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Balancing objectives of Sablefish fishing and conserving Vulnerable Marine Ecosystems in the Northeastern part of the NPFC Convention Area

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ABSTRACT

Members of the North Pacific Fisheries Commission (NPFC) are required to take action to prevent Significant Adverse Impacts (SAIs) to Vulnerable Marine Ecosystems (VMEs). In response, the NPFC has been developing approaches to quantitatively define VMEs and assess SAIs. This spatial optimization analysis aims to balance the objectives of protecting VMEs from SAIs in the eastern part of the NPFC's Convention Area while reducing impacts to Canada's Sablefish fishery. Specifically, this working paper provides an update to the proposed process for spatial optimization outlined in NPFC-2020-SSCBFME01-WP13(Rev 1) and draws on results from updated methods proposed to identify VMEs and areas likely to be VMEs. Our spatial optimization analysis provides results from a range of scenarios with differing conservation targets and parameters to be selected by managers and demonstrates how areas for protection can be identified.

INTRODUCTION

This analysis is an update to working paper NPFC-2020-SSCBFME01-WP13(Rev 1) (Warawa et al. 2020), where we outlined a proposed process using systematic planning to identify areas to protect vulnerable marine ecosystems (VMEs) from significant adverse impacts (SAIs) in the North Pacific Fisheries Commission (NPFC) Convention Area (CA). Systematic conservation planning focuses on providing support for decision making around resource use and conservation. It is one of the most highly recommended approaches to conservation planning because it enables a process that is transparent, inclusive, and defensible (Ardron et al. 2010; McIntosh et al. 2017). While systematic conservation planning can be conducted using a variety of methods, the use of decision support tools offers a systematic approach resulting in more objective decision making (Ardron et al. 2014).

Decision support tools have been widely applied in spatial management and trade-off analyses around the world. They are spatially-explicit tools that help resource planners and managers integrate data from ecological, economic, and social systems, assess management alternatives and trade-offs in a transparent way, gain stakeholder involvement, and evaluate progress on achieving management objectives (Center for Ocean Solutions 2011). Decision support tools facilitate the decision-making process by providing a range of possible scenarios.

One goal of systematic conservation planning in the NPFC CA is to identify and protect VMEs from SAIs while minimizing the impact to fisheries or other stakeholders. A proposed general process to achieve this was outlined in Warawa et al. (2020) which follows the overall procedure for systematic conservation planning (adapted from McIntosh et al. (2018) and Sarkar & Illoldi-Range (2010)) and is modeled after the South Pacific Regional Fisheries Management Organization (SPRFMO) decision-making process.

As described by Warawa et al. (2020), the process includes nine general steps: (1) identifying and involving stakeholders, (2) identifying goals and objectives, (3) defining conservation features and gathering data, (4) setting conservation targets and design principles, (5) identifying cost metrics and gathering data, (6) dividing the planning region into planning units, (7) selecting a decision support tool, (8) completing analysis, and (9) completing sensitivity analysis (Figure 1). In 2020, there were no areas identified as VMEs in the northeastern part of the NPFC CA, so Warawa et al. (2020) applied this process as a case study that was focused on identifying areas for protection that had high habitat suitability for VME indicator taxa as a proxy for VMEs based on species distribution models.

In 2021, Canada proposed a process for quantitatively identifying VMEs and areas likely to be VMEs in the NPFC CA (Warawa et al. 2021, 2022). Therefore, this working paper is meant to update our case study and demonstrate how this spatial optimization process can be used to protect areas identified as VMEs and areas likely to be VMEs areas while minimizing impacts to Canada’s fisheries. Results of this updated analysis remain preliminary.

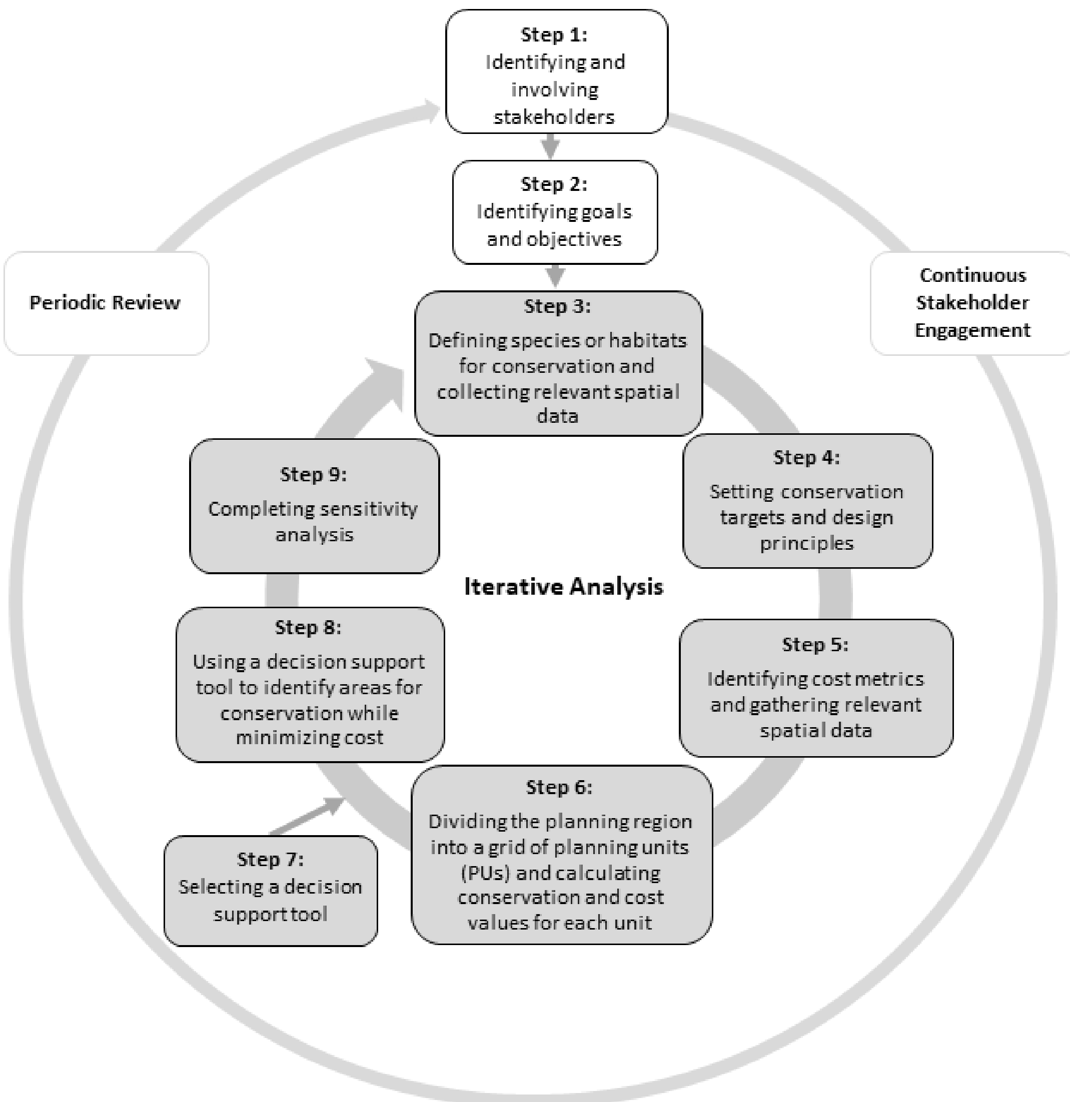

Figure 1. Proposed process for completing trade-off analysis for minimizing impacts to fisheries while protecting VMEs in the NPFC CA (from Warawa et al. 2020).

METHODS

Study Area

Our study area is the Cobb-Eickelberg seamount chain located in the northeastern part of the NPFC CA approximately 450 km offshore Vancouver Island, Canada (Figure 2). This southern part of the chain includes nine named seamounts ranging in pinnacle depth from approximately 34m (Cobb Seamount) to 1200m (Hoh Seamount). The Canadian commercial Sablefish fishery has been active in the study area since the 1980s using mainly longline trap and some longline hook and line gear (DFO 2013).

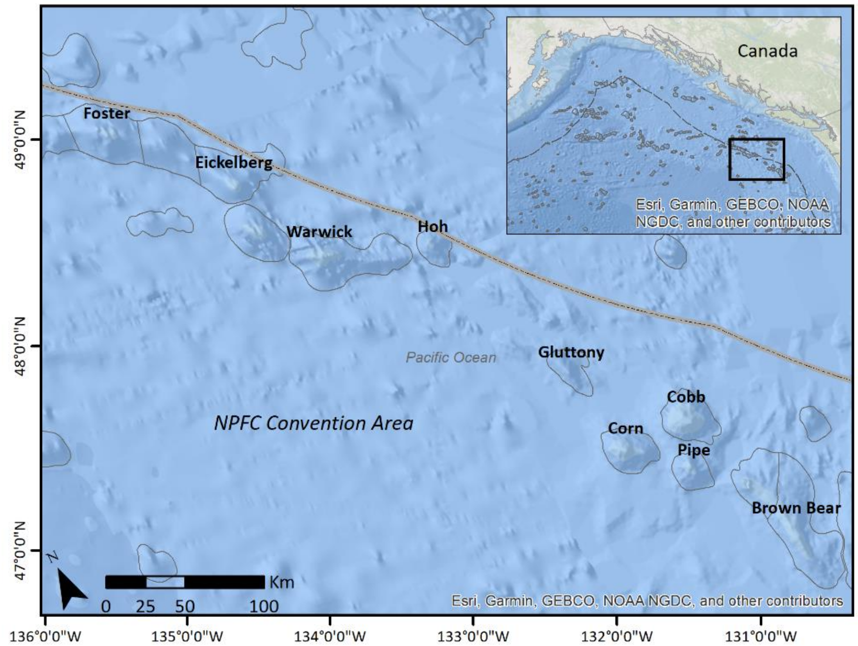

Figure 2. Study area map of the Cobb-Eickelberg seamount chain in the eastern NPFC CA.

VMEs and areas likely to be VMEs

According to the Food and Agriculture Organization's (FAO) International Guidelines for the Management of Deep-sea Fisheries in the High Seas (henceforth Deep Sea Fisheries Guidelines), "A marine ecosystem should be classified as vulnerable based on the characteristics that it possesses" and a list of characteristics is provided to be used as criteria for identification (FAO 2009). We defined VMEs based primarily on the criterion of structural complexity which is one of the VME identification characteristics and is known to increase associated species richness (e.g. Rowden et al. 2020). Our method also focusses on identifying areas with a high density or occurrence of the NPFC's VME indicator taxa (Warawa et al. 2021, 2022), which also meet at least two other FAO VME criteria: fragility and life history traits of component species that make recovery difficult. A quantitative method based on a threshold value of species biodiversity at a prescribed level of probability of VME indicator taxa presence was used to define VMEs and areas likely to be VMEs (Warawa et al. 2021, 2022). These areas are then used as conservation features to be protected in the following analyses.

Fifteen 50 km^2 areas were identified as VMEs on Cobb Seamount (Figure 3a). The areas identified as likely to be VMEs are based on ensemble model predictions of habitat suitability where at least one of the four VME indicator taxa recognized by the NPFC meets or exceeds the visual VME occurrence threshold (see analysis in Warawa et al. 2021, 2022) (Figure 3b). This resulted in 1,542 1 km^2 grid cells identified as areas likely to be VMEs that will be used as conservation feature inputs.

We incorporated a measure of uncertainty in our spatial optimization which accounts for the variability in predictive modelling used to identify areas likely to be VMEs. This allows us to set higher conservation targets for areas identified as likely to be VMEs with high confidence. For each 1km^2 grid cell, we represent the predictive models' certainty associated as the standard deviation of predicted probability of suitable habitat across three predictive model types (random forest, generalized additive model, and boosted regression tree). The standard deviation for each taxon is categorized as high, medium, or low using equal interval divisions for each taxon (see Figure 4). The criterion for identifying these areas is that at least one VME indicator taxon must meet or exceed the occurrence threshold. Therefore, each grid cell could be represented by just one VME taxon, or up to all four taxa. To select one certainty value for each grid cell, and to be consistent with the criterion that only one VME taxon needs to meet or exceed the occurrence threshold, we used the highest certainty category associated with taxa representing the area likely to be a VME in that location. For example, if black corals and gorgonian corals both represent areas likely to be VMEs in a grid cell, but their relative certainties were low and high, we would assign that cell as high certainty.

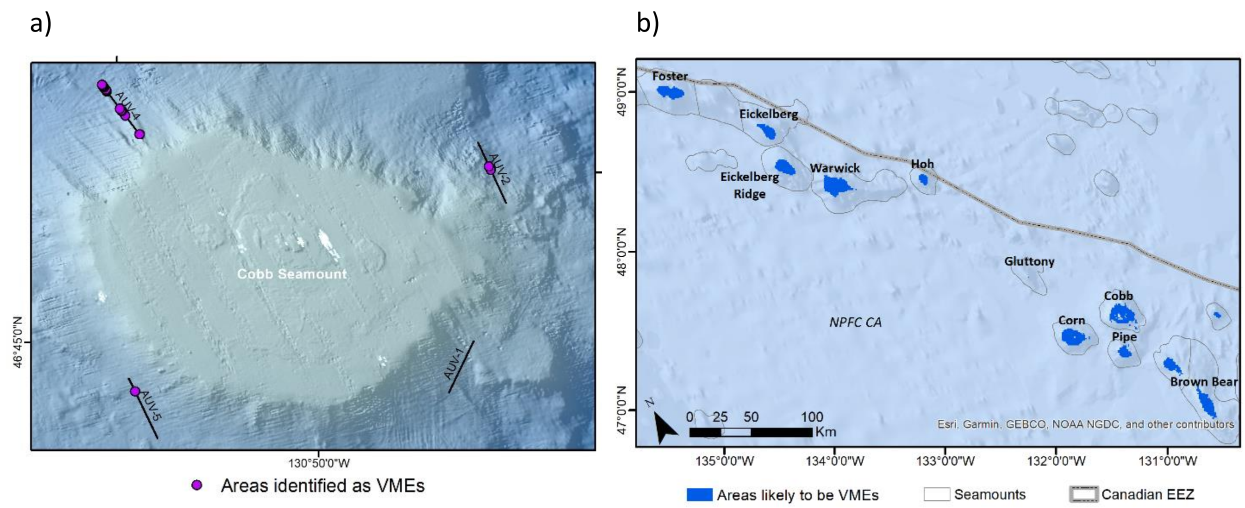

Figure 3. Areas identified as (a) VMEs (n = 15 50m² areas) based on visual data from Cobb Seamount and (b) areas likely to be VMEs (n = 1,542 1 km² grid cells) based on habitat suitability models (HSM). Black lines in (a) are four autonomous underwater vehicle (AUV) transects in a 2012 survey of Cobb Seamount (see Curtis et al. 2015).

Fisheries Data

We use the same sablefish fisheries landing values source as the previous analysis (Warawa et al. 2020) updated to include fisheries data up to the year 2021. These data were obtained from the Fisheries and Oceans Canada (DFO) Fishery Operations System (FOS) and includes the total landings in kilograms of any species landed during targeted sablefish fishing events. Each fishing event in the database has location coordinates allowing for spatially explicit analyses of landings.

Spatial optimization

The spatial optimization software, prioritizr, was used to identify areas for protection of VMEs while reducing the overlap and impact on fishing activities (see comparison of spatial optimization software in Warawa et al 2020). The analysis was conducted in R (R Core Team 2020) and required installation of the R packages “prioritizr” (Hanson et al. 2022) and “Rsymphony” (Harter et al. 2017). Planning unit, conservation feature, and cost data were input in the form of a single large spatial polygons data frame from a shapefile attribute table created in ArcGIS (ESRI 2020). Previous sensitivity analysis was undertaken to explore the influence of settings and parameters including conservation target values, uncertainty, time frame of historical landings, clumping level and planning unit grid cell size and was used to guide this analysis. Prioritizr settings used in this updated analysis are described in Table 1.

The planning unit grid was on a spatial scale of 1 km^2 that was aligned with the grid for model predictions of areas likely to be VMEs and indicator taxa habitat suitability predictions. The spatial extent was limited to grid cells identified as likely to be VMEs, which was limited to depths shallower than 1600 m (as in Warawa et al. 2021, 2022) in our study area.

Different conservation targets were applied to high, medium, and low certainty VME areas with the general idea that grid cells identified as VMEs with high certainty should be prioritized for protection over those with lower certainty. This is achieved by assigning protection to a higher proportion of the total area that is identified as likely to be VMEs with high certainty. Areas likely to be VMEs with low certainty are assigned a lower proportion of total area for protection, and medium certainty cells will have protection levels somewhere in between. As a result, more of the low certainty VME areas are not protected. A few different combinations of conservation targets are provided and represented in different solution examples; however, manager and stakeholder input and sensitivity analyses are needed to determine the optimal targets to use when providing advice on VME areas to protect from SAIs.

Table 1. Eight main functions and parameters used in our priortizr analysis and summary of the settings used in the eastern NPFC CA update analysis.

Prioritizr function	**Description**	**Analysis setting**
Loading data and initializing a problem	There are many different ways to initialize a problem depending on the format of the input data.	Data was loaded as a single large spatial polygons data frame from a shapefile attribute table created in ArcGIS and used the corresponding initialization set up for this type of data.
Objective	Used to specify the overall goal of the planning problem.	Minimum set objective ensures that all targets are met while minimizing the cost of the solution.
Targets	How much of each feature is desired or required to be conserved.	Relative targets set the proportion of the total amount of each feature in a study area. Conservation targets varied according to model uncertainty. Several target combinations are provided. (See table 2)
Constraints	Ensures that solutions exhibit specific properties such as selecting certain planning units (Pus) for protection.	Areas identified as VMEs in Warawa et al. (2022) were locked in as protected areas. (n=15)
Penalties	Penalize solutions according to specific metrics.	Boundary penalties were used to penalize solutions that are extremely fragmented and create areas that are large enough to ease enforceability. A range of “clumping” penalties are provided.

Decision types	Specify the nature of the decision.	Binary decisions are the default decision-type where PUs are either selected or not selected.
Solver	Specify the optimization software used to solve the problem.	SYMPHONY (Ralphs et al. 2019) is an open source integer programming solver and is used in this analysis. Gurobi commercial solver (Gurobi Optimization Inc. 2017) is strongly recommended due to its speed but is not freely available.

RESULTS

Inter-model uncertainty

Of the four sets of PHMs for VME indicator taxa, black coral predictions had the most high certainty grid cells, stony coral had the most low certainty grid cells, and soft and gorgonian corals had the most medium certainty grid cells (Figure 4).

When looking at the maximum certainty for each grid cell, the majority of grid cells identified as areas likely to be VMEs were associated with high certainty (67%) compared to medium (26%) and low certainty (7%) (see Figure 5). Cobb Seamount contained the largest area with low certainty predictions, followed by Corn Seamount. Eickelberg, Foster, and Hoh Seamounts were nearly all high certainty. Large areas of medium certainty was seen on Brown Bear Seamount. Out of the four grid cells that contain areas identified as VMEs, one was categorized as high certainty and three were categorized as medium certainty.

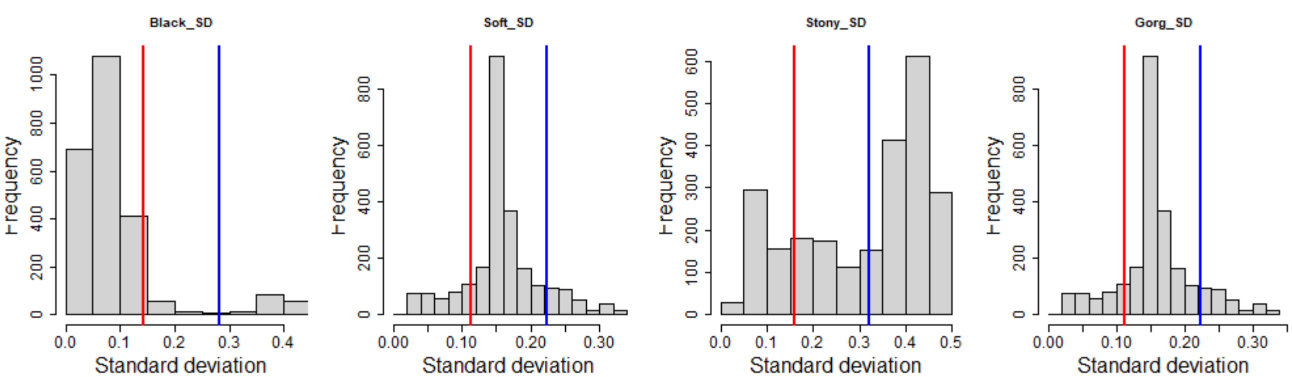

Figure 4. Frequency histograms showing the equal interval breaks in the inter-model standard deviation values to define certainty categories of VME indicator taxa. Grid cells with standard deviation between 0 and the red line were categorized as high certainty, medium certainty between the red and blue lines, and low certainty above the blue line.

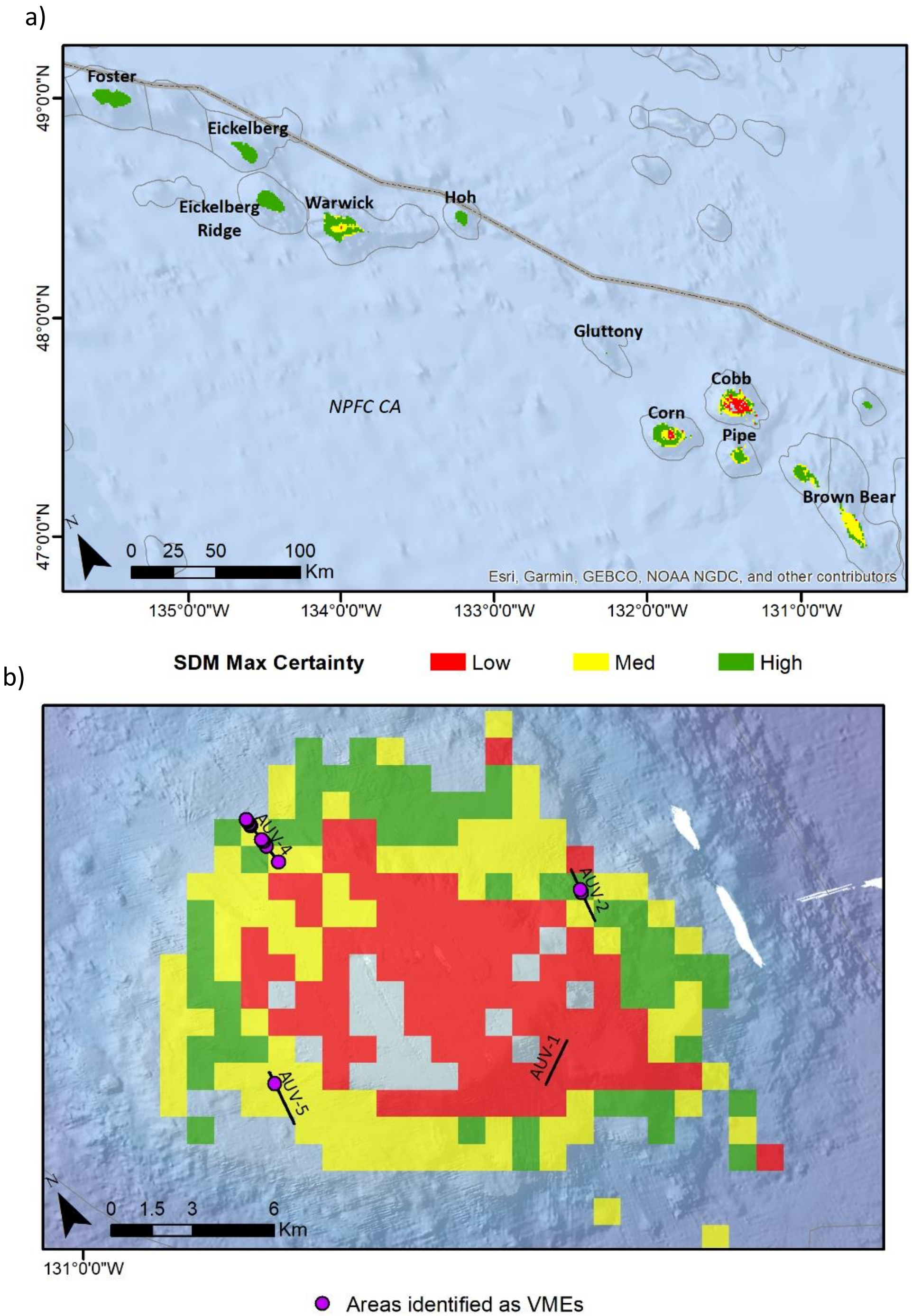

Figure 5. Inter-model maximum certainty associated with identifying areas likely to be VMEs for (a) our study area along the Cobb-Eickelberg seamount chain and (b) Cobb Seamount. Areas identified as VMEs which have high certainty as they are based on visual data (purple points, Warawa et al. 2022) are overlayed to compare with the inter model prediction certainty of identification of areas likely to be VMEs in (b).

Spatial optimization results

The prioritizr study area contained 1542 1 km^2grid cells. Areas identified as VMEs overlapped with four grid cells which were locked in as protected areas in prioritizr for all scenarios. Our sensitivity analysis allowed us to explore how spatial optimization scenarios could influence solutions (see Warawa et al. 2020 for an in-depth sensitivity analysis). In the this working paper, three scenarios of protection areas are analyzed to represent a range of solutions that correspond to different sets of conservation targets (Table 2). Scenario A and B protect all areas likely to be VMEs identified with high certainty, while Scenario C protects a balanced amount of high, med, and low certainty areas. Scenario B prioritizes protecting areas likely to be VMEs with high and medium certainty and protects 0% of low certainty areas. Areas identified as VMEs (Warawa et al. 2022) overlapped with four grid cells which were locked in as protected areas in prioritizr for all scenarios.

In general, the clumping level increased the amount of protected area which results in increased protected areas overlapping with fishing locations and landings across all scenarios (Figure 6). Scenario A resulted in the largest total area for protection, followed by scenario B and then C. Scenario C with clumping level 0.1 resulted in the solution that overlaps with historical fishing the least. In general, the majority of Foster, Hoh, Eickelberg and Corn Seamounts are consistently identified as protected areas (Figure 6). Warwick, Cobb and Brown Bear Seamounts see the most spatial variability of protection among the scenarios. Protected areas ranged from a total of 1086 km^2 to 1429 km^2 (Figure 7c) which represents 70% to 93% of areas identified as likely to be VMEs. The protected areas overlap with between 5% and 75% of sablefish fisheries landings from 2006-2021 (Figure 7b) and 23% to 82% of the grid cells that were fished during the same time period (Figure 7c).

Table 2. Scenario breakdown of conservation targets based on certainty of areas likely to be VMEs model predictions. Certainty level is based on the highest certainty VME taxa model.

Model certainty level	**Total area (km^2)**	**Conservation targets (percent of total area)**		
		Scenario A	**Scenario B**	**Scenario C**
Low	111	33%	0%	20%
Medium	404	66%	50%	60%
High	1025	100%	100%	80%

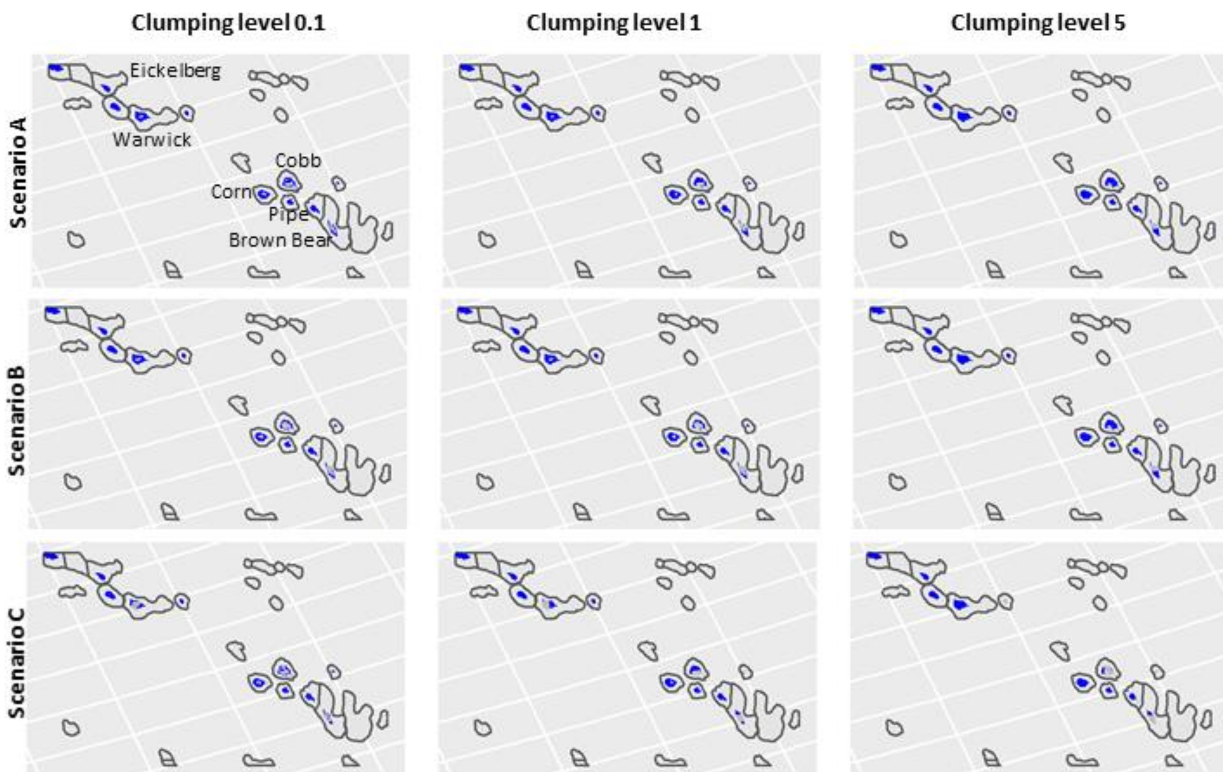

Figure 6. Areas identified for protection (blue) under 3 different scenarios with different conservation targets, each showing results for three levels of clumping parameters (columns). Higher clumping level scales the importance of selecting planning units that are spatially together. Conservation targets are based on the certainty of areas likely to be VMEs, where highly certain areas have higher proportion of protection. Scenario A: High = 100%, Med = 66%, and Low = 33 %; Scenario B: High = 100%, Med = 50%, and Low = 0%; Scenario C: High = 80%, Med = 60%, and Low = 20%.

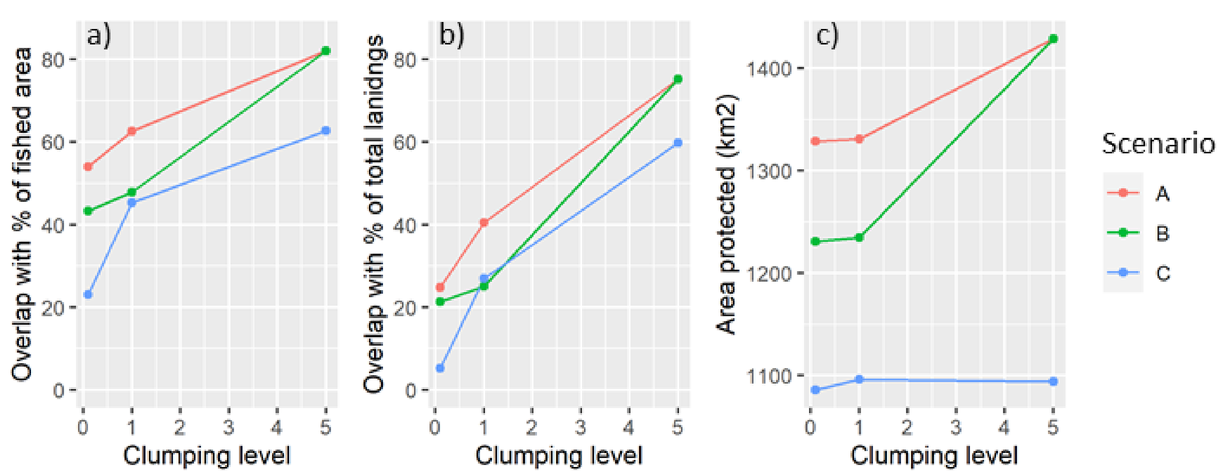

Figure 7. Summary of protection solution parameters for different conservation target combinations represented by Scenario A (pink line), B (green line) and C (blue line). The proportion of total area fished by the Sablefish fishery from 2006-2021 that overlaps with proposed protected area is shown in a); the proportion of the Sablefish fishery's landings in kg that overlaps with proposed protected areas is shown in b); and the total area in km^2 that is protected is shown in c). Clumping level refers to the scaling value parameter in prioritizr that prioritizes protecting grid cells that area closer to each other.

DISCUSSION AND CONSLUSION

Our analysis provides a range of protection area options based on different inputs and conservation priorities to be selected by managers in collaboration with stakeholders. This can be further refined and examined to better represent Canada's management goals in the eastern part of the NPFC's CA. The seamounts that showed the most variability in the resulting maps were also where the majority of fishing activity occurs.

Cobb and Brown Bear Seamounts have the most spatial variability in fishing effort, which leads to spatial variation in protection level under different scenarios. In contrast, Foster and Eickelberg Seamounts have little to no fishing effort and maintained stable levels of protection under different scenarios. In addition, Cobb Seamount had a large amount of low certainty areas likely to be VMEs, which were associated with the lowest proportion of protection given the scenario conservation targets (0%-33% of total area). This is likely because low certainty areas are concentrated on summits of Cobb and Corn Seamounts indicating that the PHM models diverge more in shallower water.

The process outlined in Warawa et al. 2020 has periodic review built in and as the identification of VMEs and areas likely to be VMEs is refined we can continue to update this analysis. Other factors we could consider including are information about significant adverse impacts (SAIs), recovering VMEs, and the projected influences of climate change on VMEs and the Sablefish fishery. Finally, in future work we aim to solicit further feedback and recommendations from NPFC, clients and stakeholders.

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