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Reducing Bycatch of Corals and Sponges in British Columbia's Groundfish Trawl Fishery through Trawl Fishery Closures

Réduction des prises accessoires de coraux et d'éponges dans la pêche au chalut de fond en Colombie-Britannique par l'imposition de fermetures de ce type de pêche

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ABSTRACT

From 1996 to 2002, about 295 tonnes of cold–water corals and sponges were observed as bycatch in British Columbia's (BC) groundfish bottom trawl fishery. Many damaged coral and sponge fragments likely remained on the sea floor, suggesting that gear impact on species was more extensive than indicated by bycatch quantity. Recovery from trawl damage is species dependent, and in some cases may take several decades to centuries. While cold-water structural habitat remains poorly studied in BC, it is generally accepted that its destruction has a negative impact on benthic ecosystem dynamics and fished stocks and should be minimised.

Year-round bottom trawling closures have been established in Australia, the European Union, New Zealand, Norway, Iceland, Scotland, the USA, and BC, all with the goal of protecting corals and/or sponges. This paper explores an efficient spatial establishment of closures in BC to significantly reduce bycatch and destruction of habitat-forming corals and sponges. Density analyses of bycatch locations indicates 12 areas of high coral / sponge species concentration, representing about 7.5% of BC's continental shelf and slope. Had these areas been closed, this would have prevented 97% of all coral/sponge bycatch by weight. The regional diversity of BC's deep water coral and sponge species appears to be represented in these twelve areas, though site-specific verification is required. Economically, these 12 areas are of average economic value to the fishery. However, because the fishery is an individual quota fishery, and because of the mobility of many groundfish species, it is difficult to estimate the potential economic cost of establishing these closures. Closing an area does not necessarily mean that mobile individuals of targeted species would not be caught elsewhere, only that they will not be caught in the closed area. Overall, the proposed potential closure areas contain about one quarter of historic (1996-2002) trawl sets.

RÉSUMÉ

Entre 1996 et 2002, environ 295 tonnes de coraux et d'éponges d'eaux froides ont été observées en tant que prises accessoires de la pêche au chalut de fond en Colombie-Britannique (C.-B.). Un grand nombre de fragments de coraux et d'éponges endommagés tapissent toujours sans le doute le fond marin, ce qui suggère que l'incidence des engins de pêche sur ces espèces soit plus étendue que ce que laisse supposer la quantité des prises accessoires observée. Le rétablissement des dommages causés par le chalutage varie selon les espèces et peut parfois nécessiter plusieurs décennies, voire des siècles. Bien que l'habitat des eaux froides n'ait pas fait l'objet d'études poussées en C.-B., on s'entend généralement pour dire que la destruction de cet habitat a des effets défavorables sur la dynamique benthique des écosystèmes et sur les stocks visés par la pêche et qu'elle devrait conséquemment être réduite au minimum.

Des fermetures de la pêche au chalut, qui ont toutes pour objectif de protéger les coraux et/ou les éponges, sont en vigueur à longueur d'année en Australie, dans les pays de l'Union européenne, en Nouvelle-Zélande, en Norvège, en Islande, en Écosse, aux États-Unis et en C.-B. Le présent rapport examine comment une répartition spatiale efficace des fermetures en C.-B. permettrait de réduire de manière importante les prises accessoires et la destruction des coraux et des éponges qui forment des récifs. Les analyses de densité aux emplacements où ont lieu les prises accessoires indiquent la présence de 12 aires à concentration élevée d'espèces de coraux et d'éponges, aires dont la superficie représente environ 7,5 % de la superficie du plateau continental et de la pente continentale de la C.-B. Si ces aires étaient fermées à la pêche, on éviterait 97 % (en poids) de toutes les prises accessoires de coraux/d'éponges. La diversité régionale des espèces de coraux/d'éponges de grand fond de la C.-B. semble être représentée dans ces 12 aires, bien qu'une vérification de chaque aire s'impose. Ces 12 aires ont une valeur économique moyenne pour la pêche. Cependant, parce qu'il s'agit d'une pêche visée par des quotas individuels, et en raison de la mobilité de nombre des espèces de poissons de fond, il est difficile d'estimer le coût économique possible de ces fermetures. La fermeture de la pêche dans une aire ne signifie pas nécessairement que les individus mobiles des espèces visées ne seront pas prélevés ailleurs. Cela signifie seulement qu'ils ne seront pas prélevés dans une aire visée par une fermeture. En gros, les aires dont on propose la fermeture représentent environ le quart (1996-2002) des chalutages historiques.

INTRODUCTION

Cold water corals have been poorly studied in British Columbia (BC) to date. Corals (referred to here as Class Anthozoa, Subclasses Alcyonaria (soft corals and sea fans), Ceriantipatharia (black corals), and Hexacorallia (stony and cup corals); and Class Hydrozoa, Order Filifera (fire corals); see Jamieson et al. 2006 for higher taxonomic classification explanation) found in BC to date are listed and mapped in Jamieson et al. (2006), and those found on the continental shelf and slope, particularly on the flanks of banks, are vulnerable to bottom trawling activities. Octocorals (Subclass Alcyonaria) can form large and long-lived colonies, or forests, and are considered to be the "backbone of the coral ecosystem" in BC (Freiwald et al 2004). The following three Families in particular are potential habitat-forming corals in BC waters (Etnoyer and Morgan 2003; Jamieson et al. submitted):

1. Family Primnoidae ("red tree"): Mostly at depths between 100-500 m (Etnoyer and Morgan 2003) attached to boulders, and species have been observed widely in BC and Alaska. Large specimens exceed one metre in height.
2. Family Paragorgiidae ("bubblegum trees"): Mostly at depths between 0-800 m (Etnoyer and Morgan 2003) and have been observed widely in BC and Alaska. Large specimens exceed 2.5 m in height.
3. Family Isididae ("Bamboo Coral"): Mostly at depths between 600-1200 m (Etnoyer and Morgan 2003) in BC and Alaska., and are rivalled in size only by paragorgids.

The reef-building hexacoral *Lophelia pertusa* has been found in Juan de Fuca Canyon (Hyland et al. 2004), Alberni Inlet and the Strait of Georgia (Jamieson et al. 2006), but their overall abundance and distribution in BC are unknown. *L. pertusa* is a highly branched massive coral that occurs on flat bottoms and its reefs can exceed two metres in height and extend over large areas. In the Atlantic, abundance of the commercially important rockfish "redfish" (*Sebastes marinus*) has been reported to be about seven times greater within these reefs than in surrounding habitat (Husebo et al 2002).

As with corals, the ecological significance of habitat-forming sponges has been scantily studied in British Columbia, although the extent of sponge reefs, or bioherms, has been better documented (Conway et al. 1991, Conway 1999, Jamieson and Chew 2002, Conway et al. 2005, Krautter et al. 2006). Cook (2005) provides the most comprehensive analysis, while Jamieson and Chew (2002) list trawl bycatch species from both the bioherms and locations close to them. The discovery of these globally unique hexactinellid (glass) sponge reefs in the BC's trawling grounds has resulted in considerable scientific and public interest. They have been mapped in four general locations in Hecate Strait and Queen Charlotte Sound and cover about 38,604 hectares (Kashka Iwanowska, Natural Resources Canada, Sidney, BC, March 2006, pers. comm.), and smaller reefs have been found in the Strait of Georgia and Queen Charlotte Strait (K. Conway, NRCan, Sidney, BC, pers. comm.). Bioherms can increase in size over the course of centuries to exceed 19 m in height, and can have live sponges up to 1.5 m high (Conway et al 2001, Krauter et al 2001). Sponge bioherms are actually communities of several different sponge species, but in BC three reef-building species dominate: *Heterochone calyx*, *Aphrocallistes vastus*, and *Farrea occa*. Other sponge species that are present, but are not believed to be reefbuilders, include *Rhabdocalyptus dawsoni*, *Acanthascus platei*, *Acanthascus cactus*, and *Staurocalyptus dowlingi* (Krauter et al 2001). Numerous species of fish and crustaceans have been observed in video transects of the bioherms (Cook 2005).

This paper seeks to explore on the basis of current data the most efficient use of spatial protection through fishery regulation closure or MPA establishment to significantly reduce both trawl coral and sponge bycatches and the destruction of suggested significant, deep-water biogenic habitat.

The Groundfish Trawl Observer Program

Beginning in 1996, 100% observer coverage became mandatory in BC's bottom trawl fishery. Coral and sponge bycatches have been recorded from that time, but as non-commercial species they were reported in much taxonomic detail, and training of observers on their taxonomic identification was minimal to non-existent. This situation has been improved since 2003, but unfortunately these more recent data were not available for this paper. Furthermore, the reporting categories to choose from were not always easily identifiable to a particular taxonomic category. For example, many observers we spoke to did not realize that hexactinellid sponges were glass sponges, and recorded them either as stony corals or in the general catch-all "sponge" category.

Coral and Sponge Trawling Closures

There is growing recognition worldwide of the damage caused by bottom trawling to deep sea corals and sponges (e.g. Hall-Spencer et al 2002, Freese et al 1999), and that such damage should be avoided as much as possible. Possible implications of trawling on the overall health of fisheries and ecosystems are beginning to emerge (Heifetz 2002, Krieger and Wing 2002, Witherell and Coon 2001). Year-round bottom trawling closures with the goal of protecting corals and/or sponges have been established in Australia, the European Union, New Zealand, Norway, Iceland, Scotland, the USA, and BC. In Norway, it is estimated that 30% - 50% of *Lophelia* coral reefs have been damaged or destroyed by bottom trawling (Fossa et al 2002). In the Pacific, trawling activities have recently been significantly more restricted in both Alaska (http://www.afsc.noaa.gov/race/groundfish/habitat/corals_hapc.htm) and from California to Washington (http://www.nwr.noaa.gov/Groundfish-Halibut/Groundfish-Fishery-Management/NEPA-Documents/EFH-Final-EIS.cfm), largely because of concerns to potential damage to deep-water coral habitat.

In British Columbia, trawl damage to the globally unique hexactinellid sponge reefs was detected by both multi-beam acoustic surveys and video transects (Conway 1999, Conway et al 2001, Krauter et al 2001). In 2000, the industry was asked to comply with voluntary closures around the reefs. However, video evidence that the 2000 voluntary closures around the reefs were not working led to mandatory fisheries closures in July 2002 (Jamieson and Chew 2002) (Figure 1).[1]

[1] Closure boundaries were modified on April 1, 2006, on the basis of improved spatial mapping of bioherms.

Gear Damage to Structural Species

Any fishing gear that touches or comes close to the sea bottom poses a potential threat to corals or sponges. Anecdotal evidence from fishers suggests that hook and line fisheries occasionally bring aboard corals. Also, sablefish traps and tanner crab traps fished with groundlines can crush or damage corals and sponges. However, the impacts of trawling are much greater than anchored passive gears such as long-lines and traps (Fossa et al 2002). In a series of survey questions based on a literature search of over 170 sources, Morgan and Chuenpagdee (2003) found consensus amongst an expert panel of scientists, managers, conservationists, and fishers that bottom trawling constituted the most ecologically damaging of all benthic gear fishing methods. Bottom trawls, along with dredges, bottom gillnets, and driftnets, were rated as having a "high impact" management category. This study also found that while the experts noted the negative impacts of bycatches associated with certain gear types, including trawl, it was damage to habitat that they found of greatest concern.

The effects of bottom trawling have been widely studied, with predominantly negative findings (for literature summaries see: Morgan and Chuenpagdee 2003, Watling and Norse 1998, Kaiser 1998). While the Pacific coast of North America has seen fewer studies than the Atlantic coast, these studies have documented a flattening of habitat complexity, destruction of long-lived structure-forming organisms such as sponges and corals, a reduction in abundance and diversity of invertebrate epifauna, and shifts in biological communities (Engel and Kvitek 1998, Krieger 2001). One study undertaken in SE Alaska recorded extensive damage to sponges (various taxa) and other invertebrates after only one trawl pass (Freese et al 1999). Fisheries and Oceans Canada (DFO) recently held a national workshop to evaluate impacts of fishing gear on bottom habitat and communities, but conclusions of this workshop were not available at the time of submission of this report.

Finding untrawled habitat (that can be trawled without gear damage in traditional depth ranges) is getting to be quite difficult. Some researchers have decried the lack of control sites with which to set their experiments or to use as a guide in monitoring the health of groundfish stocks (e.g., Walters and Bonfil 1999, Tyler 1999). In one case, researchers thought they had finally found a pristine closed area off the California coast, representative of the bottom type typically trawled, only to discover trawl tracks and that it too had been (lightly) trawled under an obscure compensation agreement (Engel and Kvitek 1998). In BC, there are areas that are either poor fishing or still too deep or too rocky to be trawled. However, trawling technology continues to develop, and these once-inaccessible areas are increasingly becoming accessible (e.g. the expanding thornyhead (*Sebastolobus*) fishery in deep water on the continental slope), and the increased trawl activity in such areas can threaten corals and sponges.

METHODS

Groundfish Trawl Observer Database, 1996-2002

Observed bycatch was collated from the DFO groundfish trawl observer database from 1996 (the year the program began) to 2002. Although the master DFO database includes start and end points (and more recently mid-points), for reasons of confidentiality the dataset that was provided to us had only calculated midpoints.[2] There were 1,351,479 records overall, of which 1,301,392 were recorded as being from bottom trawls, with one record per species observed. 3,888 records were of corals and sponges, or 0.30% overall. On a tow-by-tow basis, catches of corals and sponges were recorded in 2.62% of all bottom trawls, though many of these were incidental amounts (Table 1). Overall, from 1996 to 2002, about 295 t of corals and sponges were estimated as bycatch in BC's groundfish bottom trawl fishery (Table 2).

Because of poor taxonomy, coral and sponge data were grouped together for most analyses, using other indicators such as depth and spatial location to re-stratify the results. In practice, if there was a record of a coral or sponge observed as coming up on deck, we felt fairly confident that it was indeed a coral or sponge, but placed little confidence in the category to which it was assigned.

Initially, we looked at the following observer recording categories: "Stony Corals," "Soft Corals," "Gorgonian Corals," "Calcareous Corals," "Glass Sponges," "Bath Sponges," and "Sponges." These categories were deemed to likely represent habitat-forming and also long-lived organisms sensitive to damage. Later, we re-ran the analyses with the inclusion of sea pens (Order Pennatulacea). While not as long-lived as the other corals, they are also habitat forming. We had initially excluded this category because they are widespread. However, after including the category in the analysis, it was found that certain spatial trends did come to light, and that these did not appreciably alter the overall results. Thus, given their habitat forming characteristics, it was decided to keep sea pens in the analysis as well.

GIS Analyses

GIS played a significant role in our analyses. 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 one hectare per cell (100 m x 100 m), an unequal area projection (such as geographic long-lat) could have skewed the results.

To examine spatial trends in the data, we employed standard "out of the box" kernel density analyses using ArcView © 3.2 and 8.2 with the Spatial Analyst extension for each. A density analysis moves though each cell on the map, taking into account all other points found within a specified "search radius" of that cell. Thus, a region with several moderate landings will show up as denser in bycatch than an area with, say, only one larger landing. Given enough records, this approach avoids results being skewed by single large landings or misreporting, as can happen if only largest values are considered. Also, this approach avoids the issue of larger management grid squares straddling areas of high bycatch, and thereby dividing the results, as can occur in systems that bin results into grids or statistical areas.

Trawling in BC was found to exhibit a bimodal distribution, with two different fishing behaviours distributed according to depth. Fishing in waters deeper than 500m was limited generally to certain areas of the shelf slope, where the tows were much longer and slower.

[2] We had no data for the months of Jan. – Mar. 2001. However, we do not believe these three missing months of data appreciably altered results.

Because most trawling occurred in waters shallower than 500 m, this was the distribution we considered when determining what would constitute a neighbouring point in the density analysis. The median length of a bottom trawl in waters less than 500 m depth was calculated to be 10.0 km, for the years of 2001 and 2002 − the only years when speed was recorded. This compares to the mean tow length of 9.6 km around the sponge reefs (Jamieson and Chew 2001). Thus, all density analyses used a search radius of 10 km, with a decay function whereby points nearby were weighted more than points further away (inverse distance weighted). This 10 km search radius allowed for the density measure to take into account neighbouring tows on average of about one a tow length away, centre to centre. Longer search radii (e.g. 20 km) gave "fuzzier" more generalized results, whereas shorter radii (e.g. 5 km) appeared fragmented and somewhat more difficult to interpret. Nonetheless, the density analyses were robust to minor variations in search radii, and the results grew or contracted in a predictable and consistent fashion.

Once plotted, it was found the results of the density analyses were not normally distributed. To aid in the calculation of distribution statistics, the results were square-root transformed. Both density of observed weights $(kg/km^2)^{0.5}$ and density of catch per unit effort (CPUE) $(kg/hr/km^2)^{0.5}$ were considered. CPUE was approximated by dividing total bycatch observed by the hours the net was towed (net size data were not available). CPUE calculations tended to overly-emphasize the areas of extremely large bycatch, as well as sets of very short duration. We postulate this is because in these sets of large bycatch the presence of corals or sponges was likely detected by the fisher and the set was terminated early; or, in other cases of short duration, they may have been terminated for technical reasons. (Unfortunately, we did not have access to the "success code" of each set, which would have helped answer this.) In both cases, a key assumption of CPUE analysis − the normal distribution of fishing effort in all areas − was being violated, which appears to have produced spurious results. For this reason, it was decided to use only the density of catch weight in our results and our mapping.

RESULTS

Numerical & Spatial Distribution of Bycatch

While the number and proportion of coral and sponge observations has generally been increasing over the years, large single landings (>1000 kg) have been recorded for every year (Figure 2). It should be noted that all of these larger landing would have been visually estimated by the observers and may have been over (or under) estimated to a considerable degree. Validating these results with dockside sampling would help clarify the extent of possible error. Nonetheless, taken altogether, the observed bycatch of corals and sponges is extremely steeply skewed. Despite log-transformation, plots noticeably rise to the right whereby the heaviest quartile of landings accounts for about 96% of total landings − 99% by CPUE (Figure 3). Such curves suggest that while the majority of landings are quite small, what large landings do occur heavily influence the overall statistics. This is also likely aggravated by the aggregated taxonomic categories, wherein many small species are lumped together with a few larger ones.

Mapping the distribution of coral and sponge bycatch initially showed no particular trends; the midpoints of sets occur throughout the trawling grounds of BC's shelf and slope. Mapping the top quartile of points begins to show certain concentrations, but these were difficult to discern. A density analysis of all mid-point coral and sponge data produced much clearer patterns. From these can be identified twelve key harvest areas, based on the density of observed weight of bycatch (Figure 4). The boundaries were created following the 0.5 standard deviation line of the square-root transformed density of catch, and then smoothed visually. These smoothed outer boundaries were in the range of generally between the arithmetic mean to 0.5 standard deviations, with greater densities being captured within these areas. While these twelve areas capture 61.5% of all coral-sponge records, they account for 97% of all bycatch by weight, and 98.8% by CPUE. A closer examination of this figure revealed that the majority of bycatch was captured by the three areas that overlap the hexactinellid sponge reefs; i.e., area numbers 4, 6, and 8. These three areas, while just 16.3% of all coral-sponge records, accounted for 85.0% of bycatch by weight (92.3% by CPUE). This strongly suggests that landings from these three areas represent larger than average species, likely the hexactinellid sponges. It would also suggest that the large landings from these three areas could be obscuring trends with regard to the capture of other smaller species, and that the data ought to be re-stratified based on these three areas. When the three areas were removed from the analysis, the remaining nine areas captured 54.0% of remaining coral-sponge records, and 80.9% of bycatch by weight (84.5% by CPUE). While not as large a proportion as the overall values quoted above, which were heavily biased by the three hexactinellid reef areas, these still represent a notable spatial efficiency whereby these areas contained a much greater proportion of observations than would be expected randomly (Table 3).

(Preliminary) Biodiversity Analysis

The potential 12 protected areas were examined to consider how well each coral-sponge category in the observer database would have been protected. As stated above, while we view the reporting in these categories as being somewhat unreliable, it was hoped that by looking at these categories individually they could be used as proxies giving a first indication of the possible diversity of corals and sponges coming up on deck. From the raw data, we extracted subsets from each category that we felt likely represented the most reliable observations (due to low numbers of observations, the category “Bath Sponges” was not included). For most categories, data were from the most recent years, but for the more readily identifiable “Gorgonian” and “Sea Pen” categories, we included data from all years. Overall, results showed large proportions of each category being protected − about 80% or higher. However, “Stony Corals” had 64% protection and “Sea Pens” 47%. These lower values are because these species are fairly widespread in distribution.

Due to the low confidence placed in species identification in the data analysed, all these values should be interpreted cautiously. At best, one could say that analyses suggest that a diversity of organisms would be protected by minimising gear impacts in these areas (Table 4). Detailed surveys of the specific sites being considered here would clarify the actual spatial occurrences of the different groupings.

Economic Analysis

Using historical average species prices, the value of every bottom trawl set, 1996-2002, was estimated. From that was calculated the Value (2002 dollars) per Unit Effort (VPUE). A density analysis identified areas of higher and lower VPUE (Figure 5). While some of the potential Coral-Sponge Protection Areas are in higher VPUE areas, many were not. Overall the potential protected areas accounted for 30.3% and 30.6% of 1996-2002 historic landings and value, respectively. Spatially, they occupy about 7.5% of the BC coast (shelf and slope to 2000 m), and 24.1% of the historic 1996-2002 trawl sets in our analysis.

Evaluation of the Effectiveness of Existing Closures

Most present-day marine protected areas and fishery closures occur in areas that historically had little trawl activity (1.4% −Table 5) and virtually no coral or sponge bycatch. The exceptions are the hexactinellid fishery closures. From 1996-2001, about one third of all coral and sponge bycatch would have been prevented by the hexactinellid sponge reef closures, had they been enacted earlier than in 2002 (75,126 kg out of 229,469 kg). The remaining two thirds of all coral and sponge bycatch did not occur in the initial sponge closure areas (154,343 kg). Thus, while helpful, the current hexactinellid closures do not by themselves adequately minimise the coral and sponge bycatch issue.

DISCUSSION

A total of about 295 t of corals and sponges were observed as bycatch in BC's trawl fishery from 1996 to 2002. Because these are non-commercial species, these observations were likely under-reported. Also, it is likely that many of the damaged coral and sponge fragments remained on the sea floor. Thus, this estimate is likely many times smaller than the actual destruction that occurred.[3] We suggest this magnitude of damage is unacceptably high, particularly since the actual abundance and spatial distribution of corals and sponges is largely unknown.

Sinclair et al. (2005) have recently analysed BC trawl data to describe conditions important for determining fishing locations and areas of high fish density (Fig. 6). Differences between their analysis methods and ours were that they looked at 1996 – 2004 data, we had only 1996 – 2002 data observer data; they had start and end points, we had only mid-tow points; they binned the data into 1 km grid cells, whereas we used a 100 m grid; and they looked at deciles (data divided into ten equal sized groups) of effort (per 1 km square), whereas we looked at density of effort with a 10 km search radius. We initially also looked at deciles (as well as 5% quantiles), but felt that considering density was a more meaningful approach for identifying "hotspots." However, the density analysis could also have tended to make these hotspot areas perhaps appear somewhat larger than they actually are. In the context of conservation planning, however, a slightly larger area automatically provides a buffer against data uncertainty and spatial gaps. So, we came up with somewhat similar, but also different, results, in part because the objectives of the two studies were different. In this context, we believe the buffering effect is a reasonable and desirable attribute, since it is likely there are neighbouring corals and sponge areas where the trawlers may not yet (or cannot) trawl, but which have biogenic structures and are in the immediate vicinity. These areas that represent a high density of bycatch are not necessarily contiguously populated with corals and sponges; rather, it is likely that there would be several distinct patches. A density analysis links these otherwise disparate zones, thereby identifying spatial trends in bycatch, whereas using quantiles is limited in this regard to the size of the grid

[3] Some fishers, on the other hand, believe that because the bycatch is usually thrown overboard, fragments could be coming up again in subsequent sets.

square and where the boundaries of that grid square happen to land. Thus, we suggest our approach is appropriate for this analysis. Nonetheless, the inverse-distanced weighted interpolation, as used in the density analysis, can bridge together areas that topography or other considerations might indicate are better treated separately. These can only be identified on a case by case basis, usually requiring additional survey information, and was considered outside the scope of our preliminary analysis.

If one only wishes to map where trawling is occurring and not spatial trends of catches, then having higher resolution data and mapping quantiles is reasonable. In this regard, Sinclair et al.'s (2006) analysis is very useful and timely. It does refine the spatial mapping of the area known to be trawled in BC. Sinclair et al (2006) note that about 28% of the coast was trawled, with a smaller proportion intensively, but unfortunately it is unclear how they defined "coast." Looking at the map, it appears that they may have included waters much deeper than are currently trawled and possibly the inlets. If so, the percent of the total area within depth zones inhabited by sponges and corals that can be practically trawled with current technology may be significantly higher.

It is difficult to characterize any potential economic loss that would occur if the 12 areas identified here were closed to trawling. At first glance, the proportion of historic value (30.6%) might appear to be the appropriate statistic. However, this would be an implausible worst case, as it incorrectly assumes that commercial fishes within them would not move outside the identified potential protected areas, where they could then be caught (spill-over effect), and that species compositions would remain constant. Modelling work in the region suggests that the substantial mobility of many commercial species may largely offset conservation benefits for them from small spatial closures, such as could be the case here for at least some mobile species (Walters and Bonfil 1999). As found in protected areas worldwide, protected areas can actually allow for increases in neighbouring fisheries through spill-over effects of more sedentary fished species (Halpern 2003, Hastings and Botsford 1999, Hastings and Botsford 2003). Thus, the economic hardship of these potential coral and sponge protected areas is likely less, and could even be positive if recruitment rates through greater reproduction of some fished species were enhanced. In either case, because much fishing is in individual quota fisheries, it is likely that such quotas could be caught elsewhere. Because of the inherent complexity of the trawl fishery and its related benthic ecosystems, we believe that *in situ* studies measuring actual effects would be the only true indicator of closure costs and benefits.

While it is recognized that back-casting has limitations, it is the best tool presently available to evaluate possible futures. However, protecting areas that have shown high coral/sponge bycatch in the past may be a bit like closing the barn door after the animals have escaped. i.e., it is not presently known if and when corals could recover at these sites, or if any other sites still remain. We considered this possibility by looking across years to see if there has been a spatial shift in coral/sponge landings. Generally, we could not find such trends. This could be explained in two ways: 1) the seven-year time series is short and noise is high, perhaps too high for temporal trends to be detected; and 2) trawl tows may be interspersed on softer bottoms throughout harder bottom coral-sponge habitats, and are "nibbling" away at them. The continued reporting of corals and sponges as bycatch suggests that it is quite likely that some living healthy structural organisms, even long-lived ones, still exist in the trawled areas, but if trawling is allowed to continue, in time they will almost certainly all be destroyed.

RECCOMMENDATIONS

1. The twelve suggested closure areas identified in this paper shown to contain corals/sponges should form the basis of discussions regarding management options to be considered in the protection of these habitat-forming species. (Sinclair et al's (2005) mapping of trawled areas (Fig. 6) may help in defining the most appropriate closure boundaries).
2. Benthic habitat in the suggested closure areas not yet well surveyed by non-destructive means (e.g. multibeam, ROV, etc.) should be so surveyed as soon as practical to gain a better understanding of the spatial distributions and abundances of species and assemblages found there; and, to allow the refinement of established or proposed conservation area boundaries for biogenic habitats.
3. Trawl observers should be provided with the necessary training and taxonomic guides and keys to enhance coral and sponge field identifications and bycatch reporting. The current coral and sponge reporting categories should be reviewed and where necessary, revised to allow better capture of taxonomic groupings.
4. A sampling program should be implemented whereby samples of bycatch corals and sponges would be sent to Science Branch coral experts, along with their catch location, for full identification, so that a more complete spatial mapping of biogenic species in BC can be developed.
5. Bycatch data and the spatial mapping of bycatch species, most of which are non-commercial, should be appropriately analysed as soon as practical following collection to facilitate ecosystem-based management in BC waters.

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Table 1: Number of coral or sponge (c-s) observations by year; the percentage that these represented of all bycatch observations; and, what percentage these constituted of all fishing tows.

Year	Recorded c-s observations	Percent of all bottom trawl observations	Percent of all bottom trawl tows
1996	271	0.14	1.10
1997	365	0.20	1.91
1998	509	0.27	2.08
1999	613	0.31	2.61
2000	806	0.40	3.53
2001	611	0.42	4.20
2002	713	0.36	3.67
Overall	**3,888**	**0.30**	**2.62**

Table 2: Total observed BC groundfish trawl bycatch of corals and sponges (C-S). 2000 and 2001 were years where voluntary closures were in place around the hexactinellid sponge reefs; these became regulation groundfish closures in 2002.

Year	C-S Bycatch (kg)
1996	7,894
1997	39,444
1998	22,178
1999	21,813
2000	78,778
2001	101,332
2002	23,155
Total	294,593

Table 3: Spatial effectiveness of the 12 potential coral-sponge protection areas (CSPAs) in reducing coral/sponge bycatch. Hex = hexactinellid. Weight, catch per unit effort (CPUE), and catch per square-root unit effort (adjusted CPUE) data are examined. Adjusted CPUE accounts for the fact that a key assumption of CPUE calculations (that catch does not affect effort) is likely violated in cases where there is a high bycatch of corals or sponges and the set is cut short by the fisher. Three CSPAs in the vicinity of the hexactinellid sponge reefs account for a disproportionately high amount of bycatch (column 2). Removing these areas from the spatial calculations allows better assessment of the other nine areas (column 5).

	Three Hex CSPAs		Nine Other CSPAs		All CSPAs (sum of 3 Hex and 9 Other CSPAs)		Nine Other CSPAs on their own (3 Hex areas removed from analysis)		All C-S Trawl Sets (inside & outside of the 12 CSPAs)	
	Tows	%overall	Tows	%overall	Tows	%overall	Tows	%	Tows	%
Sets	590	17.3	1439	42.3	2029	59.6	1439	51.1	3404	100.0
Records	633	16.3	1758	45.2	2391	61.5	1758	54.0	3888	100.0
Catch (kg)	214798	85.0	30609	12.1	245407	97.1	30609	80.9	252626	100.0
CPUE (Kg/hr)	241402	92.3	16939	6.5	258341	98.8	16939	84.5	261440	100.0
adjusted CPUE (Kg/hr$^{0.5}$)	213240	90.0	19540	8.2	232780	98.2	19540	82.1	237034	100.0

Table 4: C-S biodiversity estimated to be covered by the potential Coral-Sponge Protection Areas (CSPAs), using what were considered the most reliable subsets of observations for each category as proxies (see text). Subset years are in the column headings. In the rightmost column, the dominant species groups are noted for each area. St = Stony Corals, So = Soft Corals, Sg = Sponges, Gl = Glass Sponges, Ca = Calcareous Corals, SP = Sea Pens; Hex = in the vicinity of a known hexactinellid sponge reef.

Reported Observations (Weight in Kg)

	Gorgonian	Stony	So	SP	Sponges	Glass	Calcar.	
Subset (yr)	96-02	02	02	96-02	00-02	01	97,02	
CSPA No.								Main Components
1	2396	0	0	0	2	0	0	Gorgonian
2	0	0	0	517	30	0	0	Sea Pens
3	62	3	3	3	2198	2	0	Sponges
4	24	0	0	1	907	454	0	Sponges, Hex
5	471	97	0	36	3	0	0	Gorgonian, Stony
6	196	202	1928	3	86824	2853	206	St, So, Sg, Gl,Ca, Hex
7	623	12	24	132	242	1	0	Gorgonian, Sea Pens
8	16	0	0	2	1293	0	68	Sponges, Hex
9	7	0	0	136	5875	0	9	Sponges, Sea Pens
10	59	0	5	68	242	7	3	Gorgonian, Sponges, SP
11	30	8	2	262	5549	40	102	Sea Pens, Glass, Ca
12	3	2	0	42	515	71	0	Sponges, Glass
Total	3888	324	1959	1202	103682	3428	388	
All BC	4906	510	2134	2553	105241	3486	488	
Protected	**79.2%**	**63.5%**	**91.8%**	**47.1%**	**98.5%**	**98.3%**	**79.5%**	

Table 5: Back-casting effect of existing closures on historical pre-closure sets. Total sets 1996-1997: 39,859; total sets with observed Coral-Sponge (C-S) Bycatch 1996-1997: 636. RPA: commercial rockfish capture illegal; RCA: commercial and recreational rockfish capture illegal.

.

Closure	Affected Sets 96-97		Affected C-S Sets 96-97	
Thornyhead	190	0.48%	0	0.00%
Hex. Sponges	275	0.69%	28	4.40%
RPAs	62	0.16%	0	0.00%
RCAs	7	0.02%	0	0.00%
Other Closures	17	0.04%	0	0.00%
Total	**551**	**1.38%**	**28**	**4.40%**

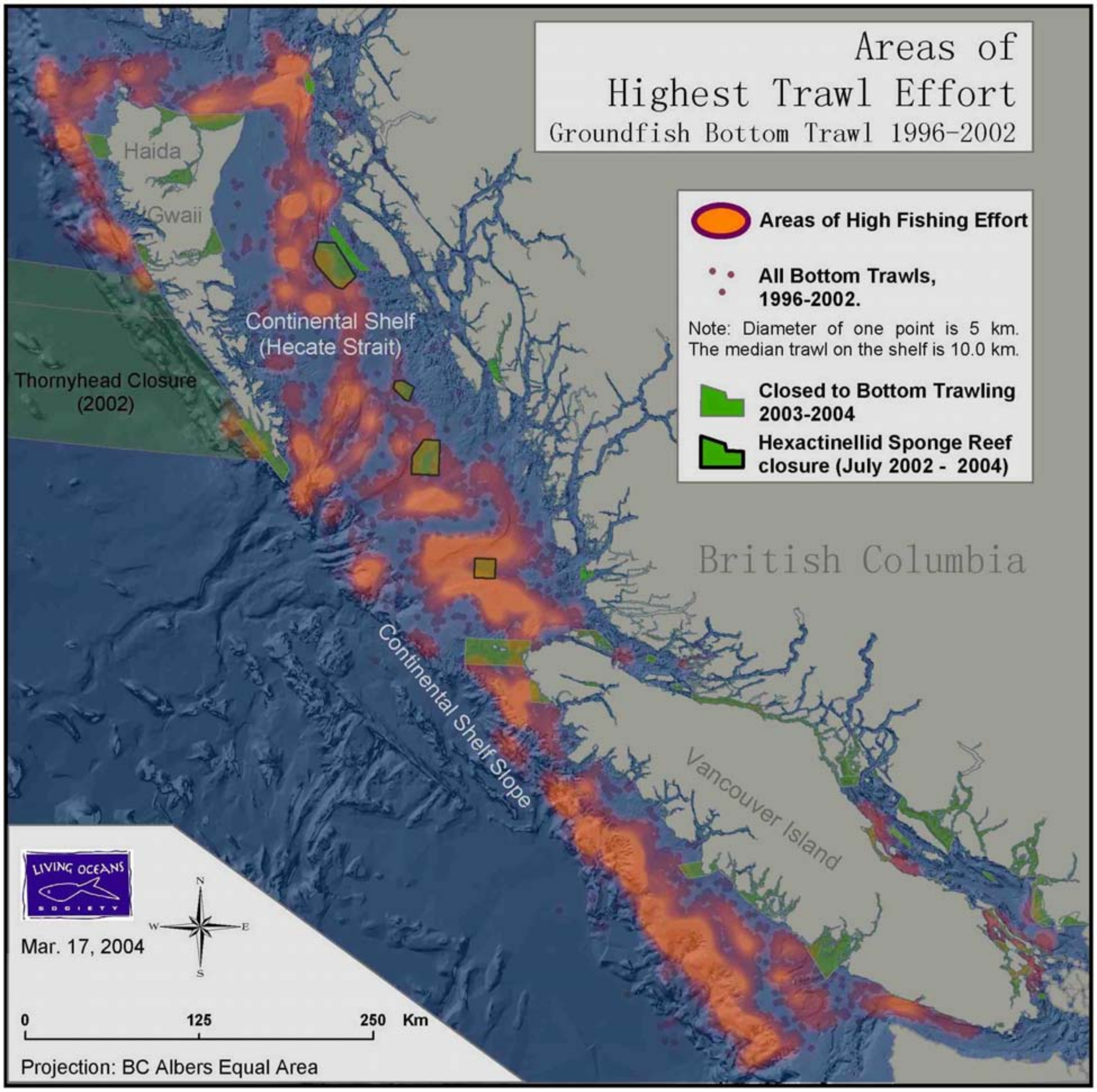

Figure 1: From 1996 to 2002, there were 129,811 bottom trawl tows, concentrated in certain areas (orange on map). Less trawled areas may represent areas of poor fishing or terrain inaccessible to present-day trawl technology**.** This map used a density analysis, which tends to visually overstate the activity (see discussion, and compare with figure 6).

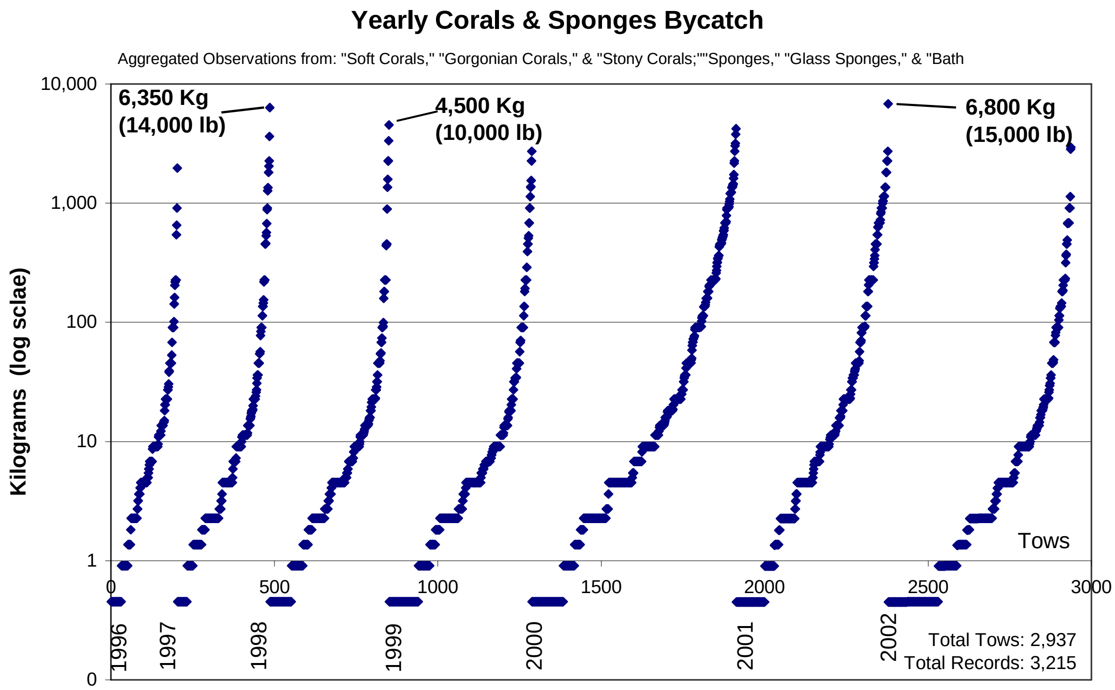

Figure 2: Yearly coral-sponge (c-s) bycatch by weight (log-transformed). In 1997, a single landing of 11,403 kg (25,000 lb) in the southernmost hexactinellid sponge bioherm was recorded as "calcareous coral" (not shown). "Calcareous corals" (anomalously high) and sea pens (low weight) are removed to show overall trends. Because some c-s tows had more than one c-s observation, the number records is somewhat higher than the number of tows.

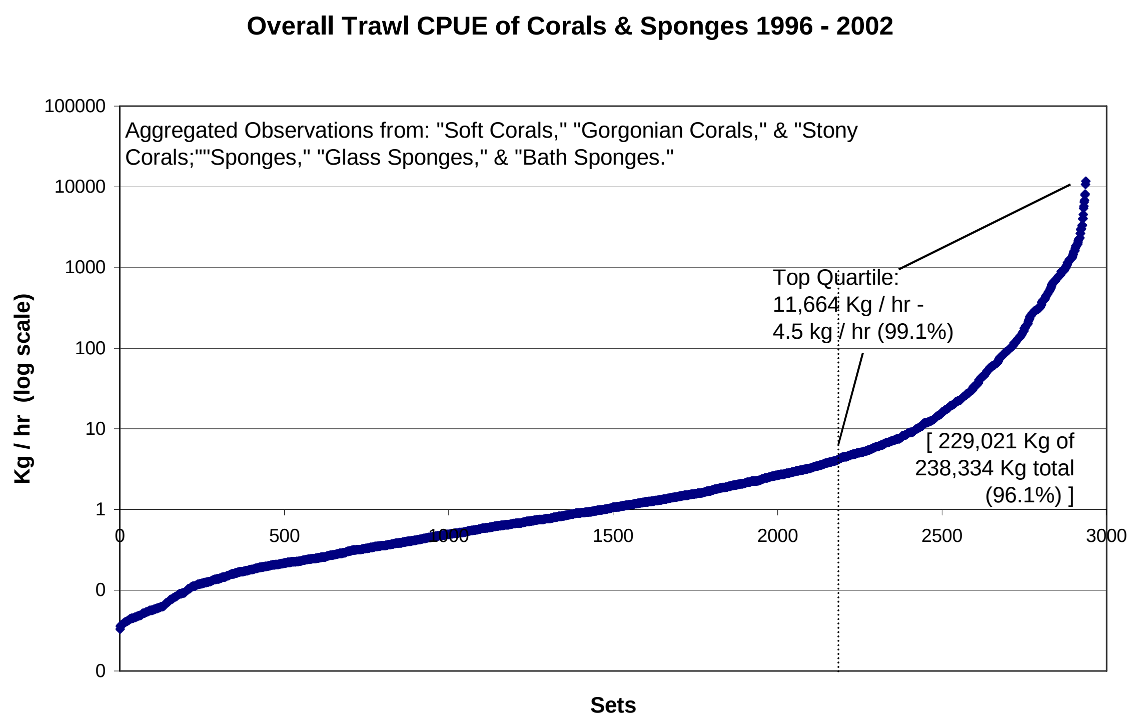

Figure 3: Log-transformed distribution of single records of coral and sponge bycatch, sorted by CPUE. “Calcareous corals” (anomalously high) and sea pens (low weight) are removed to show overall trends.

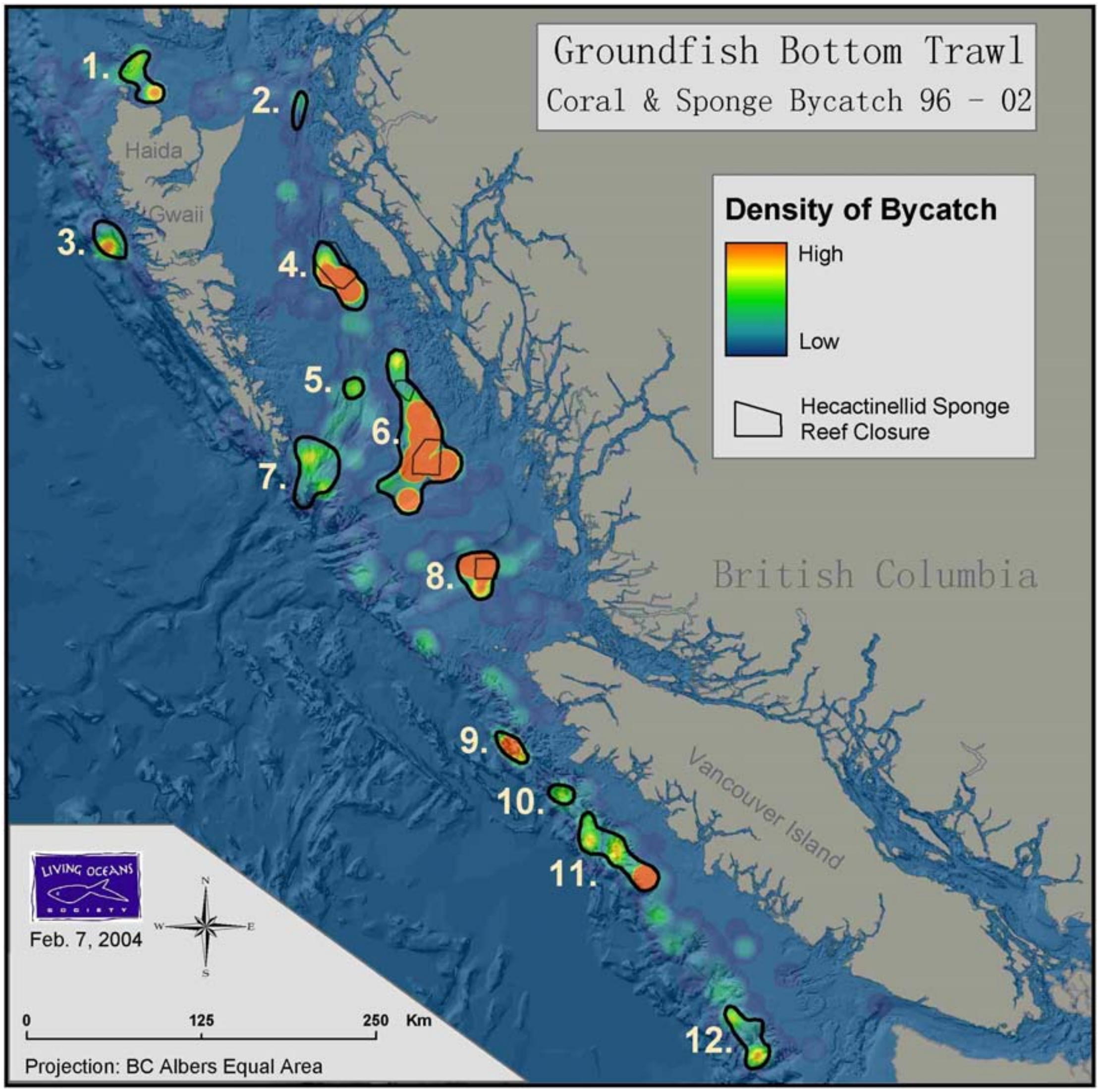

Figure 4: **1. Learmonth Bank** (Gorgonian Corals) **2. Bell Passage** (Sea Pens) **3. Kindakun** (Sponges) **4. McHarg Bank** (Sponges, Hex. Reef) **5. Mid-Moresby Trough** (Gorgonian, Stony Corals) **6. Mitchell's Trough** (Stony Corals, Soft Corals, Calcareous Corals, Sponges, Glass Sponges, 2 Hex. Reefs) **7. S. Moresby Gully** (Gorgonian Corals, Sea Pens) **8. Goose Trough** (Sponges, Hex. Reef) **9. Kwakiutl Canyon** (Sponges, Sea Pens) **10. Crowther Canyon** (Gorgonian Corals, Sponges, Sea Pens) **11. Esperanza Canyon** (Sponges, Glass Sponges, Calcareous Corals) **12. Barkley Canyon** (Sponges, Glass Sponges). Note: The above-listed corals and sponges are categories used in the trawl observer program.

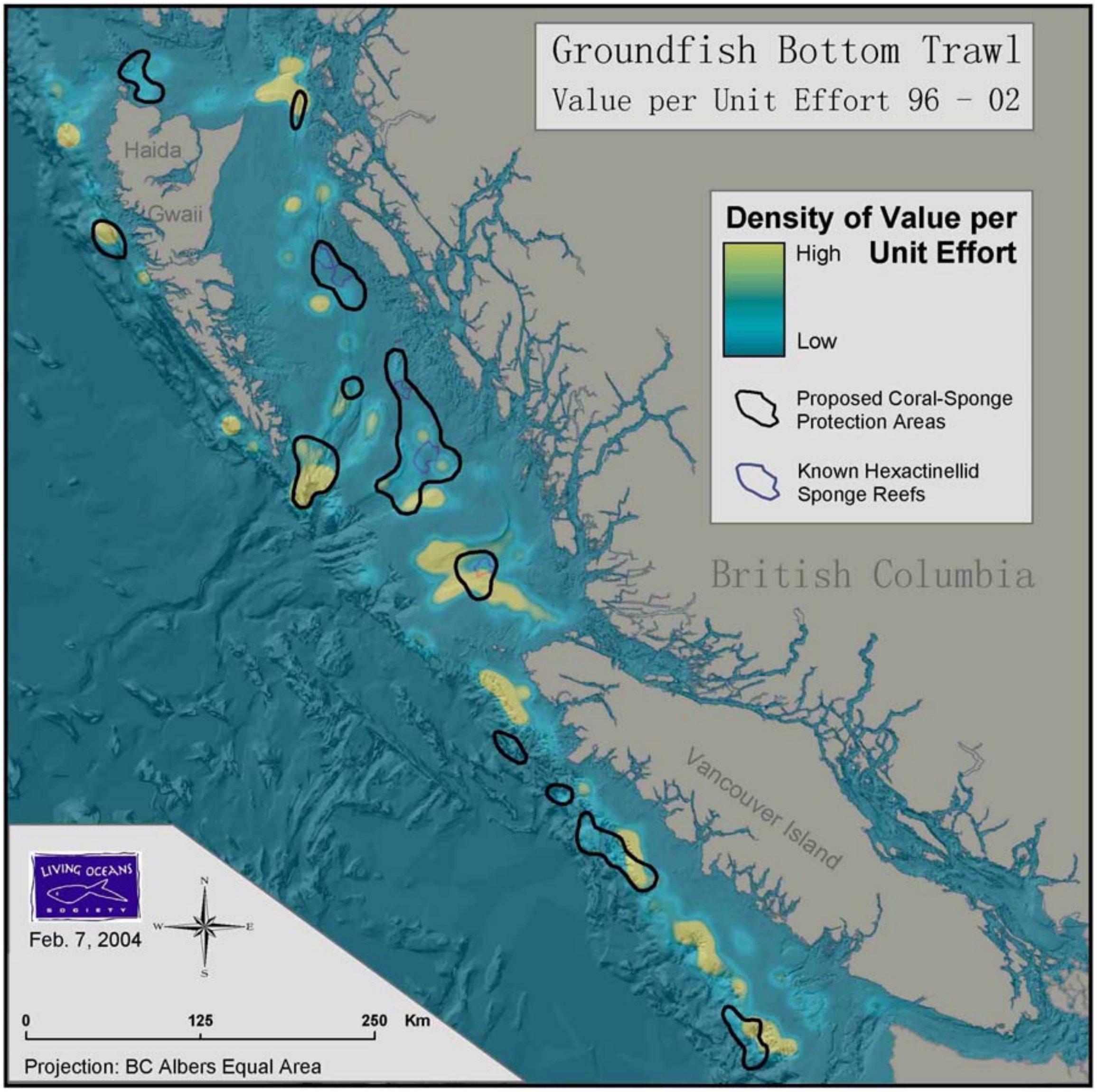

Figure 5: Economic Density Analysis. All landing values were standardised across years into 2002 dollars.

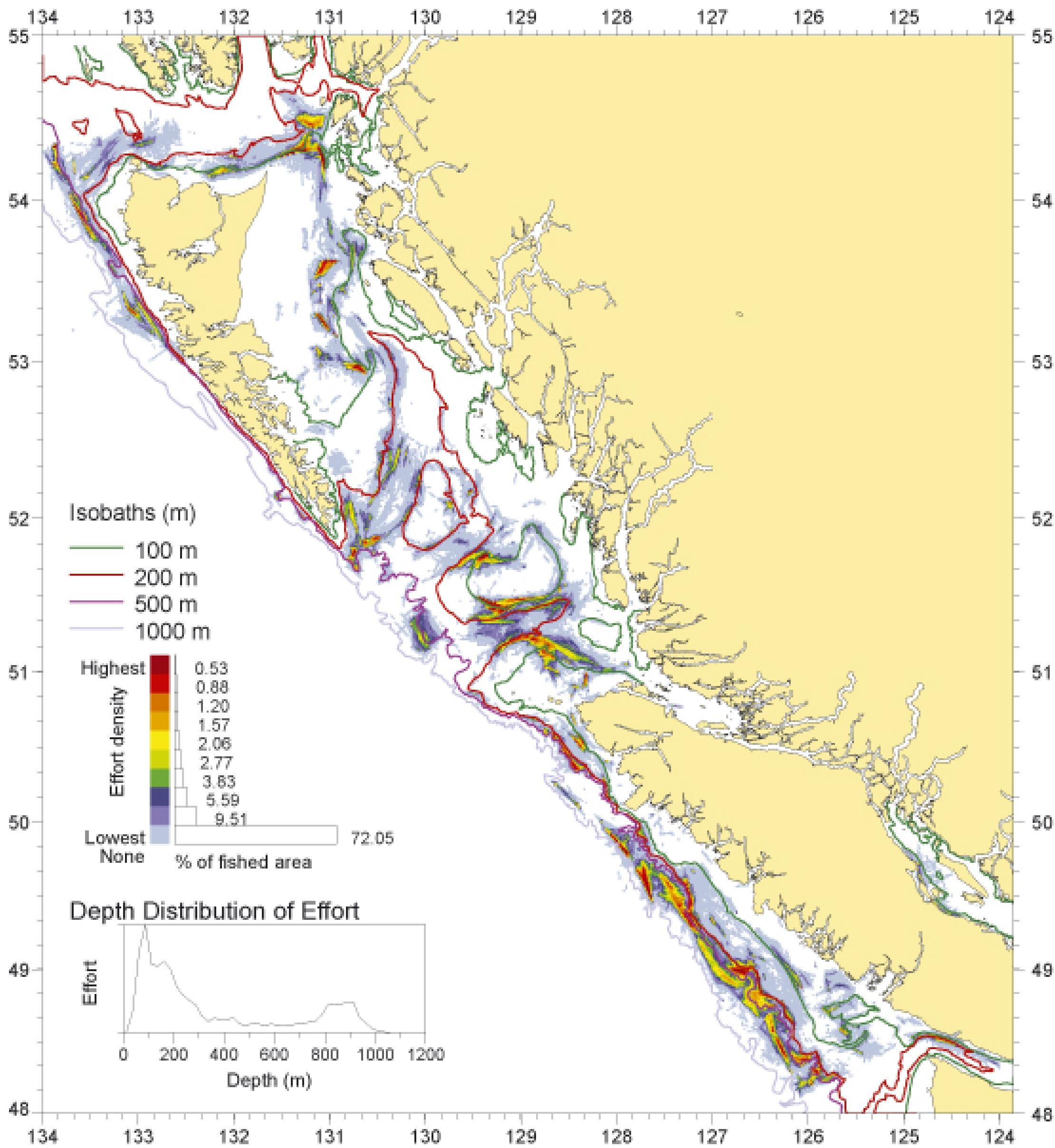

Figure 6. Spatial distribution of bottom trawl fishing effort on the BC coast from 1996-2004 (from Sinclair et al. 2005). The data were plotted using a one km^2 grid. The grids were colour coded by decile of the cumulative distribution, with the highest density coloured red and the lowest light blue. The histogram summarises the percentage of the fished areas covered by each decile. The line graph shows the depth distribution of effort.