Chapter 4

Modelling Inshore Rockfish Habitat in British Columbia: A Pilot Study

Jeff A. Ardron and Scott Wallace

Abstract

In the absence of reliable survey data, habitat modelling can direct conservation and fishery management efforts. We have constructed a model designed to predict high-value inshore rockfish habitat, based on the variables of topographical complexity and kelp density. When applied in our pilot study area, this model showed remarkable accuracy at predicting areas previously identified by commercial fishers. Ninety-four percent of high-value fishing areas were captured by our habitat model, and 79% contained our upper three scores, which we believe to be indicative of "core" habitat areas. These upper three classes account for 28% of the study area. When used to assess some recently designated rockfish conservation areas, our model and fishers' knowledge both indicate that three out of the seven conservation areas in our study area may actually represent poor choices for rockfish conservation and restoration.

Introduction

Numerous rockfish populations along the west coast of North America are depleted (Parker et al., 2000). Of particular concern in British Columbia (BC) are six species managed collectively as "Inshore Rockfish." These species exhibit resident behaviour and are highly linked to complex rocky reef habitat (Love et al., 2002), making them suitable candidates for spatial protection. Increasing evidence over the last decade has shown that a network of well-placed spatial reserves can be an effective tool for any long-term rebuilding and management strategy (Roberts et al., 2003).

In 2002, Fisheries and Oceans Canada (DFO)[1] embarked on a strategy to rebuild inshore rockfish populations; namely, black (*Sebastes*

Jeff A. Ardron, Living Oceans Society, P.O. Box 320, Sointula, British Columbia, Canada V0N 3E0, phone 250-973-6580, fax 250-973-6581;
Corresponding author: jardron@livingoceans.org

Scott Wallace, Blue Planet Research and Education, 9580 Gleadle Road, Black Creek, British Columbia, Canada, V9J 1G1
Phone: 250-337-8521, Email: scottw@island.net

melanops), china (*S. nebulosus*), copper (*S. caurinus*), quillback (*S. maliger*), tiger (S. *nigrocinctus*), and yelloweye (*S. ruberrimus*). As part of this strategy, DFO has set the objective of setting aside 20-50% of inshore rockfish habitat in the form of Rockfish Conservation Areas (RCAs). To date, the selection of candidate sites has been piecemeal, driven primarily by public meetings, and consultation with fishing associations. This piecemeal approach is not unusual. In North America, protected areas in general have been created in an ad hoc manner, in large part stimulated by the requirements of species-based legislation, or other singularly focussed planning (Noss et al., 1997). However, there is a growing body of literature to suggest that this approach is far from ideal, and in some cases can lead to decisions that would later be regretted (Allison et al., 1998; Margules and Pressey, 2000; Stewart et al., 2003). A non-systematic approach gives little assurance that selected areas represent optimal habitat required for an effective network of protected areas. Relying heavily on consultations with interested stakeholders can also lead to the possibility that certain important areas may be overlooked, or that unimportant habitat may be put forward (Wallace and Ardron, 2003).

Modelling as a tool for designing marine reserves has been underutilized (Ward et al. 1999; Leslie et al., 2003). Modelling rockfish habitat offers a more systematic approach to reserve area design, although it has yet to be widely applied. In the past decade, DFO has used a crude model consisting of bathymetric data (depth) coupled with a smoothing algorithm to identify inshore rockfish habitat for the purpose of stock assessment (Yamanaka and Kronlund, 1996).

In 1997, the province of BC released their Marine Ecological Classification, based on five physical variables, the intent of which was the creation of a universal marine habitat classification "... for preservation, planning and resource management purposes" (Howes et al., 1997). Since then, it has been somewhat revised, containing seven variables for benthic habitat (Axys, 2001). Both versions contain a measure of relief. However, independent dive surveys in the study area failed to correlate the classification system with reefs or other biological indicators (Haggarty, 2000). It has been suggested that the approach behind the classification is too generalized (Ardron, 2001). Furthermore, measures of relief can be unduly influenced by single large changes in depth, while not detecting smaller but clustered changes that would actually better indicate rocky reef habitat.

In 2000, we developed a unique GIS analysis to evaluate seafloor "complexity" using bathymetric data (Ardron, 2002). For BC's passages and the Strait of Georgia, complexity invariably translates as rocky reefs. Initially, to verify that complexity was relevant to known rockfish distributions, we interviewed local fishers on the southern Central Coast of BC (Fig. 4.1; see page XX) and compared their knowledge with our analysis of complexity alone. We also considered DFO fishery officers'

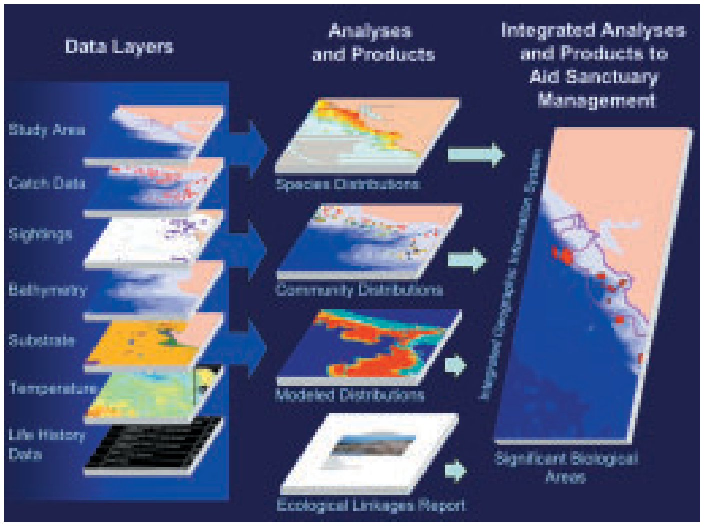


Figure 1.1. Generalized biogeographic approach to study NOAA national marine sanctuaries.

Figure 1.2. Locator map of entire study area from Point Arena to Point Sal. National marine sanctuary boundaries shown in red.

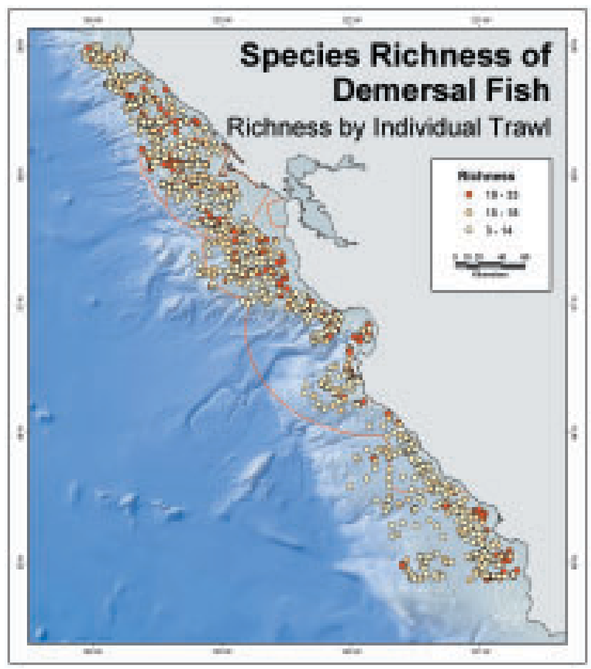


Figure 1.4. Species richness of rockfish from individual NMFS shelf and slope trawls.

Figure 1.5. Potential distribution of habitat suitability for adult and juvenile Dover sole. Map inset contains validation statistics, and Suitability Index values for bathymetry and substrate are displayed below the maps.

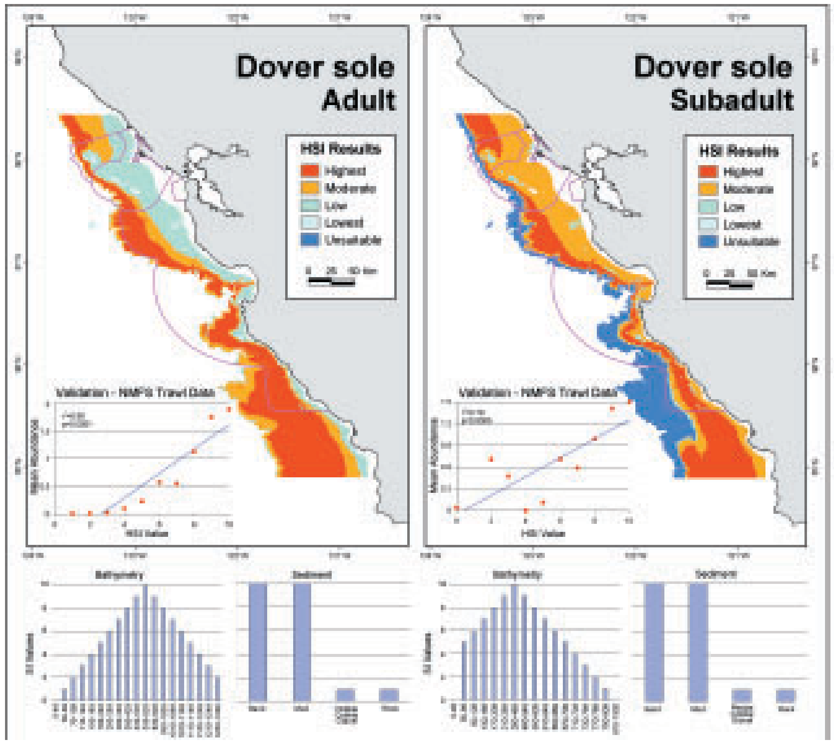
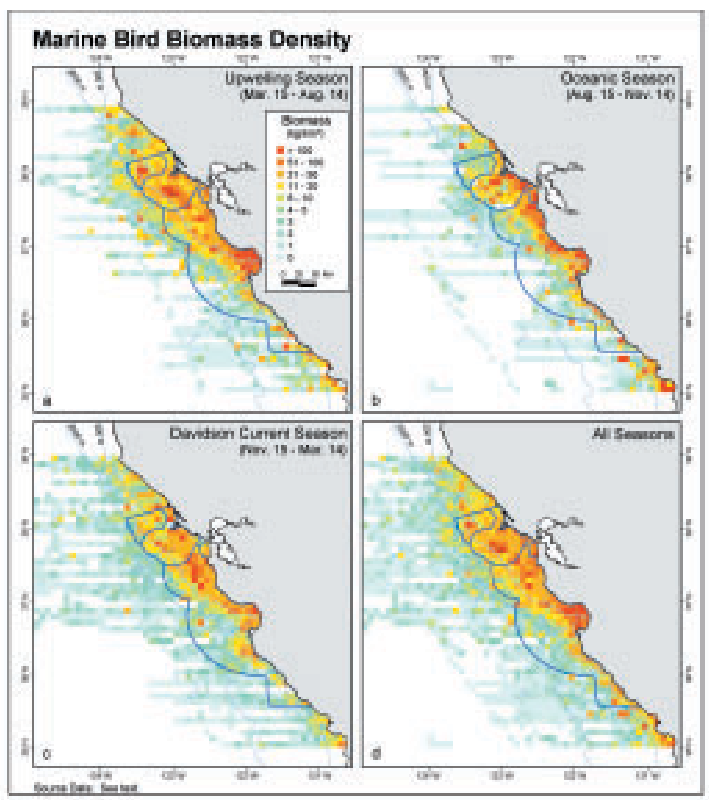


Figure 1.6. Marine bird biomass, by season and for all seasons in study area.



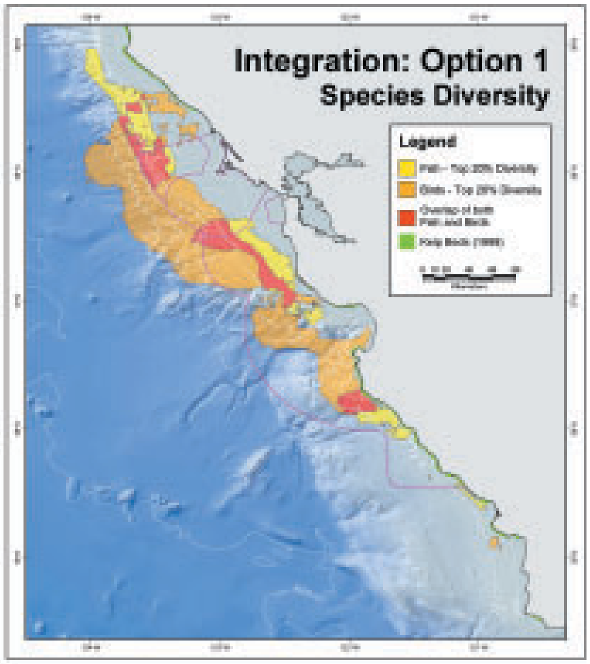
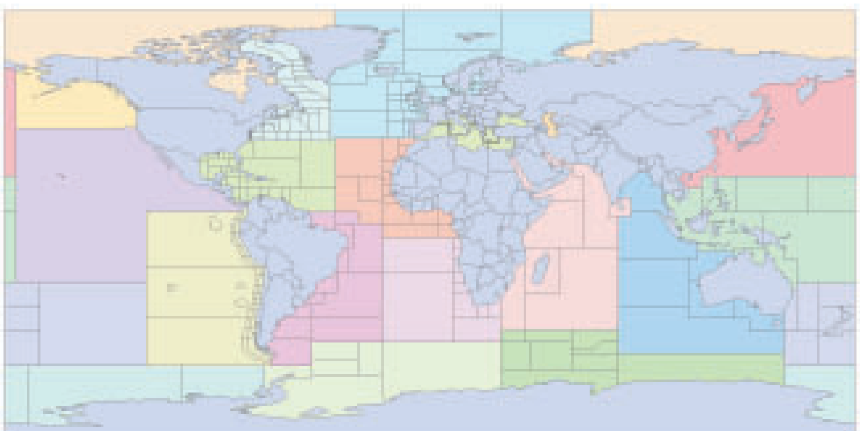


Figure 1.7. Data Integration: diversity hot spots (top 20%) for fish and marine birds. Coastal kelp bed areas are also shown.

Figure 2.1. Reporting areas used for fisheries statistics by Food and Agriculture Organization (FAO) and its regional bodies, the International Council for the Exploration of the Sea (ICES), and the Northwest Atlantic from the Northwest Atlantic Fisheries Organization (NAFO), currently used



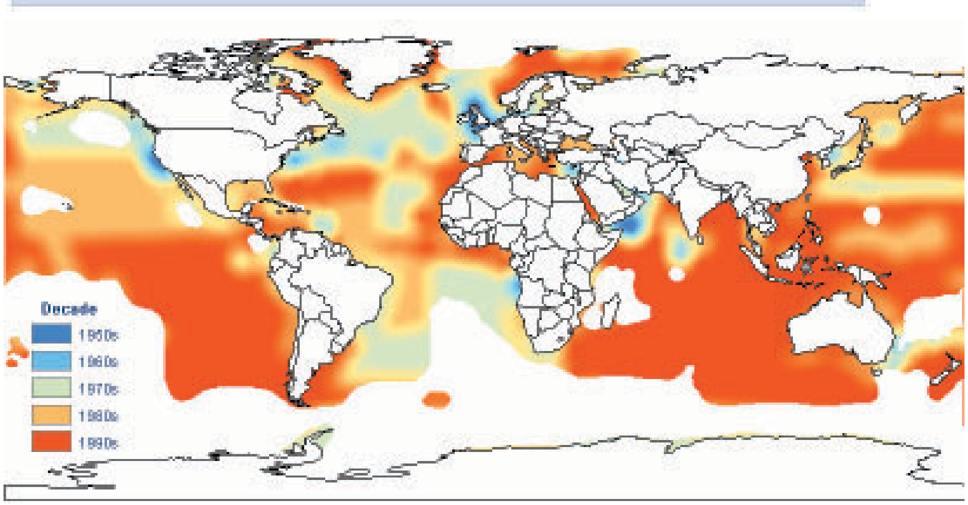


Figure 2.2. Decade of maximum commercial landings.

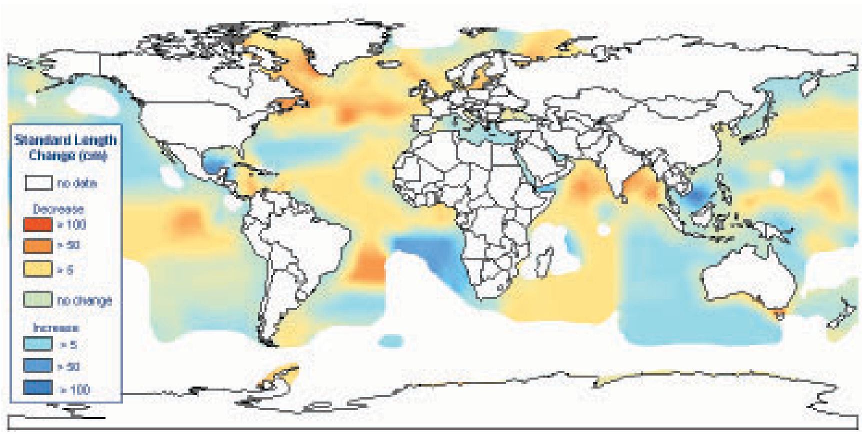


Figure 2.3. Global change in the mean length of commercial landings.

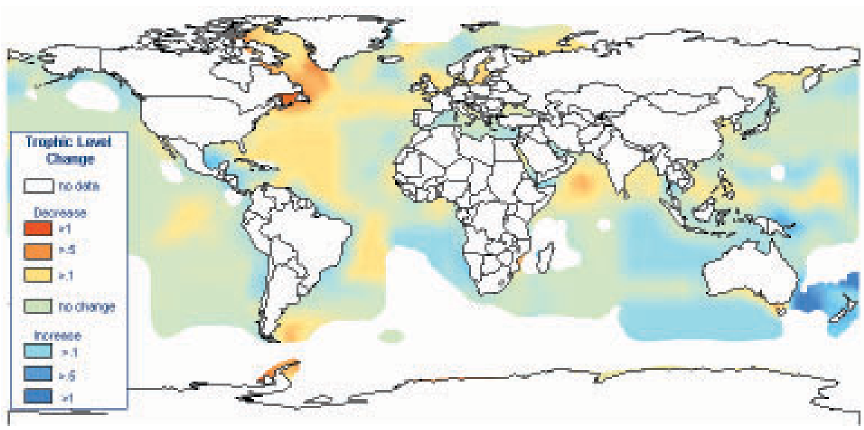


Figure 2.4. Global change in the mean trophic level of commercial landings.

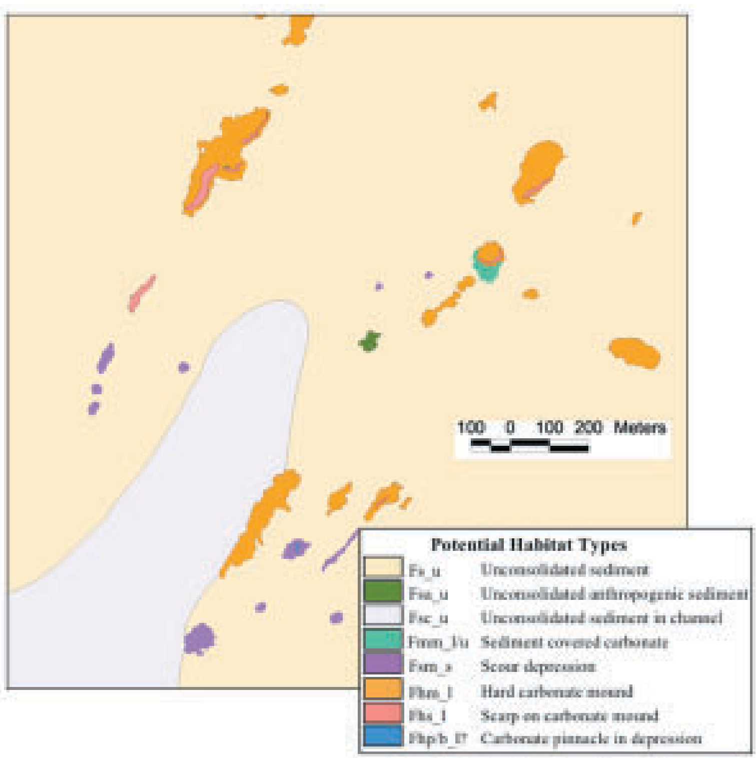


Figure 3.3. Map of potential marine benthic habitats constructed from Simrad EM 300 (30 kHz) bathymetric and backscatter imagery. See Figure 3.1a for location and Appendices 3.1 and 3.2 for explanation of habitat code. All habitat types are located on the upper continental slope, or flank (F).

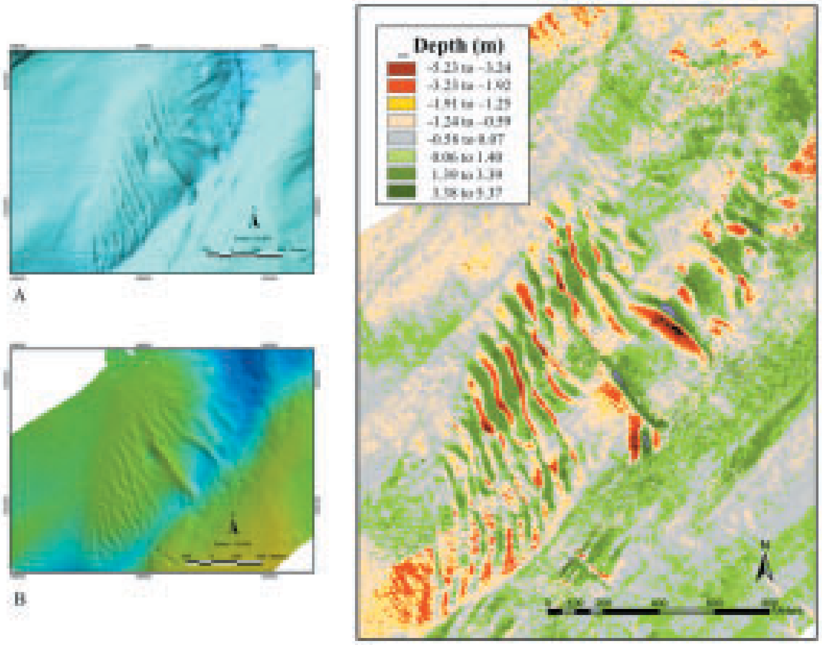


Figure 3.4. Dynamic sand waves in the Boundary Pass region, Canada, collected with a Simrad EM 1002 95 kHz system by the Geological Survey of Canada and the Canadian Hydrographic Service. Image 3.4a displays multibeam bathymetric data collected in 2001 and Image 3.4b displays data collected in 2003 in the same area. Both images were created with the GIS program, ArcMap® and are shown at a scale of 1:50,000. Using ArcMap®'s Raster Calculator, which calculates depth differences at each pixel location, two 5 m grids were subtracted (2001 grid - 2003 grid). Results are displayed in Image 3.4c. The red and green colors represent probable migration of the sand waves, where red = accumulation of sand and green = loss of sand.

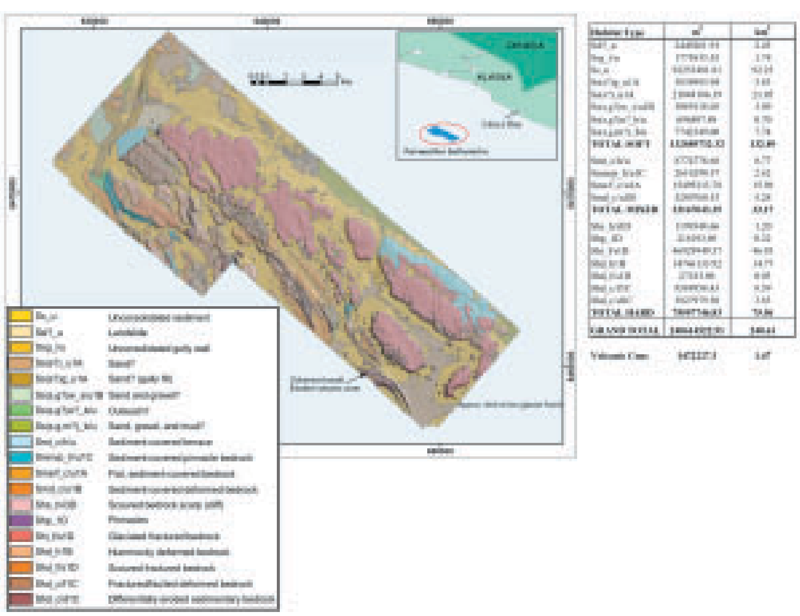


Figure 3.5. Map of potential marine benthic habitats of Fairweather Ground, a heavily fished area in SE Alaska. Refer to Appendices 3.1 and 3.2 for explanation of habitat code. Associated table displays the area of habitat and induration (hardness) types calculated in ArcView® using the Feature Geometry Extension.

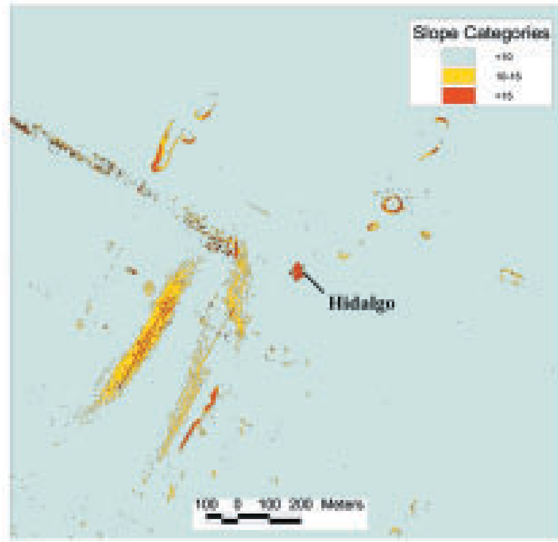


Figure 3.6. Slope inclination map generated in ArcView® using the Spatial Analyst Extension and Simrad EM 300 (30 kHz) bathymetry. Slope category values are listed in degrees.

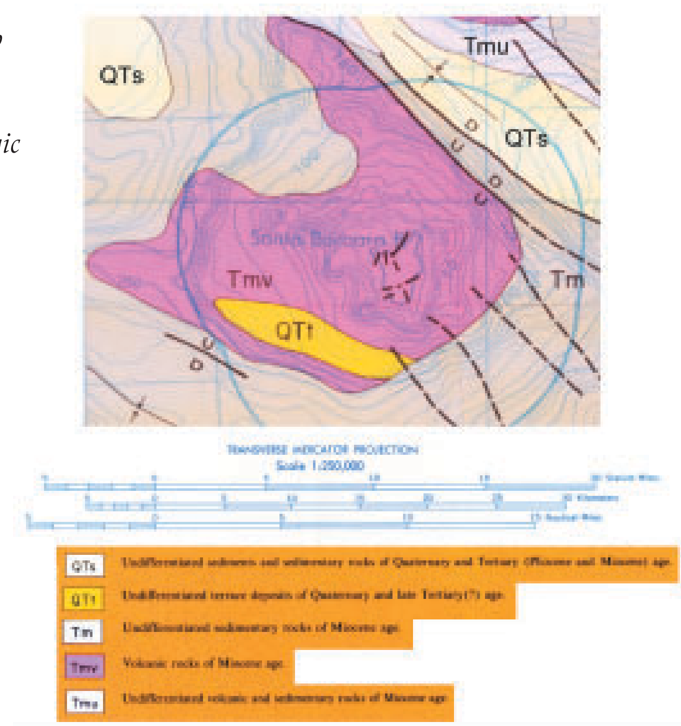


Figure 3.7. Geologic map and legend of Santa Barbara Island offshore region illustrating geologic data that can be used in mapping of potential marine benthic habitats. After Vedder et al. 1986.

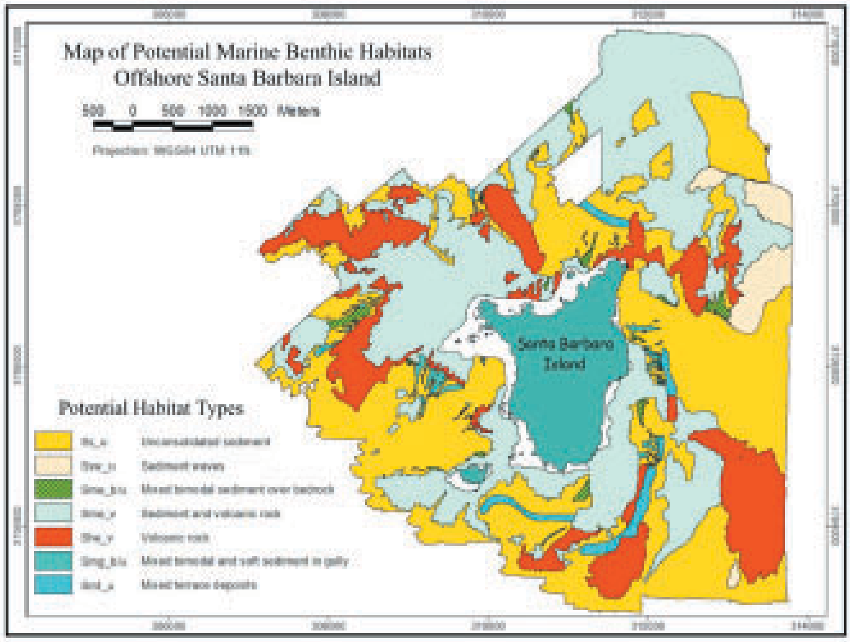


Figure 3.8. Map of potential habitats constructed in GIS from Reson 8101 (240 kHz) bathymetry collected off Santa Barbara Island. Refer to Appendices 3.1 and 3.2 for explanation of habitat code.

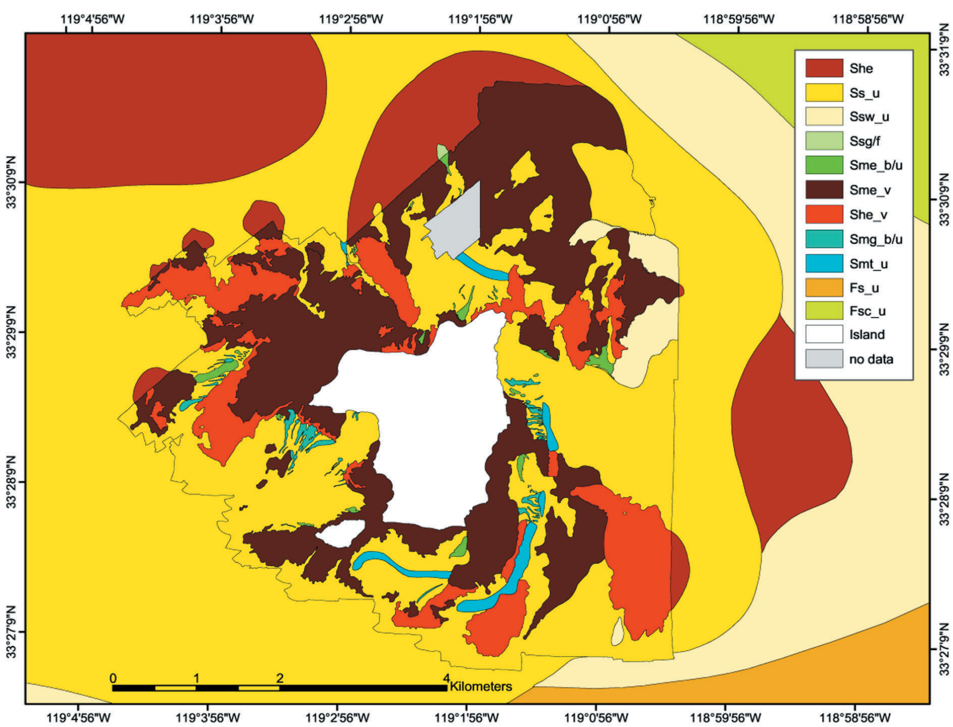


Figure 3.9. Merged map of potential habitats interpreted from Reson 8101 (240 kHz) multibeam data (Fig. 3.8) and previously mapped geologic data (Fig. 3.7) collected around Santa Barbara Island, southern California. Refer to Appendices 3.1 and 3.2 for explanation of habitat code.

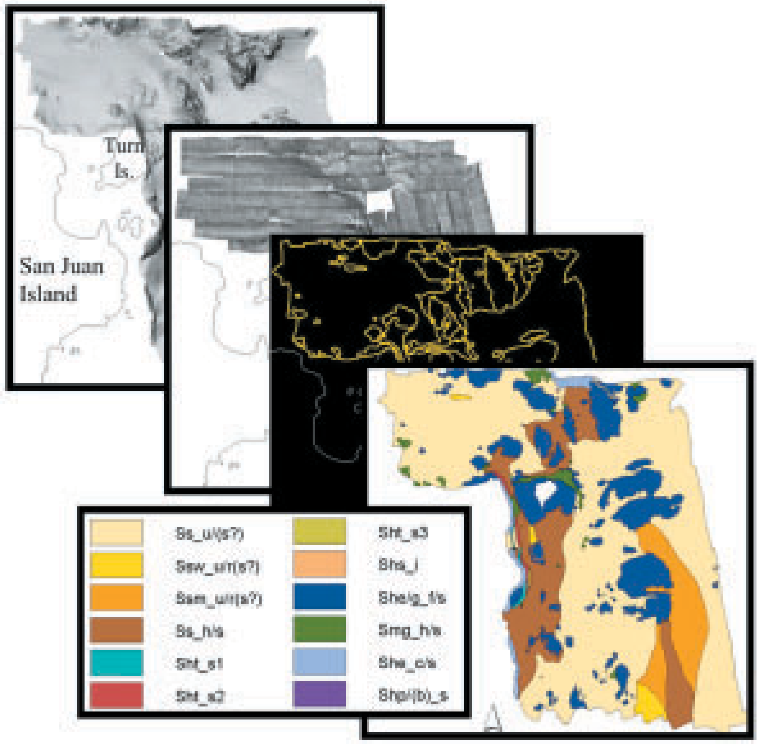


Figure 3.10. Example of nested data layers used in the compilation and construction of maps of potential marine benthic habitats. Locality is San Juan Channel offshore of San Juan Island, Washington. 3.10a = multibeam bathymetry; 3.10b = multibeam backscatter; 3.10c = line drawing of interpreted habitat types; 3.10d= potential habitat polygons. Refer to Appendix 3.1 for explanation of habitat code.

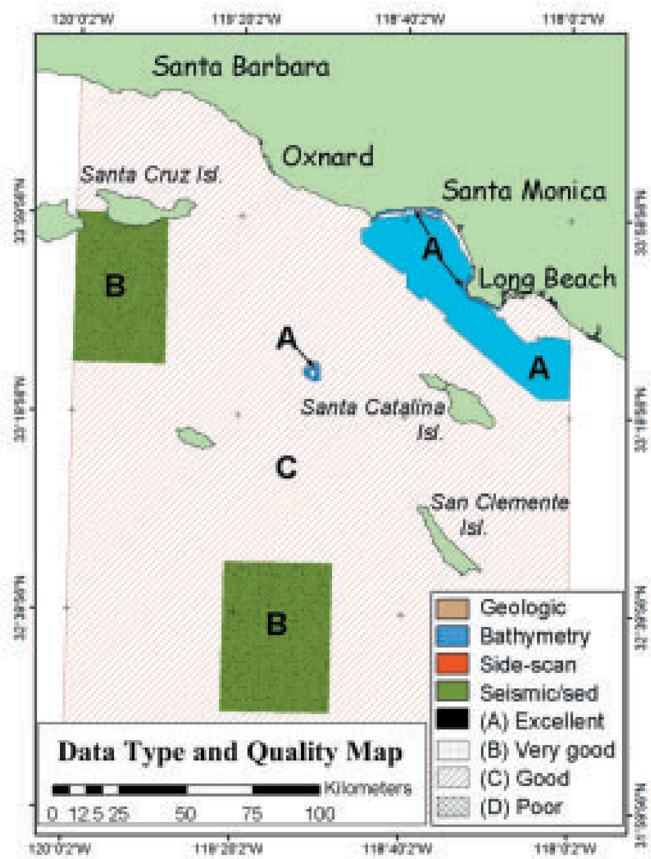


Figure 3.11. Example of data quality map showing type, quality, and coverage of data used in the compilation and construction of a map of potential habitats off southern California.

data, and we presented the analysis for verification by independent experts. Initial results were very promising. Next, we added kelp beds into the analysis, which improved the model's predictive ability. Finally, we evaluated the utility of the recently implemented Rockfish Conservation Areas against both our habitat model and local knowledge.

Methods: Creation of GIS Layers and Model Indices

GIS played a significant role in our analyses. We used ArcGIS (ArcInfo & ArcView) 8.2 with the Spatial Analyst and Geostatistical Analyst extensions, and ArcView 3.2 with the Spatial Analyst extension. All calculations were performed in the BC Albers Equal Area projection, which largely preserves area (though not shape or direction). Because our calculations used equal area grids of 0.2 ha per cell (44.72 m x 44.72 m), an unequal area projection (such as geographic long-lat) could have skewed the results.

Layer 1: Benthic Topographical Complexity

Complexity is the key variable in our model, identifying potential rockfish reefs. Complexity is not the same as relief, which looks at the maximum change in depth. Topographical complexity considers how convoluted the bottom is, not how steep or how rough, though these both play a role. Complexity is similar but not the same as "rugosity" as is sometimes used in underwater transect surveys, whereby a chain is laid down over the terrain and its length is divided by the straight-line distance. Rugosity, however, can be strongly influenced by a single large change in depth, whereas complexity is less so. Complexity is indicated by how often the slope of the sea bottom changes in a given area. This is the density of the slope of slope (second derivative) of the depth. We used ESRI's Spatial Analyst extension to calculate slopes, and its density "kernel" option to calculate densities using a search radius of 1 km—though this distance can vary, depending on the scale of the analysis. For more specifics on the GIS methodology behind calculating complexity, please refer to Ardron, 2002.

Line bathymetric data were purchased from Nautical Data International (Natural Resource Map series, nominal 1:250,000). These required extensive cleaning, including edge matching, and removal/correction of unattributed or erroneous segments. Due to the poor resolution of the nearshore line work (<50 m), these were digitized from nautical charts and merged with the NDI data. Ultimately, we wanted to interpolate these isobaths into a depth grid; however, the varying densities of line nodes can bias direct interpolation from lines to a grid. Thus, in order to ameliorate this issue, we first transformed the lines into evenly spaced (50 m) points, using Dr. Bill Huber's free script, Poly to Points available on the ESRI ArcScripts page (http://arcscripts.esri.com/details.asp?dbid=11407). We interpolated these points using a variety of algorithms, but found that the simplest, a TIN (triangulated irregular network—straight linear interpolation), is what worked best. The hard "creases" associated with TINs, which can be visually intrusive, actually have certain advantages when undergoing a complexity analysis, as they clearly demarcate a change in slope. The resulting depth grid was fed into the calculations of benthic topographical complexity.

The complexity algorithm used in this analysis and elsewhere invariably identifies areas of convoluted substrate (Fig. 4.2; see page XX). At this scale, most of these areas are rocky reefs or to a lesser extent, sills and ledges. The steep fjords common along BC's coastline, although high in relief, are not captured by complexity because they do not have many changes in slope over a given area; that is, they are either steep-sided, or relatively flat-bottomed. While their walls can offer some habitat to rockfish, it is generally only a narrow strip along their base. The purpose of the complexity measure was *not* to capture all rockfish habitat; rather, it was to capture exceptionally good areas that may warrant protection.

The complexity index was taken from an earlier analysis of the Central Coast (Ardron et al., 2002). The integer score ranged from 0 to 3 per grid cell, where 1 represented a varying buffer band, 2 represented moderate to high complexity, and 3 represented high to very high complexity. The buffer was used as a way to account for the varying scales of the water bodies in the Central Coast, whereby narrow inlets had no buffer, passages had a buffer of 500 m, and open sea had a buffer of 1500 m. Although all three buffers can be found in the pilot study area, generally it is 500 m.

Layer 2: Kelp Coverage

Initially, we included kelp (*Nereocystis luetkeana* and *Macrocystis intergrifolia*) in the model due to its known importance as juvenile inshore rockfish habitat (Fig. 4.3; see page XX). We felt that complex areas near kelp would exhibit higher recruitment than complex areas without kelp, and as such would represent more desirable rockfish habitat. Later, it became apparent that areas of thick kelp directly overlapped with known fishing areas. The inclusion of kelp improved the model's predictability vis-à-vis known fishing areas.

Kelp data were merged from many sources, mainly the provincial government aquaculture surveys, aerial surveys, and federal Canadian Hydrographic Service charts. Polygons were given a score of 1 (sparse) or 2 (continuous), based on notes in the surveys. If this was unknown, 1 was applied as a default. In areas of overlapping datasets, the higher values prevailed.

In our model we wanted to incorporate areas that had kelp in the vicinity of complexity. Although kelp is known juvenile habitat, there has been little published literature on the movements of juvenile rockfish, and thus no numbers were available upon which to base our "search radius." We decided to proceed with arbitrary distances in the range of 500 m to 2 km to calibrate the model to known fishing areas.

In GIS analyses, generally the use of a buffer is employed to capture areas within a given distance. However, in the case of kelp beds, which vary greatly in size, a fixed buffer zone around all kelp beds would have over-emphasized small isolated patches—of which there are many. Thus, instead we turned to a density measure, which would in its ranking reflect the size of kelp patches and neighboring patches. Even though the search radius is constant, areas of more numerous and larger kelp beds will be given a higher score, unlike a buffer.

We removed the lowest of 11 classes (Jenks natural breaks) and re-classed the remaining 10 equally into two categories (score = 1 or 2). Removing the lowest of 11 classes eliminated areas of low density, and had the effect of lowering the effective buffering distance from 1500 m to approximately 600-700 m.

Layer 3: Fishing According to Fishery Officers and Managers

There is a concern that releasing commercial fishing logbook data may breach fishers' right to confidentiality. As a result, outside researchers and other government agencies do not have accurate spatial knowledge of fishing activities in BC. In 1995, the provincial government hired a consultant to interview DFO fishery officers and managers to get a sense of where fishing activities were taking place within the Central Coast, which includes our study area. It should be noted that these DFO officers did not have access to the logbook data either, but were basing their opinions on their job experience. The same consultant returned in 2002 to update the information. For our study area, the 1995 information came from mainly one source (plus one polygon by another source) and exhibited a fairly high degree of localized precision. By 2002, however, there had been a change in staff, and the results were much more vague, with only one polygon in the study area.

Layer 4: Fishing According to Fishers

Remarks from local fishers suggested that the fishery officers' data were incomplete. In the summer of 2000, using the same interview techniques and database structure as had been used for the fishery officers, a contractor hired by Living Oceans Society interviewed 29 commercial fishers on the Central Coast. Five of the fishers fished rockfish in the pilot study area. Fishers were asked to draw their preferred fishing areas on nautical charts, which were later digitized and linked to an attributes database based on information given during the interviews.

It was emphasized at the time of the interviews that we wanted to know the fishers' preferred fishing locations so that we could take their use into account when proposing closures or protected areas. After the

Table 1: Sizes of fishing areas, RCAs, and modelled habitat.

	Total Area (Km^2)	*Proportion*
Fishing 2 (high)	427.16	17.7%
Fishing 1 (med.)	360.93	15.0%
RCA	156.33	6.5%
Rescinded	267.51	11.1%
Habitat 4 (v. high)	81.08	3.4%
Habitat 3 (high)	203.02	8.4%
Habitat 2 (med-high)	392.98	16.3%
Habitat 1 (med.)	444.49	18.4%
Study Area, less Inlets	2410.37	100.0%

interview, the interviewer filled out a standard form judging the precision of the polygons, and noting how cooperative the subject appeared to be (an indication of possible accuracy). Only one fisher (of 30) refused to give information after meeting with the interviewer. Of the others that did provide information, all were judged to be honest and forthcoming. In her final report, the interviewer felt that rockfish had been one of the strongest datasets for the study area (Groff, 2002).

Figure 4.4 (see page XX) illustrates the information from the three data collections: the two 1995 fishery officers; two 2002 fishery officers (different people); and five commercial fishers. Because the intent of this pilot study was to compare good fishing grounds (as a proxy for good habitat) with our model's predictions, it was decided that if one fisher identified an area as "important," then that should be sufficient to include it as "moderate" (score = 1) potential rockfish habitat, and if another fisher(s) noted the area (either as moderate or high), it was "good" potential habitat (score = 2).

We did not want to simply add up the layers because the sample size was too low to draw out emergent trends. Fishers generally did not fish the same areas and had to some extent spread themselves out over the study area.

Layer 5: Rockfish Conservation Areas (RCAs)

GIS shapefiles of the proposed (and rescinded) RCAs were initially received from the DFO groundfish management data unit in October 2003, and later revised in March 2004. The selection of candidate sites for RCAs were the result of consultations with commercial and sports fishers in BC. Shown in Figure 4.5 (see page xx) are other closures that came into effect in 1998. These could have influenced the fishers' perceptions of importance in 2002.

Identification of Complex Areas Near Kelp

Our model's combined complexity-kelp index is weighted towards complexity. As input layers, kelp has a range of 0-2, while complexity has a range of 0-3. The two were added together to give a range of 0-5. To smooth the results and take into account neighbouring areas, we then created a density surface populated with this summed score, and ranked it based on standard deviations. We discarded the first class and scored the remaining four 1-4. Discarding the lowest class removed both the lower value kelp areas not near any complexity and lower value complexity areas not near kelp. Thus, the final score of 1-4 represents areas that have either high-rated complexity or kelp, or combinations of both kelp and complexity. The sizes of the modelled habitat areas and fishing areas are shown in Table 4.1

Results

Evaluating the Model's Predictions

The habitat model displayed very good overlap with areas identified by local fishers. The four classes of the model overlapped 94.0% of the high-value fishing areas, while accounting for 46.5% of the study area. The top three classes of the model (scores 2-4) overlapped 78.9% of the high-value fishing areas, while accounting for 28.1% of the study area. Thus, the top three habitat classes were three times more common in high-value fishing areas than would be expected due to random chance (Table 4.1). In some places, the predicted habitat and fishing areas overlap with very high precision (see inset map, Fig. 4.6; see page XX). There was less overlap with the medium value fishing areas, though still much higher than would be expected by chance. This may indicate that medium value fishing areas represent less valuable habitat. Looking at the summed scores, there are clear and strong trends correlating fishers' preferred areas with our model's predictions, and vice versa; that is, each can predict the other, though there is greater predictive power going from habitat to fishing area, which may be a function of the relatively sparse fishing data. The summed scores of the fishing areas applied to each of the three highest habitat classes are well above the mean value for the study area, with the highest class being about three times higher. Within the highest value habitat areas, the fishing score is 72%. That is, the combined scores (1s and 2s) of the fishing areas added up to being 72% of what they would have been had the habitat area overlapped entirely with high-value fishing areas (2s). Conversely, of the areas represented by the lowest value habitat class, the cumulative fishing score is just 5.6%. The unidentified (value = 0) fishing areas contain a cumulative habitat score of 11%, while the high-value fishing areas have a cumulative habitat score five times greater (56%; Fig. 4.7).

Again looking at the cumulative fishing scores we find that the top three habitat classes are much above the study area mean, while the fourth class is at about the mean. This would indicate that the fourth class does not add any predictive strength to the model (Fig. 4.7). Thus,

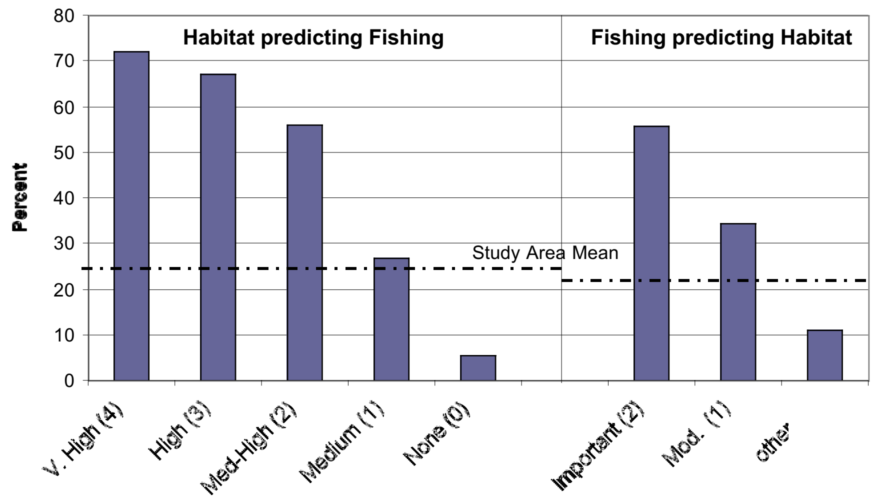


Figure 4.7. The left panel plots how well the habitat index predicts the valued fishing areas. The right panel looks at how well the fishing areas can predict the habitat identified in the model. In both cases the trends are clear. Habitat, however, is somewhat better at predicting fishing than vice versa. Note that the "none" class is actually quite good at predicting where fishing will not occur.

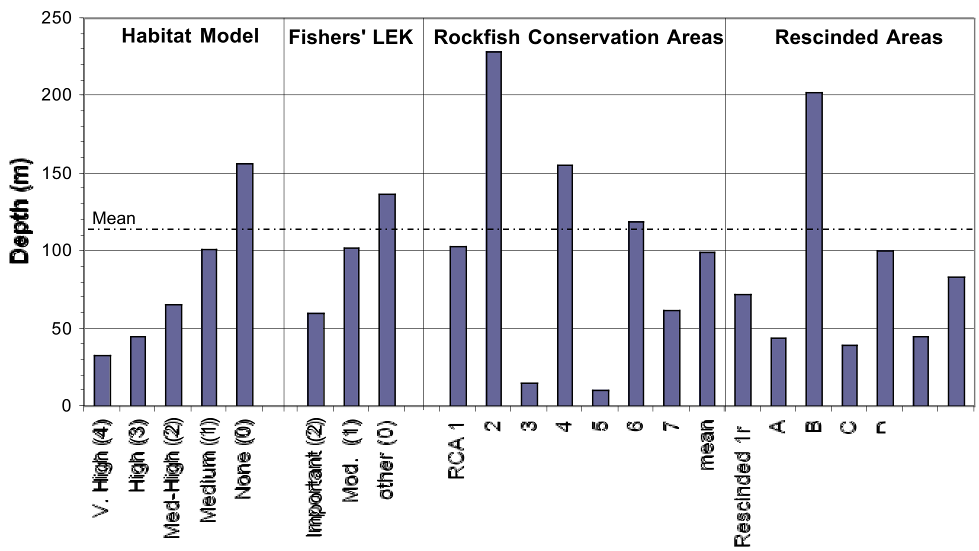


Figure 4.8. The high-value classes of the habitat model predictably contained a greater portion of shallower habitats than did the lower value classes (left panel). Likewise, higher value fishing areas ("LEK" = local ecological knowledge; also referred to as "TEK" or traditional ecological knowledge) also contained a greater portion of shallower habitats. On the other hand, the RCAs only sometimes follow this trend. Overall, the rescinded RCAs are somewhat shallower than the selected RCAs (left panels).

we suggest that the top three habitat classes represent the "core" potential rockfish habitat in the study area, and should be used when making predictions. The fourth class, however, can remain included for scoring the utility of proposed areas. While the fishery officer data were too sparse to feed into any formal habitat evaluation, visually they generally overlapped with the areas identified by the model (compare Fig. 4.4 with Fig. 4.6)

Depth versus Habitat Index, Fishing Areas, and RCAs

The inshore rockfish are found in depths of less than 200 m, and commonly in depths of less than 100 m (Love et al., 2002). As discussed above, the two variables, complexity and kelp were found to capture the fishing polygons quite well. However, reefs and kelp are both associated with shallower depths, and one might expect there to be a cross-correlation. Indeed, looking at the habitat classes, there is a clear trend from shallower, high-value areas to deeper, low-value areas (left section, Fig. 4.8). Similarly, there is a trend in the fishers' ranking of areas.

With the RCAs, we see a great deal of variability in mean depth, with the final RCAs being more variable than those that were rescinded. There is some correspondence of shallower areas scoring better than deeper ones, especially in extreme examples (e.g. #2 vs. #5), but there are also notable exceptions (e.g., #3 vs. B). Thus, while it is true that shallower areas appear to capture more features of known rockfish habitat, we would not say that depth alone is sufficient to measure this; that is, our model is not simply a depth model in disguise.

Evaluating the Rockfish Conservation Areas

Rockfish Conservation Areas were announced in March 2004 by Fisheries and Oceans Canada (DFO). These represent a subset of initial areas originally put forward in 2003. We mapped the 2004 RCAs, as well as the ones put forward in 2003 and rescinded in 2004, for the purpose of examining how well they capture known important fishing

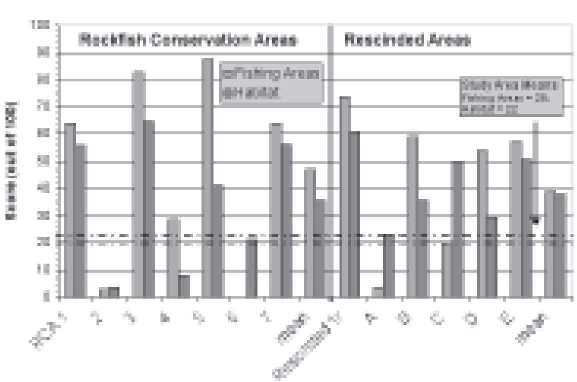


Figure 4.10. The RCAs are extremely variable in how well they capture known fishing areas (purple) or modelled habitat (green). The variability is greater in the actual RCAs than those that were rescinded. Their mean scores are very similar, with the final RCAs capturing a little more of known fishing areas, but a little less of predicted habitat.

Table 4.2. Predicted habitat vs. fishing areas and RCAs. While high-value fishing areas contain 79% of "core" potential habitat, the Rockfish Conservation Areas contain about half that, 41%. The rescinded conservation areas, however, contain more core habitat, and at 65% fall in between the two.

	Total Habitat 1-4	*Total Habitat 2-4 "Core"*	*Habitat 4 (v. high)*	*Habitat 3 (high)*	*Habitat 2 (med-high)*	*Habitat 1 (med.)*
Fishing 2 (high)	94.0%	78.9%	11.8%	27.2%	39.9%	15.2%
Fishing 1 (med.)	72.7%	43.8%	4.5%	11.3%	28.0%	28.9%
RCA	61.1%	41.3%	7.4%	9.6%	24.3%	19.8%
Rescinded	86.8%	65.1%	10.1%	21.3%	33.7%	21.7%
Study Area, less Inlets	46.5%	28.1%	3.4%	8.4%	16.3%	18.4%

areas and our modelled habitat. Furthermore, we were curious to see how the 2004 RCAs compared with those that were rescinded.

Visually, it is clear that some RCAs overlap better with high-value (potential) habitat than others; however it is difficult to discern any particular trends (Fig. 4.9; see page XX). Unlike Fig. 4.6, which shows habitat and fishing areas, any correlation between the RCAs and either habitat or fishing is not immediately obvious. In Tables 4.1 and 4.2, we find that the RCAs overlap less potential rockfish habitat than the medium value fishing areas, and much less than the high-value fishing areas. The rescinded RCAs, however, overlap more predicted habitat than the medium value fishing areas, and more than the final selection of RCAs.

Tabulating the cumulative scores ("zonal statistics"), we find the RCAs are extremely variable in how well they do at capturing known fishing areas or our modelled habitat (Fig. 4.10). Fishing area scores (out of 100) were created by calculating the mean fishing values (0-2) for each RCA, and standardizing to a score out of 1-100, where 100 would represent perfect overlap with high-value (2s) fishing areas. These RCA scores range from zero (no fishing area in RCA #6) to 87 (RCA #5). Cumulative habitat scores were likewise calculated and range from 4 (RCA #2) to 65 (RCA #3). The variability is greater in the recently announced RCAs than those that were rescinded, and have both the highest and lowest scores in the study area. Their mean scores are very similar, however.

One RCA (#1) in the study area was initially proposed to be much larger (#1r). In this case, the earlier option had higher scores than the final version; i.e., the section that was rescinded appears to have been more valuable than the section that was left behind (inset map, Figs. 4.9 and 4.10).

Discussion

Effectiveness of Complexity Modelling

We believe that our model has shown itself to be a powerful predictor of high-value fishing areas. Because of the relatively sedentary nature of inshore rockfish adults, we suggest that high-value fishing areas should often overlap with high-value habitat, and the habitat-based model would appear to support this.

Initially, we were curious to see how well complexity alone could predict rockfish habitat. A comparison of Fig. 4.2 with Fig. 4.4 does indicate that there is indeed a great deal of predictive power in that variable alone; but there are certain gaps (e.g., the strip along the shore including RCA #5). Many of these could be filled when taking kelp into account. While complexity and kelp are no doubt correlated, including these two indicators in the model allow for one dataset to fill in for weaknesses in the other, as well as indirectly taking into account other complementary ecological attributes such as primary production. Although we did not use depth as a variable in our model, it could be examined afterwards, to sort out habitats for particular species with known depth preferences.

The habitat model is somewhat better at predicting fishing areas than vice versa; that is, the fishing areas tended to be larger than the associated modelled habitat. This can be explained in three non-exclusive ways: (1) the fishers drew their polygons a little more generally than where they actually fished; (2) the model's search radii in the various density analyses were a bit too short ("tight"); and (3) the fish wander somewhat from core habitat areas and are still caught in good numbers. The first and third explanations would suggest that the model could already be doing what it should (predicting habitat), while the second explanation would suggest broadening the constraints of the analysis somewhat. Surveying actual fish distributions would answer this and other questions. In the meantime, we feel it is prudent to err on the side of caution, whereby the areas selected represent a conservative estimation of important rockfish habitat. That way, we can feel more confident that their protection would be beneficial to the species.

Rockfish Conservation Areas

While high-value habitat areas consistently overlapped with high-value fishing areas, the Rockfish Conservation Areas were much less consistent. We feel this high variability of (modelled) habitat quality within the RCAs could be a reflection of the stakeholder-driven RCA selection process.

Three of the seven RCAs appear to have been poor choices: #2 (Goletas Channel), #4 (Numas Island), and #6 (Salmon Channel). Five of the six of the rescinded RCAs (1r, B, C, D, E) scored better than any of these three RCAs. In light of these findings, we would suggest that the five higher-scoring but rescinded RCAs could be re-considered as replacements for the three low-scoring RCAs currently under protection. However, this would be our second choice.

Our preferred methodology, as stated in the introduction to this paper, would be to adopt a systematic approach in identifying all possible rockfish habitat. Providing numerous options from the onset offers the opportunity to include other essential elements into reserve design (e.g., source-sink relationships, connectivity, enforcement). Once all habitats are identified, and other necessary design criteria are considered, only then should socioeconomic criteria be applied for removing contentious areas. However, we would like to emphasize that the opinions and concerns of fishers should be taken very seriously. In collecting our data from fishers, we stressed that we wanted to find solutions that optimized both conservation and fishing.

Future Research

The analysis presented in this paper is a first step towards a better understanding of the utility of complexity-based habitat modelling. The measure of complexity is heavily dependent on the quality of available bathymetry data. Unfortunately, affordable good quality bathymetry data are still difficult to acquire in Canada, and remains an issue that needs to be addressed. Nonetheless, bathymetry is often the best dataset when considered next to other options. Similar data to those presented in this paper exist for other regions of BC and would allow for further testing of the model.

We are presently engaged in the collection of additional local fishers' knowledge, both commercial and recreational, for the Central Coast, with plans to have surveyed most of coastal BC by 2005. Also, we are examining divers' data to see if these can be incorporated, though there are some issues of scale.

We believe this same model may prove useful in the management of other species (e.g., lingcod), which utilize complex habitat, and we are presently looking for data with which to calibrate and verify such models. If successful, modelling would be used to direct conservation and survey efforts at a fraction of the cost presently required through broader, less directed surveys.

Finally, the results of the Rockfish Conservation Area analysis clearly show the need for a systematic habitat-based approach for reserve selection. Our analysis covered only a small section of the BC coast containing seven RCAs. At present, 90 RCAs have been designated coastwide. Our results suggest that a significant proportion (perhaps 40%) of the RCAs are not actually protecting valuable rockfish habitat. We feel this warrants a larger coastal analysis and survey verification. Results from our complexity-based habitat modelling demonstrate an effective approach to narrowing down possible rockfish conservation sites, and could assist with the selection of high quality sites, while avoiding the selection of poor choices in the future.

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Notes

1. Fisheries and Oceans Canada is the current name of the department, but they elected to retain the acronym from their original name, Department of Fisheries and Oceans.

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