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Overlap of predicted cold-water coral habitat and bottom-contact fisheries in British Columbia

Chevauchement des prédictions concernant les habitats coralliens en eaux froides et la pêche de fond en Colombie-Britannique

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ABSTRACT

In recent years there has been increased interest, both within Canada and the international community, to protect vulnerable marine ecosystems from anthropogenic serious adverse impacts. Cold-water corals (class Anthozoa) are of particular interest due to the role corals play in providing biogenic habitat as well as their limited capacity to recover from disturbance. A lack of information on the distribution of cold-water coral in British Columbia (BC) limits our ability to evaluate the extent and intensity of fishing activity in coral habitat. In this document, suitable habitat for four orders of cold-water coral (Alcyonacea, Antipatharia, Pennatulacea, and Scleractinia) is predicted using the species distribution modelling tool Maxent. The extent of overlap between the fishing footprints of three bottom-contact fisheries (groundfish trawl, sablefish longline, and sablefish trap) and predicted suitable coral habitat is determined. Depending on the order, fishing effort has occurred on 30.4 to 46.5% of predicted habitat, with effort being disproportionately concentrated in areas of predicted coral habitat. Results suggest that cold-water coral habitat in BC requires protection from fishing activity to guarantee the long-term viability of coral populations.

RÉSUMÉ

Au cours des dernières années, on a noté un intérêt accru, tant au Canada qu'à l'étranger, pour la protection des écosystèmes marins vulnérables contre les impacts anthropiques négatifs graves. Les coraux des eaux froides (classe des anthozoaires) suscitent tout particulièrement l'intérêt en raison, d'une part, de l'habitat biogénique qu'ils contribuent à offrir et, d'autre part, de leur capacité limitée de se rétablir à la suite d'une perturbation. Le manque de données sur la répartition des coraux des eaux froides en Colombie-Britannique (BC) réduit notre capacité d'évaluer l'étendue et l'intensité des pêches dans les zones d'habitats coralliens. Dans le présent document, les prévisions concernant les habitats convenant à quatre ordres de coraux des eaux froides (Alcyonaire, Antipathaire, Pennatulida et Scleractinia) ont été établies au moyen de Maxent, un outil de modélisation de la distribution des espèces. On y détermine l'ampleur du chevauchement entre l'empreinte de trois types de pêche de fond (pêche au chalut, pêche à la palangre de la morue charbonnière et pêche au moyen de casiers de la morue charbonnière) et les habitats prévus pouvant convenir aux coraux. Selon l'ordre, la pêche est pratiquée dans 30,4 à 46,5 % des zones d'habitats prévues, et elle se pratique de manière disproportionnée dans les zones d'habitats coralliens prévues. Les résultats montrent qu'en Colombie-Britannique les habitats coralliens en eaux froides doivent être protégés contre l'activité de la pêche pour garantir la viabilité à long terme des récifs coralliens.

INTRODUCTION

Recently, there has been increased interest in studying impacts of bottom-contact fishing on cold-water corals (class Anthozoa) due to the role corals play in the deep-sea environment as well as their vulnerability to impacts from human activities. Given the limited capacity of many species of coral to recover from disturbance, Canada has become involved in both international and domestic efforts to provide some protection to these sensitive benthic organisms. Canada is a signatory to several international agreements that promote increased protection for cold-water coral and other sensitive benthic habitats, including the Convention on Biological Diversity (CBD) and several United Nations (UN) conventions. Specifically, UNGA *Resolution 61/105* calls on States to apply the precautionary approach and ecosystem approach in order to sustainably manage fish stocks and protect vulnerable marine ecosystems (VME) from significant adverse impacts (SAI).

Domestically, Canada is implementing several initiatives to provide protection to VME, including the Sustainable Fisheries Framework, the Policy for Managing the Impacts of Fishing on Sensitive Benthic Areas, and several Regional cold-water coral and sponge conservation strategies.

In support of these commitments, a national Canadian Science Advisory Secretariat (CSAS) science advisory process was held in Ottawa from March 9-12, 2010 to aid in advancing Canada's domestic and international commitments to sustainably manage fish stocks and protect corals from serious or irreversible harm due to fishing activities. This paper was written in preparation for that meeting and aims to address two of the Terms of Reference (TOR) (see DFO 2010). Specifically, this paper aims to (1) map where four orders of coral could potentially occur using species distribution modeling (TOR 4); and (2) assess the proportion of potentially suitable habitat threatened by bottom-contact fishing (TOR 5).

SPECIES DISTRIBUTION MODELS (SDM)

Predictive modeling was undertaken in order to address TOR 4 (map where corals could potentially occur within the Canadian EEZ). In the absence of complete information on the distribution of taxa, species distribution models (SDMs) can help meet science and management needs for conservation and planning by predicting areas of high habitat suitability for species or other taxonomic groups of concern. SDMs use algorithms based on habitat or environmental conditions to predict the distribution of a species in as-yet-unsampled areas by relating occurrence data to background environmental data (Guisan and Zimmermann 2000; Guisan and Thuiller 2005).

Several modelling approaches can be used to predict suitable habitat. Maxent is a general purpose machine-learning method for making predictions with only presence information (Phillips et al. 2006). Maxent has been shown to perform better than other presence-only techniques and some presence/absence methods (e.g. general linear models, generalized additive models) that have been modified for use with presence-only data (e.g. Elith et al. 2006; Phillips et al. 2006). A recent study by Tittensor et al. (2009) used two presence-only models, Ecological Niche Factor Analysis (ENFA) and maximum entropy (Maxent) to predict the global distribution of scleractinian corals on seamounts. They found that Maxent produced significantly better predictions than ENFA. Maxent's excellent performance even with small sample sizes (Pearson et al.

2007; Hernandez et al. 2006) and its previous use as a tool to assess threats and set conservation priorities for vulnerable and threatened primates in Indonesia (Thorn et al. 2009) make it an ideal SDM for the present analysis.

OVERLAP WITH BOTTOM-CONTACT FISHERIES

The proportion of suitable habitat potentially impacted by bottom-contact fishing was assessed to respond to TOR 5 (indicators of the ecological function served by coral and conservation limits for that threshold). Cold-water coral in BC waters are currently unprotected. The World Conservation Union (IUCN) Red List Categories and Criteria assess the status of species at high risk of global extinction (IUCN 2001). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has a complementary assessment process based on the IUCN criteria designed to provide advice regarding the status of Canadian species nationally at risk of extinction or extirpation (COSEWIC 2009). The absence of high-quality data should not deter attempts to apply the assessment criteria, and indeed methods involving estimation, inference and projection are emphasised as being acceptable (IUCN 2001). In fact, taxa that are poorly known can often be assigned a threat category on the basis of background information concerning the deterioration of their habitat (IUCN 2001).

This study is not a report on the status of cold-water coral in BC. A full evaluation using the IUCN or COSEWIC criteria needs to be completed before a recommendation can be made regarding the conservation status of corals. However, the IUCN and COSEWIC criteria can be used here to put the level of overlap between predicted suitable coral habitat and bottom-contact fishing into the context of internationally recognized and applied conservation status criteria, and to provide managers with target amounts of coral habitat to protect from SAIs, such as bottom-contact fishing, to ensure the long-term viability of coral populations and to ensure they continue to serve their ecological functions.

Five groundfish fisheries gear types are used in BC: bottom trawl; mid-water trawl; demersal longline; trap; and jig. These gears either intentionally contact the bottom or do so occasionally by design or mistake. In situations where fishing gear does contact the bottom it is possible that they come into contact with coral and inflict SAIs. There is much empirical evidence demonstrating that cold-water corals are substantially damaged and killed by bottom-contact fishing. Considerable damage to, and removal of, these corals by fishing activities has been documented in BC (Ardron and Jamieson 2006), Alaska (Krieger 2001; Stone 2006), the north-east Atlantic (Waller et al. 2007), on seamounts in Australia (Koslow et al. 2001) and New Zealand (Probert et al. 1997), and off the coast of Norway (Fosså et al. 2002). This paper considers the potential overlap between trawl (bottom and mid-water), longline and trap fishing activity and predicted coral habitat, and assesses the extent of overlap, and inferred population size reduction as a result of that contact, with IUCN and COSEWIC threat criteria.

METHODS

STUDY AREA

The study area was defined as the region within the Exclusive Economic Zone (EEZ) of Pacific Canada and less than 2450 m depth (Figure 1). The depth threshold was selected to include the deepest coral record used in the modelling while minimizing the overall size of the study area. The study area was divided into a grid of 500 m-by-500 m cells. There were a total of 666,010 grid cells in the study area.

RECORDS FOR MODELLING

Records of species presence used for the predictive modelling were originally obtained as part of research surveys, other scientific studies, and from bycatch in commercial fisheries that were sent to museums and identified by experts. On-board observers in the groundfish trawl fishery in BC provide 100% coverage of the fishery and are required to report all bycatch, but their taxonomic identification of corals is generally unreliable (J. Boutillier, Pacific Biological Station, Nanaimo, BC, pers. comm.). Hence, these observer records were not used in this study. Records used were collected between 1882 and 2008, though the majority were collected in the past 20 years. All records were checked for consistent taxonomic classification (according to the Integrated Taxonomic Information System; http://www.itis.gov/). Records represent 35 genera from 23 families and 4 orders. Limited data meant that records had to be grouped by order rather than species or family so that reasonable sample sizes could be obtained.

The recorded accuracy of spatial references ranged from several meters to several kilometres. Observations with a spatial resolution poorer than 500 m were excluded to ensure records were assigned to the correct grid cell. Multiple records of the same order that were located within the same grid cell were counted as a single observation. In total, 121 unique presence locations were used to construct the models for the order Alcyonacea (which includes Gorgonacea), 49 for Antipatharia, 84 for Pennatulacea, and 32 for Scleractinia. At least 87% of the records used to build the model came from fishery-independent sources, thereby reducing the likelihood that the model is predicting the distribution of commercial fishing effort rather than the distribution of coral.

ENVIRONMENTAL DATA

Decisions regarding which environmental variables to include were made based on ecological relevance and data availability. Data on depth, slope, spring surface chlorophyll *a* concentration, bottom tidal speed, and summer and winter values for bottom non-tidal current velocities, temperature, and salinity were collated to build a model of habitat suitability for cold-water corals. Factors that are likely to influence coral distribution but for which data were not available include bottom type, dissolved oxygen, phosphate, nitrate, silicate, inorganic carbon, per cent oxygen saturation, and aragonite saturation (Clark et al. 2006; Davies et al. 2008; Tittensor et al. 2009). The available data were imported into ArcMap 9.2 and interpolated to a 500 m-by-500 m raster using the natural neighbour technique (Watson 1992). The types and sources of environmental data used in this study are summarized in Table 1.

PREDICTED CORAL HABITAT

Maxent

Maximum entropy (Maxent) is a general purpose machine-learning method for making predictions or inferences from incomplete information (Philips et al. 2006).

Maxent estimates the most uniform distribution (maximum entropy) that defines a taxon's spatial distribution within a study area given the constraint that the expected value of each environmental variable for the predicted distribution matches the average values for the set of occurrence data (Philips et al. 2006). Each cell in the output map is assigned a probability of coral presence, which can be interpreted as the suitability of the habitat in that cell. Maxent results are provided as a continuous gradient ranging from 0 (completely unsuitable) to 1 (perfectly suitable habitat).

Maximum entropy modelling was carried out using Maxent software version 3.2.19 (http://www.cs.princeton.edu/~schapire/maxent/). This program implements algorithms that are deterministic and guaranteed to converge to the maximum entropy distribution (Dudík et al. 2004).

Model building

A model for each coral order was constructed using the default parameter settings. Default parameters were determined using data on 226 terrestrial species, ranging from plants to mammals, from six regions in the world (Phillips and Dudík 2008). The default values are well suited to a wide range of presence-only datasets as long as those data do not have characteristics that substantially deviate from the ones used by Phillips and Dudík (2008), and are well suited for use with these coral data (Finney 2009). All presence locations within the study area were included in the construction of the models and thus contributed to estimating the corals' distribution. The contribution of each environmental variable to a model's fit to the data on presence of corals was evaluated using Maxent's built-in heuristic estimate of variable contribution. However, due to the high level of correlation between many of the environmental variables, it was difficult to ascertain the relative importance of each variable in determining habitat suitability. Therefore, these results should be interpreted with caution.

The final predictive maps of habitat suitability for cold-water corals off the BC coast were divided into areas predicted to have a high probability of suitable coral habitat (predicted suitable habitat) and areas predicted to have a low probability of suitable coral habitat to facilitate statistical analyses of the overlap with fishing effort. In the base case, maps were divided using the maximum sum of sensitivity-plus-specificity threshold value calculated for each order. The maximum sum of sensitivity-plus-specificity threshold is equivalent to finding the point on the receiver operating characteristic (ROC, see "Evaluation of models" section below) where the slope of the tangent line equals 1 (Cantor et al. 1999). This threshold was selected for its relative insensitivity to prevalence (i.e. the proportion of the study area with occurrence data) (Liu et al. 2005; Jiménez-Valverde and Lobo 2007), which is particularly important in this study due to the use of presence-only data.

Evaluation of models

The area under the curve (AUC) of the receiver operating characteristic (ROC) is a commonly used threshold-independent measure of model accuracy (Fielding and Bell 1997) and was used here to evaluate model performance. The AUC is a measure of predictive accuracy and can have values ranging from 1.0 (indicating perfect distinction between presence and absence) to 0.5 (indicating a model that is no better than random). Though originally designed for presence and absence data, the AUC can be adapted for use with presence-only data by replacing absences with a random sample of background locations, or pseudo-absences (Phillips et al. 2006).

BOTTOM-CONTACT FISHING ACTIVITY

Spatially explicit data on effort in the commercial groundfish trawl, sablefish trap, and sablefish longline fisheries between 1996 and 2004 were obtained from a database maintained by Fisheries and Oceans Canada (DFO 2006). The trawl data include information on both bottom and mid-water trawls (excluding mid-water hake trawls). Data on fishing effort were provided on a 4 km-by-4 km grid. To protect the privacy of fishers, data were binned over all years, and at least three vessels had to record activity in a grid cell for it to be reported. Grid cells contained information on cumulative fishing effort for each fleet (measured in hours trawled, traps set, or number of hooks). For ease of calculation, all 500 m-by-500 m cells falling within 4 km-by-4 km fishery grid cells were assigned the same values as larger cells. The values of the smaller cells should therefore be considered as rates per 16 km^2 rather than per 0.25 km^2. Potential overlap between bottom-contact fishing activities and coral habitat were evaluated by calculating the proportion of cells in areas of predicted habitat exposed to some level of fishing activity. The proportion of overlap between predicted suitable habitat and bottom-contact fishing was calculated for the base case (using the maximum sum of sensitivity-plus-specificity threshold), and using thresholds of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, and 0.9.

RESULTS

CORAL LOCATIONS

Records of alcyonacean corals used in the modelling were primarily concentrated along the continental slope, with approximately 40 records in the central and northern parts of Queen Charlotte Sound (Figure 1), and about 20 in the Strait of Georgia (Figure 2a). Records ranged in depth from 14 m to 2304 m and represented 8 families and 13 genera (Table 2). Records of antipatharian corals were nearly exclusively found along the continental slope (Figure 2b) and ranged in depth from 40 m to 2273 m. The Antipatharia records represented 3 families and 9 genera (Table 2). Records of pennatulaceans were also concentrated along the continental slope, with approximately 20 located in northeastern waters (Hecate Strait and Chatham Sound) (Figure 2c). Records ranged in depth from 22 m to 2158 m and represented 9 families and 9 genera (Table 2). Scleractinian coral records were dispersed throughout the study area, with records found along the continental slope, in Chatham Sound, Hecate Strait, Queen Charlotte Sound and the Strait of Georgia (Figure 2d). Records ranged in depth from 14 m to 2158 m and represented 3 families and 4 genera (Table 2).

PREDICTED SUITABLE HABITAT

The final models all had high AUC and true positive values and low false negative rates (Table 3), indicating that the Maxent models have good predictive capabilities.

Alcyonacea

Areas predicted by the final model as being suitable habitat for Alcyonacea were mostly concentrated along the shelf break, particularly in the northern and southern extents of the study area, and in the Goose Island, Moresby, and Mitchell's Gullies projecting into Queen Charlotte Sound (Figure 3a). Summer salinity contributed most to explaining the variation in location of Alcyonacea (27%), followed by spring chlorophyll *a* concentration (20%), winter salinity (14%), summer current speed (14%), summer temperature (12%), and depth (7%) (Figure 3a). Winter temperature, slope, tidal speed and winter current speed explained only a small proportion of variation in the data.

Antipatharia

Predicted suitable habitat for the order Antipatharia was identified primarily on the shelf break (Figure 3b). Depth explained the greatest proportion of variability in the model of habitat suitability (61%) followed by summer current speed (28%) (Figure 3b). The other environmental variables each explained less than 4% of the variation in the data.

Pennatulacea

Predicted suitable habitat for pennatulacean corals was identified primarily along the shelf break, with patches located along the mainland and to the west of Vancouver Island (Figure 3c). The Maxent model for these corals was largely based on tidal speed (30%), and depth (22%) (Figure 3c). Other important environmental variables include summer salinity (10%), summer temperature (10%) and winter salinity (9%). The remaining variables each contributed less than 6% to the model.

Scleractinia

For the order Scleractinia, predicted suitable habitat was identified along the shelf break in the southern extent of the study area, throughout the Strait of Georgia and Queen Charlotte Sound, around the Queen Charlotte Islands, Chatham Sound, and in the northwestern extent of the study area (Figure 3d). Spring chlorophyll *a* concentration contributed the most to the model (33%) (Figure 3d). Depth, tidal speed, and summer current speed all contributed similar amounts (21, 20, and 18%, respectively). Other variables each explained less than 4% of variability.

BOTTOM-CONTACT FISHING ACTIVITY

The following results, unless otherwise noted, are for when the base-case threshold is used (maximum sum of sensitivity-plus-specificity). Trawl fishing effort is distributed throughout the study area landward of the shelf break and occurs in 41,721 km^2 (25.1%) of the study area (Figure 4a). The cumulative trawling intensity over the nine year study period (1996-2004) ranges from 3 to 44,851 hours of trawling/16 km^2, with a median value of 769.6 hours of fishing/16 km^2 (Table 4). Median values are reported rather than means because the data are not normally distributed.

Trawl activity has occurred in 22.2 – 37.5% of predicted suitable habitat for the four orders of coral (Table 5). Trawl fishing has occurred in a disproportionately larger area of the predicted suitable habitat of three of the coral orders studied than it does in the total study area (Figure 5). For example, trawling has occurred in 25.1% of the total study area, yet it has occurred in 35.7% of the area in which the final Maxent model predicted suitable habitat for Alcyonacea (Figure 5). The exception to this disproportionally higher intensity of fishing in coral habitat is the order Antipatharia, which are more likely to occur in deeper parts of the shelf break where trawlers do not traditionally go.

Generally, the proportion of habitat potentially impacted by trawl fishing increases as the threshold used to distinguish between predicted unsuitable and suitable habitat increases (Figure 6). The main exception is for Scleractinia. The maximum potential overlap occurs when a threshold of 0.2 is used (37.8%) and then decreases to a minimum of 7.1% when a threshold of 0.8 is used (Figure 6d).

The sablefish trap and longline fisheries cover substantially less area than the groundfish trawl fishery. The trap fishery occurs in 11,829 km^2 (7.1%) of the study area, while the longline fishery occupies 8,318 km^2 (5.0%) of the study area. The effort in both fisheries is concentrated along the shelf break (Figure 4b and 4c). Cumulative fishing effort over the nine year study period ranges from 125 to 63,531 traps/16 km^2 (median: 1,652 traps/16 km^2) for the trap fishery and from 800 to 763,675 hooks/16 km^2 (median: 16,900 hooks/16 km^2) for the longline fishery (Table 4).

The sablefish trap fishery occurs in 15.3 – 27.4% of predicted coral habitat, whereas the longline fishery occurs in 7.2 – 14.5% of predicted habitat (Table 5). As with the groundfish trawl fishery, effort in the trap and longline fisheries is disproportionately concentrated in areas of predicted suitable coral habitat (Figure 5).

As with the trawl fishery, the proportion of habitat potentially impacted by trap and longline fishing generally increases as the threshold used to distinguish between predicted unsuitable and suitable habitat increases (Figure 6). Again, Scleractinia is the main exception. In both fisheries, the maximum potential overlap occurs when a threshold of 0.5 is used (16.2 and 11.6% for trap and longline, respectively). The estimate of overlap then decreases to minimum of 1.0% for trap and 0.0% for longline at thresholds of 0.8 and 0.9, respectively (Figure 6d).

Combined, the three fisheries cover 47,330 km^2 (28.4%) of the study area, and occur in 30.4 - 46.5% of predicted suitable coral habitat (Table 5). Thus, bottom-contact fishing generally occurs with disproportionately greater frequency in areas of predicted suitable coral habitat than in the entire study area (Figure 5).

Using the maximum sum of sensitivity-plus-specificity threshold, areas of overlap between predicted suitable habitat and bottom-contact fishing activity as well as areas that may contain pristine coral aggregations are highlighted in Figure 7 for each of the four coral orders considered. For all orders of coral and types of fishing there is a significant, though weak, correlation between the intensity of fishing activity and the predicted suitability of habitat (Spearman's rho: -0.19 and 0.24, $p < 0.001$ in all cases).

DISCUSSION

This study predicts the distribution of four orders of coral in BC and provides an estimate of the extent of overlap between predicted suitable coral habitat and bottom-contact fisheries. Even with limited data, Maxent seems to have provided reasonable predictions of the distribution of coral along the coast of BC, though independent validation through ground-truthing work is required. Initial ground-truthing is currently underway.

Depending on the taxonomic order, overlap of predicted suitable coral habitat and areas of all types of bottom-contact fishing is estimated to be between 30.4 and 46.5% when the maximum sum of sensitivity-plus-specificity threshold is used. Generally, as the threshold used to distinguish between predicted unsuitable and suitable habitat increases, so does the proportion of suitable habitat that has potentially been impacted by bottom-contact fisheries. This study demonstrates the utility of using SDMs to predict the distribution of cold-water corals and to identify areas of potential overlap between predicted suitable habitat and known threats using a variety of thresholds. These results can help managers make more informed policy and conservation decisions and guide future scientific research on the distribution of coral.

PREDICTED CORAL HABITAT

In general, suitable habitat for the four coral orders examined here was predicted to occur primarily along the shelf break, and in the Malcolm Island, Goose, and Mitchell's Gullies. These results are supported by earlier findings by Bryan and Metaxas (2007), who predicted the distribution of two families of alcyonacean coral in BC using Ecological Niche Factor Analysis (ENFA), and Ardron and Jamieson (2006), who performed a density analysis on bycatch data from the BC groundfish trawl to identify 12 areas of high coral and sponge concentration.

OVERLAP WITH BOTTOM-CONTACT FISHING

The overlap between predicted suitable coral habitat identified in this study and bottom-contact fisheries in BC is substantial. When using the base-case threshold (maximum sum of sensitivity-plus-specificity), bottom-contact fisheries overlap with between 30.4 and 46.5% of predicted suitable coral habitat. Fishing effort is disproportionately concentrated in areas of predicted suitable coral habitat relative to the entire study area, and there is a very small but significant correlation between the intensity of fishing and habitat suitability. These estimates of overlap are similar to those of other studies that have attempted to quantify the proportion of cold-water coral habitat impacted by fishing in Norway (30-50%; Fosså et al. 2002) and Alaska (39%; Stone 2006).

Varying the threshold used to distinguish between predicted unsuitable and suitable habitat has a large impact on estimates of overlap between predicted suitable habitat and bottom-contact fishing. In almost all cases, the proportion of predicted suitable habitat potentially impacted by bottom-contact fishing increases as the threshold increases (Figure 6). The main exception is Scleractina, likely due to the fact that areas predicted to be more suitable (i.e., areas with higher probabilities of occurrence) tend to be closer to shore in areas not targeted by the fisheries studied. Therefore, the proportion of potentially impacted predicted suitable habitat tends to decrease as the threshold increases beyond about 0.4. For the other orders, the positive correlation between threshold selection and the proportion of habitat potentially impacted by fishing suggests that there is a relationship between the fish being targeted by the trawl, trap, and longline fisheries and coral habitat. Whether that relationship is based on similar habitat preferences of the fish being targeted and coral, or an association between those fish and coral needs to be determined with future research.

These results emphasize the importance of selecting an accurate threshold for distinguishing between unsuitable and suitable habitat, especially if management decisions are being based on the proportion of habitat that has been impacted by fishing. The final decision of what threshold indicates suitable or unsuitable habitat can only be made through independent validation of the model results.

GOALS FOR MANAGING IMPACTS

According to the IUCN and COSEWIC criteria, a taxon can be listed as vulnerable (IUCN) or threatened (COSEWIC) if there is “an observed, estimated, inferred or suspected population size reduction of ≥ 30% over the last 10 years or 3 generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or may not be reversible, based on…a decline in index of area of occupancy, extent of occurrence and/or quality of habitat.” (IUCN 2001). Bottom-contact fishing in BC has not ceased and will continue to occur in the foreseeable future. Given the vulnerability of many cold-water corals to bottom-contact fishing (e.g. Krieger 2001; Stone 2006; Waller et al. 2007; Koslow et al. 2001; Probert et al. 1997; Fosså et al. 2002; Troffe et al. 2005), it is reasonable to assume that contact with fishing gear will result in a reduction in population size and therefore a reduction in area of occupancy. Corals are not uniformly distributed throughout their area of occupancy, nor are they equally susceptible and vulnerable to fishing gear. The type and intensity of fishing activity will influence the extent of damage to and mortality of coral. It is, therefore, unlikely that the reduction in population size caused by bottom-contact fishing is linearly related to the area fished. Future research is required to provide estimates of the relationship between the intensity and frequency of fishing effort and reduction in population size. Thus, at this time, estimates of overlap can only be used as a coarse proxy for reduction in population size.

Bearing those caveats in mind and using the IUCN and COSEWIC criteria as a guideline, managers should consider implementing some protective measures in approximately 70% of the habitat of coral species identified as VME (e.g. gorgonians, antipatharians, Cerianthid anemone fields, sea pen fields) to ensure the they do not get listed as vulnerable or threatened, and to ensure that they can continue to serve their ecological functions within benthic ecosystems.

Unfortunately, based on the results of this study, we are not meeting those targets. In the nine-year period between 1996 and 2004, an estimated 30.4 to 46.5 % of predicted suitable coral habitat potentially came into contact with bottom-contact fishing gear. For three of the orders examined, Alcyonacea, Pennatulacea, and Scleractinia, the estimate of potential overlap is over 40% (46.5, 46.2, and 41.9% respectively) when using the base-case threshold (maximum sum of sensitivity-plus-specificity). In fact, the 30% threshold is surpassed for Alcyonacea and Pennatulacea when any threshold equal to or over 0.1 is used, when thresholds equal to or greater than 0.3 are used for Antipatharia, and when thresholds between 0.1 and 0.5 are used for Scleractinia (Figure 6). Although an area being fished does not necessarily equal an area cleared of corals, the estimates of potential overlap, and by proxy, estimates of potential population reduction, are above the 30% metric used to list a taxon as vulnerable (IUCN) or threatened (COSEWIC), even if we allow error margins of ± 10% with the base-case threshold. This high degree of overlap suggests that cold-water corals in BC are being put at risk by bottom-contact fishing, and precautionary measures, such as spatial gear restrictions, need to be considered to ensure they are protected.

INFORMATION GAPS

Although the methods used here appear to provide good predictions of the location of coral on the BC coast, there is much room for improvement. The species distribution models can be refined by increasing coral sample sizes and including additional environmental variables. Estimates of the overlap between suitable habitat and bottom-contact fishing can be improved by better reporting of the location of fishing activities. Understanding the impacts of specific fishing gear and the recovery potential of coral will also help to determine the vulnerability of coral to fishing activity in BC.

CONCLUSIONS

This paper has predicted suitable habitat for four orders of cold-water coral in BC and has identified areas where there are potential conflicts between the footprints of bottom-contact fisheries and suitable coral habitat. Estimates of the extent of overlap between predicted suitable coral habitat and bottom-contact fishing are substantial. The results presented here, as well as the innate vulnerability of many species, suggest that cold-water coral habitat in BC requires protection from fishing activity to guarantee the long-term viability of coral populations and to ensure that they continue to serve their ecological functions in the deep-sea environment.

Future research efforts need to focus on testing predictions of this study by ground-truthing with new surveys and data mining previously recorded ROV footage. This ground-truthing will help validate model results, identify the appropriate threshold to use to distinguish between unsuitable and suitable habitat, and could also help improve model predictions. Field comparisons should also be made between areas that are predicted to have come into contact with bottom-contact fishing and those predicted to be untouched to evaluate the impact of fishing on coral.

Canada has national and international obligations to protect cold-water corals, but has yet to provide such protection in BC. The UN has called for a stop to bottom trawling in areas where vulnerable marine ecosystems are known to occur, and to ensure that destructive fishing does not continue until conservation and management measures have been established. A full status report on all orders of cold-water coral in BC and Canada is needed to assess their conservation status so that appropriate protective measures can be taken. Until such assessments can be made, Canada needs to take a proactive and precautionary approach to cold-water coral conservation so that these important and vulnerable marine ecosystems are not irreparably damaged. In the absence of spatial or gear restrictions designed to protect coral, continued bottom-contact fishing in BC will result in continued damage to coral habitat.

RECOMMENDATIONS

1. Establish targets for the proportion of habitat to be protected from bottom-contact fishing and other SAIs (e.g. 70%);

2. Identify areas for protection;

3. Determine the relationship between the intensity and frequency of fishing activity and coral mortality;

4. Initiate long-term monitoring following disturbance and/or implement protected areas to characterize the trajectory of recovery.

5. Increase and improve monitoring, identification, and reporting of all coral encounters (by any activity);

6. Independent verification of model predictions to determine model accuracy and assess the appropriate threshold to distinguish between unsuitable and suitable habitat; and

7. Improve characterization of habitat parameters, e.g., bottom type and aragonite saturation.

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TABLES

Table 1 The type and source of environmental data used in this study, showing range and median values for each environmental variable.

Environmental variable	Source	Original resolution	Minimum	Maximum	Median
Depth (m)	Canadian Hydrographic Service US Geological Service	75 m 250 m	1	2450	330
Slope (degrees)	Derived from depth layer using Spatial Analyst Extention of ArcMap 9.2		0	70.73	0.79
Chlorophyll *a* concentration (μg/L)	Ocean Color http://oceancolor.gsfc.nasa.gov/	4 km	0.26	38.46	1.50
Summer current speed (m/s)	M. Foreman (Institute of Ocean Sciences, Sidney, BC, pers. comm.)	Variable	3×10^{-6}	1.03	0.015
Winter current speed (m/s)	M. Foreman	Variable	7×10^{-6}	1.27	0.021
Summer salinity (psu)	M. Foreman	Variable	17.63	34.68	33.95
Winter salinity (psu)	M. Foreman	Variable	25.56	34.68	33.91
Summer temperature (°C)	M. Foreman	Variable	1.50	16.86	5.42
Winter temperature (°C)	M. Foreman	Variable	1.53	9.38	6.13
Tidal speed (m/s)	M. Foreman	Variable	0.0052	0.92	0.046

Table 2 Families and genera represented in each taxonomic order used in this study.

Order	Families	Genera	
Alcyonacea	Acanthogorgiidae Alcyoniidae Gorgoniidae Isididae Nephtheidae Paragorgiidae Plexauridae Primnoidae	*Acanthogorgia* *Anthomastus* *Callagorgia* *Eunephthya* *Gersemia* *Isidella* *Keratosis* *Lepidisis*	*Narella* *Paragorgia* *Parastenella* *Primnoa* *Swiftia*
Antipatharia	Antipathidae Cladopathidae Schizopathidae	*Antipathes* *Bathypathes* *Chrysopathes* *Cladopathes* *Dendrobathypathes*	*Lillipathes* *Parantipathes* *Trissopathes* *Umbellapathes*
Pennatulacea	Anthoptilidae Funiculinidae Halipteridae Kophobelemnidae Ombelluiidae Pennatulidae Protoptilidae Stachyptilidae Virgulariidae	*Anthoptilium* *Distichoptilum* *Funiculina* *Halipteris* *Kophobelemnon*	*Ombellula* *Pennatula* *Ptilosarcus* *Stylatula*
Scleractinia	Caryophyllidae Dendrophyllidae Flabellidae	*Caryophyllia* *Paracyathus*	*Balanophyllia* *Javania*

Table 3 Maximum sensitivity-plus-specificity threshold, area under the receiver-operator curve (AUC), null model median AUC, 95% confidence interval (CI) of the AUC, and the true positive rate (cases in which coral occurred and were predicted to occur) and false negative rate (cases in which coral occurred but was not predicted to occur) of the final model for each coral order.

Order	Maximum sensitivity-plus-specificity threshold	AUC	True positive rate	False negative rate
Alcyonacea	0.331	0.908	0.88	0.12
Antipatharia	0.295	0.940	0.94	0.06
Pennatulacea	0.350	0.947	0.90	0.10
Scleractinia	0.352	0.864	0.84	0.16

Table 4 Cumulative minimum, maximum, and median values for fishing effort of the groundfish trawl (hours/16 km^2), sablefish trap (traps/16 km^2), and sablefish longline (hooks/16 km^2) fisheries over a nine-year period (1996-2004).

	Fishing effort (per 16 km^2)		
Type of fishing	Minimum	Maximum	Median
Trawl (hours)	3	44,851	770
Trap (traps)	125	63,531	1,652
Longline (hooks)	800	763,675	16,900

Table 5 Percentage of area of predicted suitable habitat for each order of coral and the entire study area that overlaps with three bottom-contact fisheries - trawl, trap, and longline (individually and cumulatively).

		Percentage of area that overlaps with fishing activity			
	Area (km^2)	Trawl	Trap	Longline	Cumulative
Alcyonacea	32,765	35.7	25.5	14.5	46.5
Antipatharia	23,669	22.2	21.3	7.2	30.4
Pennatulacea	18,496	37.5	27.4	11.0	46.2
Scleractinia	36,292	35.6	15.3	10.7	41.9
Study area	166,503	25.1	7.1	5.0	28.4

FIGURES

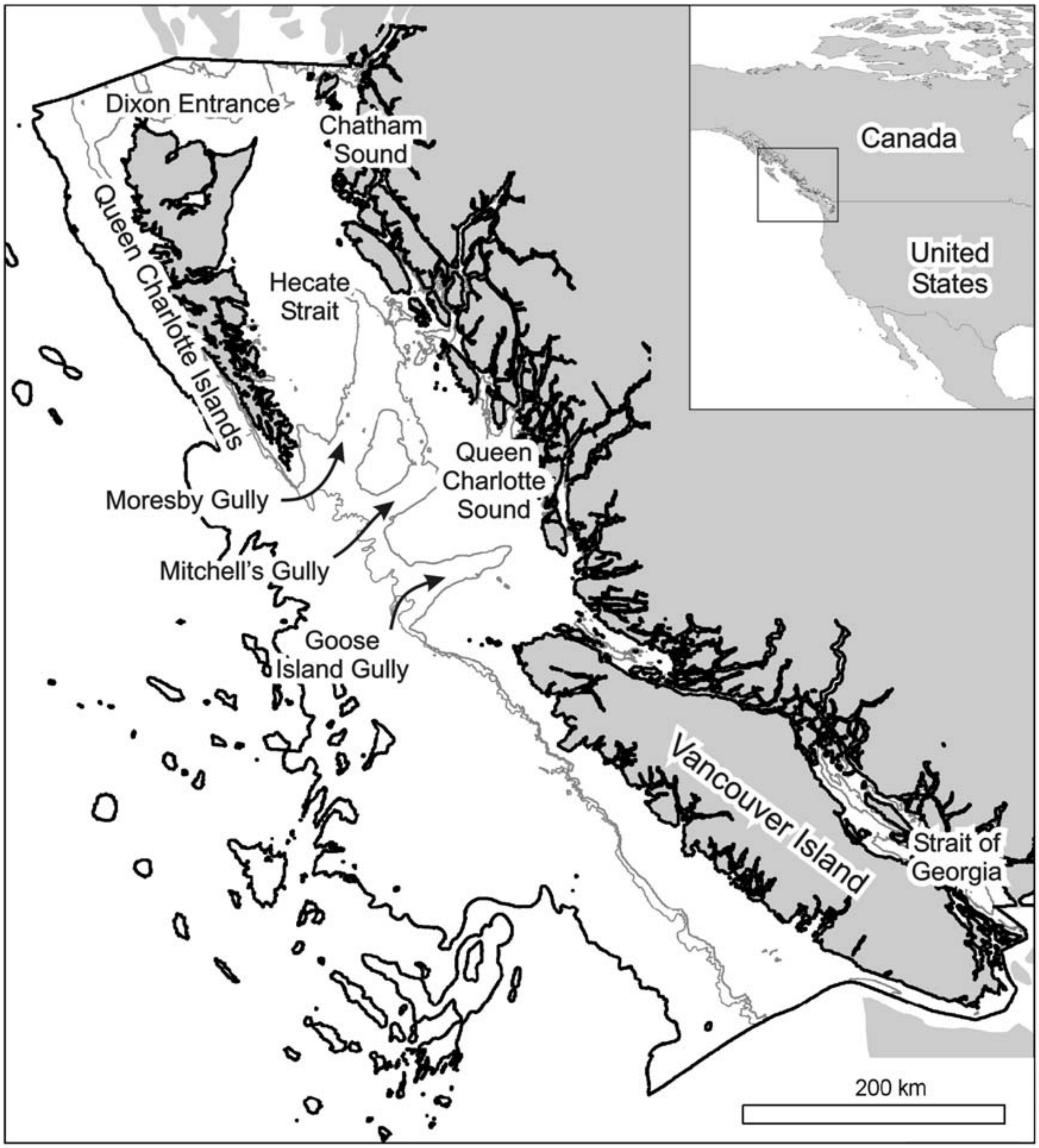

Figure 1 Map of the study area and places described. The thicker black line indicates the 2450 m depth cutoff of the study area, while the lighter grey lines indicate the 200 m and 500 m contours.

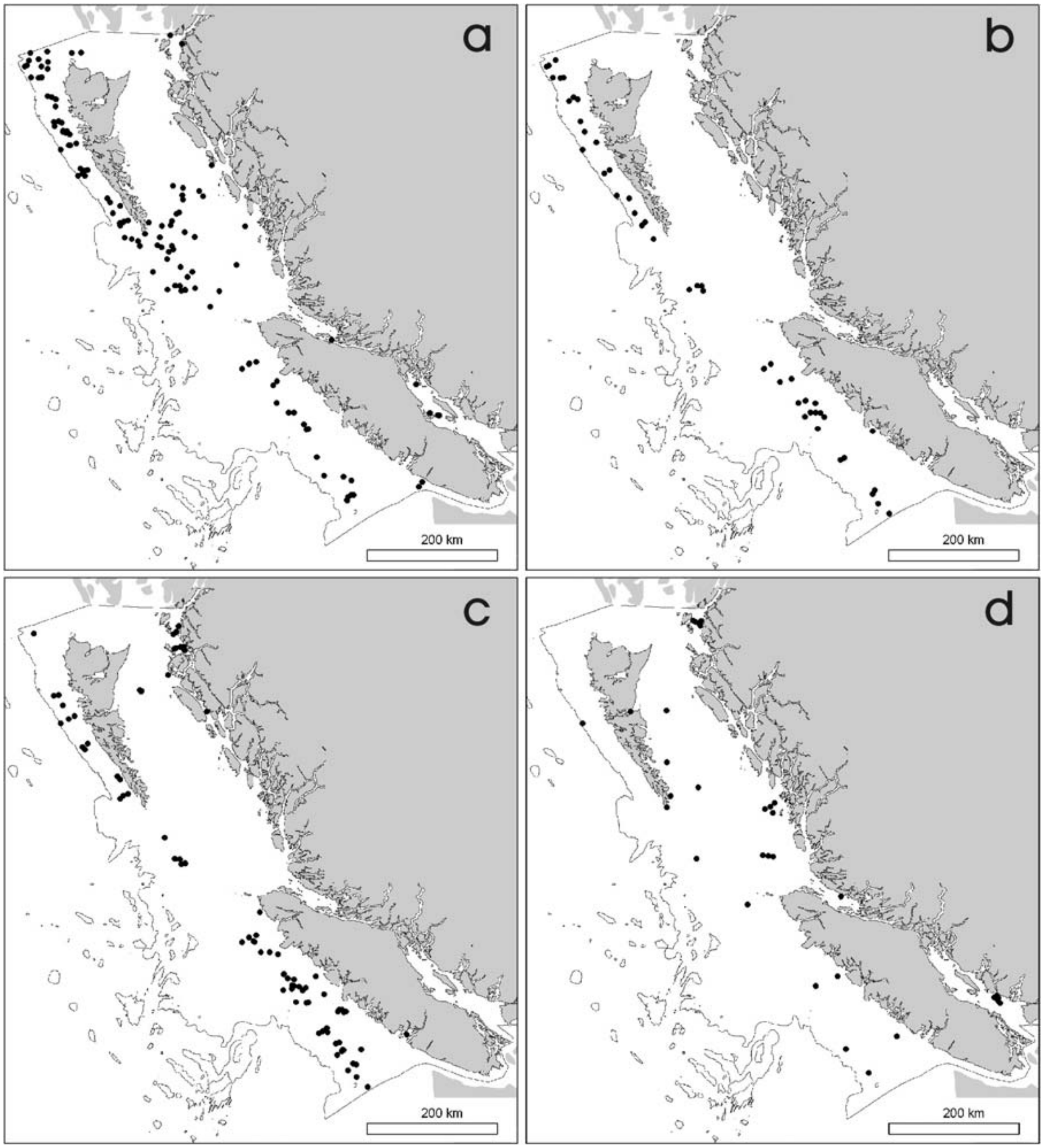

Figure 2 Distribution of coral observations used in the present study for (a) Alcyonacea (n = 121); (b) Antipatharia (n = 49); (c) Pennatulacea (n = 84); and (d) Scleractinia (n = 32). The black lines represent the 2450 m depth contour used to define the study area.

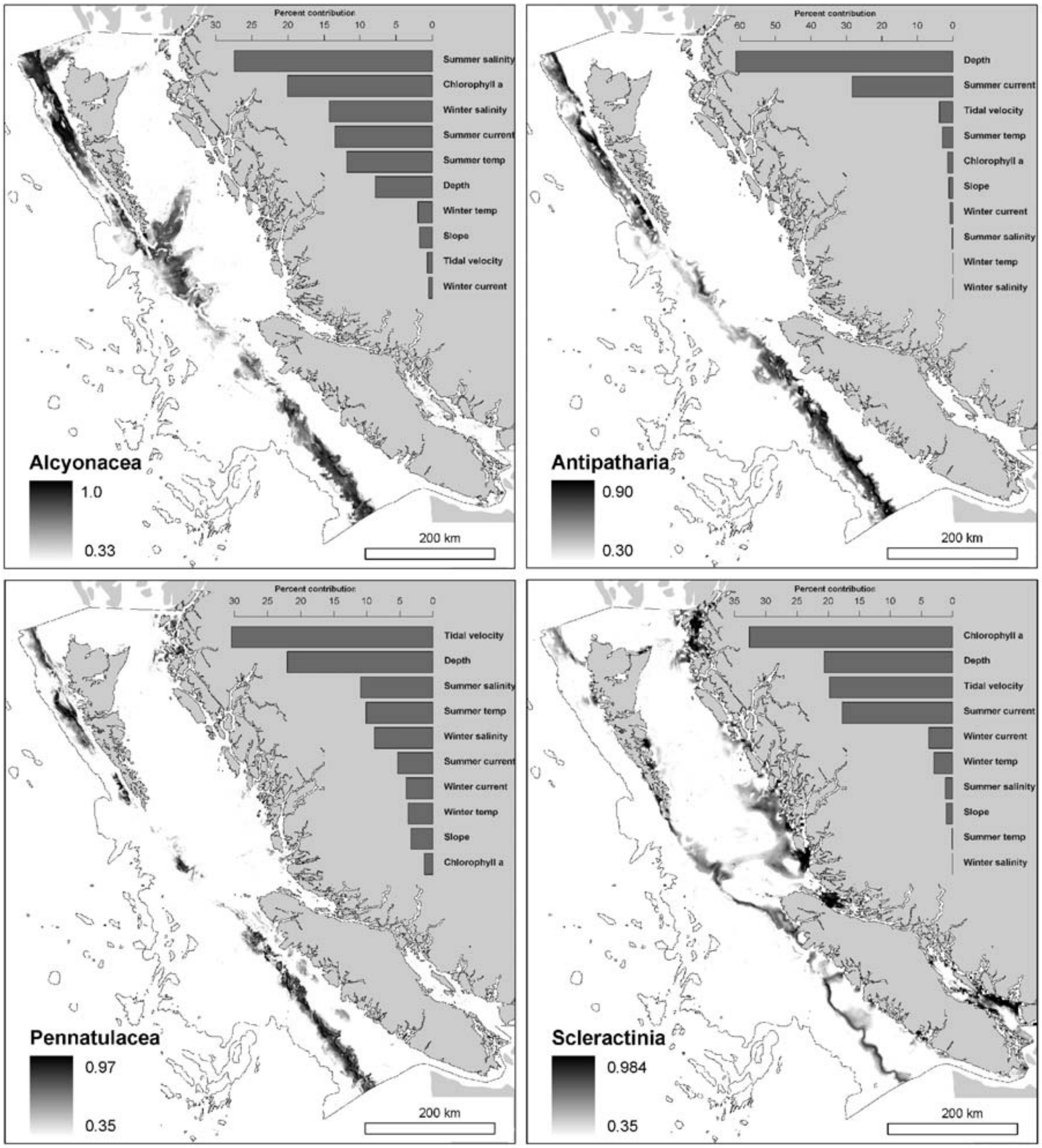

Figure 3 Distribution of suitable habitat predicted by the final Maxent model for each of the four orders of coral. Darker shades indicate higher suitability. White areas indicate less suitable habitat. Insets indicate the relative contribution of each environmental variable to explaining the variation in location of coral according to the Maxent model.

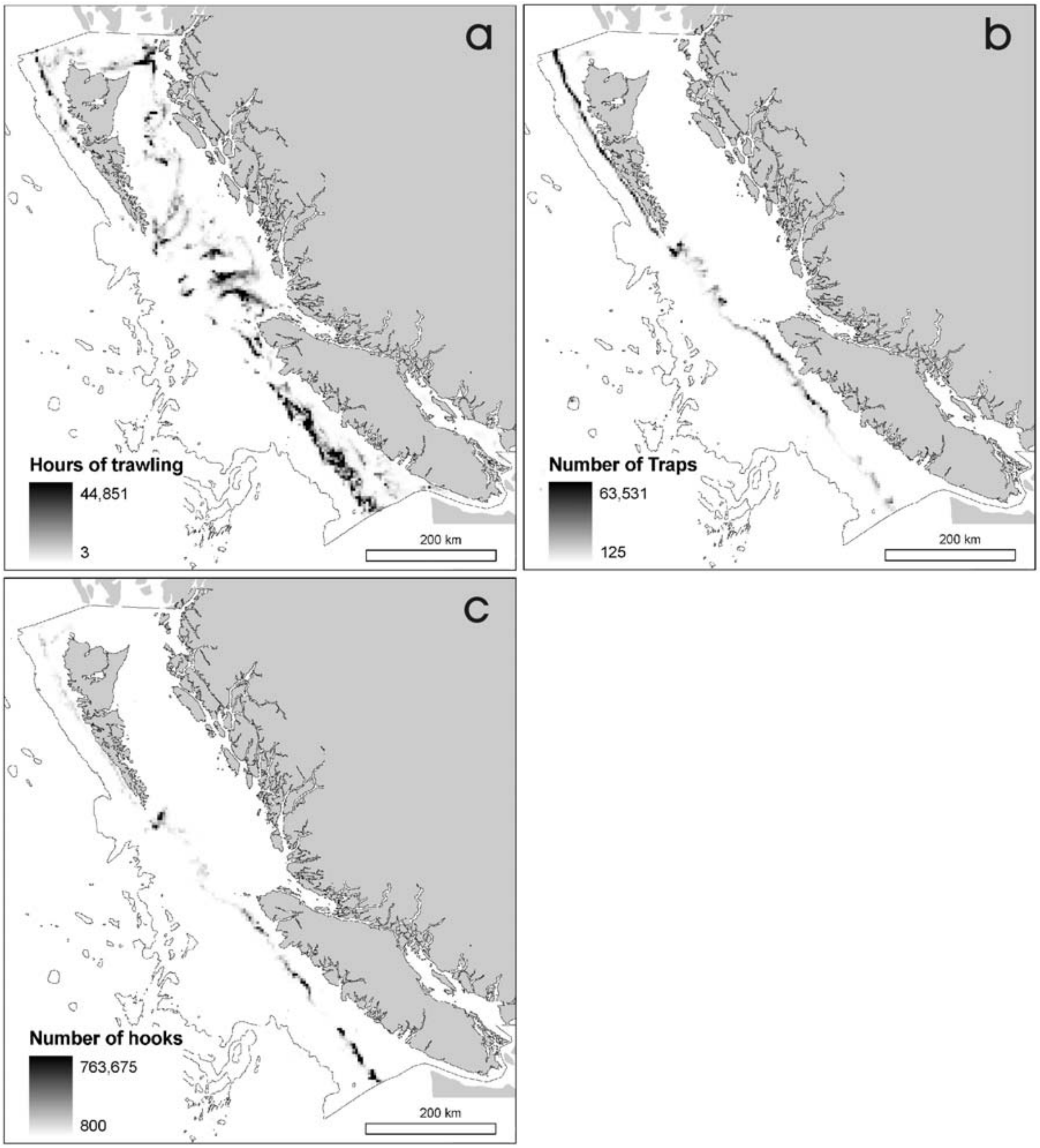

Figure 4 Spatial distribution and intensity of cumulative bottom-contact fishing effort over a nine-year period (1996-2004) for (a) groundfish trawl (trawl hours/16 km^2); (b) sablefish trap (traps/16 km^2); and (c) sablefish longline (hooks/16 km^2).

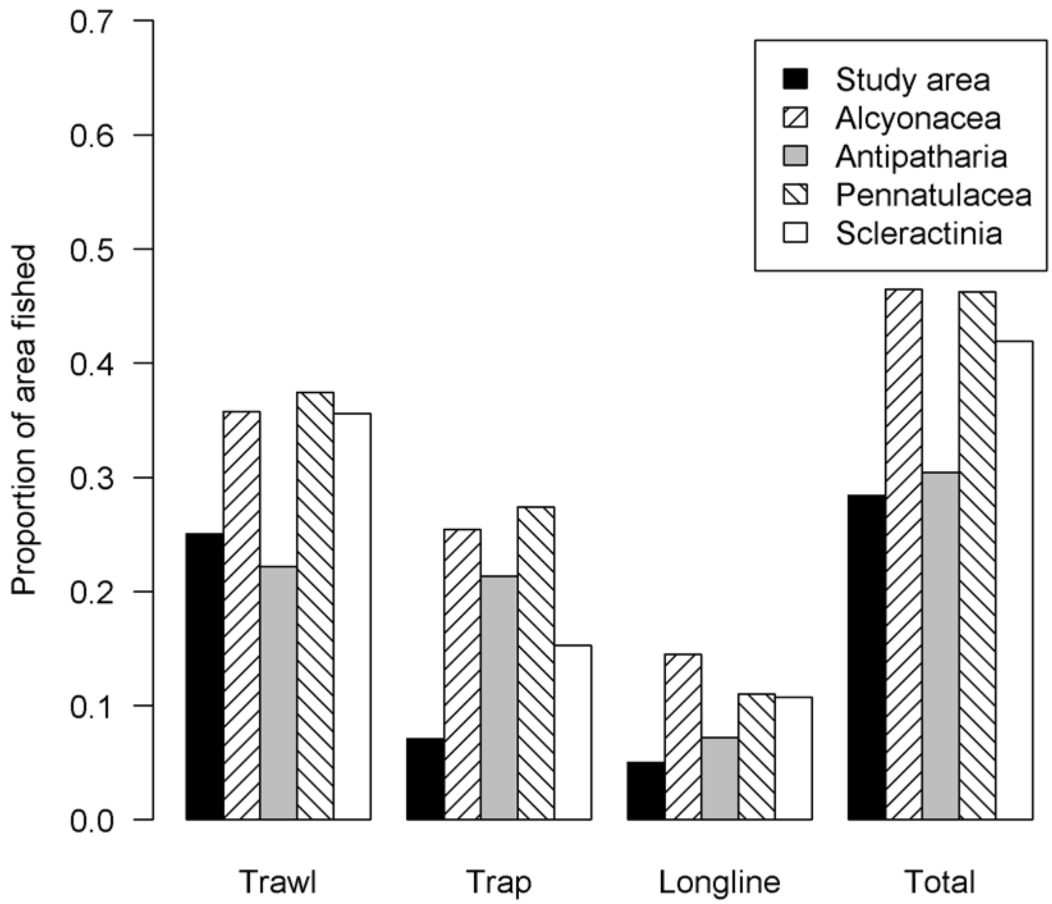

Figure 5 Proportion of area fished by the three bottom-contact fisheries in the entire study area (dark bars) and in areas of predicted suitable habitat for each order of coral. In nearly all cases, fishing effort is disproportionately concentrated in areas of predicted suitable habitat for corals.

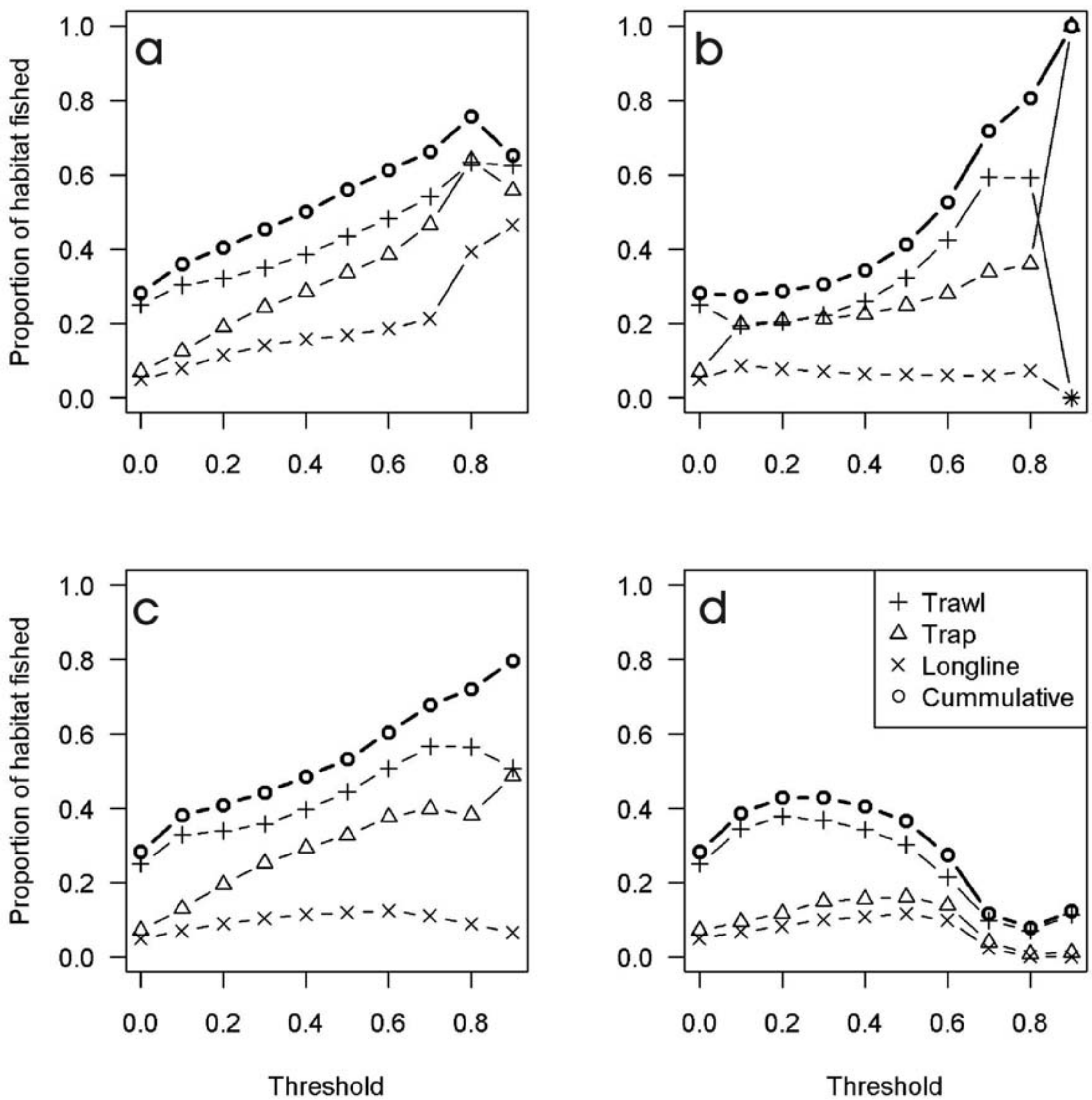

Figure 6 Proportion of area fished by the three bottom-contact fisheries when using different thresholds to identify predicted suitable and unsuitable habitat. Plots are for (a) Alcyonacea; (b) Antipatharia; (c) Pennatulacea; and (d) Scleractinia. A threshold of 0 indicates the proportion of the entire study area that is fished. In all cases, except for Scleractinia, the proportion of habitat potentially impacted by fishing activity increases as the threshold increases, indicating that fishing tends to be disproportionately concentrated in areas predicted to be more suitable for coral.

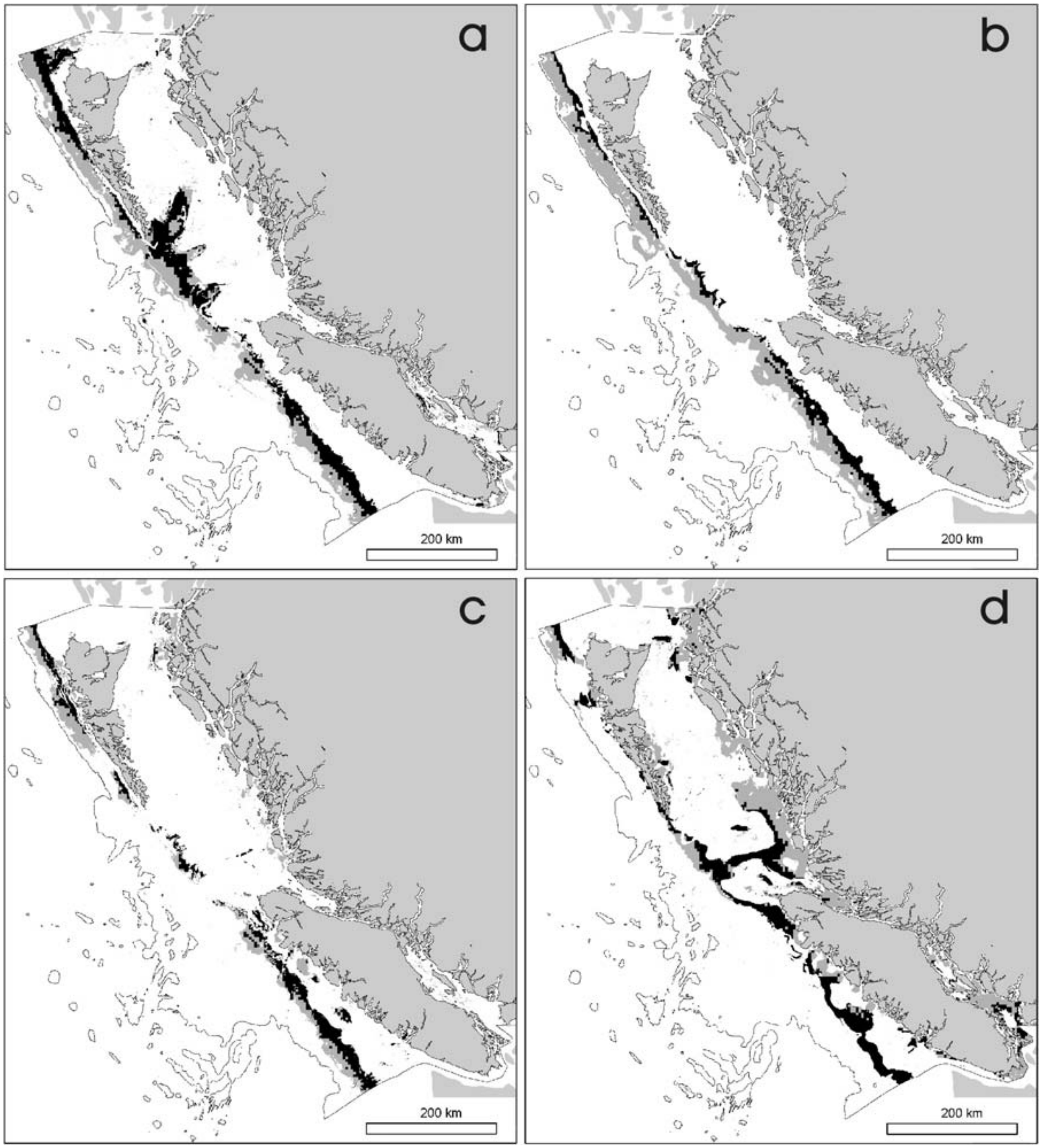

Figure 7 Areas of overlap (black) between predicted suitable habitat for corals and bottom-contact fishing when the maximum sum of sensitivity-plus-specificity is used. These areas represent potentially vulnerable marine ecosystems. Marine grey areas indicate predicted suitable habitat that does not overlap with bottom-contact fishing. Maps are for (a) Alcyonacea; (b) Antipatharia; (c) Pennatulacea; and (d) Scleractinia.