosystems is species distribution modelling (SDM; Figs 1 and 2)

(Robinson et al. 2011; Robinson et al. 2017). Constructing marine SDMs (MSDM) is a challenging and multi-faceted process (Fig 2), that requires a broad understanding of not only statistical modelling techniques, but also of species biology and ecology, bathymetric, geological and habitat mapping, physical oceanography and data handling (Vierod et al. 2014). SDMs take three main forms, 1) correlative, 2) hybrid correlative and process-based, and 3) mechanistic (Fig 2). Correlative models are currently the most commonly used in marine systems. They are empirical models that relate data from species occurrences (and sometimes absences) to a selection of ecologically relevant biological, environmental or spatial variables, deriving an understanding of a species niche (Guisan and Zimmermann 2000). These models can then be extrapolated geographically into areas where environmental data are available to predict the potential distribution of a species in unsurveyed locations or times. Hybrid and mechanistic models are rarely used in marine systems, largely due to the specific data requirements that are needed to apply such approaches, but adoption is emerging (e.g. Schibalski et al. 2018; Thomas and Bacher 2018).

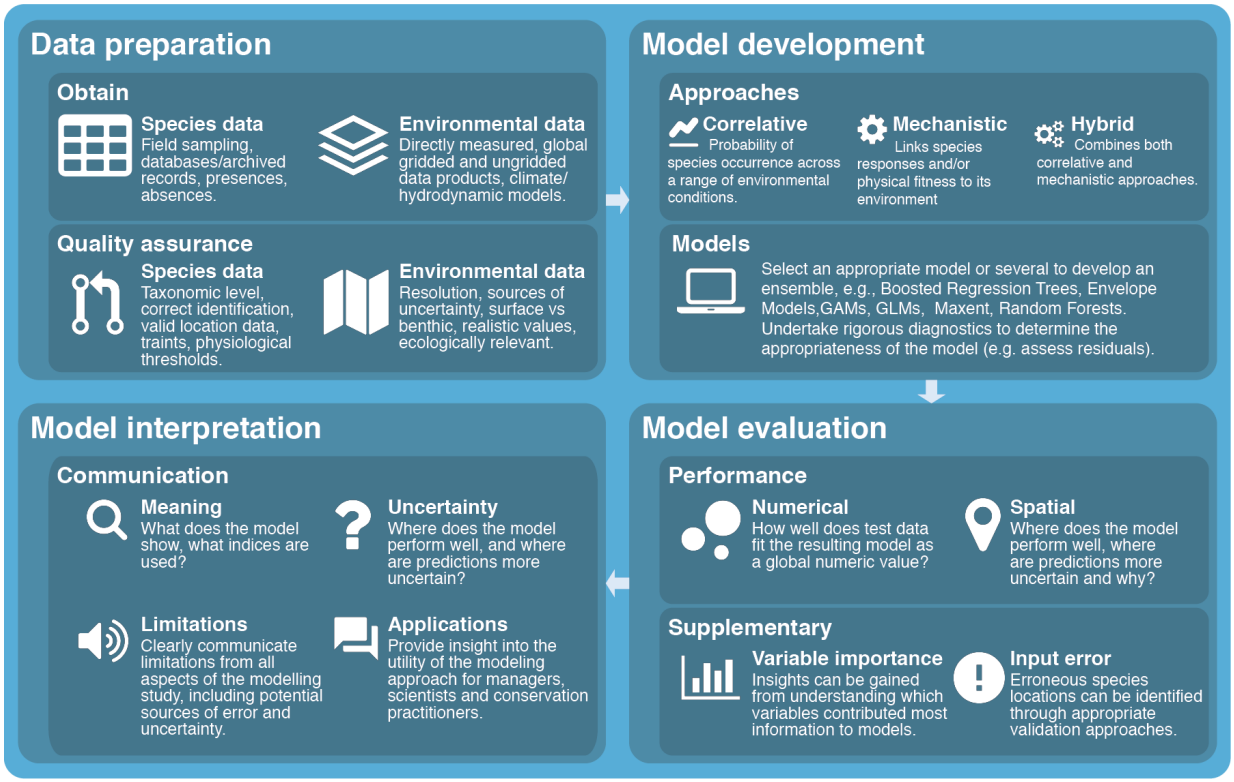

Fig 2: Flow diagram of the MSDM development.

SDMs have been employed in many marine environments, ranging from shallow coastal waters (Robinson et al. 2017) to the deep ocean (Vierod et al. 2014), at a variety of spatial scales, including local, regional and global. In terms of taxonomic application, fish are the most common group modeled, followed by marine mammals, macroalgae, seabirds and

corals (Robinson et al. 2011; Robinson et al. 2017). MSDMs have been used for a variety of purposes, including 1) marine spatial planning (both management and conservation perspectives) (e.g., Gormley et al. 2014), 2) MPA network planning (e.g., Hooker et al. 2011), 3) distribution assessment of taxa or living marine resources (e.g., Yesson et al. 2012), 4) extent assessment of vulnerable marine ecosystems (e.g., Howell et al. 2016), 5) delineation of essential fish habitats, including the abundance of juveniles (e.g., Asjes et al. 2016), the abundance of adults at spawning stage (e.g., González-Irusta and Wright 2015) and fish egg distribution (e.g., Loots et al. 2011), 6) studying responses to anthropogenic impacts (e.g., Foster et al. 2015), 7) determining species responses to climate change (e.g., Jueterbock et al. 2013), and 8) studying biological invasions and disease risk (e.g., Tanaka et al. 2017) (Fig 3).

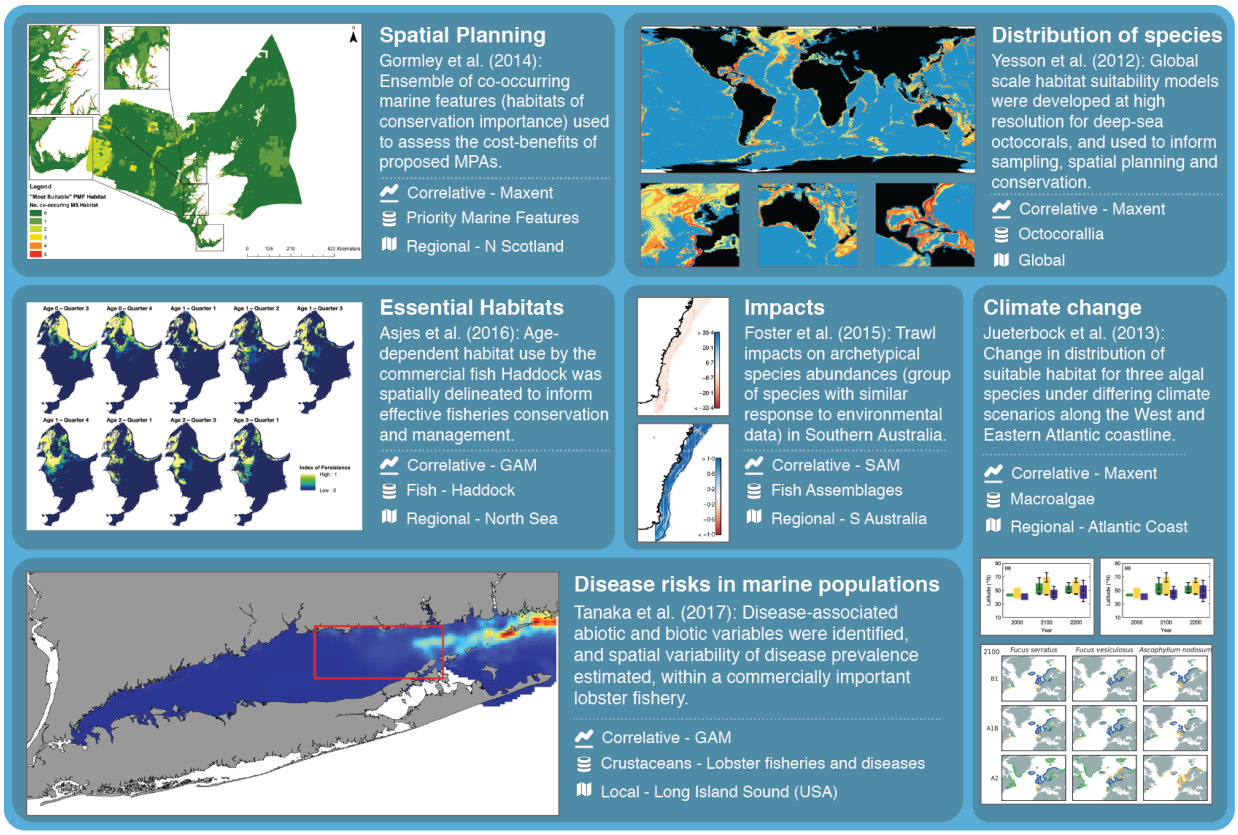

Fig 3: Examples of the potential uses of published MSDMs.

Challenges for MSDMs

The underlying data and techniques required for robust MSDMs have developed rapidly in the last decade, but there are limitations that hinder the adoption of outputs by the marine scientific and policy communities. If they are to embrace MSDMs in planning, five main criteria must be met and clearly explained:

- *Relevance*: MSDMs should be relevant to the management, scientific or conservation task at hand. For example, much of the distribution data for marine organisms comes with a level of taxonomic uncertainty (e.g., identifying species from images can be difficult) and spatial bias (i.e., datasets largely comprised of ad hoc rather than structured data collection), which are often not considered in detail within MSDM studies.
- *Scale*: MSDMs should be developed at an appropriate resolution, not coarser or finer than is required by stakeholders, as this can create difficulties in adopting them into spatial management plans, or at scales that are unsuitable for input data (e.g., how the variance in observations is related to the spatial and temporal variance in covariates).
- *Appropriate and conservative approaches*: Reliance on a model approach without sufficient diagnostics or consideration of assumptions, can reduce confidence in MSDMs. Well justified single or multiple model approaches are more trusted by stakeholders and can be particularly important in data-poor regions.
- *Verifiable*: The use of appropriate and understandable validation approaches (e.g., correlation metrics, area under curve, *k*-fold, cross-validation), that may include independent test data or field validation and consider the sampling bias evident in many marine observations, are highly valued by stakeholders.
- *Uncertainty*: Understanding the uncertainty in input data and resulting predictions is important for communicating the limitations of outputs. Any sources of error in an MSDM output must be explained and, if appropriate, demonstrated spatially, a particularly useful resource for designing spatial management measures.

Meeting these criteria has been an issue for many MSDM efforts, largely due to highly variable data quality, lack of access to appropriate tutorials regarding best-practice and a disconnect with end-user stakeholders. There is also a need for openness and reproducibility associated with MSDMs and their inputs (e.g., distribution or environmental), and outputs (e.g., predictive surfaces, uncertainty surfaces), and the approaches used, which would facilitate uptake and advance the scientific community. This SCOR WG, through its global and multifaceted approach will address these issues, leading to coherent improvement in the application of MSDM. We will engage the MSDM community in creating a best-practice framework, and supplement this by providing developers with the appropriate tools and examples to enhance practice. Ultimately, we aim to strengthen the adoption of MSDMs by management and policy makers. With multiple international efforts, currently ongoing or planned, which aim to enhance data collection in the ocean (e.g., Nippon Foundation-GEBCO, UN Decade of Ocean Science for Sustainable Development), there is a pressing need to ensure that practitioners are able to adopt a rigorous and effective MSDM framework that is accepted by stakeholders.

Terms of Reference

1. Identify best practices for the development of marine species distribution models (MSDMs), identify current gaps and limitations in MSDM applications, provide guidance on future MSDM development and publish this in a peer-reviewed output.
2. Increase access to prior-published MSDM outputs (including input and output datasets) and computer code by a) promoting open access, transparency and repeatability and b) the development of a data portal (oceanmodels.org) that will consolidate and curate both model predictions and meta-data records from published MSDM outputs.
3. Coordinate the development of a massive open online course (MOOC) to build capacity and competency in this field, with materials provided by WG participants, designed to incorporate best practices and cover environmental and species data processing, multiple modelling approaches, model development and model validation.
4. Build capacity by mentoring early career scientists who aim to develop and publish MSDMs in the adoption of appropriate approaches, best-practices and application/impact strategy.

Deliverables

Deliverable 1: Peer-reviewed output(s) that reviews the current development of MSDMs:

Milestone 1.1: Review of the current state-of-the-art in MSDM applications, identifying specific challenges and solutions.

Milestone 1.2: Review available ocean datasets (both species and environmental) and data processing procedures to create MSDM inputs.

Milestone 1.3: Present future directions that should be explored by scientists interested in building impactful MSDMs in the future.

Deliverable 2: Produce a community-driven code of practice that encourages the developers of MSDMs to embrace the open access, repeatability and transparency of MSDM inputs, outputs and code:

Milestone 2.1: Draft code of practice produced as a technical report for dissemination and feedback from the MSDM community.

Milestone 2.2: Finalized code of practice submitted as a perspective manuscript in a relevant journal.

Deliverable 3: Develop a web-mapping portal (oceanmodels.org) dedicated to assimilating published MSDM studies and promotes open access and sharing:

Milestone 3.1: Develop the interactive website and populate this with information from the WG.

Milestone 3.2: Populate the web-mapping portal with studies published between 2000 and present.

Deliverable 4: Create training materials and opportunities covering theoretical and applied concepts of MSDMs to assist in capacity building:

Milestone 4.1: Report outlining the online course structure and materials to be developed and released.

Milestone 4.2: MOOC Module 1: “Introduction to MSDM”. MOOC Module 2: “Effective species and environmental data for MSDMs”. MOOC Module 3: “Forecasting impacts using MSDMs”.

Milestone 4.3: Hold an early career/introductory MSDM workshop utilizing the SCOR Capacity Development program to support participants from developing countries.

Working plan

To achieve the terms of reference for this WG:

Year 1 - 2020

We will hold an initial 3-day workshop among the participants during Summer 2020 at the University of Rhode Island (USA).

This workshop will:

a. Outline the current state of the art for the development of MSDMs and likely future directions.
b. Discuss the challenges facing MSDM practitioners and begin the development of best-practice guidelines and codes of practice for building management relevant MSDMs.
c. Discuss the scope and structure of the proposed MSDM data portal and online course.

d. Allocate tasks among participants.

Following the meeting, we will:

a. Release website pages that summarize the activities and outputs of the working group (Aug 2020; Milestone 3.1).
b. Start a draft working document that summarizes the current state of the art, challenges and future directions for MSDMs (Feb 2020; Milestones 1.1-1.3).
c. Release a draft data-sharing and open-access code of practice as a technical report for review by the MSDM community. (Dec 2020; Milestone 2.1).
d. Consult with the SCOR Committee on Capacity Building (SCOR CCB) to gain insight on how to solicit participation of scientists from developing countries and to integrate our work with capacity-building activities within SCOR (Oct 2020; Terms of Reference 4 and Deliverable 4).

Year 2 – 2021

During year two, we will progress several of our proposed outputs, and hold a series of virtual meetings between sub-groups of the WG that are responsible for delivering specific tasks, we will:

a. Formalize the draft data-sharing and open access code of practice and submit a peer-reviewed output (Oct 2021; Milestone 2.2).
b. Release the web-mapping component of the data-portal with meta-data extracted from peer-reviewed marine SDM publications dating from 2000-present (August 2021; Milestones 3.1-3.2).
c. Release the first module for the online course, “Introduction to MSDM” (Sept 2021; Milestone 4.2) and trial it with early career scientists and others identified by SCOR CCB.

Year 3 – 2022

We will hold a further 3-day workshop among the participants during 2022. Plus, a 2-day training workshop on marine species distribution modelling for early career scientists and scientists from developing countries. We would aim to plan this around a major conference, possibly the 6th World Congress of Marine Biodiversity.

The participants workshop will:

a. Discuss future directions for the working group and highlight potential additional sources of funding to maintain progress.
b. Finalize best-practice guidance for MSDMs based on community and peer-review.

Following the participants workshop we will:

a. Finalize current MSDM state of the art, best-practice guidance and future directions as peer-reviewed outputs (Dec 2022; Milestones 1.1-1.3).
b. Release the final modules for the online course (Aug 2022; Milestone 4.2).

The training workshop (Milestone 4.3) will:

a. Provide a series of training sessions regarding best-practice in MSDM development.
b. Give early career scientists and scientists from developing countries the opportunity to receive mentorship from established MSDM practitioners.
c. Establish a network of early career scientists and scientists from developing countries interested in developing marine SDMs.

Capacity Building

Our outputs will provide a lasting contribution to the field of MSDM and enhance the capability of stakeholders to better manage and conserve marine ecosystems in light of increased demands in much of the global ocean. By building this momentum, the WG will follow capacity building initiatives through three streams and will explore funding to achieve these:

Stream 1 - Established MSDM Community: By providing coherent guidance in the form of published best practice, benchmarks and training materials, we will ensure that the established MSDM community produces outputs that meet minimum agreed standards, improving confidence in MSDMs. Policy makers, management and conservation practitioners will benefit significantly from improved outputs, ensuring that MSDMs develop into the accepted tool that many scientists and policy makers think they can be. We will increase transparency and discoverability of MSDM approaches and input/output

data by producing an online data-portal which will be supported and maintained by the University of Rhode Island in perpetuity at no cost to this WG Group. The data-portal will be linked to SCOR resources website for Students and Early Career Scientists and for Scientists and Institutions.

> **Capacity Building 1:** Increased demand for MSDMs following the establishment of best practice and improved stakeholder confidence will lead to further funding and project opportunities for MSDM practitioners around the world.
>
> **Capacity Building 2:** Continue the WG as an informal or potentially a formal society following completion of WG activities that is devoted to the continued development of MSDMs and practitioners.

Stream 2 - Early Career Scientists (ECSs): We will reduce barriers for early career scientists who aim to adopt MSDMs by providing rigorous training through the development of online courses and the provision of training workshop. This will be a platform for building a network of early career MSDM practitioners who will continue the future development of the approaches with rigorous standards and an understanding of the strengths and weaknesses of approaches. ECSs will have the opportunity to collaborate with experienced practitioners and enhance their scientific networks.

> **Capacity Building 3:** Establish a network for early career researchers, including opportunities to share current work, explore problems and disseminate outputs to potential stakeholders, potentially through email listserv, social media, oceanmodels.org.

Stream 3 - Scientists from Understudied Regions: Much MSDM research has been concentrated in areas around developed countries. Our objectives to produce high quality and freely accessible training materials through online courses, is specifically designed to increase access and uptake to MSDMs by scientists and stakeholders in developing countries and regions of the world that are fundamentally understudied. Linking with the SCOR CCB will enable us to use that experience and expertise to effectively target individuals and institutions who could most benefit from participation. The WG Chair will apply for SCOR CCB travel funds to support this effort.

> **Capacity Building 4:** Explore how to better build links with stakeholders and scientists interested in building MSDMs in understudied regions through working with the SCOR CCB. Providing collaboration, mentorship and expertise to help advance national and international MSDM-related research.

Relationship to other international programs and SCOR Working groups

This working group has arisen from a 2018 workshop on deep-sea species distribution modelling that was co-organized by the EU Horizon 2020 projects SponGES (grant agreement: 679849) and ATLAS (grant agreement: 678760) and supported by the Convention on Biological Diversity and Fisheries and Oceans Canada. This workshop brought together for the first time, global experts working on MSDM in the deep sea, the core of whom are members of this proposed WG. Our discussions noted the need for the continued development of MSDM and establishment of best-practices, particularly due to the increased pressures that are being faced in many ocean ecosystems around the world and set the foundation for the objectives and deliverables proposed as part of this SCOR WG. We anticipate benefiting from and contributing to major international projects working on marine ecosystems such as the Horizon 2020 iAtlantic project (several members are involved, and iAtlantic may be able to contribute to the working group), global seabed mapping by the Nippon Foundation-GEBCO and the 2021 launch of the UN Decade of Ocean Science for Sustainable Development.

We have built a proposal that brings together a geographically diverse group of internationally recognized scientists and created terms of reference that has potential to have long-lasting influence on our understanding of ocean ecosystems at a global scale and leave a digital legacy as well as a powerful leap forward in capacity development in this field. SCOR offers the international profile and experience in capacity building that is needed to achieve our goals. We note that SCOR has not supported a similar working group in this field, and that MSDMs are a true multi-disciplinary application that benefits from and contributes to multiple sectors of oceanographic and marine biological research.

Working Group composition

Our working group covers an expansive geographic network that reflects the global utility of MSDMs. Please note, due to significant Canadian expertise and interest in MSDMs, we have elected to offer a third tier of membership, Observer Members, to ensure that individuals and agencies who wish to be involved can do so, and not be omitted due to geographic locality.

Full Members

Name	**Gender**	**Place of work**	**Expertise relevant to proposal**
Andrew J Davies	M	USA	Proposed Chair - Oceanographic drivers of distributions, MSDMs, deep-sea data.
Margaret FJ Dolan	F	NO	Multibeam and habitat mapping, geo-bio interactions, geomorphic characterization.
Piers K Dunstan	M	AUS	Multispecies MSDMs, SAM & RCP, marine data.
Kerry Howell	F	UK	Atlantic MSDMs, marine spatial planning, MPA networks, connectivity.
Ellen Kenchington	F	CAN	MSDMs, international science into policy (e.g. RFMOs, FAO-NANSEN, FAO expert)
Telmo Morato	M	POR	Forecasting MSDMs, climate change, anthropogenic impacts.
Ashley Rowden	M	NZ	Policy and stakeholder applications of MSDMs, survey planning and integration.
AJ Smit	M	ZAF	Marine biogeography, coastal oceanography, marine data.
Jarno Vanhatalo	M	FIN	Statistician developing MSDMs including joint species SDMs.
Chris Yesson	M	UK	Invasive species, MSDMs, climate refugia, education.

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
Ward Appeltans	M	BEL	Species occurrence and marine data, lead of the OBIS database project.

José Manuel González Irusta	M	SPN	Application of MSDM to ecosystem management.
Christian Mohn	M	DK	Physical oceanography, hydrodynamic modelling, interfacing across disciplines.
Jose Angel A. Perez	M	BRA	Diversity and distribution of deep-sea fauna and habitats, anthropogenic impacts
Chris Rooper	M	CAN	MSDM, validation surveys and linkages to management applications
Kisei Tanaka	M	USA	Shallow water MSDMs, climate variability, climate change impacts on biogeography.
Joana Xavier	F	POR	Taxonomy, diversity and distribution of deep-sea habitats/VMEs

Observer Members

Name	Gender	Place of work	Expertise relevant to proposal
Lindsay Beazley	F	CAN	MSDMs, marine biodiversity, habitat mapping.
Jessica Finney	F	CAN	Mapping lead at DFO, worked on best-practice guidance for MSDM.
Scott Foster	M	AUS	Development of multispecies statistical models and sampling programs
Kevin Friedland	M	USA	Fisheries expert, MSDM development in data rich regions.
Anders Knudby	M	CAN	MSDM comparison, evaluation, uncertainty estimations
F Javier Murillo	M	CAN	MSDMs, marine biodiversity, habitat mapping.
Emily Rubidge	F	CAN	Species-environment interactions, mapping diversity, ecological connectivity
Rodrigo Sant'Ana	M	BRA	Bayesian spatial, temporal and spatial-temporal hierarchical models.
Ryan Stanley	M	CAN	Genetically informed SDMs, marine connectivity.
Benjamin Weigel	M	FIN	Joint species distribution models.
Skipton Wooley	M	AUS	Developer of statistical methods to quantify single or multiple species distributions.

Working Group contributions

Andrew J Davies: Has improved global understanding of the distribution of marine species using SDMs and observational techniques, with his work on cold-water coral distribution being amongst the highest cited deep-sea MSDM publications.

Margaret FJ Dolan: Leading analyst of bathymetric data in the context of benthic habitat mapping, who has significantly advanced awareness of marine geomorphometry and the integration of benthic terrain data into modern MSDMs and habitat maps.

Piers K Dunstan: Internationally renowned ecological modeler with specific expertise in the development and application of multispecies distribution models, species archetype models and regions of common profile models.

Kerry Howell: Focuses on the application of MSDM for marine conservation. Currently lead and participant in several international research programs that use MSDM for Atlantic-wide marine spatial planning.

Ellen Kenchington: Significant experience in providing advice at an international level, to managers and policy makers, regarding marine spatial planning and the application of MSDMs to vulnerable marine ecosystems.

Telmo Morato: Focused on the development of MSDMs for deep-sea fish species and habitats. Currently leading international efforts to map how species distributions will change under future climate conditions.

Ashley Rowden: Internationally leading researcher, with interests including the use of MSDM to inform policy and stakeholders. Substantial experience in planning surveys to best take advance of MSDM techniques in logistically challenging environments.

AJ Smit: Expertise in coastal systems modelling, marine biogeography and environmental data layer development for MSDMs.

Jarno Vanhatalo: Statistician with experience in developing predictive models and MSDM in multiple marine habitats.

Chris Yesson: Substantial experience in the field of MSDM, with data products used in a variety of conservation and management settings including defining EBSAs in NE

Atlantic. Taught SDM workshops in 6 countries and has supervised numerous research students in this field.

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Jueterbock A et al. (2013) Climate change impact on seaweed meadow distribution in the North Atlantic rocky intertidal. Ecology and Evolution 3: 1356-1373

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Appendix

For each Full Member, five key publications related to the proposal:

Andrew J Davies

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Margaret FJ Dolan (Wilson)

- Dolan, M.F.J., Grehan, A.J., Guinan, J.C., Brown, C. 2008. Modelling the local distribution of cold-water corals in relation to bathymetric variables: Adding spatial context to deep-sea video data. Deep-Sea Research Part I-Oceanographic Research Papers 55, 1564-1579.
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Piers K Dunstan

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