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Proceedings of the National Advisory Meeting on Cumulative Impact Mapping and Vulnerability of Marine Ecosystems to Multiple Anthropogenic Stressors

Meeting dates: November 29–30 and December 2, 2021
Location: Virtual Meeting

Chairperson: Tana Worcester
Editors: Alex Tuen, Noreen Kelly, Jocelyn Nelson, Selina Agbayani, Cathryn Murray, Grace Murphy, and Tana Worcester

Fisheries and Oceans Canada
200 Kent Street
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Canada

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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TABLE OF CONTENTS

SUMMARY

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) virtual National Peer Review Meeting was held November 29–30 and December 2, 2021 to provide science advice on cumulative impact mapping and vulnerability of marine ecosystems to multiple anthropogenic stressors. This science advice will be used to inform marine spatial planning processes.

This process reviews the established Halpern et al. (2008) method to see how it could and should be used, with the goal of establishing expertise that Fisheries and Oceans Canada could deploy. The Cumulative Impact Mapping (CIM) method is an existing, published, semi-quantitative method that spatially represents the additive effects of anthropogenic activities and stressors on marine ecosystems. CIM gathers information about human activities and ecosystem components at the desired resolution, transforms the stressors to the same scale, adds the expected impacts together into a total cumulative impact score, and presents a map of the cumulative impacts in an area. CIM is a spatially-explicit cumulative impact model that requires three types of data: habitat classes, human activities and stressors, and a matrix of vulnerability scores.

External reviewers provided their comments on, and suggested improvements for, the Working Paper. This Working Paper reviews the Halpern et al. (2008) work for a modern Canadian context, while acknowledging that it inherited the legacy of its applications, and did not perform or redo that original work. The Working Paper also sought to balance the level of detail needed in order to understand the model, preferring to be high level without much detail on the individual layers. Discussion of the advantages and weaknesses of the method were helpful although weaknesses were largely knowledge problems rather than methodological problems. The CIM method is modular and easy to adapt and could be useful in a number of ways for marine spatial planning.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) virtual National Advisory Meeting was held November 29–30 and December 2, 2021 to provide science advice on cumulative impact mapping and vulnerability of marine ecosystems to multiple anthropogenic stressors.

Participants introduced themselves (Appendix 3). The Chair provided an overview of the CSAS policies, reviewed the Terms of Reference (Appendix 1) that served as the foundation for this CSAS process, and reviewed the Agenda (Appendix 2).

CONTEXT SETTING

This CSAS process provides an opportunity to incorporate the best available science into how DFO evaluates the spatial extent and intensity of cumulative impacts of human activities on marine ecosystems.

Marine Spatial Planning (MSP) is the way forward in managing Canada's oceans. It will support the government's commitments and priorities. The first-generation MSP plans are to be completed by 2024 in four of the six planning areas, identifying suitable areas for marine activities and areas that need to be avoided or special measures implemented for conservation or protection.

The driver of the request for science advice is data and knowledge products to inform the MSP process that includes ocean data. This feeds into MSP key questions, leading to foundational data categories, knowledge products and tools, sharing, scenario design, and MSP plans.

The MSP Process Blueprint is internal and not formally published, but DFO and other government departments are starting to formalize it. It consists of the following steps:

1. Pre-planning ("getting ready").
2. Establishing MSP governance and defining the MSP vision, goals, and objectives with partners ("setting the stage for working collaboratively").
3. Integrating and analyzing data ("gathering what we know"). This is the current step.
    a. Characterizing cumulative impact areas.
    b. Map of cumulative impact areas.
4. Developing MSP scenarios ("how do we want to use our oceans?").
5. Finalizing the MSP ("how do we realize our MSP vision?").
6. Implementing the MSP ("making it real"). This step needs to be developed.

PRESENTATION AND DISCUSSION OF THE WORKING PAPER

This CSAS process is to review the established Halpern et al. (2008) method to see how it could and should be used, with the goal of having a scientifically-informed knowledge product that DFO could deploy. The Cumulative Impact Mapping (CIM) method uses an existing, published, semi-quantitative method that spatially represents the additive effects of anthropogenic activities and stressors on marine ecosystems. The method:

- Was the first to combine cumulative human impacts into a map.

- Has been cited more than six thousand times since 2008.
- Has been applied in many places internationally.
- Is improved every time it is applied.
- Has strengths and weaknesses that are well understood.

Conversely:

- It is not the best or only available method.
- There are analyses of uncertainties and assumptions of this method.

Essentially, CIM gathers information about activities and ecosystem components at the desired resolution, transforms the stressors to the same scale, adds the expected impacts together into a total cumulative impact score, and presents a map of the cumulative impacts in an area.

DATA

CIM is a spatially-explicit cumulative impact model that requires three types of data, listed below with a summary of their discussion points:

Habitat classes

- Examples were presented of habitat classes in the Pacific and Atlantic, including benthic, biogenic, and pelagic habitats.
- In the Working Paper, Table 1 looks different than its corresponding Figure because the 2015 map originally used as a foundation was updated.
- Clarification on habitat types will be added to the Working Paper.
- For Atlantic deep biogenic classes, the Working Paper can also include other areas along the slope identified by the species distribution models or specify that the layer represents significant areas dominated by cold-water corals, sponges, and sea pen communities.
- Both Atlantic and Pacific maps are being updated. The habitat classes will continue to be updated as more data becomes available.

Human activities and stressors

- Marine activities and stressors occurring in the ocean include fishing, shipping, recreational boating, disposal at sea, etc.
- Coastal activities and stressors occur in close proximity to the coast and include ports, marinas, pulp mills, aquaculture, log booms, etc.
- Land based activities and stressors occur in watersheds and include mining, forestry, agriculture, industrial sites, roads, towns, pipelines, etc.
- Relative intensities differ across activities and are modeled according to the way each stressor interacts with the habitats.
- For the marine activities, polygon data such as fishing footprints were area weighted, and the impact was calculated only in depths and habitats where that fishing activity was likely to occur.

- Marine and coastal kernel density was used to model decreasing intensity of the stressor versus distance from the stressor source. For the Murray et al. (2015) analysis, the minimum distance was two kilometers.
- The Land Index (LI) is a relative measure of the amount of activity or stressors within a watershed. LI is calculated over the watershed and applied to the mouth of the estuary. The kernel density distance is the average size of the estuary plume which is dependent on stream order.
- Regardless of data type, relative intensities need to be standardized across all activities by using log transformation and rescaling, or classifying into categories of low, medium, or high.
- A Cumulative Impacts Toolbox and accompanying user manual are under development and will help standardize the process.

Vulnerability matrix

- Vulnerability scores are displayed typically in a matrix. The same activity may have different effects on different habitats.
- Experts for each habitat were asked to assess the vulnerability of their habitat according to their expertise. They used five criteria, including spatial scale, frequency, trophic impact, percentage change, and recovery time.
- Two previous vulnerability matrices were evaluated, including the California Current matrix and the Massachusetts matrix. Both followed the same methodology. Resulting matrices differed slightly in habitats included or excluded. Differences in biogeography and oceanography resulted in differences compared to Canada.
- To answer the question of how applicable they were to Canadian habitats, Canadian Atlantic and Pacific experts were asked to evaluate the above matrices and rate the scores as negligible, low, medium, high, or extreme.
- The experts were permitted to re-rank the stressors based on their expert opinion. They provided ample justification about why certain stressors should increase or decrease in ranking.
- The re-ranked surveys were subjected to anonymous blind peer reviewers who responded in agreement or rebuttal.
- The reviews were used to enact changes. The rankings were converted back to numerical scores and are shown in the Working Paper.
- For this study, the focus remained on the stressors in the two original matrices. The Working Paper will mention the experts' suggestion that certain stressors should be added that were not included.
- The Working Paper included freshwater increase and decrease stressors which affects salinity.
- In the original California Current and Massachusetts studies, experts did not come up with scores directly. They had different scenarios to be ranked. The authors of the matrices took the results of the survey, averaged across different scores, weighted them using a multi-criterion decision model, and arrived at an overall vulnerability score. The CSAS experts were asked whether the original vulnerability score numbers were valid for a Canadian context, not to recreate the original work done on the two matrices. The Working

Paper originally omitted providing this detailed background, but some details may be beneficial to include, perhaps as an Appendix.

- The science advice will clarify that the scores represent annual averages, though there is the potential to have dynamic scoring to reflect different times of the year. For example, the Bering Sea application used the same vulnerability scores but varied the intensity of activities between seasons to distinguish cumulative impacts in winter and summer. When considering a dynamic method, the relative intensity of activity through the seasons means that the solution is to change the activity rather than having different vulnerability scores per season.

ASSUMPTIONS, UNCERTAINTIES, ACTIONS, ANALYSIS, AND APPLICATIONS

Assumptions

There are nine major assumptions of CIM. The Working Paper focused on the main four:

- Stressor layers are of equal importance.
- Ecosystems have a linear response to stressors.
- Vulnerability scores are sufficiently accurate.
- Stressor impacts are additive.

Uncertainty

Uncertainty has been quantified in the following ways:

- Global model: Robust areas of high and low modeled human impact on the oceans (red and dark blue have highest certainty).
- Eastern Mediterranean Sea: Local sensitivity confidence index (higher numbers indicate higher confidence in expert judgment).

Actions

CIM does not prescribe particular management actions, but rather provides information to help improve management decision-making by:

- Illustrating areas of relative impact.
- Identifying impact by specific activities.
- Comparing scenarios of impact (current versus future).

In mapping, patterns of impact can become very evident when stressors are grouped together as Marine, Fishing, Coastal, and Land.

Analysis

CIM results can be used to perform scenario analyses. For example, the Murray et al. (2015) analysis found:

- Climate change had widespread impacts and the highest cumulative effects scores.
- Localized effects of planned industrial and pipeline activities.
- Future developments increased footprint of potential impact (7582 square kilometers).

- Nearshore habitats were most vulnerable.

Applications

Cumulative impact scores can be used in various other applications, such as:

- Survey design: Cumulative impact scores as gradient of impact to stratify field surveys.
- Define thresholds of impact using quantitative tolerance limits.
- Cost layer in Marxan for planning.

REVIEWER PRESENTATIONS AND DISCUSSION

External reviewers provided their feedback on the Working Paper.

REVIEWER 1: EMILY RUBIDGE

Review

The Working Paper was well written with clear objectives. Tables and maps were well organized. The flow of ideas was well presented.

The Working Paper would benefit from more context on the pros and cons of the Halpern et al. (2008) approach and to determine whether a different approach should be developed or to continually refine and update Halpern. It would be helpful to know the limitations for applying some of the alternative approaches (for example, synergistic rather than additive impacts).

More information could be provided on how habitat classes align with other habitat classifications used in each region.

More details should be included on how the scores in Table 5 are used to generate vulnerability weightings. In addition to the paragraph explaining it, an example should be provided.

More details should be provided about why the scores vary between regions.

More explanation should be included about how a change in score from the expert review resulted in a change in vulnerability weighting.

In Section 4.3.1, a summary of the expert review should be included, with comparisons of each region. Examples of questions to address would include whether scores tended to go up or down in the vulnerability category, and if the scores matched across regions where the habitats were in common.

A list of stressors suggested by reviewers should be included as it may be useful for future work or highlight research gaps.

The Working Paper should elaborate on the top scoring combinations of stressors for each coast after expert review. Explanation should be provided for why climate change stressors consistently score higher than stressors like habitat destruction.

Discussion

The Working Paper authors recognized that some of the comments were addressed in the presentation of the Working Paper but should be included in the Working Paper itself. The authors acknowledged the challenge of deciding how much background information to include in the Working Paper because they did not perform the original work.

The authors agreed to add the comparison to other methods and how the category change resulted in a numerical change. When moving from one category to another and there was a range of numbers, the authors used the lowest number in the new category. Vulnerabilities were listed in a ranked order and labelled with binned levels, but did not have a numerical score associated with them when they were sent to experts for review.

It would be valuable to see a comprehensive example of how changes were made to original scores. Some of the experts involved in the review asked for original scores for the five components, but they do not exist. The vulnerability scores used as the starting point for the matrices were calculated through a complicated set of elicitations where experts were asked to rank scenarios provided with hypothetical but realistic vulnerability scores. These scores were then turned into model weights using a statistical model to reflect the importance of each variable in the ranking decisions made by the experts.

This is not how the authors would have devised the method but still chose to work with it and the legacy of the original Halpern method. The scores are not to be considered quantitative. Where scores are lacking for any stressor-habitat combination, existing information about one or more of the five vulnerability criteria can be substituted to fill in gaps. This is a decent approach to reflect vulnerability because the experts emphasized the weighting on consequence more than the frequency or spatial scale which tend to overlap with exposure.

REVIEWER 2: DAVID BEAUCHESNE

Review

The Working Paper did a good job of presenting the Halpern method in a Canadian context. The presentation of the Working Paper complemented the Working Paper itself.

Elements of the presentation could help clarify the Working Paper. The Working Paper should provide more detail for the method that was used for the pre-review and the results from that process.

The first objective of the Working Paper was to review individual scores given. The information in the big tables needed to be interpreted. Additional information should be provided on the results from the experts and the discussions between experts regarding how they arrived at their final scores.

It would be helpful to examine the effects of re-evaluating scores based on multiple criteria, what loss of information would this have, and what information is lost when changing the score at the end. List the consequences of doing this instead of using the original criteria. It is acknowledged that the original criteria cannot be revisited, but this should be addressed in the Working Paper.

Pros and cons should be listed together in a single table.

Lack of information on the spatial footprint of stressors is cited as a limitation of the model, but it needs to be contextualized as a knowledge problem rather than a methodological problem.

Discussion

The Working Paper authors wanted to balance the level of detail provided. The expert pre-reviews could be supplied in an Appendix if requested, but presently omitted because they may not be helpful or respectful to the experts. The authors agreed to add more details on the methods and results of the previous survey. An attempt will be made to summarize the results seen in the Tables and the validation of the changes.

The authors provided a disclaimer that each coast has its own vulnerability score values and are not directly comparable because the scores are relative to each other within a study area rather than a stand-alone quantitative value. For example, a score of 17 in the Pacific cannot be compared to a 17 in the Atlantic. The intention is to have a cumulative impacts map of Canada relative within regions, rather than across regions because the scales are different. To be applied nationally, bigger decisions need to be made.

Expertise on specific stressors is uncommon. In a hypothetical scenario where stressor-specific experts are sought for their opinion on how stressors might impact the habitat, commenting across all habitats would be difficult. This is why using habitat experts was more realistic.

Ideally, where activity data is available, stressors can be assigned and matching vulnerability scores can be pulled from the matrix for each habitat. However, some vulnerability scores are at the activity level. The authors explained the link between the activity and the stressor. Activities are used because they can be managed at the human level (for example, aquaculture), as opposed to stressors (for example, noise). The authors agreed to explain that the model includes both vulnerability scores at the activity level due to pre-existing scores that were adapted to our coast, and scores for individual stressors.

A participant mentioned it was unclear which activities have preassigned stressor values and which are more derived from the area to which they are applied, that there seems to be a mix between these two, and the information currently provided does not explain this well or does not show where it was used. The authors explained that the choice of what is used in a location is seen in the giant matrix, but that it can be confusing to see how to go from the vulnerability matrix to mapping the stressors from activities. Mapping the stressors from activities is done using available data about either the stressor or the activity of interest, with the vulnerability scores identified based on which habitats and stressors overlap. In subsequent papers, only a subset of stressors is chosen from the large amount listed in the table. Another consideration is which elements are regional versus national in scope.

Table 3 lists stressors related to nutrient input. These could mean nutrient input:

- Into eutrophic waters.
- Into oligotrophic waters.
- Causing harmful algal blooms.
- Causing hypoxic waters.

Concern was expressed that there could be overlap between activities and stressors for the stressors listed above. It would be useful to know if they overlap, or to provide advice on when and how to use each of these nutrient input stressors to avoid overlap. The authors acknowledged that these definitions were challenging, welcomed any advice on how to clarify them, and do not believe these stressors have yet been mapped.

A participant asked whether the authors looked at stressors for habitats that have gone through an Ecological Risk Assessment Framework (ERAF), and if so, whether the two processes ended up with similar rankings, and if not, whether it should be investigated more. The authors spent time looking at similar processes when considering vulnerability and tried to find habitats that are in both or just one. They do not include all the same activities and stressors, so it is a difficult comparison to make and it is difficult to determine whether a good job was done comparing. The same vulnerability criteria were not used. A consideration for the future is to find a way to compare like-for-like.

A participant asked whether the stressor of “noise” is counted three times when it includes noise, ship-related noise, and aquaculture-related noise, and if there are multiple entries for the same stressor. The authors explained that the tables and definitions are aspirational to provide a wide list of options that hopefully will not be needed in an assessment. The Working Paper will indicate that only some stressors are chosen. An example was provided that sedimentation from forestry and roads could be a source of multiple activities generating the same stressor, and that different activities may generate the same stressor but have different footprints. This is another way activities and stressors can be represented.

A participant believed an overview would be helpful of how the values on the matrix and its applicability were changed with the expert review and asked several questions regarding:

- How these maps are being used in MSP.
- If the impacts of climate change are dominant across space and time.
- If climate change is difficult for DFO to manage at a site level.
- If there is any consideration of looking at maps without climate change stressors to be more applicable for MSP.

The authors responded that it depends on how the results are presented. A map for Pacific was shown by activity class. An aggregate map is driven by climate change. In the Maritimes, climate change stressors may be considered as scenarios. Some results for Maritimes are the rate of change between the present and the future, so they are futuristic impacts and useful as a scenario analysis.

A participant found it useful to be able to extract the climate layer to note its contributions to the bigger picture. Regarding the application of the tool, the participant noted that the Working Paper did not seem to consider advice or recommendations for how often layers should be updated or how often scientific literature should be searched for updates, given the evolving science. The authors responded that it may be difficult to give overarching advice because different things are updated at different times, and that the tool tries to take a snapshot of many different things. In a DFO context, dynamic reporting would be used and updated periodically, which is different from creating a new scientific manuscript each time a data layer is updated.

REVIEW OF DAY 1

The second day of the Meeting began with a recap of the first day and an invitation to raise new discussion points or revisit previous ones:

- A table of pros and cons would help to understand and inform conversations about how to apply these products for decision-making.
- Habitat was discussed, and Figure 1 and Table 1 do not quite match.
- On the Atlantic side, some biogenic habitat layers do not exist yet (such as kelp in Atlantic) but some do. It would be good to know which ones listed are not yet available.
- Marine versus coastal was clear in the presentation but should be clarified in the Working Paper.
- Regarding stressors, Table 3 should show how they were derived, and what seasonality (summer versus winter) to pursue going forward.
- For vulnerability, a description of the original process, surveys, and reviews could perhaps be included as an Appendix.

- Because interactions can change quickly, gaps should be clearly identified.
- Climate change is included because it is so predominant and ubiquitous, but seems to override vulnerabilities when overlapping the footprint of directly manageable activities.
- Consideration of hydrodynamics of receiving waters for intensity and spatial distribution are not included. Intensity depends on the activity or stressor being mapped. For trawl fishing, intensity might come from the number of trawl events in a polygon. For finfish aquaculture, it might be kilograms of fish kept per farm, and two farms close together would increase the intensity in the polygon. Recreational boating routes in 2015 had rankings of low, medium, and high for the intensity.
- The Atlantic deep biogenic class should be updated to specify that they represent areas dominated by the deep biogenic species.
- In deeper areas, there is no biomass data. Some areas have observation data, but in other areas, there is a species distribution model only.
- The Working Paper was kept high level, without much detail on the habitat map. The description of habitat could be changed to reflect the data source. The map will hopefully be sent for peer review in the future.
- Present discussions are valid. Those are knowledge problems rather than methodological problems. The program is modular and easy to adapt. Every stressor and habitat layer can be reviewed by experts. It would be useful to reframe questions that are repeatedly raised as knowledge problems. Hydrodynamics cannot be applied if that information is not available coastwide. The Working Paper will reinforce that the best information available is used, and it is a modular model.
- For hydrological variables, it is useful to utilize stressor experts to map stressors. However, discussion has not occurred about how the model data can or should be used by DFO in these situations.

DECISION RULES

The authors presented the decision rules for expert pre-review and for converting classes to numerical scores. Four examples demonstrated how the expert rankings and scores were revised.

The first Atlantic example showed seagrass and finfish aquaculture. The most conservative change and lowest values were chosen. In the matrices in the Working Paper, the values that are changed are bolded and have an arrow next to them. For example, Original Score 0.6 and Proposed Score **1.4**↑ shows a slight increase in the revised score. The most conservative values were chosen to provide more weight to the experts who participated in the past compared to the authors' updated higher numbers.

The second Atlantic example showed seagrass and an increase in sediment input. The most conservative value was chosen.

The first Pacific example showed hard intertidal and disease or pathogens. Experts agreed it should be re-ranked as High, and one expert thought it should be Extreme, so a high value in the High category was chosen.

The second Pacific example showed soft intertidal and shellfish aquaculture.

Variability in the numbers provides room for sensitivity analyses and looking at the uncertainties. The Working Paper will include language about the conservative change rule to explain that the full range of experts will not be captured and how there was no access to the original scores.

The Working Paper will clarify the use of “conservative”. In the above examples, it means having less numerical intensity (lower scores). In a management aspect, being conservative is taking the precautionary approach which would imply choosing higher numbers. The authors cautioned that managers should not make decisions based on the vulnerability table alone which may be taken out of context.

The authors took the habitat approach and noted that different habitats will have different vulnerabilities to stressors. Participants recommended also looking across activities. These include whale-watching, which was not in the original activity list, and research trawling, which may be considered part of the scientific activity that involves the removal of biomass and alteration of habitat as the trawl nets drag across the floor of the water body.

DISCUSSION OF TERMS OF REFERENCE OBJECTIVES 1 AND 2

A cumulative impacts map can be used within Marxan as a cost layer. The map can be used post-Marxan to inform decisions regarding the preferred scenario selection. The map and associated reports can be used to prioritize management actions and inform MSP management in the implementation phase, such as which management tools to use to minimize impacts.

Advantages of cumulative impact maps

- A map shows where cumulative impact hot spots and cold spots occur.
- Maps would be useful as a suite of analyses. Because Marxan can only take one cost layer, a map can be used as a cost layer in Marxan to consider multiple activities. These include areas with lower impact as well as areas of high conservation value that may have higher impacts but have potential for restoration.
- Maps are also useful as a check against the results of decision support tools for MSP (for example, Marxan with Zones) or potential MSP zoning scenarios to evaluate how different options influence cumulative impacts at the broader scale.
- Maps are used for Marine Protected Area (MPA) network planning in the nearshore soft bottom as part of a sensitivity analysis to assess the “naturalness” of the draft network scenario.
- Maps overlay human activities with existing MPAs in the region. This is a useful predictive method to help inform management on how human activities can impact the areas inside and outside the MPA borders. Boundaries do not necessarily reflect the nuances, but would help introduce the discussion.
- Maps communicate visually how much of the ocean is used by humans, which can frame subsequent work.

Disadvantages of cumulative impact maps

- It is not straightforward to determine prioritizing areas with high impact or low impact.
- Maps are not directly useful to Marxan analysis.
- From a management perspective, maps do not represent total information and need underlying data for meaningful discussion.

Given how the scores have been produced and the acknowledged uncertainties, a participant expressed nervousness about the risk of using the low impacts for anything, and a preference to be wrong about high impacts than low impacts. Action can be taken with high impacts, but something with low impact should be checked before taking action.

A participant noted that some of the areas of high impact should not be avoided for conservation protection. They might be areas of high value and affected by human stressors.

Minimum data standards may be necessary to implement cumulative impact mapping in new areas, such as the Arctic. If vulnerability scores are not available in an area, new expert elicitations can be done from scratch. Habitats mapped would need to match the habitat definitions in vulnerability scoring. Local groups, such as indigenous peoples, could collaborate to develop a list of activities to appear on a map and make the map representative of the knowledge base in an area.

There is the consideration to create a pan-Atlantic map for DFO regions. Experts from different eastern regions were included to gain a broader Atlantic perspective, allowing use of this vulnerability matrix for the different DFO bioregions. This assumes the stressor layers can be obtained for the region.

In the matrix for the Gulf of St. Lawrence to be published soon, the target components are species, which cannot be compared with the assessment on habitats. It would be better to conduct separate cumulative impact mapping analyses for species and habitats.

DISCUSSION OF TERMS OF REFERENCE OBJECTIVE 3

Historical impacts are not included, which could be indicated in the Science Advisory Report.

A participant noted a lack of discussion on the robustness of the method. A map with few stressors identified would be affected when more layers of stressors are added. The authors acknowledged that the cumulative impact on the habitats will be affected by data changes. When applying this method, the goal is a holistic view capturing as many stressors as possible. A management application needs to provide caveats of what is and is not portrayed in the information presented.

A participant stated that results should be interpreted within the confines of the method itself, that the addition of more information would change the scope of the analysis, and it cannot be compared to the previous application. Because adding information changes the scope, evaluating the robustness of the end score is not as simple as comparing the outputs of two sets of information. The authors responded that while the informational needs of future marine spatial planning processes are currently unknown, cumulative impact maps can support these planning decisions. Cumulative impact mapping results can be affected by two optional categories of changes, which should be distinguished from each other. These are:

- Temporal changes. With the same scope and stressors but including changes through time, some things will get better and some things will get worse.
- Updates. New stressor layers and new habitat information will affect the output.

A participant noted the Working Paper and previous applications have reported uncertainty in CIM model outputs derived from sensitivity analyses, and asked about the value in doing sensitivity in vulnerability weightings or the set of sensitivity analyses used. The authors said they were working on how to apply sensitivity to maps for MSP and do not currently have all the answers. Maps are used globally which provides an idea of how the rest of the world has conducted work. It is anticipated that more will be known next year.

A participant asked if the Working Paper should indicate a plan when sensitivity analyses are not done but should be. The authors hesitated to include that in the Working Paper but agreed that the Science Advisory Report could include a recommendation which would allow not needing to fully commit, given the uncertainties.

REVIEW OF DAY 2

The Chair presented a list of revisions for the Working Paper that the authors assembled based on feedback from the first two days. The Chair captured participants' additional updates and revisions. Participants expressed their satisfaction with the list. With these proposed changes integrated, participants accepted the Working Paper being upgraded to a Research Document.

EXPECTED PUBLICATIONS AND THEIR NEXT STEPS

The Chair explained the layout of the sections of the draft Science Advisory Report. The Chair invited participants to provide their own Summary Bullets to supplement the ones already drafted. Participants worked together to suggest updates and revisions to the Summary Bullets and arrived at consensus on the science advice. The rest of the Science Advisory Report will be completed and circulated to participants for editorial comments only, with no changes to the consensus-based science advice.

The Working Paper will be revised based on revisions discussed throughout this meeting and eventually published as the Research Document.

The Proceedings will be completed and circulated for comments.

APPENDIX 1: TERMS OF REFERENCE

Cumulative impact mapping and vulnerability of marine ecosystems to multiple anthropogenic stressors

National Advisory Meeting - National Capital Region

November 29, 30 and December 2, 2021
Virtual Meeting

Chairperson: Tana Worcester

Context

A standard method to represent the different human uses of marine ecosystems and their cumulative ecological impacts in Canadian marine waters is required by Fisheries and Oceans Canada's (DFO's) Marine Spatial Planning program. It is proposed to use an existing, published, semi-quantitative method for cumulative impact mapping (Halpern et al. 2008) that spatially represents the additive effects of anthropogenic activities and stressors on marine ecosystems. The Halpern et al. (2008) method transforms the distribution and intensity of human activities and their associated stressors into a single metric to display relative impacts within regions and ecosystems and is well established, having been applied at a global scale (Halpern et al. 2007; Halpern et al. 2015; Halpern et al. 2008) and at a regional scale in Pacific Canada (Ban et al. 2010; Clarke Murray et al. 2015a; Clarke Murray et al. 2015b; Singh et al. 2020), California (Halpern et al. 2009), Massachusetts (Kappel et al 2012a), Hawai'i (Selkoe et al. 2009), the Arctic (Afflerbach et al. 2017; Andersen et al. 2017), the Baltic Sea (Andersen et al. 2015) and the Mediterranean and Black Seas (Micheli et al. 2013).

The method uses a spatially-explicit cumulative impact model to relate the footprints of human activities to the potential impact on habitats using vulnerability metrics (Halpern et al. 2008; Teck et al. 2010; Kappel et al 2012b). This requires three data sources: 1) spatial distribution and intensity of human activities (e.g., fishing, shipping, industrial sites, etc.), 2) spatial distribution of marine habitat classes (e.g., rocky reef, shallow pelagic, eelgrass, etc.), and 3) a matrix of vulnerability scores to quantify the relative impact of each stressor on each habitat class. The method has been applied in Pacific Canada (Ban et al. 2010; Clarke Murray et al. 2015a; Clarke Murray et al. 2015b; Singh et al. 2020), and is underway in the Maritimes region, but has not been evaluated for use within Fisheries and Oceans Canada.

The vulnerability matrix used in cumulative impact mapping has also not been evaluated formally by DFO. The vulnerability (or sensitivity) of ecosystem components to stressors or threats is a key component of any environmental assessment, and is increasingly used in environmental impact assessment, cumulative effects assessment, and cumulative impact mapping. Vulnerability assesses differences in how ecosystems respond to stressors, which may not be taken into account by solely mapping the locations of activities or stressors. Vulnerability scores for habitats or species may be calculated in a variety of ways, but commonly include combinations of variables such as spatial scale, stressor frequency, functional impact, resistance to change, and length of recovery time (Halpern et al. 2007; Teck et al. 2010). The matrix of vulnerability scores used in published cumulative impact mapping studies based on the Halpern method, all originate from a single expert-elicitation study for the California Current region (Teck et al. 2010) that has been modified for use in other regions. This peer review process will be used to evaluate the existing, published vulnerability matrices for use in Pacific and Atlantic Canada (Clarke Murray et al. 2015b; Teck et al. 2010; Kappel et al 2012b), and revise as needed to better reflect Canadian habitat classes and the stressors to which they are exposed.

The advice arising from this Canadian Science Advisory Secretariat (CSAS) National Peer Review (NPR) will be used to inform marine spatial planning processes. The cumulative impacts mapping methodology further expands the suite of cumulative effects assessment tools available for Fisheries and Oceans Canada. This study provides an opportunity to incorporate best available science into how DFO evaluates the spatial extent and intensity of cumulative impacts of human activities on marine ecosystems.

Objectives

A peer review process is needed to evaluate an established cumulative impact mapping method and validate the vulnerability scores contained in the associated vulnerability matrices. The working paper will be reviewed and provide a basis for discussion and advice based on the objectives outlined below:

1. Review the scores in the Pacific and Atlantic vulnerability matrices and recommend revisions to individual scores, as necessary.
2. Assess the cumulative impact mapping method in terms of the utility of its outputs for marine spatial planning and other conservation programs.
3. Identify areas of uncertainty and knowledge gaps.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Expected Participation

- Fisheries and Oceans Canada (Ecosystems and Oceans Science, Marine Planning and Conservation)
- Academia
- Environmental non-governmental organizations
- Other invited experts

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APPENDIX 2: AGENDA

Canadian Science Advisory Secretariat

National Peer Review Process

Cumulative impact mapping and vulnerability of marine ecosystems to multiple anthropogenic stressors

November 29, 30 and December 2, 2021

Virtual

Chair: Tana Worcester

DAY 1 – Monday, November 29

Time (EST)	Subject	Presenter
11:00	Introductions Review Agenda and Housekeeping CSAS Overview and Procedures	Chair
11:20	Review Terms of Reference	Chair
11:30	Context Setting	Client
11:45	Presentation of working paper, including questions of clarification	Authors
12:45	**HEALTH BREAK**	
13:15	Reviewer presentations (10-15 min per reviewer) and discussion	Reviewers
14:30	Discussion of ToR Objective 1 – review of Pacific vulnerability matrix	All Participants
15:00	Adjourn for the day	

DAY 2 – Tuesday, November 30

Time (EST)	Subject	Presenter
11:00	Review of Day 1	Chair
11:15	Discussion of ToR Objective 1 – Review of Pacific vulnerability matrix	All participants
11:45	Discussion of ToR Objective 1 – Review of Atlantic vulnerability matrix	All Participants
12:45	**HEALTH BREAK**	
13:15	Discussion of ToR Objective 2 – Utility of the cumulative impact mapping method for marine spatial planning and other conservation programs	All Participants
14:00	Discussion of ToR Objective 3 - Identify areas of uncertainty and knowledge gaps	All Participants
15:00	Adjourn for the day	

DAY 3 – Thursday, December 2

Time (EST)	Subject	Presenter
11:00	Review of Day 2	Chair
11:15	Draft Science Advisory Report (SAR) – review draft SAR with participants	Chair
12:00	Science Advisory Report (SAR) Development including Consensus on: • Summary Bullets • Sources of Uncertainty • Results and Conclusions	All Participants
13:00	**HEALTH BREAK**	
13:30	Science Advisory Report (SAR) Development including Consensus on: • Summary Bullets • Sources of Uncertainty • Results and Conclusions	All Participants
14:30	Next Steps: • SAR review/approval process and timelines • Research Document & Proceedings timelines Other follow-up or commitments (*as necessary)*	Chair
15:00	**Adjourn Meeting**	

APPENDIX 3: LIST OF PARTICIPANTS

Name	Affiliation
Agbayani, Selina	Fisheries and Oceans Canada
Archer, Stephanie	Louisiana Universities Marine Consortium
Beauchesne, David	Université Laval
Bundy, Alida	Fisheries and Oceans Canada
Chassé, Joël	Fisheries and Oceans Canada
Cormier, Roland	Fisheries and Oceans Canada
Gagliardi, Kayla	Fisheries and Oceans Canada
Giangioppi, Martine	Fisheries and Oceans Canada
Guyondet, Thomas	Fisheries and Oceans Canada
Hunt, Heather	University of New Brunswick
Kelly, Noreen	Fisheries and Oceans Canada
Kristmanson, James	Fisheries and Oceans Canada
Lévesque, David	Fisheries and Oceans Canada
Longtin, Caroline	Fisheries and Oceans Canada
Martone, Rebecca	Tula Foundation
Metaxas, Anna	Dalhousie University
Morris, Corey	Fisheries and Oceans Canada
Murillo-Perez, Javier	Fisheries and Oceans Canada
Murphy, Grace	Fisheries and Oceans Canada
Murray, Cathryn	Fisheries and Oceans Canada
Nelson, Jocelyn	Fisheries and Oceans Canada
Niemi, Andrea	Fisheries and Oceans Canada
Pretty, Christina	Fisheries and Oceans Canada
Robb, Carrie	Fisheries and Oceans Canada
Rubidge, Emily	Fisheries and Oceans Canada
Sonier, Remi	Fisheries and Oceans Canada
Tuen, Alex	Fisheries and Oceans Canada
White, Hilary	Fisheries and Oceans Canada
Worcester, Tana	Fisheries and Oceans Canada