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The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound glass sponge reef

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound glass sponge reef

ABSTRACT

Fishing activities currently take place within Adaptive Management Zone (AMZ) of the proposed Hecate Strait and Queen Charlotte Sound Area of Interest (AOI). DFO Science has been asked to (1) assess the nature and extent of risks associated with remobilization of sediment from fishing gear, and (2) provide managers with options to mitigate these risks.

This paper summarises fishing activities that have occurred in the AMZ from 2007 – 2011, and outlines a framework to estimate the footprint of the remobilized sediment. This framework describes: the intensity of the various fishing activities as they relate to remobilization of sediment; the various sediment types within each reef complex; the factors that affect the resettlement rates of remobilized sediment; and the dispersion of the remobilized sediment as a result of ocean currents in the region under a variety of fishing activity scenarios.

For the purposes of this paper, the potential footprint of remobilized sediment is determined for theoretical interaction of bottom trawl gear with sediment that has an average grain size and composition of: 55% silt (3.9 to 63um), 30% clay (0 to 3.9um) and 15% sand (63um+).with a calculated D50 = 20um. Two models were used to calculate the area of impact: a model which calculated the resettlement rates for the average settlement size and a dispersion model which used the resettlement rates within a regional oceanographic current model to estimate the area that would be covered. Three variations of the dispersion models were calculated for the area. The first model calculated the maximum sediment transport around the AOI. The second model calculated the potential area of impact based on historic bottom-trawl fishing boundaries. The third model calculated the potential area of impact if fishing were restricted to those days with the lowest tide cycles.

The findings of the sediment dispersion models were then used to inform the risk of exposure of the sponge reef to remobilized sediment under 6 mitigation scenarios. In addition, the information needs from biological and ecological science perspective were outlined for a cost-benefit analysis that could be used to evaluate the social and economic consequences of the various mitigation measures.

L'ampleur et la nature de l'exposition à la remobilisation des sédiments provoquée par la pêche dans les récifs d'éponges siliceuses du détroit d'Hécate et du détroit de la Reine-Charlotte

RÉSUMÉ

Des activités de pêche sont actuellement menées dans la zone de gestion adaptative (ZGA) de la zone d'intérêt (ZI) proposée pour le détroit d'Hécate et le détroit de la Reine-Charlotte. On a demandé au secteur des Sciences du MPO de : (1) évaluer la nature et l'ampleur des risques liés à la remobilisation des sédiments engendrée par les engins de pêche; (2) fournir aux gestionnaires des options permettant d'atténuer ces risques.

Le présent document résume les activités de pêche qui ont eu lieu dans la ZGA de 2007 à 2011. De plus, on y expose un cadre visant à évaluer l'empreinte laissée par les sédiments remobilisés. Ce cadre décrit : l'ampleur des diverses activités de pêche sur le plan de la remobilisation des sédiments, les différents types de sédiments se trouvant dans chaque complexe de récifs, les facteurs qui affectent le taux de rétablissement de sédiments remobilisés et la dispersion de ces sédiments résultant des courants océaniques dans la région, pour divers scénarios d'activités de pêche.

Pour les besoins du document, l'empreinte potentielle laissée par les sédiments remobilisés a été établie en fonction d'une interaction théorique entre les chaluts de fond et les sédiments dont la taille des grains est moyenne qui présentent la composition suivante : 55 % de limon (3,9 à 63 µm), 30 % d'argile (0 à 3,9 µm) et 15 % de sable (63 µm et plus), avec une taille de grains de $D50 = 20$ µm. Afin de calculer la zone d'impact, on a utilisé deux modèles : un modèle permettant de calculer les taux de rétablissement pour les établissements de taille moyenne et un modèle de dispersion utilisant des taux de rétablissement d'un modèle océanographique des courants régional pour estimer la superficie qui serait couverte. On a fait des calculs de la zone suivant trois modèles de dispersion différents. Dans le premier scénario, on a calculé la valeur du transport maximal de sédiments autour de la ZI. Dans le deuxième, on a calculé la zone potentiellement touchée à partir des frontières historiques de la pêche au chalut de fond. Dans le troisième, on a calculé la zone potentiellement touchée si la pêche n'était pratiquée que les jours où les cycles de marée étaient les plus bas.

On a ensuite utilisé les résultats des modèles de dispersion des sédiments afin de connaître le risque d'exposition des récifs d'éponges aux sédiments remobilisés pour six scénarios d'atténuation différents. De plus, les besoins en matière d'information suivant la perspective des sciences biologiques et écologiques ont été décrits en vue de réaliser une analyse des coûts-bénéfices qui pourrait servir à évaluer les conséquences socio-économiques des différentes mesures d'atténuation.

1. INTRODUCTION

The purpose of this CSAS review is twofold: 1) to assess the extent and nature of the risks posed by remobilized sediment from historical fisheries within the proposed Adaptive Management Zone (AMZ) on the Core Protection Zone (CPZ) of the Hecate Strait and Queen Charlotte Sound Sponge Reef proposed Marine Protected Area (which will also be referred to as the AOI in the remaining text) and 2) to provide managers with an analysis of various options to mitigate these impacts and their potential for reducing the risks. The request for working paper and the Terms of Reference for this CSAS session is available in Appendix A and B respectively.

The focus of this request for advice is directed solely at the historical fisheries that have been working in the AMZ in the last five years as these are the only activities that have been occurring in the area that could potentially remobilize sediment. In the future, if other activities (including other fisheries) are going to be considered for inclusion in this area, they would need to be the subject of a separate evaluation.

The remobilization of sediment due to fishing has been a concern expressed in studies for decades. Remobilized sediments could have a variety of effects depending on the extent and duration of remobilization. These effects vary but could include range of effects from: altering nutrient recycling such as the silica cycle from the loss of remobilized sediments from fish movement due to overfishing (Katz et al. 2009) to eutrophication of shallow water areas due to excess nutrient loading from trawling (Dounas et al. 2007). Remobilization of sediment has also be found to cause resuspension of phytoplankton cysts and copepod eggs and smothering of the feeding and respiratory organs of some benthic species (O'Neill and Summerbell 2011)

There are two papers being presented to address this issue: one which will concentrate on the physiological **consequences** of the effects of sediment on glass sponges and sponge reefs and this document which will discuss a **framework** for measuring the level of **exposure** of the impact of remobilized sediment from the various types of fishing methods which have historically employed within the AMZ under a variety of mitigation scenarios. The **framework** approach taken for paper is to layout the essential information necessary to undertake an ecological risk analysis (ERA) following the guidance provided by the ERA Framework developed under the Sustainable Fisheries Framework (SFF) for the implementation of the *Policy to Manage the Impacts of Fishing on Sensitive Benthic Areas* and recent guidance provided by a CSAS review of a broader ERA Framework for Ecosystem-based Oceans Management in the Pacific Region (EOM-ERAF) (Figure 1) (O et al. in prep.[1]). The SFF-ERA Framework is based on the most current version (in prep draft as of 29 June, 2012[2]) of the *Ecological Risk Analysis Framework (SFF-ERAF) for Coldwater Corals and Sponge Dominated Communities* and is expanded as necessary using the EOM- ERAF when additional information is available. Both the SFF-ERAF and EOM-ERAF are based on a tiered assessment methodology from the risk analysis frameworks produced by (Fletcher 2007) and (Hobday et al. 2007).

[1] O et al. in prep. An Ecological Risk Assesment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc.

[2] This edition of the SFF-ERAF may not be the final version as it has not been approved as of the date of the preparation of this paper

2. DESCRIPTION OF THE AOI AND ITS PROPOSED BOUNDARIES

The Area of Interest Regulatory Intent Statement for the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs describes the significance of this benthic area in the following statement. "*The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs have been identified as an ecologically and biologically significant area. They are globally unique, particularly vulnerable to damage and disturbance and provide important habitat for invertebrate and vertebrate animals including corals, tubeworms, shrimp, and various fish species. The existence and formation of the reefs requires a combination of unique geological conditions combined with the occurrence of the particular reef-forming species of hexactinellid (glass) sponges. The reefs occur in four complexes with large, steep reef mounds and ridges and vast, flat sponge meadows covering a discontinuous area of 1,000 square kilometres. They are located in glacial troughs at depths between 140m and 240m. Small patches of reefs grow over time and coalesce to form large, irregular structures extending to 25m in height and several kilometres wide. Although the glass sponge reefs are about 9,000 years old, the sponges themselves are slow growing, fragile and particularly vulnerable to damage and disturbance. Recovery of a destroyed reef surface may take several tens to several hundreds of years.*

The proposed boundaries and zones for the Hecate Strait and Queen Charlotte Sound Sponge Reefs proposed MPA have been established and described in the Regulatory Intent document which was signed off by the Minister of Fisheries in January 2012 (Figure 2). The final description is part of the final Regulatory Package which was completed in early September 2012.

"The proposed Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs MPA will include the four glass sponge reef complexes located in Hecate Strait and Queen Charlotte Sound, the water column and the surrounding waters, and the seabed and subsoil to a depth of 20m. The proposed MPA consists of three separate areas totalling approximately 2410 square kilometres. These areas are referred to as the Northern Reef, the Central Reef, and the Southern Reef. Also included in the proposed MPA are three internal management zones for each of the three reef areas, referred to as the Core Protection Zone (CPZ), the Adaptive Management Zone (AMZ) and the vertical Adaptive Management Zone (vertical AMZ). The AMZ extends out from the CPZ. The vertical AMZ extends above the CPZ. Together, the CPZ, AMZ and vertical AMZ provide for the protection of the structural habitat, biodiversity, and ecosystem function of the glass sponge reefs as the overriding purpose. Each zone addresses the key components of the primary conservation objective for the MPA in the following manner:

- *CPZ – The CPZ is designed to mitigate the risk of direct impacts to the structural habitat, biodiversity, and ecosystem function of the glass sponge reefs through the prohibition of bottom contact activities, and provides the highest amount of protection within the MPA. The CPZ is comprised of the seabed and subsoil to a depth of 20m and the water column from the seabed to a minimum of 40m from the highest point of each reef (varies between reef complexes) to protect the reefs from direct impacts.*
- *AMZ – The AMZ surrounds the CPZ and is designed to mitigate the risk of indirect impacts to the structural habitat, biodiversity, and ecosystem function of the glass sponge reefs through the adaptive management of allowed human activities within the zone such that they are compliant with the conservation objective. It extends above the horizontal extent of the CPZ, comprising the height of the water column from the vertical extent of the CPZ to the sea surface.*

The extent of the three areas and their respective zones are described as follows:

Northern Reef (Figure 3)

- *CPZ – consisting of the northern glass sponge reef complex. Horizontally the area is defined by a straight line polygon approximating a 200m spatial extent from the reefs. Vertically the area is defined from the seabed as extending subsoil to a depth of 20m and vertically to a height above the seabed of 100m from the sea surface. This area is approximately 524 square kilometres in size.*
- *AMZ – consisting of the area surrounding the CPZ to a straight line polygon representing the maximum sediment transport distance from the reefs. This area is approximately 235 square kilometres in size.*
- *Vertical AMZ – comprises the horizontal extent of the CPZ and the vertical extent of the height of the water column from 100m depth to the sea surface.*

Central Reefs (Figure 4)

- *CPZ – consisting of two separate central glass sponge reef complexes and horizontally defined by two straight line polygons approximating a 200m spatial extent from the reefs.*

  Vertically the area is defined from the seabed extending subsoil to a depth of 20m and above the seabed to 120m from the sea surface. The area of the northern central reef is approximately 313 square kilometres in size. The area of the southern central reef is approximately 498 square kilometres in size.
- *AMZ – consisting of the area surrounding both the northern central reef CPZ and the southern central reef CPZ to a straight line polygon representing the maximum sediment transport distance from the reefs, and encompassing the area between the northern and southern central reefs. This area is approximately 573 square kilometres in size.*
- *Vertical AMZ – consisting of the horizontal extent of the two separate central glass sponge reef complex CPZs and comprising the height of the water column in each of these complexes from 120m depth to the sea surface.*

Southern Reef (Figure 5)

- *CPZ – consisting of the southern glass sponge reef complex and horizontally defined by a straight line polygon approximating a 200m spatial extent from the reefs. Vertically the area is defined from the seabed extending subsoil to a depth of 20m and above the seabed to 146m from the sea surface. This area is approximately 168 square kilometres in size.*
- *AMZ – consisting of the area surrounding the CPZ to a straight line polygon representing the maximum sediment transport distance from the reefs. This area is approximately 100 square kilometres in size.*
- *Vertical AMZ – consisting of the horizontal extent of the CPZ and comprising the height of the water column from 146m depth to the sea surface.*

Table 1 Size and vertical depth of the CPZ, AMZ and Vertical AMZ for each of the four assessment areas

	Northern Reef	Central Reef (N section)	Central Reef (S section)	Southern Reef
Core Protection Zone (CPZ) size (sq kilometers)	524	313	498	168
Adaptive Management Zone (AMZ) size (sq kilometers)	235	573*	-*	100
Maximum depth of Vertical AMZ (meters depth) over the CPZ	-20 to 100	-20 to 120	-20 to 120	-20 to 146
*The AMZ for the central reefs is the common for both the Northern and Southern sections				

3. METHODS

To assess the potential for remobilization of sediment by various fishing gear types, the first element that must be considered is extent and nature of the contact of the gear with the benthos. Within the SFF-ERAF, the Level 1 assessment is largely a **qualitative** assessment on the likelihood and consequences that various gear types and potential remobilize sediment that could impact the sponge reef community. A similar approach was undertaken in a pilot study of the British Columbia Groundfish fisheries (Holt et al. 2011). If a specific fishing gear results in a medium to high risk within the Level 1 assessment, it is necessary to conduct a more in-depth scientific examination of consequence and likelihood of interaction as they relate to a variety of potential management options.

To undertake a more in-depth examination of the nature and extent of remobilization of benthic sediments of various fishing gears, a **quantitative** assessment was conducted following the guidance outlined in the EOM-ERAF (O et al. in prep.[3]). This quantitative assessment was based on the various elements that O'Neill and Summerbell (2011) detailed for bottom trawling including: the hydro-dynamic drag of the gear type and/or gear component being measured (doors vs. footrope); the sediment type which the gear is working on; and temporal and spatial components of the bottom currents which will act to distribute the remobilized material. In combination these elements are used to determine the volume of material remobilized, length of time the material remains in the water column and the potential area of impact.

The scope of this paper will focus solely on the potential risk of exposure of remobilized sediment from commercial fishing activities in the AMZ interacting with the CPZ of the Sponge Reef AOI. The Exposure term will be used in the context defined within the Exposure/Consequence metrics of the EOM-EFAF.

3.1. RISK ANALYSIS

This ERA will be restricted to historical fishing activities (2007-2011) within the AMZ of the Hecate Strait and Queen Charlotte Sound Sponge Reefs and will address the various fishing activities and evaluate the nature and extent of their potential impacts only as they relate to remobilized bottom sediment.

[3] O et al. in prep. An Ecological Risk Assesment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc.

The ERA Frameworks risk analysis can be conducted using various levels of qualitative and quantitative detail. The SFF-ERA notes that the appropriate level of detail, cost and effort for any risk assessment will depend on a number of factors, in this case we will be undertaking a hierarchical approach to the risk assessment starting with a qualitative approach to the level of risk of the gear to bottom contact and becoming more quantitative if the risks warrant further analysis. The risk assessment will focus on the objectives outlined for the analysis, the availability and reliability of data and information, the extent of that data and information, and available expertise.

3.1.1. Qualitative Risk Assessment

The initial stage of the ERAF is a qualitative assessment of the consequences and likelihood of the gear contacting and remobilizing the bottom sediment. The ranking of the consequences and the descriptors of the likelihood levels is found in Appendix C.

- **Consequences**

Consequences are defined is the extent of interaction *between the four different fishing activities that take place in the AMZ and the benthic environment.*

- **Likelihood**

Likelihood is based on the likelihood of interaction between the fishing activity and the areas identified as benthic attributes which in this case is habitat that is readily remobilized.

- **Scoring**

The ERAF requires that the "consequence" level of interaction and "likelihood" likelihood of interaction of each fishing activity interacting with bottom sediment can be remobilized be plotted in the risk matrix presented in Appendix C: Elements of The Risk Assessment Framework and the scores multiplied to determine an estimated level of risk.

- **Categorization**

The resulting scores are then categorized to determine the relative level of risk associated with fixed and mobile gear causing remobilization of sediment which may in turn result in acute or chronic deleterious effects on the Sponge Reef organisms, essential habitat, and ecosystem function. If the resulting risk categories are medium to high it will indicate that they deserve a higher level of scrutiny and potential management action.

3.1.2. Quantitative Risk Assessment .

As noted in the SFF-ERAF, changes are expected to the qualitative approach ERAF when further information and experiences indicate that significant improvements to the framework are appropriate, or where it is to be applied to benthic attributes other than coldwater corals and sponge dominated communities.

This stage of risk analysis will draw from the approaches outlined in the risk analysis framework outlined in the CSAS working paper "An Ecological Risk Assessment Framework for Ecosystem-based Oceans Management in the Pacific Region (EBM-ERAF)" (O et al. in prep.[4]). The quantitative framework of the EBM-ERAF considers two principal terms of the risk

[4] O et al. in prep. An Ecological Risk Assesment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc.

assessment (***Exposure*** and ***Consequence***) and provides guidance on the scoring of the subcomponents of these terms Equation 1.

Equation 1 Calculation of Risk in the EBM-ERAF

$$\boldsymbol{Risk_{sc} = Exposure_{sc} \times Consequence_{sc}}$$

Where (O et al. in prep[4]):

- $\boldsymbol{Exposure_{sc}}$ is the estimated magnitude of interaction between the remobilized sediment (s) and Sponge Reef (c); and
- $\boldsymbol{Consequence_{sc}}$ represents the potential for long-term harm to the Sponge Reef (c) as a result of interaction with the remobilized sediment (s) and is estimated from metrics that represent the capacity of the component to resist and/or recover from exposure to remobilized sediment

Exposure itself is calculated from: $\mathbf{Exposure_{sc}}$ = Proportion of sponge reef exposed ($\mathbf{PExposed_{sc}}$) times the intensity of the remobilized material ($\boldsymbol{Intensity_{sc}}$).

The proportion of the sponge reef exposed ($\boldsymbol{PExposed_{sc}}$) to remobilized sediment is an effect that is based on a number of factors that influence the: the **%areaoverlap**; the **%depthoverlap**; and the **%temporaloverlap**.

- **%Areaoverlap** takes into account seasonal aggregation of the component and the area of impact of the stressor. The sponge reef is stationary but the area of overlap will be driven by the factors that drive the area of impact of the remobilized material in relation to the area of occupancy of the sponge reef.
- **%Depthoverlap** takes into account depth and terrain barriers (e.g. slopes) that may limit interaction. In the AMZ the only barriers that would stop remobilized sediment from reaching the sponge reefs would be those that carried the remobilized material away from the Sponge reefs such as daily or seasonal tidal and current patterns.
- **%Temporaloverlap** is the fraction of the year in which the fisheries propagating the remobilized sediment overlaps with the sponge reef. As these fisheries do not always take place at the same time the cumulative impacts from all fisheries needs to be considered in the overall risk.

The $\mathbf{Intensity_{sc}}$ term is a measure of the amount of remobilized sediment and the height of the resulting cloud of the re-suspended material which in turn will inform the length of time the remobilized sediment will remain in the water column.

The information, data and models used to quantify $\mathbf{Exposure_{sc}}$ of remobilized sediment **(**the stressor) on the AOI glass sponge and the sponge reefs include:

1. The locations and time of the previous five year fishing patterns for the four commercial fisheries within the AOI. All data acquired from commercial fishing records that have been submitted to the Groundfish and Shellfish Data Units. Data is summarized and presented to respect individuals' rights to privacy, as described in the *Access to Information* and *Privacy Acts*.
2. A description of the various types of sediment in the region from sampling information conducted by Natural Resources Canada.
3. A description of sediment characteristics that effect the potential settlement rates of remobilized sediment
4. A Regional Oceanographic Model (ROMS) that calculates strength, timing and directions of the oceanographic currents in the AMZ;

5. The literature review level of disturbance provides **Intensity$_{sc}$** estimates of interaction between bottom trawl fishing gear operating on mud type sediment which in turn will be used to estimate of the **height** off the bottom that the remobilized sediment will achieve as a result of the impact with the bottom trawl fishing gear.
6. The **height** of the remobilized material and the sediment type are in turn used in **Remobilized Sediment Settlement models** to calculate the **sediment settlement rates**. For the purposes of this exercise, the sediment settlement model was based on a literature derived estimate of intensity of interaction between bottom trawl gear with average mud type sediment for the region
7. **Sediment Dispersion models** are used to calculate the potential **Exposure** of the CPZ to the remobilized sediment from a ROMS of the area and the calculated **sediment settling rates**. Three temporally and spatially explicit scenarios will be modeled to estimate the area and extent of the remobilized sediment footprint in relation to the CPZ.
8. The effects of Exposure are then discussed under six mitigation options based on typical management mitigation measures to be used within the AMZ. These include:
    i. No new mitigation measures
    ii. Restricting the fishing effort by gear type to historic levels and areas
    iii. Restricting the fishing days to those with those days that have the smallest impact
    iv. Restricting the fishing on a time/area basis so that any remobilized material will settle away from the CPZ of the reef complexes
    v. Restrict the height off bottom for mid-bottom trawling
    vi. Exclude certain types of gear from the AOI completely.

The first three of these are used in the sediment remobilization section 4.2.2 and depositional models 4.2.3. The results from these models along with information on historical location and timing of the fishing activities 4.1 will be used to inform the discussion on the efficacy of mitigation and management options outlined below as they relate to the components of the ***Exposure***.

4. ANALYSIS AND RESULTS

4.1. HISTORICAL FISHERIES IN THE ADAPTIVE MANAGEMENT ZONE

4.1.1. Description of the Fishing Activities

For the purposes of this risk assessment an analysis of the Groundfish bottom trawl, Groundfish midwater trawl, Groundfish longline, and prawn by trap activities from commercial logbook and observer data was conducted for the period 2007-2011. These activities fall under four different fisheries; Groundfish trawl, Halibut, Groundfish Hook and Line, and Prawn and Shrimp by Trap (Figure 6, Figure 7, Figure 8, and Figure 9). Historically shrimp trawl fishing activities also took place in the central and southern reef complexes. The shrimp trawl fishery was closed in Queen Charlotte Sound in 2000 due to eulachon by-catch concerns and it is not known when or even if it will reopen in the foreseeable future.

The Groundfish bottom and midwater trawling are both mobile fishing operations. The main difference between the two is that midwater trawling is typically operated in a manner to avoid the bottom contact. However it is known that contact with the bottom during fishing operations can and does occur depending on the spatial distribution of the target species and the bottom type (Rogers et al. 2008). The main target species for the bottom trawl in the area analyzed is a variety of demersal slope and shelf rockfish and flatfish species. The main target species for midwater trawl in the tows analyzed was Pacific hake (*Merluccius productus*) and a variety of shelf and slope rockfish.

Longline gear as part of the hook and line fishery is considered to be stationary fixed gear which in the AOI is targeting a number of species of demersal groundfish. The main target species in the area analyzed is Pacific halibut (*Hippoglossus stenolepis*) and very small portion of lingcod (*Ophiodon elongatus*) and inshore rockfish.

Prawn trap gear is a stationary fixed string of gear in which prawn traps are attached to a longline that is anchored at each end of the string. Prawn traps have a small opening that does not have any triggers on the entrances so that ingress and egress are not impeded. The main target species is British Columbia's largest shrimp commonly known as a B.C. prawn or spot prawn (*Pandalus platyceros*).

4.1.2. Fishing Season and Management Areas

The Option A Groundfish trawl fisheries (bottom trawl and midwater trawl) are open year round, with the exception of seasonal closures. The Hecate Strait/Dixon Entrance - Protection of Pacific Cod closure to protect the spawning biomass of Pacific cod encompasses the northern reef complex and occurs from January 1st to April 30th (Figure 10). The Halibut fishery is open from mid-March to early November. The Groundfish hook and line fishery is open year round with spawning closure for the retention of lingcod from November 15th to March 31st in all areas.

The northern reef complex of the proposed Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs MPA is contained within Groundfish Management Area 5C as is the northern portion of the central reef complex (Figure 11). While the southern portion of the central reef complex is contained within the Groundfish Management Area 5B. The majority of the southern complex is also contained within the Groundfish Management Area 5B, however a small portion extends into 5A. Quota for Groundfish species is allocated on either an area or a coast-wide basis, depending on the species.

The prawn and shrimp by trap fishery for prawn is managed using a fixed escapement model, the Spawner Index Model which ensures a minimum number of female spawners are available each year at the time of egg hatch. The commercial fishery opens each year in May and there is no fixed date for the coast-wide closure; in-season commercial fishery closures of local areas are announced when at-sea catch monitoring indicates that the spawner-indices in the catch approach management targets. The average annual opening for the commercial fishery was 59 days over the period from 2007-2011 (D. Rutherford, Pacific Biological Station, Fisheries and Oceans Canada, personal communication, 2012). The prawn by trap fishery is managed within Pacific Fishery Management Area (PFMAs) (Figure 12). The northern reef complex is contained within PFMAs 105 and 106. The central reef complex is contained within PFMAs 106 and 107. The majority of the southern reef complex is within PFMA 110 with a small portion contained within PFMA 111.

4.1.3. Targeted Species

Fisher logbooks document the targeted species for each fishing event (set or tow). Over the five year period (2007-2011), 107 fishing events were documented that intersected the proposed AMZ. The target species was documented in the Groundfish Catch database (the Fishery Operations System or FOS) for 101 of these fishing events. Pacific Ocean Perch (*Sebastes alutus*) was targeted 61% of the time (61 tows). Other targeted species include yellowtail rockfish (*Sebastes flavidus*), silvergray rockfish (Sebastes brevispinis), yellowmouth rockfish (*Sebastes reedi*), redstripe rockfish (*Sebastes proriger*), and Dover sole (*Solea solea*).

For the midwater trawl fishing events 43 of the 115 fishing events that intersected the AMZ over the 5 year period (2007-2011) have targeted species documented in the FOS database. Pacific hake was targeted 91% of the time (39 tows) while the remaining 9% of the fishing events (4 tows) targeted Pacific Ocean perch.

Of the 596 fishing events in the hook and line fishery 595 have targeted species documented in the FOS database. Halibut was targeted in 98% of the fishing events; the remainder of fishing events targeted Lingcod, and quillback rockfish (*Sebastes maliger*).

In the prawn and shrimp by trap fishery, there were 40 fishing events that intersected the AMZ over the 5 year period (2007-2011) and the targeted species was spot prawn.

4.1.4. Fishing Effort within the AMZ

From 2007– 2011 the proposed AMZ has been fished by 23 different vessels using bottom trawl gear, some vessels fishing in the AMZ in multiple years. There were a total of 107 tows from 80 trips where the tow intersected a portion of the AMZ. These activities have taken place in all three reef complexes; however the majority of the fishing events occurred in the southern reef and the southern portion of the central reef. Proportionally 7 tows (7%) were located in the northern reef, 33 tows (31%) were found in the central reef and 67 tows (63%) were located in the southern reef. Table 2 summarizes the number of trips, vessels, fishing events, and fishing effort for bottom trawl by reef complex. Tow times were calculated using start and end times recorded in the fisher logbooks. The number of fishing days reflects the number of calendar days in which fishing activities took place. The average tows per day were calculated using the count of tows and the number of calendar fishing days.

Table 2 Bottom trawl fishing effort by reef complex from 2007-2011

Year	Reef Complex	Count of Trips	Count of Vessels	Count of Tows	Total Tow Time (hours)	Calendar Fishing Days	Average Tows/Day Fished
2007	Central	3	2	3	3.0	3	1.0
2007	Northern	2	2	2	4.2	2	1.0
2007	Southern	13	9	14	34.4	12	1.2
2008	Central	7	1	12	31.9	9	1.3
2008	Northern	2	1	3	3.1	2	1.5
2008	Southern	15	9	20	48.4	16	1.3
2009	Central	3	2	3	2.1	3	1.0
2009	Northern	1	1	2	6.1	2	1.0
2009	Southern	6	4	14	16.7	8	1.8
2010	Central	8	1	10	29.4	9	1.1
2010	Northern						
2010	Southern	11	7	13	25.5	11	1.2
2011	Central	4	2	5	15.3	4	1.3
2011	Northern						
2011	Southern	5	4	6	15.8	5	1.2

From 2007 – 2011 the proposed AMZ has been fished by 32 different vessels using midwater gear, some fishing in the AMZ in multiple years. There have been a total of 115 midwater trawl tows from 79 trips in which a portion of the tow was found within the AMZ. These activities have taken place in all three reef complexes; however the majority of the fishing events have occurred in the southern reef complex. Of the 115 midwater trawl tows that have occurred in the region over the last 5 years, 8 tows (7%) were located in the northern reef Area AMZ, 6 tows (5%) were found in the central reef area and 101 tows (88%) were located in the southern reef

Area. Table 3 summarizes the number of trips, vessels, fishing events, and fishing effort for midwater trawl by reef complex.

Table 3 Midwater trawl fishing effort by reef complex from 2007-2011.

Year	Reef Complex	Count of Trips	Count of Vessels	Count of Tows	Total Tow Time (hours)	Calendar Fishing Days	Average Tows/Day Fished
2007	Central	1	1	2	3.6	1	2.0
2007	Northern						
2007	Southern	21	12	29	46.1	19	1.5
2008	Central	3	3	4	9.4	2	2.0
2008	Northern	4	4	8	10.4	3	2.7
2008	Southern	45	25	64	201.3	22	2.9
2009	Central						
2009	Northern						
2009	Southern	2	2	3	4.7	2	1.5
2010	Central						
2010	Northern						
2010	Southern	3	2	4	11.8	2	2.0
2011	Central						
2011	Northern						
2011	Southern	1	1	1	2.8	1	1.0

Within the five year time frame noted previously, there have been 590 longline fishing events targeting Pacific halibut in which a portion of the longline set was found within the proposed AMZ. In addition, over the five year period there have been three fishing events that have targeted rockfish, specifically quillback using longline gear and three fishing events that have targeted lingcod using hook and line gear. Under license regulations for the hook and line fishery lingcod cannot be targeted using longline gear (DFO 2012). All three fishing events that targeted lingcod took place on the northern reef complex. Longline activities have taken place in all reef complexes; however the majority of the fishing events have occurred on the eastern side of the northern complex. Of the 593 fishing events over the last 5 years, 566 sets (95%) were located in the northern reef complex, 25 sets (4%) were located in the central complex, and 2 sets were located in the southern complex. Table 4 summarizes the number of trips, vessels, fishing events, and fishing effort using hook and line and longline by reef complex.

Table 4 Hook and line and longline fishing effort by reef complex from 2007-2011.

Year	Reef	Count of Trips	Count of Vessels	Count of Sets	Calendar Fishing Days	Average Sets/day Fished
2007	Central	1	1	1	1	1
2007	Northern	12	8	148	55	2.7
2007	Southern					
2008	Central	2	1	14	6	2.3
2008	Northern	15	10	140	45	3.1
2008	Southern					
2009	Central	5	4	5	5	1
2009	Northern	11	9	102	32	3.2
2009	Southern	2	2	2	2	1
2010	Central	1	1	2	2	1
2010	Northern	9	6	69	33	2.1
2010	Southern					
2011	Central	1	1	3	2	1.5
2011	Northern	7	5	110	42	2.6
2011	Southern					

From 2007– 2011 the proposed AMZ has been fished by 5 different vessels using prawn trap gear, some fishing in the AMZ in multiple years. Prawn fishing has taken place in all three reef complexes; however the majority of the fishing events have occurred on the northeastern side of the northern complex. In the period from 2007-2011 there have been 40 prawn by trap longline sets within a portion of the proposed AMZs identified for the Hecate Strait Sponge Reefs. Of the 40 fishing events that have occurred in the region over the last 5 years, 29 sets (72.5%) were located in the northern reef AMZ, 3 sets (7.5%) were found in the central reef area and 8 sets (20%) were located in the southern reef area. Table 5 summarizes the number of trips, vessels, fishing events, and fishing effort for prawn by trap by reef complex.

Table 5 Prawn by trap fishing effort within the AMZ from 2007-2011.

Reef	Count of Vessels	Count of Sets	Fishing Days
Central	2	3	3
Northern	4	29	18
Southern	1	8	7

Fishing Effort within Management Areas

To understand the level of fishing activity within the AMZ it is necessary to compare the number of fishing events with those in the management area in which the reef complex is contained. For the five year time frame of this analysis the majority of bottom trawl fishing events occurred within Groundfish Management Area 5B. Table 6 summarizes the number of trips, vessels, fishing events, and fishing effort for bottom trawl that occurred within the AMZ and within the entire management area.

Table 6 Bottom trawl fishing effort within Groundfish Management Areas from 2007-2011.

GMA	Area	Count of Trips	Count of Vessels	Count of Tows	Average Tows/Day
5A	AMZ only	4	2	4	1.0
	GMA	904	35	5,235	15.1
5B	AMZ only	69	21	92	1.4
	GMA	1,077	41	11,947	36.4
5C	AMZ only	9	3	11	1.1
	GMA	434	22	2978	10.8

From 2007-2011 the majority of the midwater trawl fishing events occurred within Groundfish Management Area 5B or 5A, with only a small proportion occurring in 5C. Table 7 summarizes the number of trips, vessels, fishing events, and fishing effort for midwater trawl that occurred within the AMZ and within the entire management area.

Table 7 Midwater trawl fishing effort within Groundfish Management Areas from 2007-2011.

GMA	Area	Count of Trips	Count of Vessels	Count of Tows	Average Tows/Day
5A	AMZ only	1	1	1	1
	GMA	620	42	1,911	6.2
5B	AMZ only	74	31	104	2.7
	GMA	743	41	3,032	16.0
5C	AMZ only	5	5	10	2.5
	GMA	37	14	163	3.5

Due to the small number of sets that targeted lingcod or rockfish specifically this risk analysis will focus on fishing events that targeted halibut by longline within the AMZ. The majority of fishing effort is within the Groundfish Management Areas 5B and 5C. There were no fishing events that took place within the AMZ portion of Groundfish Management Area 5A.

Table 8 summarizes the number of trips, vessels, fishing events, and fishing effort for Halibut longline that occurred within the AMZ and within the entire management area.

GMU	Area	Count of Trips	Count of Vessels	Count of Sets	Average Sets/day Fished
5A	AMZ only	-	-	-	-
	GMU	604	255	6,613	37.3
5B	AMZ only	3	3	3	2
	GMU	703	330	8,031	39.3
5C	AMZ only	63	43	593	14.3
	GMU	738	318	10,202	48.5

The prawn fishery is managed within Pacific Fishery Management Areas (PFMA) and the AMZ is encompassed by six different PFMAs (105, 106, 107, 109, 110, and 111). These six management areas make up a large portion of Hecate Strait and Queen Charlotte Sound. Table 9 summarizes the number of vessels, sets, and fishing effort for the prawn by trap fishery within the AMZ and the surrounding management areas. Due to the small amount of prawn fishing within the AMZ the effort has been combined for all PFMA that encompass the AMZ and is not broken out into specific management areas.

Table 9 Prawn by trap fishing effort within Pacific Fishery Management Areas 105, 106, 107, 109, 110, and 111.

Year	Count of Vessels		Count of Sets		Fishing Days		Average Sets/Day	
	AMZ only	PFMA	AMZ only	PFMA	AMZ only	PFMA	AMZ only	PFMA
2007	2	7	3	444	2	41	1.5	10.8
2008	1	4	2	179	2	42	1	4.3
2009	3	6	17	191	9	44	1.9	4.3
2010	1	7	13	313	7	37	1.9	8.5
2011	1	11	5	152	5	30	1	5.1

4.2. CALCULATION OF THE REMOBILIZED SEDIMENT FOOTPRINT

4.2.1. Gear Effects

Two National Advisory Processes under the Canadian Science Advisory Service were held in March 2006 (DFO 2006) and January 2010 (DFO 2010) on the potential impacts of certain types of fishing gear on habitat and biodiversity, including: bottom trawls, midwater trawls, hook and line longline gear. The Science Advisory Reports from these processes (DFO 2006) and (DFO 2010) state that, bottom trawls, midwater trawls, hook and line longlines impact the benthos.

- Bottom trawling interacts with benthic attributes regularly as part of normal operations (DFO 2006; Rice 2006). As part of normal operations the area of potential impact is significantly larger than the relative size of the gear. There are a number of different gear configurations for the Option A bottom trawl fleet. The average door-spread and trawl wingspread for the Option A bottom trawl fishing events that occurred since 2007 were 50.3 and 26.2 meters respectively. The average tow length was 5.97 km for fishing events that occurred in the AMZ from 2007-2011. In studies carried out that measured the height of the remobilized material behind a trawl, the calculated sediment cloud was estimated to be 12 m off the bottom (Churchill et al. 1988; Churchill 1989; Dounas et al. 2007) on sediment that composed of approximately 30% silt and clay. In a recent paper on mobilisation of sediment by Scottish demersal otter trawls (O'Neill and Summerbell 2011), the authors concluded that the amount of sediment mobilized by otter trawls depends on: the component (doors, rubber discs, rock-hopper gear etc.) of the gear that contacts the bottom; the hydrodynamic drag of the component; and the type of sediment that gear is towed over. Of the four types of sediments tested, the authors found that the finer the sediment and the greater the drag, the greater the amount of sediment remobilized. Their tests were conducted on four types of sediment in which the silt and clay components increased from 2% in sand; 20% in Muddy-Sand 1, 42% in Muddy-Sand 2; and 69% in Sandy-mud.
- Midwater trawling is a type of mobile fishing operation in which the pelagic gear is typically operated in a manner to avoid the bottom contact. However it is known that contact with the bottom during fishing operations can and does occur depending on the spatial distribution of the target species and the bottom type (NMFS. 2005; Rogers et al. 2008). There are a number of different gear configurations used but the average opening configuration during fishing operations of an Option A midwater trawl net since 2007 has a door-spread of 139.6 meters, a wingspread of 94.2 meters and a vertical opening of 35.4 m when fishing. For tows that occurred in the AMZ from 2007-2011 the average tow length was 5.1 km. The main target species for midwater trawl in the tows analyzed is reported to be Pacific hake and Pacific ocean perch. Many of these animals are characterized as having a broad (probably diurnally based) distribution range within the

water column which at times includes schooling distributions that are tightly aligned to the bottom topography. As part of the hydroacoustic assessment survey for hake, it is found that hake has a strong association with the bottom. During daylight hours, hake typically form dense layers that are 10-20 meters off the ocean floor. These layers often come in and out of contact with the bottom, and the backscatters of many aggregations are observed all the way down to the substrate (S. Gauthier, Institute of Ocean Sciences, Fisheries and Oceans Canada, personal communication, 2012). A review of the catch data from the AMZ area revealed that up to 13% of the tows contained benthic species that could only be caught if the gear was on the bottom at some point during the tow. Though this value should be considered an estimate due to the possibility of transcription errors with the FOS database.

- Groundfish longline gear is set along the bottom, under best case conditions the gear can be retrieved in a manner such that the impact is no wider than the gear itself, however this can vary depending on the weather and if the gear gets snagged on the bottom (DFO 2010). Both ends of the gear are usually anchored with a buoy line going to the surface. Other factors that may increase the area of impact might include the movement of the gear in relation to the fish struggling to get off which in turn may be a function of whether the gear was set slack-line from a coiled skate or taut-line from a drum. For the longline fishing events that took place within the AMZ the average number of skates for each set was 3 (ranging for 1 to 12 skates). The length of each skate ranged from 228.6m to 548.6m; the number of baited hooks per skate ranged from 80 to 204; hooks were set between 2.7 and 8.2 apart.
- Prawn traps are a stationary fixed gear set along the seafloor attached to a longline which is anchored at both ends. On average there are 50 shrimp traps, that are up to 1 meter in diameter, are each snapped onto the longline at 10 m intervals. Stationary fixed gear on the bottom typically impacts the benthic substrate within an area equivalent to the relative size of the gear. This can vary however depending on the weather at the time of retrieval and in the event that the gear gets snagged on the bottom (DFO 2010). The prawn fishing events that intersected the AMZ each contained 50 traps spaced about 10m apart with an average soak time of 25 hours. The minimum soak time was 9 hours while the maximum soak time was 72 hours.

4.2.2. Bottom sediment type within and adjacent to the AOI

Work conducted by Natural Resources Canada has determined that the surface sediments and shallow subsurface geology of the seabed adjacent to sponge reef complexes on the western Canadian shelf controls to a great extent the distribution of reefs in these locations. The surfical seabed materials must include a gravel component to allow attachment and growth by the reef forming sponges, and for reef formation to progress. The geological units in question that include gravel as components are glacially derived, and would also include till and a variety of glaciomarine sediments from various ice-proximal or ice-distal glacial settings. Where the glacial deposits are thickly (>50 cm) buried by subsequent finer sedimentation of sand, silt and clay no reefs will develop. The sediments adjacent to the reefs are variable and depend on the age and genesis of the geological unit. The sponge reefs themselves capture flocculated material that is characterized by high levels of organic carbon, opaline silica and carbonate relative to other geological units (Conway et al. 2001). These flocculated “marine-snow-like” materials may comprise of up to 70 % biogenic constituents as opposed to mineral or quartz rich terrigenous constituents (Whitney, W. et al. 2005). Organic carbon of the reef sedimentary unit was found to be above 3% (Conway et al. 2001) while organic carbon in the adjacent recent sediments was about 0.8 to 1.5 % (Luternauer and Murray 1983; Conway and Luternauer 1985). In terms of sediment texture the sponge reef unit is finer than the adjacent recent mud units (Blue unit in Figure 13, Figure 14, Figure 15). The reef unit would be described as a silty clay (mean grain size clay – finer than 4 microns) while the non-reef sediments consist of a clayey-silt (mean grain size is silt – between 63 and 4 microns) (Conway et al. 2001). In addition the texture of sediments around the southern reef complex (Figure 15) consist of up to 10% sand and 80 % silt with much less clay (Conway and Luternauer, 1985). These sediments are very different than the reefs sediments.

The sand content of the material being captured at the reef complexes is largely biogenic formed of foraminifera and sponge spicules. This material is thus created in situ and is not lithic or quartz material brought in by sediment transport mechanisms. These sediment differences have implications for consideration of effects of remobilization of these sediments. The adjacent mud units are quite different in terms of texture, organic carbon and origin than the reef sediments themselves and this difference in type and quality of sediment has an addition effects to that of simply adding some volume of sediment to the oceanographic environment of the sponge reefs.

<u>Surficial geology adjacent to sponge reef complexes on the western Canadian continental shelf</u>

- Northern Hecate Strait (Banks Island sponge reef complex (Figure 13) (Conway et al. 2008a)

The sponge reefs in the northern most reef complex overlie a glaciomarine ice distal unit that contains ice rafted gravel and minor lenses of gravel and sand. The unit may be thinly covered by a few centimetres of recent mud. The periphery of the complex to the south and west is surrounded by recent mud unit (Blue unit on map) which consists of approximately equal amounts of clay and silt (45 - 48%) and a few percent sand. At the northwest margin of the complex, a glacial till unit or ice contact unit is exposed at the seafloor and is in contact with this edge of the complex.

- Northern portion of the Central Reef complex (Aristazabel Island sponge reef complex – (Figure 14) (Conway et al. 2008b; Conway et al. 2008c)

The sponge reefs in this complex also overlie the ice contact glacial unit in most locations. A few reefs appear to rest on the glaciomarine ice distal unit. The sponge reefs are in contact with a variety of surfical geological units ranging from bedrock in the north to being completely surrounded by the post glacial mud unit that has equal clay and silt concentrations (Blue unit on map) in the central area.

- Southern portion of the Central Reef complex (Mitchells Trough sponge reef complex – (Figure 14) (Conway et al. 2008c)

The sponge reefs in this complex overlie ice contact sediments and in a few cases a glaciomarine ice distal geological unit both of which contain gravel (Conway et al., 2008b). The reefs and the gravelly unit on which they grow are surrounded by a post glacial mud unit that is a slightly sandy silty-clay or clayey-silt (Luternauer et al., 1989). The silt and clay contents are approximately the same (45 – 48 %) with a few percent sand content. (Blue unit on map).

- Southern Queen Charlotte Sound Reef complex (Goose Island Trough sponge reef complex – (Figure 15).(Conway et al. 2008d)

The sponge reefs in this complex overlie ice contact sediments which are a sandy gravelly mud that may be covered with a thin veneer of sand and gravel. The reefs are adjacent to this geological unit over much of the northern, eastern and southern boundaries of this reef complex. In the western (seaward) portion of the reef complex, the reefs are adjacent to a different geological unit. This unit is designated a lowstand sublittoral sand and silt. It is well-sorted sandy silt to silty sand that was eroded from bank margins during a post glacial sea level low stand and covers the underlying glacial sediments. This unit contains 5-20 % sand and 40-60% silt with smaller amounts of clay (Luternauer et al. 1989). (Light brown unit on map).

Description of Remobilized Sediment Settlement Rates

The sediment type used in these settlement model was similar to that found around many of the sponge reefs, silty clay with some sand The average grain size and proportion of sediment type of: 55% silt (3.9 to 63um), 30% clay (0 to 3.9um) and 15% sand (63um+).with a calculated D50 = 20um. For the purposes of this initial calculation of settlement rates, the value used for maximum tidal current velocity = 0.35 m/s.

Settlement rates of remobilized sediment depend on the content of clay and fine silt. In an area of high levels of clay, silt and high bottom currents, the sediment would be expected to be very cohesive. That is, it aggregates together, and would not be expected to be easily disaggregated into its constituent particles(Lintern et al. 2002; Sills et al. 2007). This means that it would need a stronger current to erode it from the bed (as in the Hjulström curve, and it also means that when disturbed by trawling it is likely to be highly flocculated near the bottom. The settlement rates of cohesive, flocculated material will be faster than for non-cohesive individual particles.

The non-cohesive individual particle fraction of the sediment will settle according to Stokes settling equation.

Equation 2: Stokes settling equation

$$V_t = \frac{gd^2(\rho_p - \rho_m)}{18\mu}$$

The maximum current speed measured is at 3.5m from the bottom is 0.35m/s. Closer to the bottom the current would normally be lower than this. According to Equation 2 and (Figure 16), most of the non-cohesive particles at most ejection heights will re-settle to the bottom in under 3 hours (10,800 seconds). The silts larger than the median 0.025mm to 1mm may be re-eroded, according to the Hjulström curve (Figure 17), but in no way different than they would be eroded and transported under non-trawled conditions.

If resuspended through trawling activity, under a maximum current flow of 0.35m/s, a non-cohesive material with a median particle size 0.02mm would settle in less than one hour (Figure 16Figure 16) and travel 1000m if ejected 3.5m or 10000m if ejected 10m into the water column (Figure 18). Larger non-cohesive particles will be deposited more quickly and closer than this to the original disturbed location. For instance, the largest silts (>0.05mm) and sands will settle up to a maximum of 100m away (Figure 18), assuming they are ejected 10m into the water column. Note that these numbers for settling time and distance traveled double as the ejection height doubles.

The majority of particles smaller than 20um however likely act as cohesive aggregates. The settling rates calculations for cohesive aggregates are calculated using data from Lintern (2003). The clay-silt cohesion meant that overall equivalent spherical particle diameter of a floc was normally above 20um. The settling velocities achieved varied greatly, but majority of flocculated particles settled between 200 and 300um per second (=0.2 to 0.3mm/sec or 0.72 to 1.08m/hr). Due to the relatively lower effective density of the floc, this settling velocity is equivalent to a slightly smaller diameter non-cohesive particle of near 15um. In three hours, sediment ejected to 3.5m will have settled and reformed with the bottom at a distance of no more than 2 to 3 km while sediment ejected higher than this (up to 10m) could travel as far as 7-8 km.

The tests from Lintern (2003), report on flocs that are formed in the water column. Flocs formed by erosion of a cohesive bed could be expected to be larger and to settle more quickly. Thus, there is uncertainty with the distances and times reported here as they could be overestimated if the floc size is larger and underestimated if the height of the ejected sediment is higher. In addition there are various types of sediment around the different reef complexes and if some of this sediment does not flocculate easily, which would be uncommon, the smallest particles could travel tens to hundreds of miles.

The cohesive nature of the median sized particle suggests it will likely reform a bond with the bottom sediment when it settles, and is unlikely to be re-eroded through natural currents according to the Hjulström curve (Figure 17). Therefore the calculation of distance travelled need not involve successive tides.

4.2.3. Sediment Dispersion Modelling using the Regional Oceanographic Current Model

There have been three dispersion models developed for the area:

1. To calculate the maximum tidal excursion and sediment transport from the present trawl exclusion boundary within the AOI;
2. To calculate the potential area of impact from the bottom trawl fishery using existing bottom trawl boundary restrictions;
3. To estimate the mitigation potential of only allowing fishing days with the lowest tide cycles;

For all the sediment dispersion models, estimates are based on the assumption of an ejection height such that if a sediment particle moves with the ocean current as a passive tracer it takes a maximum of three hours to settle to the ocean floor. This is consistent with Section 4.2.2 above in which it is demonstrated that most of the non-cohesive particles at most ejection heights will re-settle to the bottom in under 3 hours.

<u>Model 1: Using the bottom trawl boundary estimation of maximum tidal excursion and sediment transport around Glass Sponge Reefs of Hecate Strait and Queen Charlotte Sound</u>

The objective of this analysis is to estimate maximum tidal excursion around the bottom trawl fishery closures surrounding the glass sponge reefs of Hecate Strait and Queen Charlotte Sound, and then use these estimates to determine the maximum distance necessary to allow sediment disturbed outside the reef area to settle to the ocean floor before reaching the sponge reef. The estimates are derived from an implementation of a 3-dimensional numerical model the Regional Ocean Modeling System (ROMS), to the BC coastal ocean (Masson and Fine 2012)(Figure 19).

- **Use of fishery closures**

Within the IFMP there are fishery closures established around the glass sponge reef complexes to protect the reefs against physical damage caused by bottom trawl activities (Figure 20). These boundaries are located approximately 1 km from the known extent of the reefs. In the case of the two central reef complexes, the fishery closure boundary has been extended to encompass both reefs.

- **Numerical Model**

To estimate the width of the buffer zone, we use the results from the application of the BC Regional Ocean Modeling System (ROMS), which is a 3D numerical model of the ocean circulation in the region of interest. For a more detailed description of the model and major parameters used see Masson and Fine, (2012).

- Regional Ocean Modeling System (ROMS) software, implemented to the BC coast region
- Fully non-linear 3D prognostic primitive equation modeling using generalized s-coordinate system and regular curvilinear horizontal grid

- Model includes tidal forcing through lateral boundaries, the values of the eight tidal constituents at the model boundary are taken from the North-east pacific tidal model (Foreman et al. 2000).
- Horizontal resolution is 3 km, and the model includes 31 vertical (s-coordinate) layers.

➢ **Estimate of tidal currents along the fishery closures**

Using the results of the ROMS model for the bottom ocean layer, we computed the tidal currents (U [east-west] and V [north-south] components) for each vertex of the three bottom trawl closure boundaries shown on Figure 20. Altogether there are 32 geographical points for which the tidal currents were computed. The time step for the simulated currents was chosen as 1 hour and the length of each time series was 4400 points (around half of year).

Examples of the two components (U and V) of the computed tidal currents along the northernmost point of the northern closure are shown on (Figure 21), which shows that the meridional current (V: North-South) is generally stronger that zonal (U: East-West) current, and can reach up to 40 cm/s. (Figure 22) plots the two components on X-Y axes to create an ellipse which shows that the near-bottom current undergoes strong steering in the north-west direction (i.e. parallel to the troughs along the coastal line).

➢ **Estimate of maximum tidal excursion for sediment particles**

To obtain the value of the maximum tidal excursion at each vertex point of the fishery closures, we integrate the current time series over a three hour period for each time, t_i: as in Equation 2.

Equation 2 Integration of current time series over a three hour period

$$X(t_i) = \int_{t_i}^{t_i+3h} u(t)dt$$

$$Y(t_i) = \int_{t_i}^{t_i+3h} v(t)dt$$

The final position is (X,Y), t is time, and (u,v) the velocity components. Then, assuming that a sediment particle moves with the ocean current as a passive tracer and that it takes a maximum of three hours (for ejection heights of up to 10 m) to settle on the ocean floor, the final position of a drifting particle with an initial release time t_i (X_i, Y_i) is estimated at every hour and for three hours duration over a six month period.

The result of the integration for the Figure 21 example is shown on Figure 23, where each point represents the final position calculated with the integration of the tidal currents for each of the three hour periods.

➢ **Calculation of the boundary for the buffer zone around the fishery closures.**

The boundary of the buffer zone is determined by first calculating an ellipse (Figure 24) for each boundary segment immediately on either side of one fishery closure vertex. The point of origin (Figure 23) of each ellipse is then used to calculate the distance perpendicular to each boundary segment at the vertex (Figure 25), thus providing the estimated maximum distance travelled by a sediment particle before reaching the fishery closure at that point. This process is then repeated for each vertex of each fishery closure.

➢ **Results.**

The resulting boundaries are shown on Figure 25, Figure 26 and Figure 27. The area (km^2) of fishery closures and sediment transport buffers are provided in Table 10.

Table 10 Area (in square km) for fishery closures, buffer zones, and total area (closure plus buffer zone).

	Fishery Closure (km^2)	Buffer Zone (km^2)	Total Area (km^2)
Northern Reef	588.21	310	898.21
Central Reefs	1033.8	479	1512.8
Southern Reef	213.55	168	381.55
Total	1835.6	956	2791.6

Model 2: Using the 200 m CPZ boundary estimation of maximum tidal excursion and sediment transport around Glass Sponge Reefs of Hecate Strait and Queen Charlotte Sound to evaluate the efficacy of the existing bottom trawl closures in the AMZ

The objective of this exercise was to evaluate the efficacy of the existing bottom trawl fishing closure in terms of deposit of remobilized sediment resulting from the fishery

- **Calculations**

Calculations for this model are the same as Model 1 but this time using the existing 200 m buffer zone boundary proposed for protection of the CMZ: Northern, Central North, Central South, and Southern and the existing bottom trawl fishing closure boundaries in the AMZ as seen in Figure 28 and Figure 29.

The 200m zones provide clean lines and vertices located at a distance of approximately 200 m from the reef extent which lend well to use within the computations undertaken in this analysis.

- **Results**

The results of the tidal excursion calculation are given in the Table 11 below and on the Figure 30, Figure 31and Figure 32.

Table 11 Area (in square km) for fishery closures, 200m zone, sediment excursion zones, and total area (200m zone plus buffer zone).

<table>
<tr><th colspan="2"></th><th>Fishery Closure (km^2)</th><th>200 m reef zone (km^2)</th><th>Sediment excursion Zone (km^2)</th><th>Total Area (km^2)</th><th>Area of 5% excursion exceedance (km^2)</th><th>Area of 20% excursion exceedance (km^2)</th></tr>
<tr><td colspan="2">Northern Reef</td><td>588.21</td><td>473.33</td><td>264.09</td><td>737.42</td><td>646.16</td><td>576.18</td></tr>
<tr><td rowspan="2">Central Reefs</td><td>Northern</td><td rowspan="2">1033.8</td><td>289.96</td><td>254.72</td><td>544.67</td><td>455.70</td><td>382.53</td></tr>
<tr><td>Southern</td><td>445.74</td><td>229.28</td><td>675.02</td><td>586.30</td><td>520.26</td></tr>
<tr><td colspan="2">Southern Reef</td><td>213.55</td><td>158.51</td><td>114.68</td><td>273.19</td><td>233.58</td><td>199.94</td></tr>
<tr><td colspan="2">Total</td><td>1835.6</td><td>1367.53</td><td>862.77</td><td>2230.3</td><td>1921.7</td><td>1688.9</td></tr>
</table>

Model 3: Estimate the mitigation potential of varying the time of the fishery to coincide with the lowest tidal cycles around the Glass Sponge Reefs of Hecate Strait and Queen Charlotte Sound

The 200m buffer reef zones (Figure 33) used in Models 1 and 2 will be used in this model to estimate the extent of impact on the CMZ. The goals of the current study are to estimate the effect of the partial restriction of fishing days within the AMZ to days with the weakest tidal velocities

- **Methods**

A 3-hour tidal excursion of the sediment for the each of the vertex point along the CMZ boundaries, for each hour of the year 2012, was calculated by the same method as above. Then, for each hour, the area affected within the 200m buffer zone was calculated using the method described below.

First, the total impacted area was estimated for each of the reef areas, at every hour of the year 2012. The method of the estimation of the impact area is illustrated on Figure 34. Suppose the reef area bounded by the polygon with vertex A1 to A8 and a disturbance happening just on the reef border. For the each vortex we calculate the final position of the tidal excursion of the sediments B1 to B8. Some of these points (B1 to B4) are inside the reef area and some (B5 to B8) are outside. The unaffected zone , in grey on the figure, contains the original vertex point A5 to A8, because the corresponding final point B5 to B8 are outside the initial 200m zone, and the final positions vertex B1 to B4, because they are inside of the initial 200 m zone. The difference between the initial 200 m zone area and the unaffected area (grey zone) is the area of the reef zone impacted by the disturbed sediment for the specific time period (in red). Such an affected area is computed for each hour of the year 2012.

The hourly estimate of the areas affected (in km^2) was then averaged for each day of the year and were computed for each of the four reef zones. It is clear that the affected areas mostly varies fortnightly (twice a month), though there are also monthly cycle and semi-annual cycle. Though the shape of the plots is different from reef to reef, the maxima and minima are synchronous for all the zones, which is mostly related with the phase of the moon (maxima at spring tide and minima at neap tide)

The latter provides us with the opportunity to estimate one universal schedule for the fishing activity inside the four reef zones to minimize the negative effect of the fishing activity on the reef. The schedule outlines “restricted days” when any activity inside the sediment excursion zones is prohibited. The greater the number of restricted days in the schedule the less impact the fishing activities will have on the reef.

The universal schedule was calculated by the following method Equation 3. Firstly, for each reef complex, the results of the estimated impact area were ranked in ascending order. Then, starting from the lowest value (defined as day 1) and consequentially adding a day, the cumulative effect, $A_k(j)$, is calculated for the time period of allowed activities.

Equation 3 Cumulative impacts for each day fished for each reef complex.

$$A_k(j) = \sum_{i=1}^{366} B_b(i, j) c_k(i)$$

where $c_k(i)$ is the affected area for the reef *k* at day *i*, and $B_k(i, j)$ is a 366 x 366 matrix, the column number *i* of which corresponds to the number of the total allowed days, and row number *j* corresponds to the current day of year. The matrix contains 1 if the specific day is allowed and 0 if it is not. Then we calculate matrix *D* as an average of matrix B_k for all 4 areas which is used to calculate a new universal schedule matrix *F* with the following assumption

$$F(i, j) = 0, \quad if \quad D(i, j) < 0.5,$$
$$F(i, j) = 1, \quad if \quad D(i, j) >= 0.5,$$

➢ Results

The daily averaged CMZ area impacts can be seen for each sponge reef complex in Figure 35, Figure 36, Figure 37, and Figure 38.

The results of the different schedule calculation are given in Table 12. Schedule A assumes 31 days of fishing activity in 2012 (i.e. 8.5% of the year), and results in 5% (Northern Zone) to 6 % (Central Northern and Southern Zones) of the original values. Schedule B allows 61 days of fishing (i.e. 17% of the year) in the sediment excursion zones, which leads to 10-13% of the original sediment loading inside the reef zones (more precisely, inside the 200m buffer zones). If nearly 50% of the days are allowed (schedule E), the impacted areas are 40.5% to 44.5 % of the initial ones. Therefore, a restricted activity schedule based on the days where the sediment impact is estimated as minimum slightly reduces the total impact relative to a schedule chosen randomly.

Table 12 The results show how restricting fishing activities to various numbers of low tide days affects the percentage of the sediment loading (referenced to the unrestricted case).

Schedule	**Days allowed**	**Percentage of the sediment loading**			
		Northern Zone	**Central North Zone**	**Central South Zone**	**Southern Zone**
A	31	5.07	6.01	5.46	6.00
B	61	10.8	13.26	11.57	13.33
C	91	17.29	20.92	18.04	20.15
D	120	24.22	28.16	24.67	26.97
E	182	40.48	44.47	40.53	42.15

Table 13 Day to day schedule of the allowed days for the variants A-E. White cells – all activity are allowed, Gray cells means all activity are prohibited for all variants. Blue cells means dates allowed in variant B (in addition to the white spots), Green cells means day additionally allowed for the variant C (in addition to the white and blue spots), Yellow cells means addition allowed days for the variant D and red cells means additional allowed days for the variant E.

January

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

February

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29			

March

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

April

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May

S	M	T	W	T	F	S
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

June

S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

July

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

August

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

September

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

October

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

November

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	

December

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

4.2.4. Risk Assessment Results

For the preliminary qualitative assessment of risk the following are the scores for consequences and likelihood of the gear contacting and remobilizing the bottom sediment.

- **Consequences**

Hook and line longline and trap fishing activities take place mainly on the eastern edge of Northern reef complex while the majority of bottom and midwater trawl fishing takes place on the Queen Charlotte Sound Southern reef complex (Figure 7).

Under the consequence scoring, mobile bottom trawl and midwater trawl gear scored a “high” (score 4) consequence level as the *gear is known or has a high probability of interaction with the benthic environment as part of normal operations and the area of interaction is larger than the actual size of the gear (mobile gear).* Stationary hook and line, longline and trap gear have a “moderate” (score 3) consequence level *as if the area of interaction is the same size as the gear (set-line gear).*

- **Likelihood**

As noted above in the section characterizing the bottom-type in the areas, NRCan found that much of the area in the AMZ is considered to contain the **benthic attribute** of a bottom-type that is easily remobilized i.e. a soft sandy mud bottom with a clay/silt content of >30%. Based on this, the likelihood of interaction between the fishing activity and the areas identified as **benthic attributes** occurs on regular basis under normal fishing practices. All the fishing activities that take place in AMZ areas would get a likelihood score of 4.

- **Scoring**

The ERAF requires that the “consequence” (3-4) and “likelihood” (4) of the fishing activity remobilizing bottom sediment be plotted in the risk matrix presented in Appendix C: Elements of The Risk Assessment Framework and the scores multiplied to determine an estimated level of risk. In this case, the resultant scores ranged from 12-16 which are classified as high risk.

- **Categorization**

Scores of 12-16 suggests that the level of risk associated with fixed and mobile gear to cause remobilization of sediment is “high” which in turn may cause an acute or chronic deleterious effect on the Sponge Reef organisms, essential habitat, and ecosystem function and as such deserved a higher level of scrutiny and potential management action.

4.3. MITIGATION SCENARIOS AND AN EVALUATION OF THEIR EFFECT ON THE PEXPOSED$_{SC}$ RISK TERM

Key to the development and selection of any mitigation scenarios is the need to develop a clear understanding of the conservation objectives and the level of risk that resource managers are willing to accept in potentially not being able to achieve these conservation objectives. Mitigation is a mechanism that can be used to within a Risk Management framework when an unacceptable level of risk has been identified in within a Risk Assessment. Mitigation is used to reduce or eliminate the level of exposure in the risk assessment by modifying the ***PExposed$_{sc}$*** or the ***Intensity$_{sc}$*** values. This section will describe examples of a range mitigation scenarios which resource managers might decide to employ in the AMZ. A range of mitigation scenarios was chosen to show a range of outcomes in modifying the ***Exposure$_{sc}$*** value. The mitigation scenarios are not meant to be exclusive but are examples and further mitigation scenarios are needed to be developed within the management framework for their respective fisheries. The management scenarios chosen include:

1. No mitigation measures: This level of management would remain the same as have been historically used within the area including seasonal closure for protection of cod spawning areas and the voluntary trawl closure. The other fisheries will be controlled by quotas, spawner indices and seasonal closures as outlined in the IFMP for the appropriate fishery.
2. Restrict the fishing activities to historic levels of effort, timing and areas: Under this scenario each reef complex would be limited to the same level of ***Exposure$_{sc}$*** that it has been subject to over the period from 2007-2011.
3. Restrict the fishing days to those with those days that have the smallest impact.
4. Restrict the fishing on a time/area basis so that any material will flow away from the reef complex.
5. Restrict the height off bottom for mid-bottom trawling.
6. Exclude certain types of gear from the area completely. With this option will be a section to look at the biological considerations that are important in the analysis of the social and economic costs and benefits of this mitigation option.

5. DISCUSSION OF FINDINGS FROM MODELS AND ERAF

The purpose of this framework is to lay out the information needs that would be used to develop mitigation scenarios for reducing or eliminating the impacts of remobilized sediment from bottom tending fishing activities. To do this bottom trawling was used as an example of fishing activity and the bottom sediment was a generic type of mud from the region. As a result there are a number of assumptions and uncertainties that have been identified in the analyses presented in this paper, but the results do provide a better understanding of the key elements that need to be considered in estimating the level of ***Exposure$_{sc}$*** i.e. **PExposed$_{sc}$** which is a product of %Area overlap x %Depth overlap x % of Temporal overlap and **Intensity$_{sc}$** which is a function of the gear type and sediment type. O’Neill and Summerbell (2011) found that the factors influencing mobilisation of sediment by the Scottish demersal otter trawls depends on: the component (doors, rubber discs, rock-hopper gear etc.) of the gear that contacts the bottom and the hydrodynamic drag of the component. They were able to measure the intensity of particular gear configuration in terms of the amount of silt remobilized in the Scottish demersal whitefish fleet which typically tow two 5 m^2 Tyboron Type 12 doors, 180 m of 28 mm wire sweeps and 54 m of ground-gear at 1.5 m s^{-1} . In this case they estimated that 248.5 kg m^{-1} to 119.2 kg m^{-1} of sediment was mobilized for sediment with 69% and 42% silt and clay respectively. For a 5 Km tow this equates to 1242 and 596 tons respectively of remobilized sediment from this configuration of demersal bottom trawl

5.1. ASSUMPTIONS AND UNCERTAINTIES

5.1.1. Sediment

There were a number of sediment types classified in the area surrounding the CPZ. The types/size of sediments and their locations on the various reef complexes is outlined in section 0. In O'Neill and Summerbell (O'Neill and Summerbell 2011), the authors concluded that the amount of sediment mobilized by otter trawls depends on not only the gear being utilized but also on the type of sediment that gear is towed over. Of the four types of sediments tested, the authors found that the finer the sediment and the greater the drag, the greater the amount of sediment remobilized. Their tests were conducted on four types of sediment in which the silt and clay components increased from 2% in sand; 20% in Muddy-Sand 1, 42% in Muddy-Sand 2; and 69% in Sandy-mud.

The resettlement model was carried out on the remobilization characteristics of a composite mud sediment type based on the average characteristics of the mud sediment types in the area (see section 0). The resettlement model provides estimates of the potential distance of dispersion under steady flow conditions in relation to the height off bottom attained by the remobilized bottom sediment Figure 18. For the purposes of this **framework**, the sediment settlement and transport modeling was based on a sediment composed of 55% silt (3.9 to 63um), 30% clay (0 to 3.9um) and 15% sand (63um+).with a calculated D50 = 20um.

The resettlement model found that:

- The majority of large silt to sand-sized particles will settle to the bottom within one tidal cycle
- The majority of cohesive-sized particles (small silt and clay), which is the most common particle size, are likely to be flocculated and will travel up to 8 km if ejected 10m into the water column. They will travel 4km if ejected 5m into the water column, 3.5km if ejected 3.5m, etc (linear relationship). Due to their cohesive nature, these will not likely be easily eroded again.
- There will be unflocculated grains that can travel much further (10s to 100s km), but material eroded from a stable cohesive bed is likely to be highly aggregated. Furthermore, the high concentration of remobilized material, as well as the turbulent nature of the trawl is likely to bring particles in contact so that they flocculate and settle at high rates as compared to individual particles.

The resettlement rates are affected by the clay content and if reduced to <30% the resettlement time will increase and the area of impact will expand. This is the case for the lowstand sublittoral sand and silt sediment found on the seaward edge of the southern reef complex which is the most heavily trawled area.

5.1.2. Gear

Four general fishing gear types that have been used in the AOI as described in Gear Effects 4.2.1. More importantly the configuration of the gear especially for the bottom and mid-water trawls varies quite substantially between vessels. The intensity in which the gear might interact with the bottom is a function of: the size of the gear; whether the gear is mobile or stationary; the hydrodynamic drag of the gear when it is towed or retrieved; and the sediment type in the potential area of impact. As noted earlier in the paper, the resettlement and dispersion modeling for the framework was based on the interaction of an average bottom trawl on a generic mud type.

The resettlement time was estimated using a fixed height of 10 m for remobilization of sediment with a grain size of 20 um. The fixed height of 10 m for bottom trawls is a conservative estimate in comparison to the 12 m height of the remobilized material measured for the US bottom trawl fishery on the NE Atlantic seaboard (Churchill et al. 1988; Churchill 1989; Dounas et al. 2007). The 10 m height of remobilized sediment cloud resulting from bottom trawling on a mud sediment is in no way comparable with the remobilized sediment effects resulting from an interaction of lighter stationary (except during setting and retrieval) longline and prawn trap gear fished on a bedrock, gravel or sand substrate

The sediment dispersion models in section 4.2.3 can be used to inform the %areaoverlap of exposure and were calculated using a fixed resettlement rate of 3 hours, (estimated from the resettlement models) combined with the strength and direction of the bottom currents analyzed using the Region Oceanographic Models for the area as outlined in section 0.

Having a better understanding of the nature and extent of the gear effect is essential in both the calculation of $\mathbf{Intensity_{sc}}$ and the %areaoverlap. Research like that carried out for bottom trawls by O'Nell and Summerbell (2011) is possible for other gear configurations and bottom types however since there is no restriction on a standardized gear configuration, it would require constant updating, every time the gear is configured differently.

There are other important factors that affect the calculation of intensity such as: fisher experience, weather, snags, etc. In most cases are unknown quantities and do not readily lend themselves to management.

5.2. MEASURING THE EFFECTS ON EXPOSURE OF THE VARIOUS MITIGATION SCENARIOS

In spite of all the uncertainties and assumptions associated with the estimates from the models, the information is still useful to inform the discussion of type and mitigation measures needed reduce or eliminate the potential level of exposure from various fishing activities in different areas. The models calculate for maximum distance traveled by average mud type sediment with a modal fixed grain size of 0.2 mm; a fixed height of the remobilized material of 10 m; the calculated sinking rate (10,800 sec); and the modelled average hourly regional currents. If the grain size and currents remain constant for an area then the distance traveled would depend on the remobilization height which is proportional to the sinking rate. For example if sediment remobilized to a height of 10m takes 180 minutes (10,600 sec) to sink and travels 10,000m then sediment remobilized to a height of 1m takes 18 minutes (1,060 sec) to sink and travels 400m.

5.2.1. Scenario 1: No additional mitigation measures

Under this scenario the level of effort, location or timing of the fishing activities in the AOI would not be restricted. The other management measures outlined in the description of fishing activities in section 4.1.2 would remain in place: fishing activities can take place within the AMZ; the seasonal closure for protection of cod spawning areas; the quotas and caps for quota fisheries; the spawner index for the prawn fishery; and 1 km bottom trawl closure, etc. Historically, longline and prawn by trap fishing have been concentrated along the eastern edge of the Northern Reef complex, the bottom trawl fishing has been concentrated along the western edge of the Southern Reef complex and the midwater trawl fishing has been concentrated throughout the southern reef. It is important to note that the 1 km bottom trawl closed area within the AMZ does not apply when using midwater trawl fishing gear. Under this scenario the there is potential for increased levels of effort, expansion of the use of midwater trawling to harvest demersal fish species and expansions of areas fished within the AMZ. These expansions in timing, location and effort would result in increases in the %Areaoverlap, %Depthoverlap and %Temporaloverlap terms which define the **PExposed$_{sc}$** term of the Exposure element in the Risk Assessment. This scenario would provide the greatest uncertainty with respect to the value of ***Exposure$_{sc}$*** criteria and could ultimately provide the highest possible risk to the CMZ.

5.2.2. Scenario 2: Restrict fishing to historic levels of effort, timing and areas

Under this mitigation scenario, fishing would be restricted to historic levels of effort by gear type, timing and areas fished (Figure 7) and the current levels of the %Areaoverlap, %Depthoverlap and %Temporaloverlap terms at historical (2007-2011) levels by Reef Complex. At best this would be exposing the reef complexes to the same level of ***Exposure$_{sc}$*** that they have been subject to over the period from 2007-2011.

Under the present management system the Sediment Dispersion Model 2 (0) indicates that the bottom trawl closure in the AMZ is reducing the amount of sediment impacting on the CMZ. Along the south-western edge (Figure 31) and the western edge of the southern reef complex (Figure 32) which have the highest use would still impact the CMZ. These impacts to areas with bottom trawling will be well in excess of 20% of the respective maximum potential effected area (i.e. 45 and 27 km^2 / hour towed Figure 37and Figure 38 respectively). The longline and trap fishing activities along the CMZ boundary would still have an impact on the CMZ albeit very much lower intensity than the trawl fishing activities.

In addition, the present bottom trawl closure in the AMZ does not apply to the midwater trawl fishery so the potential impact could be as high as 100%. There are no restrictions in the midwater trawl fishery with respect to the amount of bottom contact they can have, so if there were a change in target species or fishing patterns which resulted in increased contact with the bottom it could result in an increase in all three terms of ***Exposure$_{sc}$*** in the areas of historical use. Mid-water trawling is restricted in the CMZ to 40 m above the bottom, in measuring where the net is fishing it is important to recognize that the net is usually measured using a headrope sensor. The average depth of a mid-water trawl is 35 m, for those trawls that are deeper then 35 m it would be possible to contact the bottom if the restriction on the fishing activity is measured from the headrope.

5.2.3. Scenario 3: Restrict the fishing days to those days that have the smallest tides

Under this scenario fishing would be restricted to those days with the smallest tides. The results of scenario 0 show that there could be some small reductions in the %areaoverlap component of ***Exposure$_{sc}$*** assuming the overall effort from bottom contact fishing remains the same. The effects of this scenario would only be realized if it were combined with Scenario 2; however, the same caveats apply if the midwater trawl fishing activity were to change its fishing patterns as outlined in Scenario 2 above.

5.2.4. Scenario 4: Restrict the fishing on a daily basis to time/area in which the remobilized sediment will flow away from the reef complex

Under this scenario fishing operation when the gear is mobile i.e. all trawling activities and setting and recovery of fixed longline and prawn trap gear would be restricted by area and time of day to those periods of time when the remobilized sediment would drift away from the CMZ.

The concept can be seen in the drift patterns seen for the drift and direction in Figure 34 for vertices A5-A8. This analysis was not been completed for this scenario at the time of writing of this paper. It is hoped that this scenario if implemented for all fishing activities could eliminate ***Exposure**$_{sc}$* completely. However until the analysis is complete it is not possible to understand what the time/area restrictions might look like.

5.2.5. Scenario 5: Restrict the height off bottom for mid-bottom trawling

This scenario only applies to the mid-water trawl fishing activities and would restrict the depth that midwater trawling could take place such that bottom contact within the AMZ would not occur. This would result in a decrease in the %depthoverlap term for the midwater trawl fishery and reduce it's ***Exposure**$_{sc}$* to zero which could reduce the cumulative effect of exposure in areas where other fishing activities occurred if this scenario were combined with Scenario 2 and or 3.

5.2.6. Scenario 6: Exclude certain types of gear from the area completely

Under this scenario, all fishing activities for which mitigation measures do not eliminate the ***Exposure**$_{sc}$* term, would not be allowed within the outer boundary of the AMZ which was set from the results of Sediment Dispersion Model 1 (0). Under this scenario there may be a high risk of social and economic impacts.

5.3. IMPLICATIONS

Fisheries and Oceans as part of its federal regulatory policy conducts a cost-benefit analysis (CBA) on the positive and negative socio-economic impacts associated with the proposed major management actions. There was an initial CBA conducted for the AOI as a whole (DFO 2011). The 2011 analysis was conducted on all historical fisheries with the exception of the midwater trawl fishery. The midwater trawl fishery was excluded from the analysis as it was not identified at that time as having any benthic impacts.

The DFO's Practitioners Guide for conducting a CBA sets out a process that are intended to measure what is to be achieved and how human uses are to be altered once the management plan is in place for the MPA. The CBA includes cost factors such as: decreased landings and/or displacement of the effort; as well as benefit factors such as: direct effects such as conservation of the attributes of an Ecologically and Biologically Significant Area (CBD 2007; CBD 2008; CBD 2009) which for this AOI is a globally rare and unique area. Additionally, there are potential benefits derived from including these areas into a network of MPAs that are designed to address functions such as: an Insurance Policy to protect stocks against potential failure of management to keep human uses sustainable in areas outside the MPAs; a Benchmark function to disentangle impacts of human activities from 'natural variation' in monitoring data: and a Seedstock function to facilitate recovery of outside areas to a more desirable state (Rice and Houston 2011).

Costs associated with reduction in harvest is based on: 1) the potential to exploit the population in fishing areas outside the closed area and\or 2) are there other fishable populations outside the closure which are deemed to be not "fully subscribed". Key to this assessment is an understanding of: what a population/stock is; the population's distribution; the availability of the population to be fished; and an understanding of what "fully subscribed" means.

Cost associated with displacement of effort includes cost associated with changing search patterns however there is no data from which to directly estimate the resulting changes in search patterns. The proxies that are presently used include the amount of effort that will be displaced and the location and abundance of available fishing grounds in proximity to the closed area and the port of landing.

5.4. FURTHER WORK REQUIRED

A fourth Dispersion Model that shows promise at eliminating exposure is a model that evaluates if the stage of the tidal cycle for each calendar day could be used to determine when remobilized sediment would not impact the CMZ from fishing locations based on historical fishing patterns within the AMZ.

This framework was developed as a generalized model of information needs that would be required to assess the effectiveness of any mitigation scenario. To do this effectively the intensity of each interaction between gear type and sediment type would have to be calculated. There is several sediment types described in the AMZ and the mobile bottom trawl gear used is highly variable at this time, as the industry has been working on a number of modifications to doors and foot ropes to reduce their overall impacts on the benthos.

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APPENDIX A: REQUEST FOR WORKING PAPER

REQUEST FOR PEER REVIEWED SCIENCE INFORMATION AND/OR ADVICE

Title of Request ID# (for internal use only)

Identification and evaluation of biological effects and impacts of sediment to sponge communities in Hecate Strait.

Request Details

Issue requiring science information and/or advice (i.e., "the question" or "the need").

What is the available information on sedimentation effects on sponge communities?

What are the effects of sediment to sponge communities in Hecate Strait, and specifically to hexactinosidan 'glass' sponges?

What types of management measures are most effective at mitigating effects of sediment on sponge communities, and specifically hexactinosidan 'glass' sponges?

Rationale or context for the request: What will the information/advice be used for? Who will be the end user(s)? Will it impact other DFO programs or regions?

The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs have been identified as an ecologically and biologically significant area. They are globally unique, particularly vulnerable to damage and disturbance and provide important habitat for invertebrate and vertebrate animals including corals, tubeworms, shrimp, and various fish species. This area is currently in the process of being designated as an Oceans Act MPA. The proposed MPA will include the four glass sponge reef complexes located in Hecate Strait and Queen Charlotte Sound, the water column and the surrounding waters, and the seabed and subsoil to a depth of 20m. Also included in the proposed MPA are two internal management zones for each of the three areas, referred to as the Core Protection Zone (CPZ) and the Adaptive Management Zone (AMZ). The AMZ is both horizontal and vertical in extent, extending out from and above the CPZ, respectively. Some activities that re-suspend sediment due to contact with the bottom will be allowed to occur in the AMZ.

Advice on 1) the potential nature and extent of the effects of sedimentation on the reefs, and 2) the types of management measures that are most effective at mitigating sedimentation effects, is needed in order to implement proper management measures and licence conditions through a management plan once the MPA is designated. While this request has elements specific to hexactinosidan 'glass' sponges, a comprehensive review of our knowledge and understanding of the extent and nature of sedimentation on sponge reef communities will have broader application for Fisheries Management and Habitat programs within the Department.

APPENDIX B: TERMS OF REFERENCE

Identification and Evaluation of Biological Effects and Impacts of Sediment to Sponge Communities in Hecate Strait

Pacific Regional Science Advisory Process

October 23-25, 2012
Nanaimo, BC

Chairperson: Linda Nichol

Context

The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs have been identified as an ecologically and biologically significant area due to their global geological uniqueness (Conway et al. 1991, Conway et al. 2001 & Kruatter et al. 2001), and there is international and national recognition that cold-water corals and sponge dominated communities can serve as key structural habitat for many fish and invertebrate species (DFO 2010). This area is currently in the process of being designated as an *Oceans Act* Marine Protected Area (MPA) as part of the Health of the Oceans Initiative. It has been identified as an Area of Interest in consideration of an ecosystem-based management (EBM) approach for the Pacific North Coast Integrated Management Area (PNCIMA), within which the reefs are located.

The proposed MPA consists of three separate areas totalling 2410 square kilometres that include the four glass sponge reef complexes located in Hecate Strait and Queen Charlotte Sound, the water column and the surrounding waters, and the seabed and subsoil to a depth of 20 meters. The three areas are referred to as the Northern Reef, the Central Reef (containing two reef complexes), and the Southern Reef. Each of the three areas is proposed to have three internal management zones, referred to as the Core Protection Zone (CPZ), the Adaptive Management Zone (AMZ) and the Vertical Adaptive Management Zone (VAMZ).

Understanding both direct and indirect stressors from activities is key to the implementation of ecosystem-based management. Indirect effects due to resuspension of sediment from human activities may affect sponge communities, including hexactinellid 'glass' sponges (Conway et al. 2001, Whitney et al. 2005, Austin et al. 2007, Yahel et al. 2007, Tompkins-MacDonald & Leys 2008), however, the nature and extent of these effects is unclear. As some activities that resuspend sediment due to contact with the bottom may be permitted in the AMZ, DFO Ecosystem Management Branch Pacific Region has requested DFO Science Pacific Region to provide an assessment of the nature and extent of the potential effects of sedimentation on glass sponge reefs and recommend mitigation measures for activities/areas where there risks to these communities are identified.

A risk-based assessment framework, previously reviewed through the Canadian Science Advisory Secretariat (CSAS), will be utilized to identify activities likely to create sedimentation in the AMZ and evaluate the nature and extent their potential risk to these sponge communities (O et. al. in prep.). This risk-based framework is a tool that assists in the identification of priorities, conservation objectives, management strategies and action plans including monitoring, research and management assessments as appropriate. This assessment will then be utilized to propose and evaluate possible mitigation measures. The value of this risk-based framework is that it allows for a transparent process for gathering, evaluating and recording information related to the risk of harm from human activities/stressors on the glass sponge communities.

Objectives

The objective of this science advisory process is to:

(i) Identify and evaluate the biological effects and impacts of sediment on sponge communities in Hecate Strait (Working Paper 1);

(ii) To identify those activities that could occur in the adaptive management zone that could impact the sponge reefs through re-suspension of sediment (Working Paper 2), and;

(iii) To identify mitigation measures for relevant activities and impacts (Working Paper 2).

The following working papers will be reviewed to provide the basis for discussion and advice:

The effects of sediment on glass sponge reefs. Leys, S.P. Centre for Science Advice – Pacific (CSAP) Working Paper 2012/P44a.

> Paper overview: Summary of knowledge of the nature sedimentation effects on sponge communities, with a specific focus on the effects of sediment on glass sponge communities in general and Hecate Strait sponge reef communities in particular.

An Ecological Risk Assessment Framework for fisheries induced resuspended sediment impacts on Hecate Strait glass sponge reefs. Boutillier, J. CSAP Working Paper 2012/P44b.

> Paper overview: Discussion of extent of the potential exposure of the CPZ to remobilized sediment and a discussion of various mitigation measures that may reduce the extent of the impact. This will address what activities are likely to resuspend sediment (look at Pathways of Effects (PoEs) and quantify effects), and the potential extent of the impacts (question 3 from original request) considering the currents, sediment, and nature of the activity.

Considerations for the review of these working papers include:

Objective (i) - Working Paper 1:

1. Completeness of information provided and summarized regarding the effects of sediment on sponge communities.
2. Accuracy of identified effects of sediment on the sponge communities in Hecate Strait (particularly to hexactinosidian ‘glass’ sponges).

Objective (ii) - Working Paper 2:

1. Completeness of the PoEs evaluation.

2. Soundness of the ocean current modelling and results describing the potential distribution of suspended sediments.

Objective (iii) – Working Paper 2:

1. Effectiveness of suggested mitigation measures to address the identified effects.

Expected publications

- CSAS Proceedings
- CSAS Science Advisory Report (1)
- CSAS Research Documents (2)

Participation

- DFO Science
- DFO Oceans
- DFO Habitat
- DFO Species at Risk
- DFO Fisheries Management
- Province of BC
- Fish harvester experts
- Environmental Non-governmental Organisations experts
- Academic experts

Additional Information and References Cited

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APPENDIX C: ELEMENTS OF THE RISK ASSESSMENT FRAMEWORK

The tables in this appendix are copied from the national Ecological Risk Assessment Framework (draft of 19-June-2012). They are provided here for ease of reference.

Table C1: Consequence Levels and Descriptors

Level	Descriptor
None (1)	Gear is not known to interact with the benthic environment under normal operations. Gear types include harpoon and diving.
Low (2)	Gear is known to have minimal interaction with the benthic environment as part of normal operations. Gear types include pelagic longline and purse seine.
Moderate (3)	Gear is known to interact with benthic attributes regularly as part of normal operations. Area of impacts is roughly equal to the size of the gear itself, as the gear is generally fixed in place once it is deployed (i.e. bottom contact fixed gear).* Gear types include pots, bottom set gillnets, and bottom set longline.
High (4)	Gear is known to interact with benthic attributes regularly as part of normal operations. Area of potential impact is significantly larger than the relative size of the gear, as the gear is moved over the benthic environment as part if it normal operations (i.e. bottom contact mobile gear). Gear types include otter trawl and scallop dredge.

** It should be noted that the area of impact for fixed gear may extend far beyond the relative size of the gear, depending on the manner and environmental conditions in which the gear is deployed and retrieved (e.g. pots being dragged across the benthic environment during retrieval). If this is a known regular occurrence or anticipated within the area/fishery being assessed, this should be documented as part of the risk analysis process. Such information will be useful in determining potential management options.*

Table C2: Likelihood Levels and Descriptors

Level	Descriptor
Never (1)	Interactions between fishing activity and the benthic attribute never occur; the fishing activity does not occur in or adjacent to areas identified as benthic attributes.
Rarely (2)	Interactions between fishing activity and the areas identified as benthic attributes are rare; occurring only in exceptional circumstances.
Occasionally (3)	Interaction between fishing activity and the areas identified as benthic attributes occur occasionally under normal fishing practices, but not on a regular basis.
Regularly (4)	Interaction between fishing activity and the areas identified as benthic attributes are expected to occur on a regular basis under normal fishing practices.

Table C3: Risk Categories

Risk Level	Descriptor
1 - 6	**Low Risk** – The fishing activity presents a negligible risk of serious or irreversible harm to the significant benthic areas.
8-9	**Moderate Risk** - The fishing activity presents a moderate risk of serious or irreversible harm to the significant benthic areas.
12-16	**High Risk** – The fishing activity presents a high risk of serious or irreversible harm to the significant benthic areas.

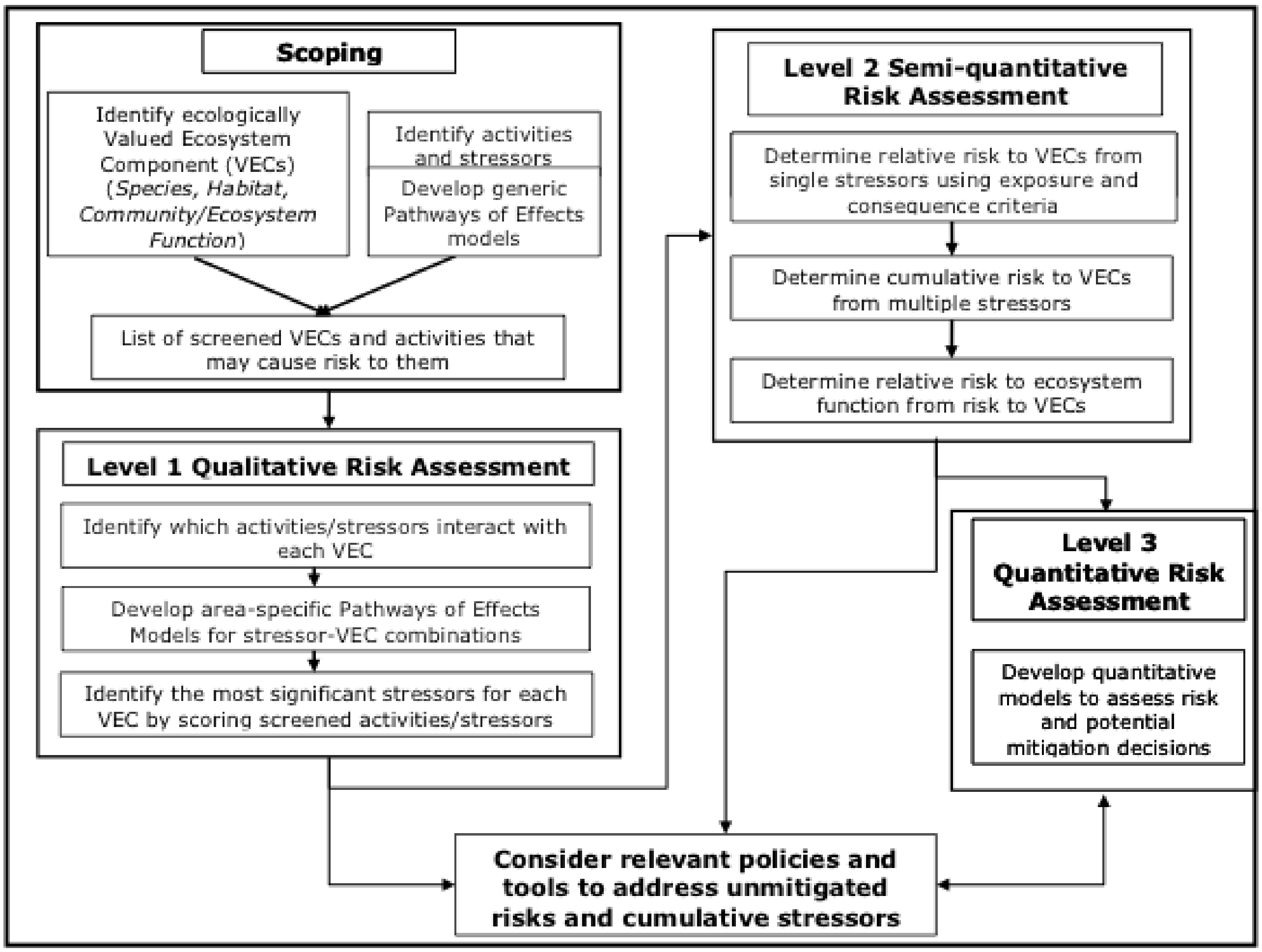


Figure 1 Methodology for the Pacific region hierarchical approach to the EBM-ERA. Taken from O et al. in prep.[5]

[5] O et al. in prep. An Ecological Risk Assesment Framework (ERAF) for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Res. Doc.

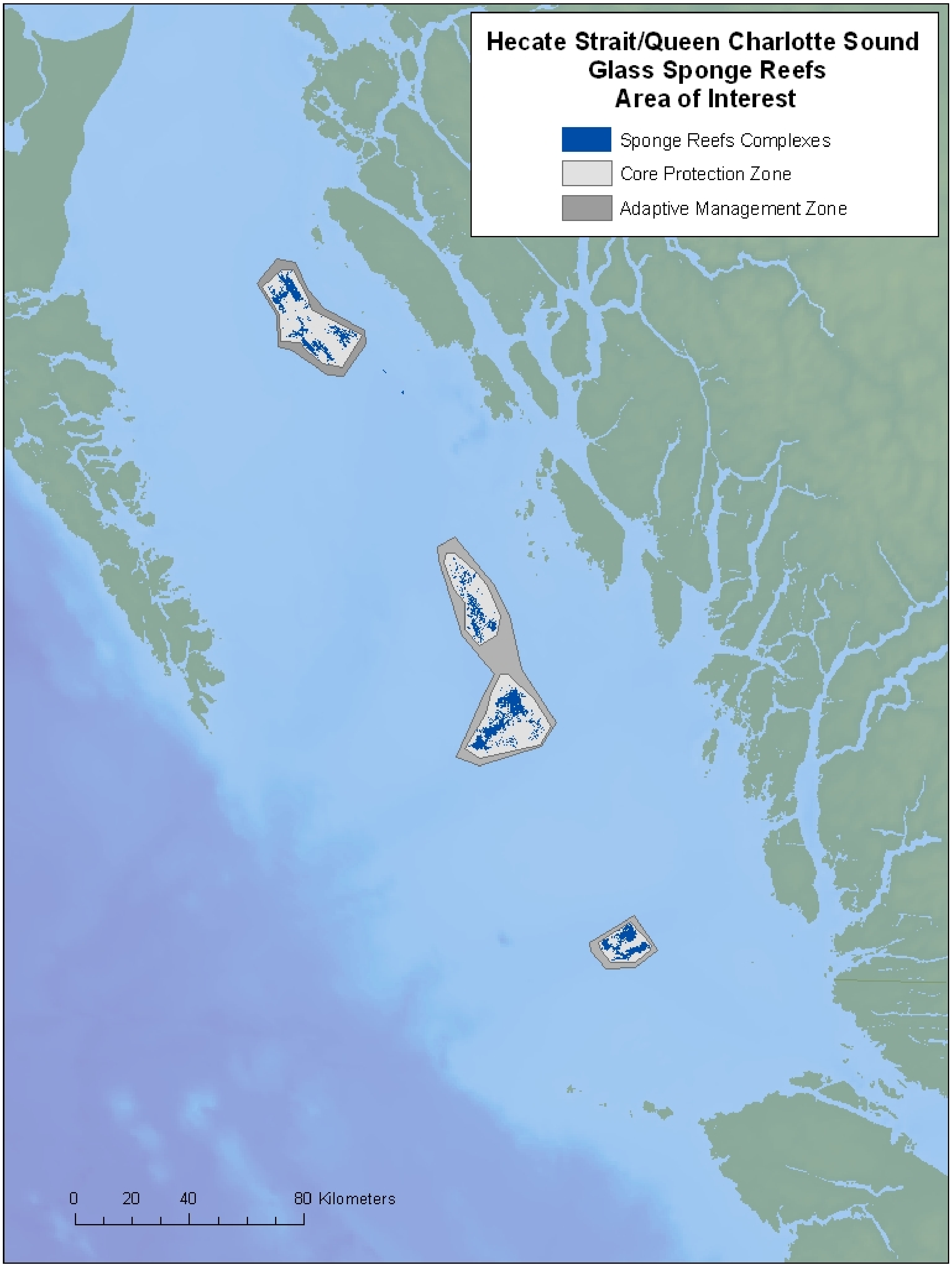


Figure 2 Overview of the Hecate Strait and Queen Charlotte Sound Sponge Reef Area of Interest and their proposed boundaries.

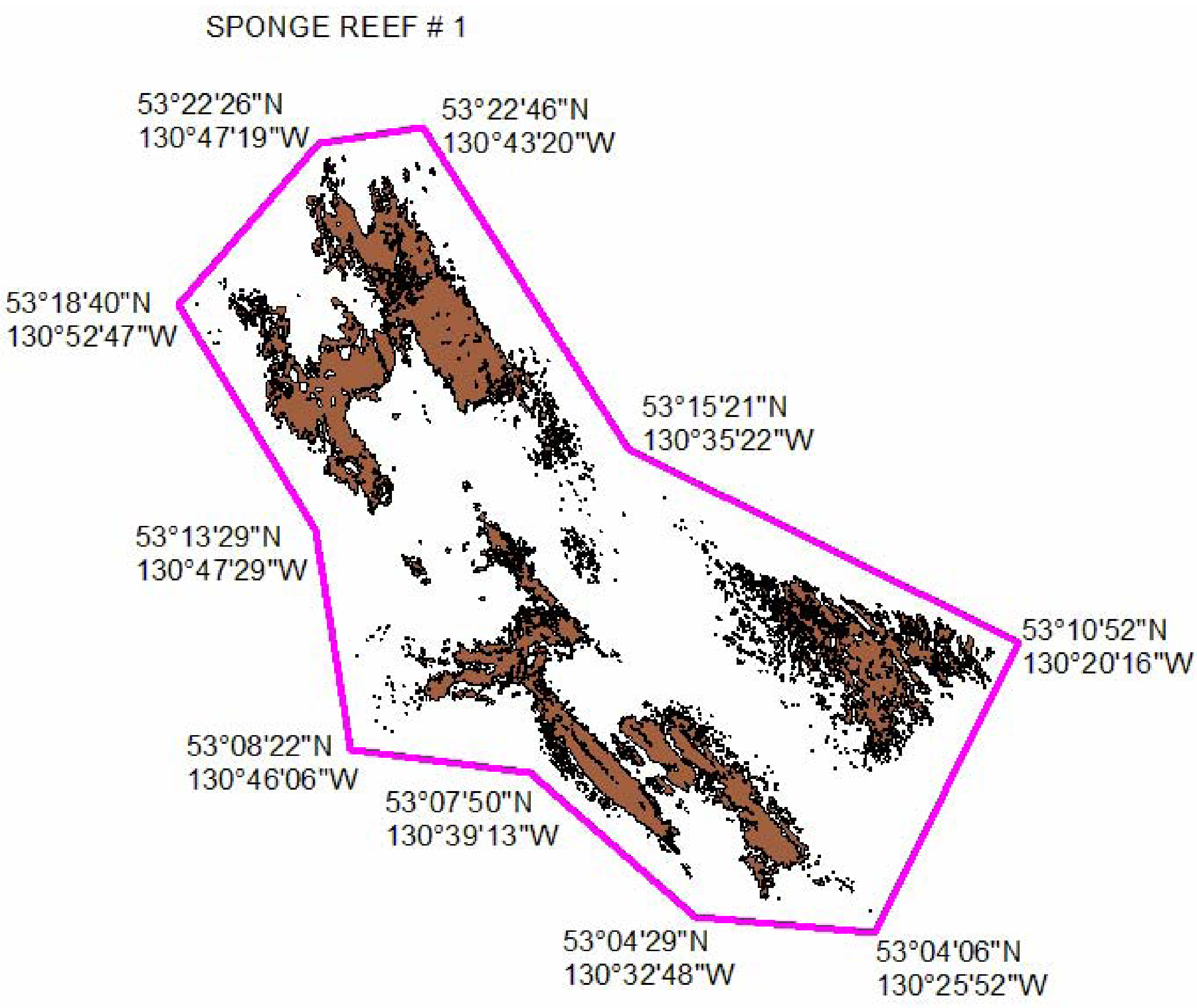


Figure 3 Northern Hecate Strait and Queen Charlotte Strait Sponge Reef complex AOI boundary

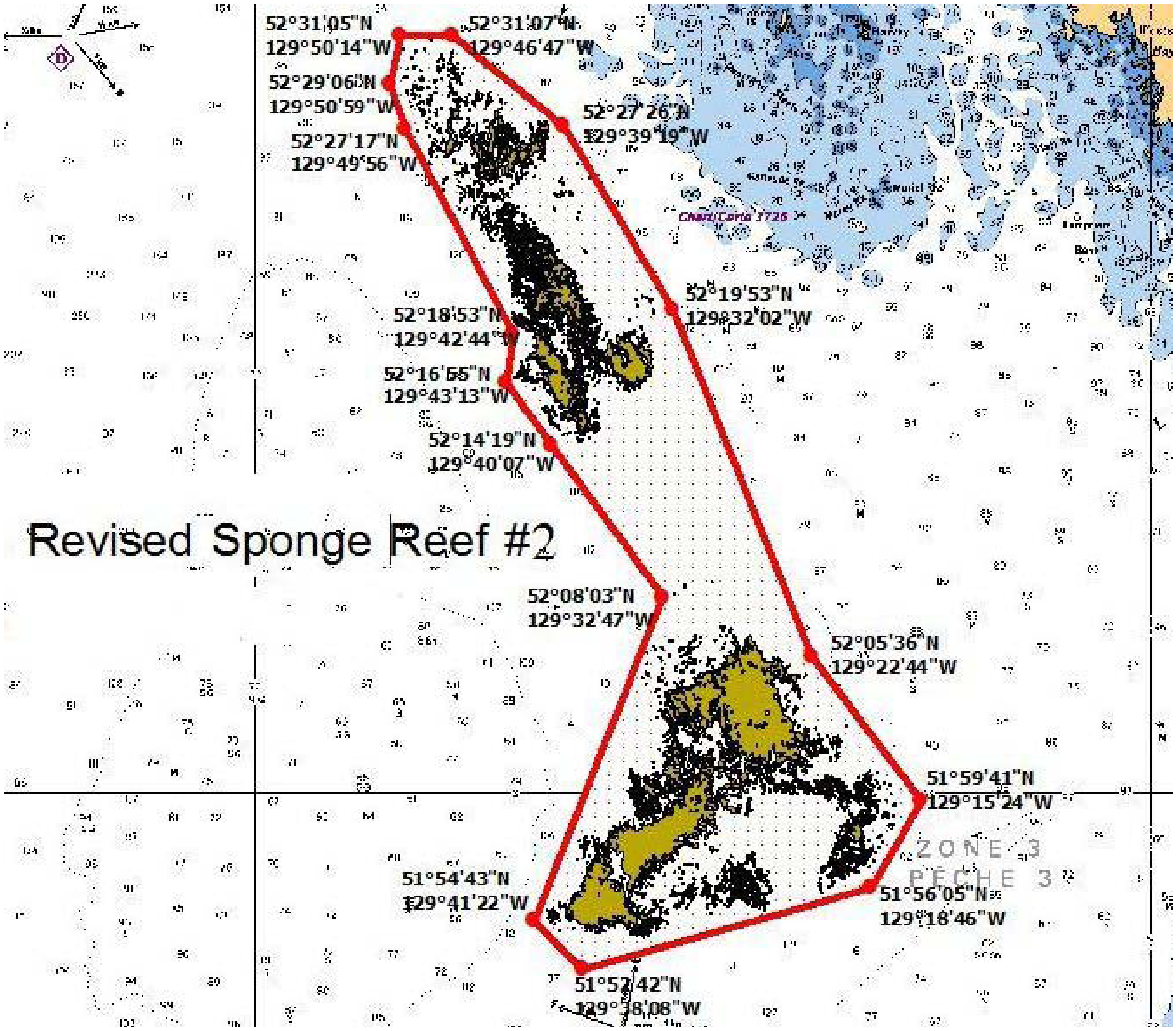


Figure 4 Central Hecate Strait and Queen Charlotte Strait Sponge Reef Complex AOI boundary.

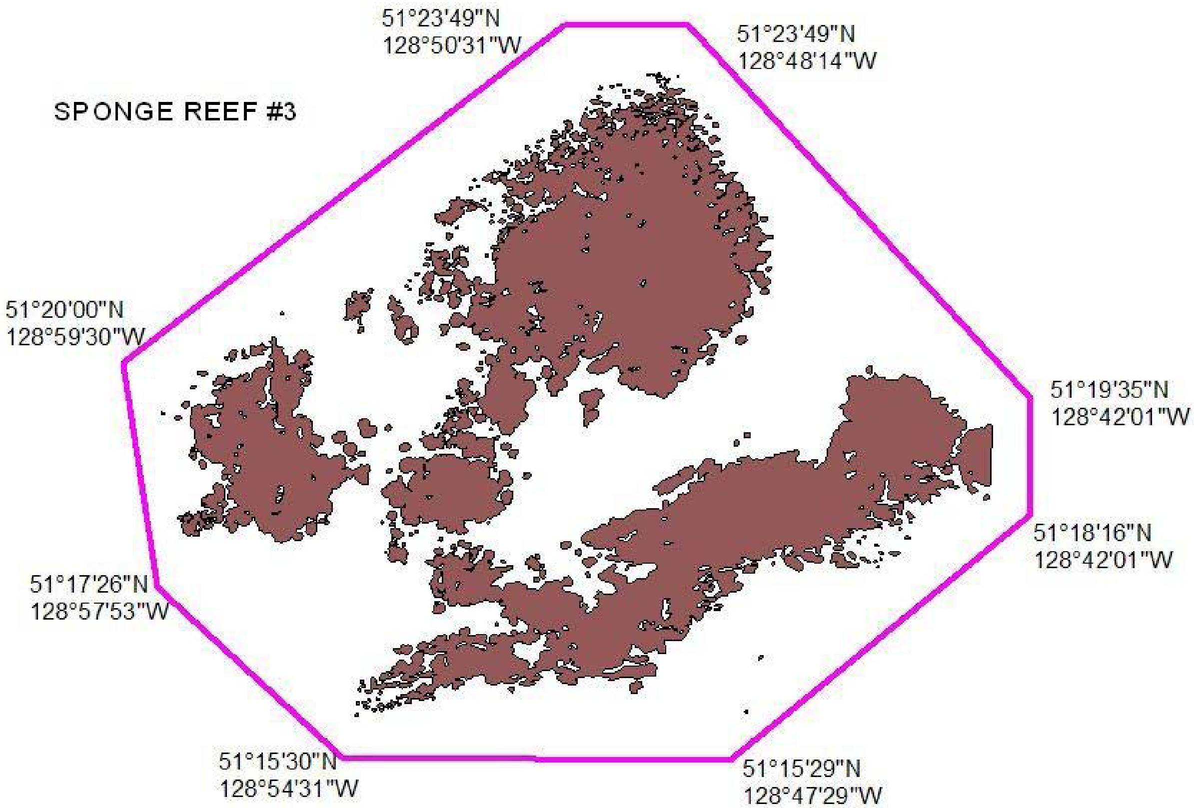


Figure 5 Southern Hecate Strait and Queen Charlotte Strait Sponge Reef Complex AOI boundary

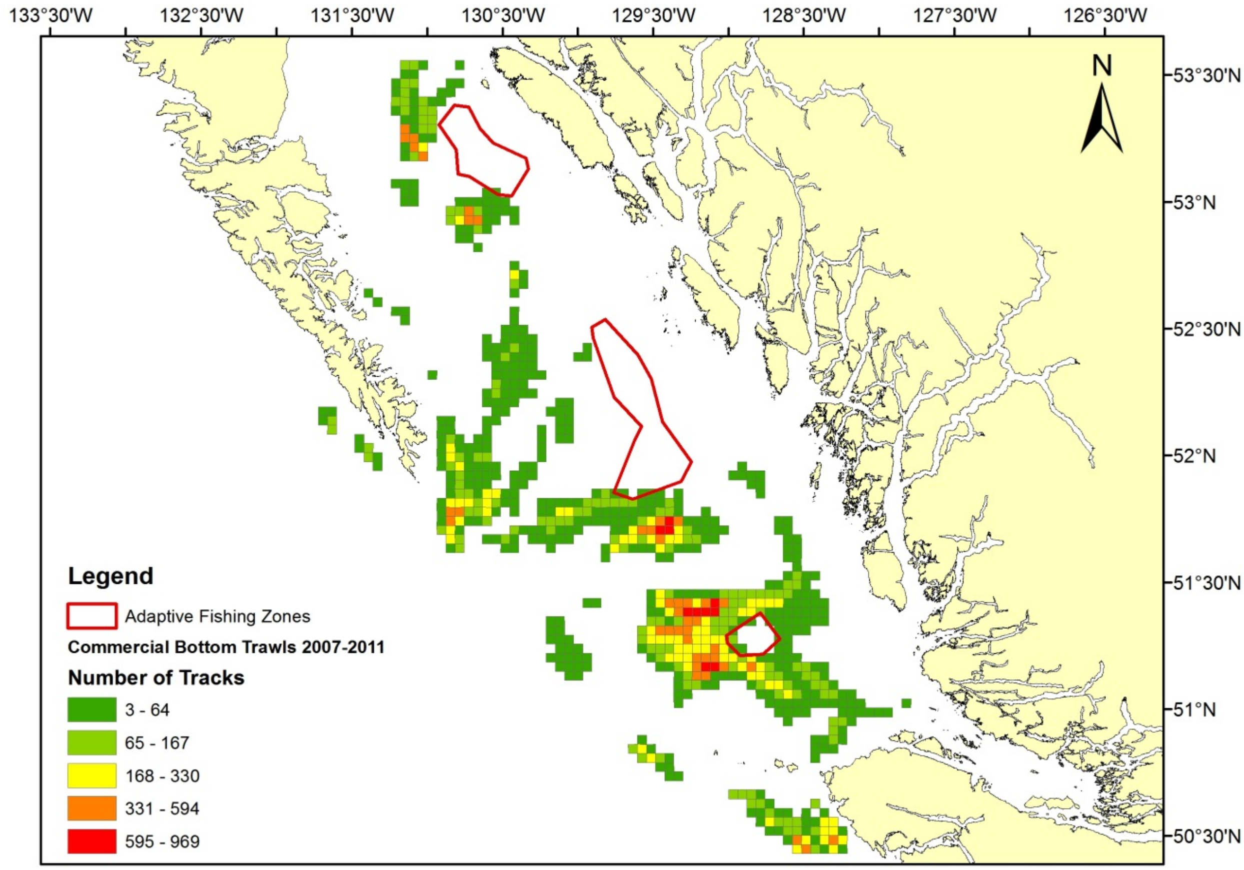


Figure 6 AOI Historic fishing patterns for commercial bottom trawls (2007-2011).

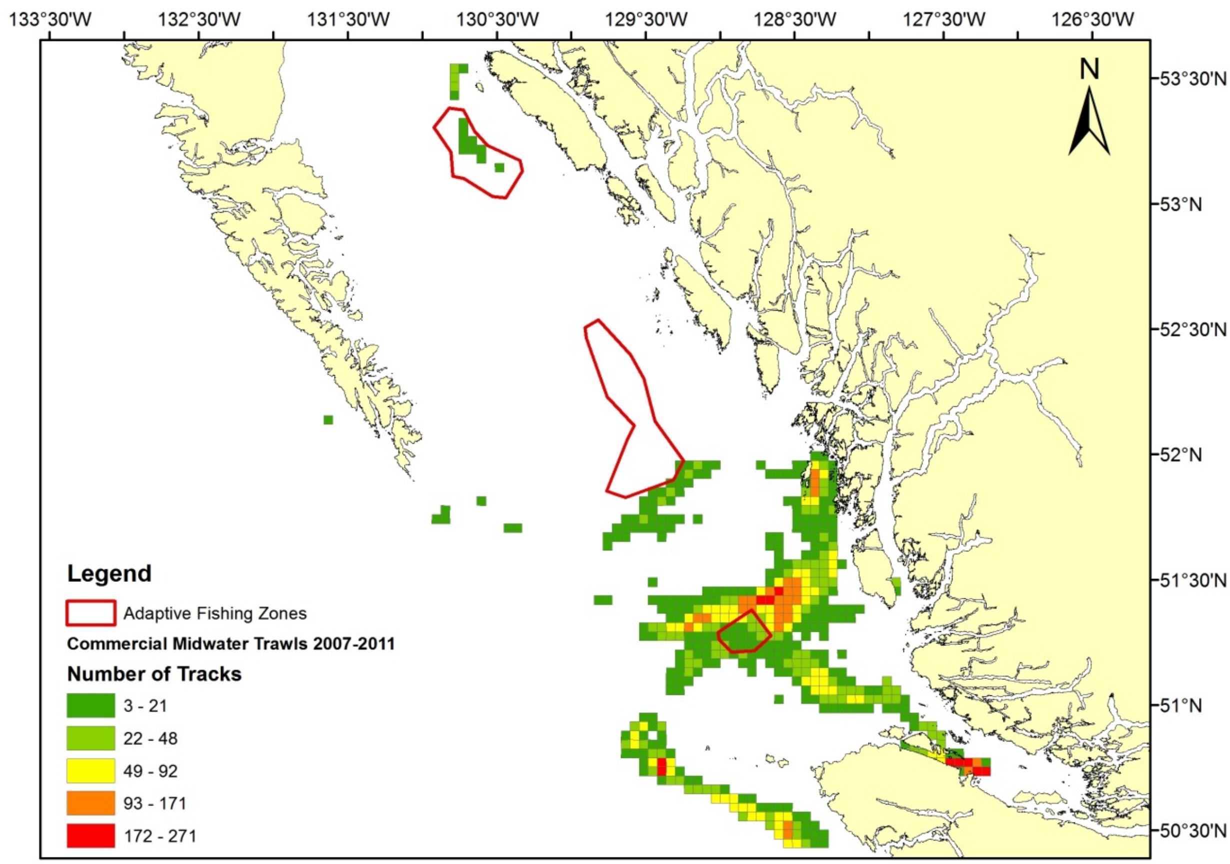


Figure 7 Historic fishing patterns for commercial mid-water trawls (2007-2011).

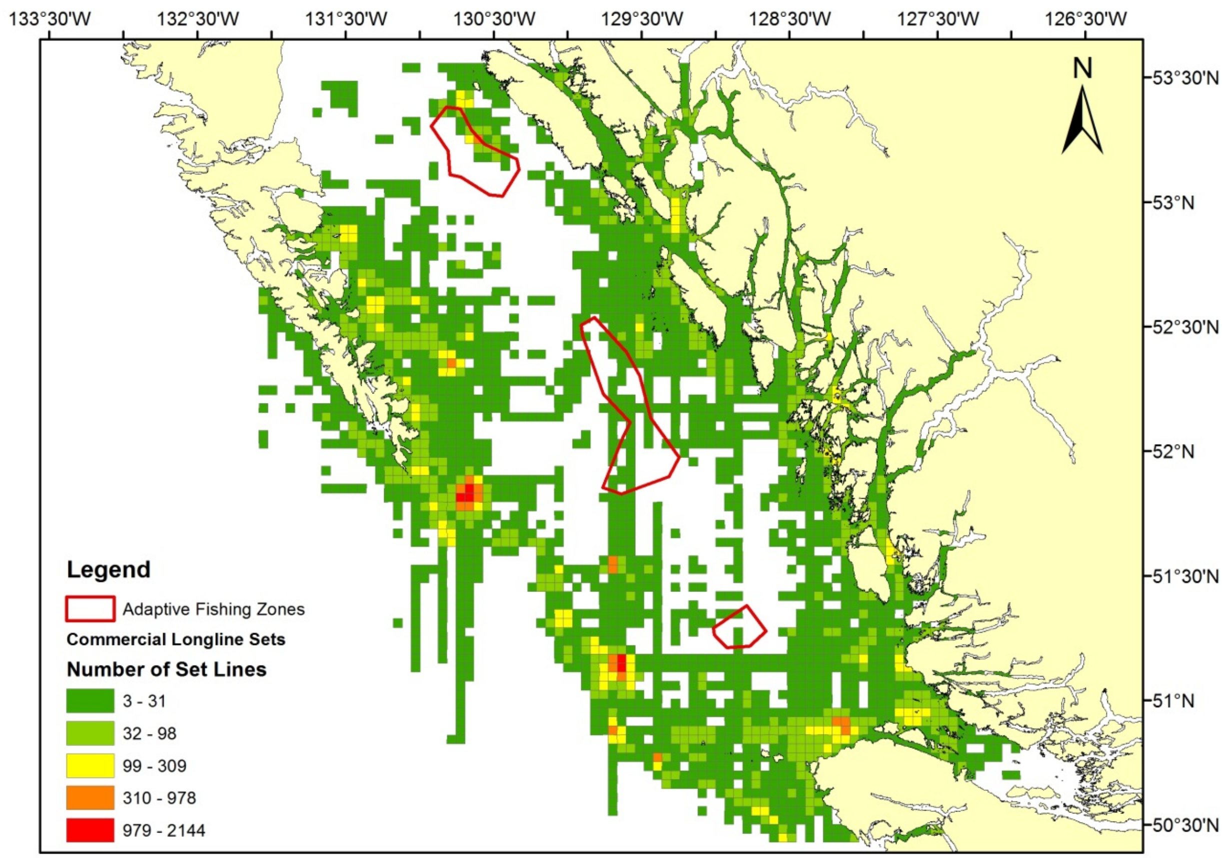


Figure 8 Historic fishing patterns for commercial longline (2007-2011)

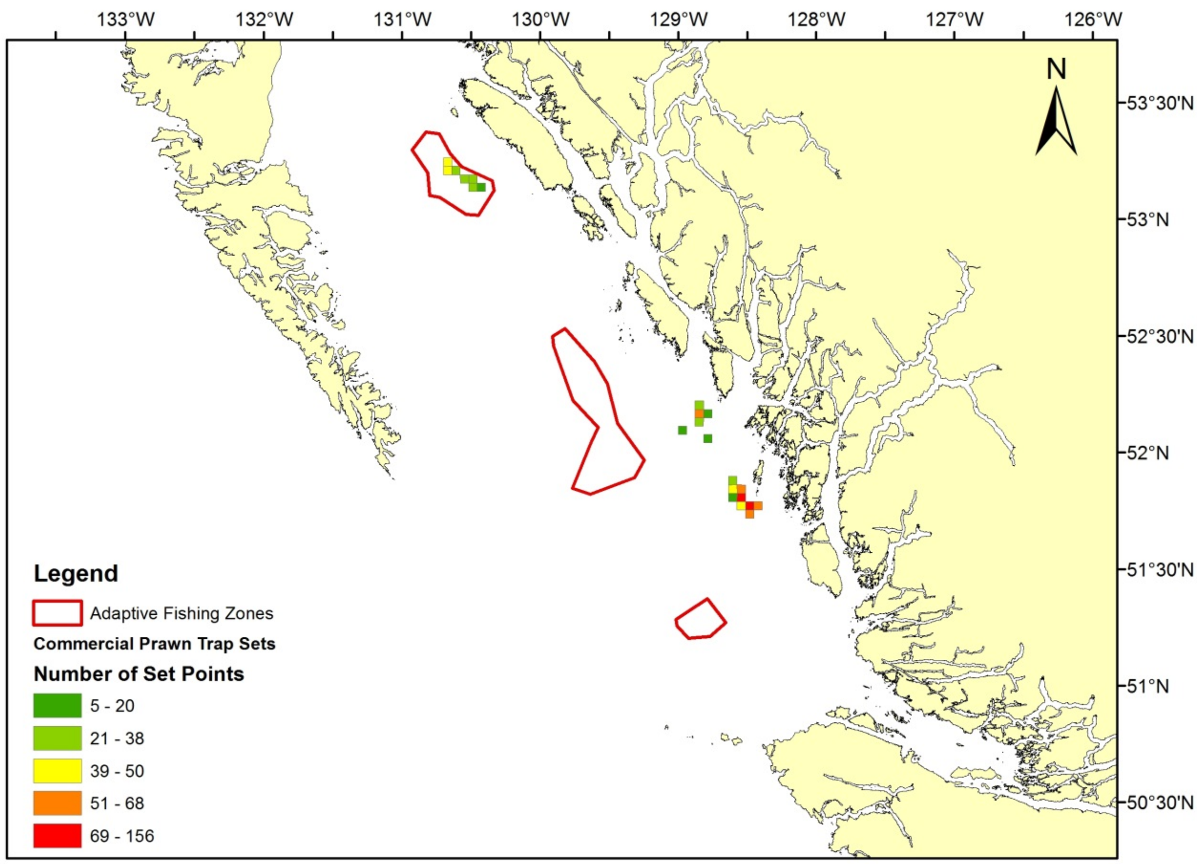


Figure 9 Historic fishing patterns for commercial prawn by trap (2007-2011)

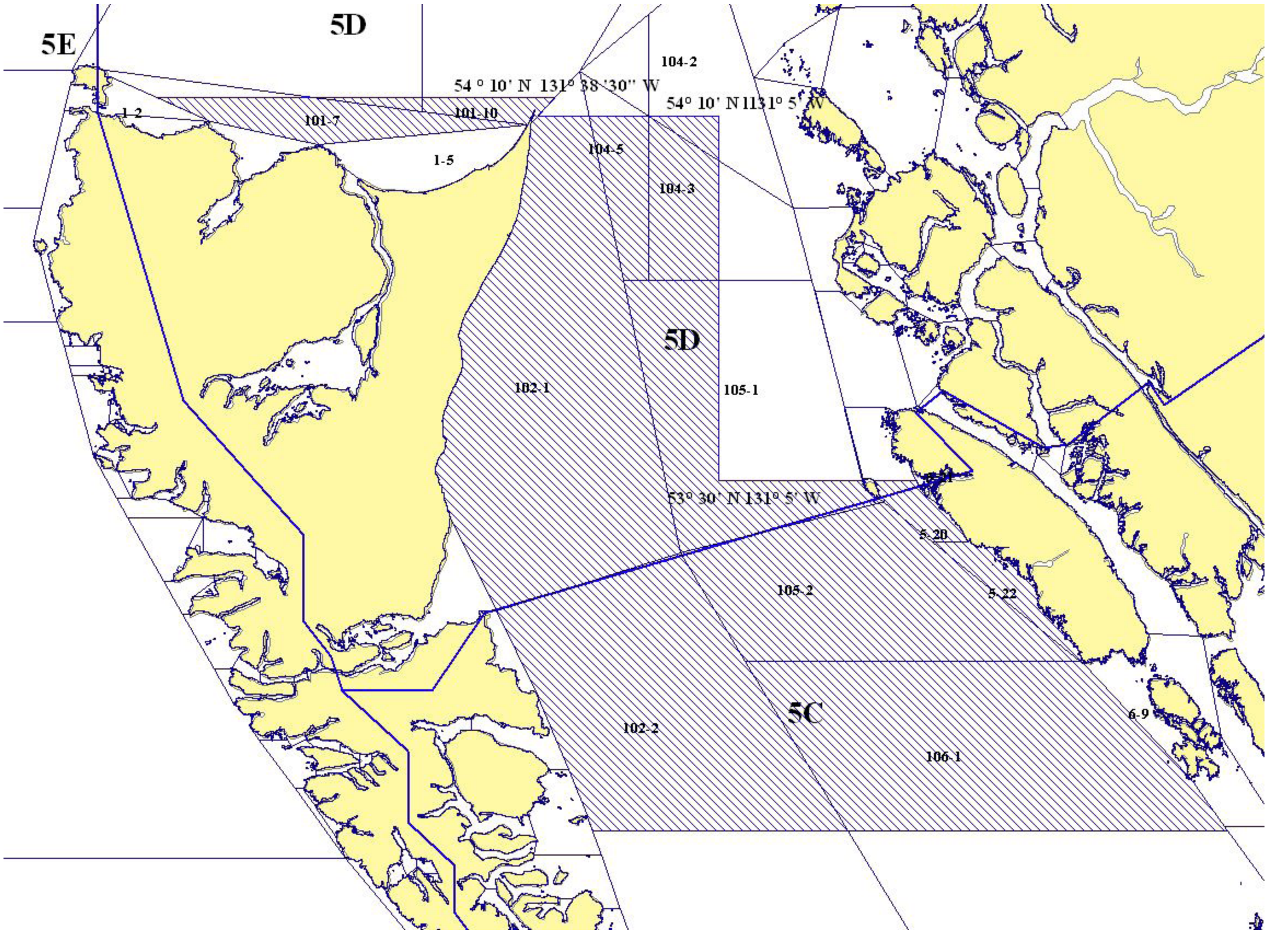


Figure 10 Hecate Strait/Dixon Entrance -Protection of Pacific Cod Closure.

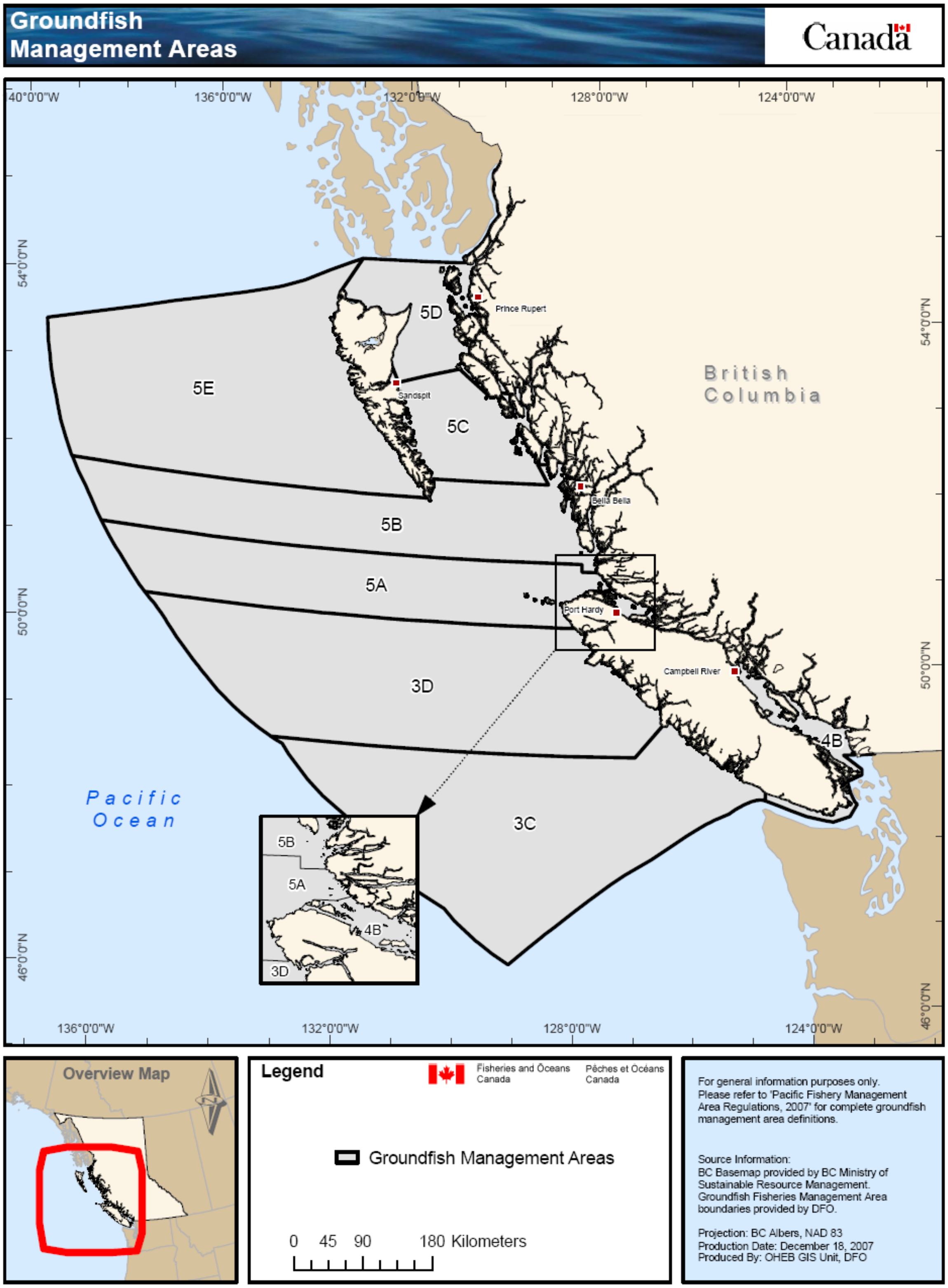


Figure 11 Groundfish Management Areas.

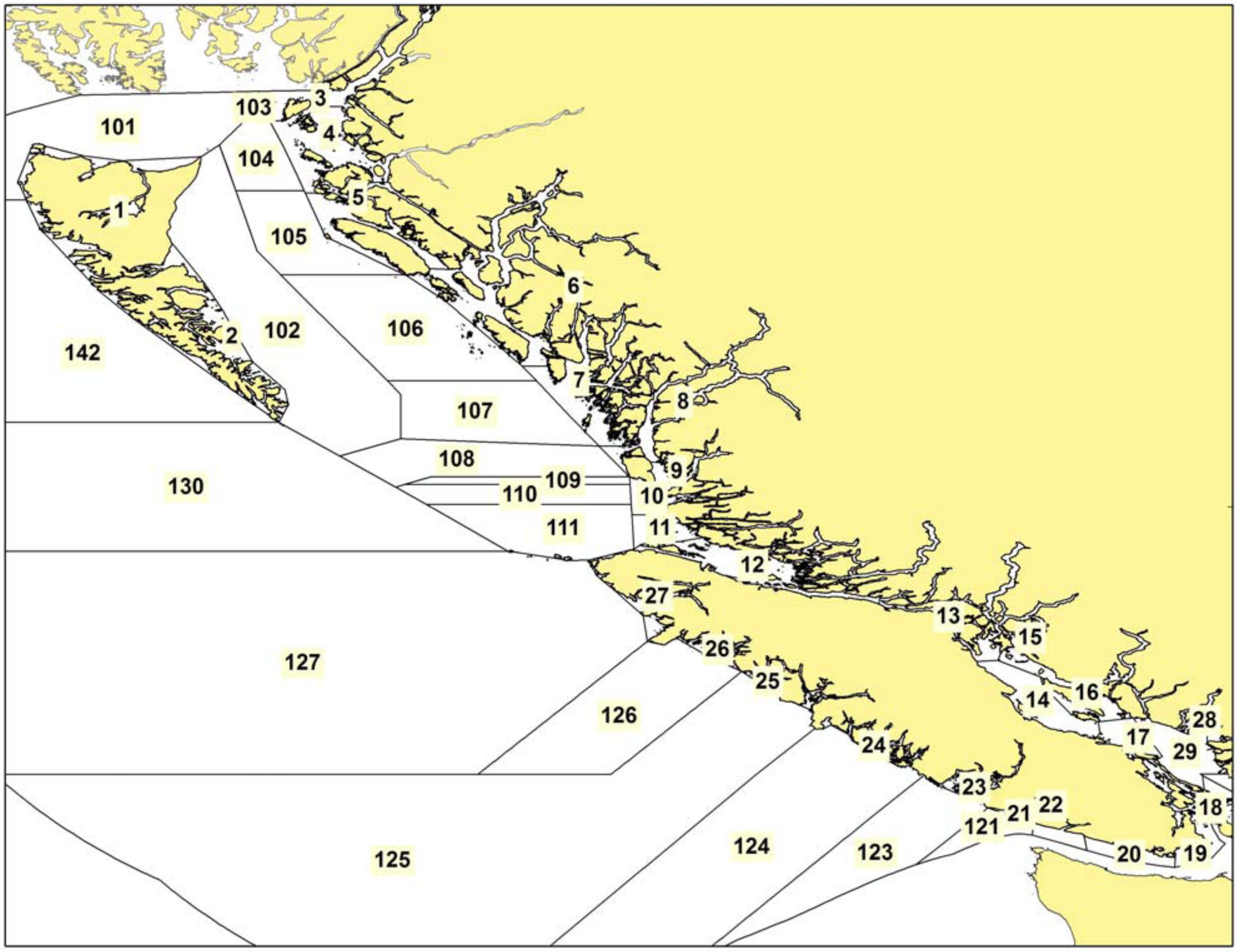


Figure 12 Pacific Fisheries Management Areas

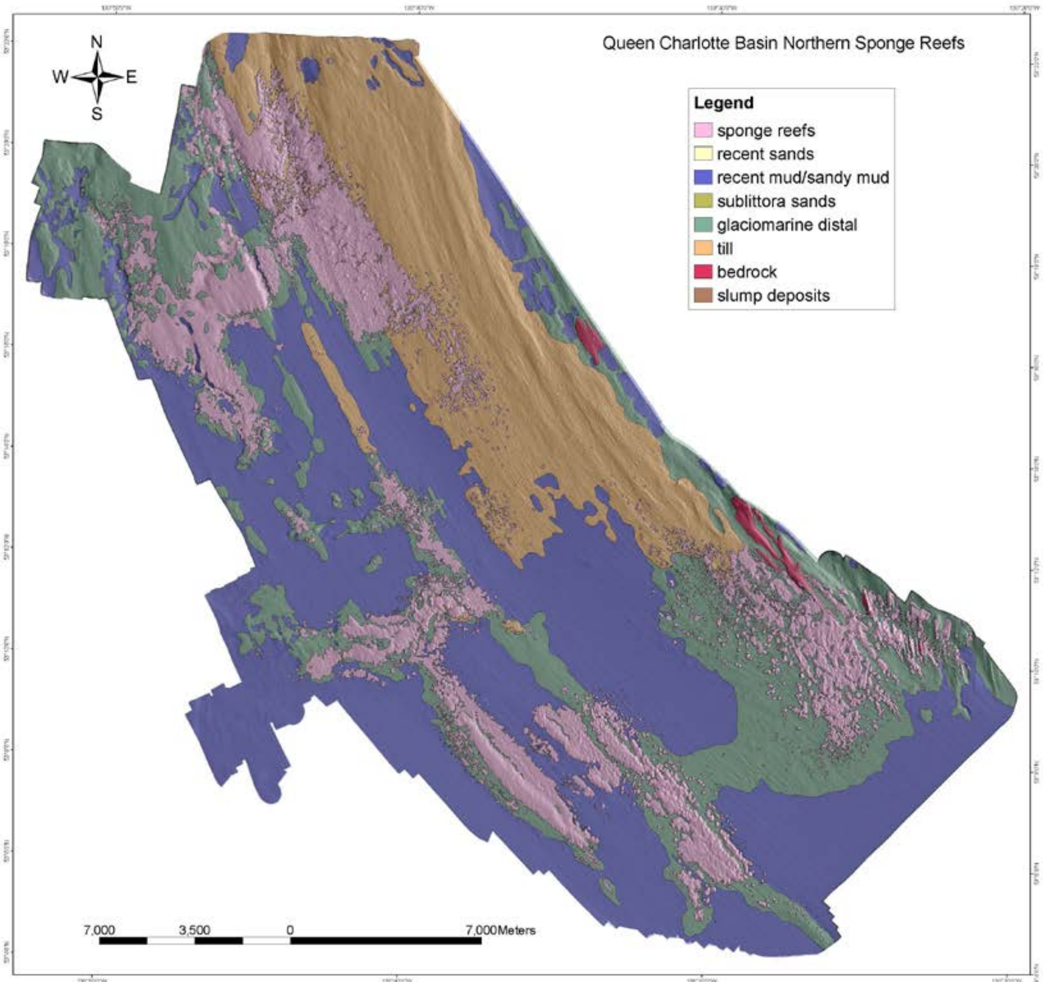


Figure 13 Sediment map of the Northern Sponge Reef Complex

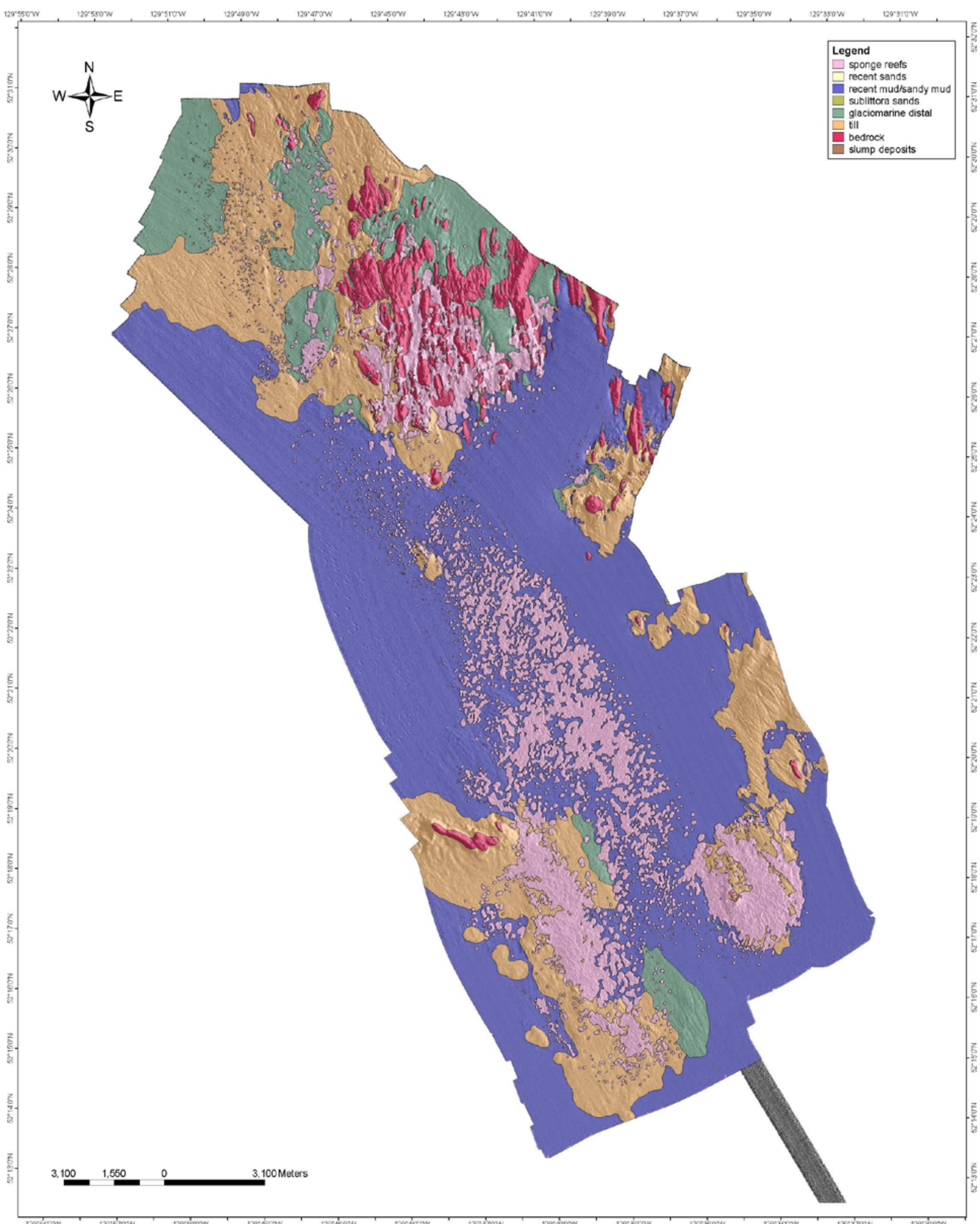


Figure 14Sediment map of the Central Sponge Reef Complex

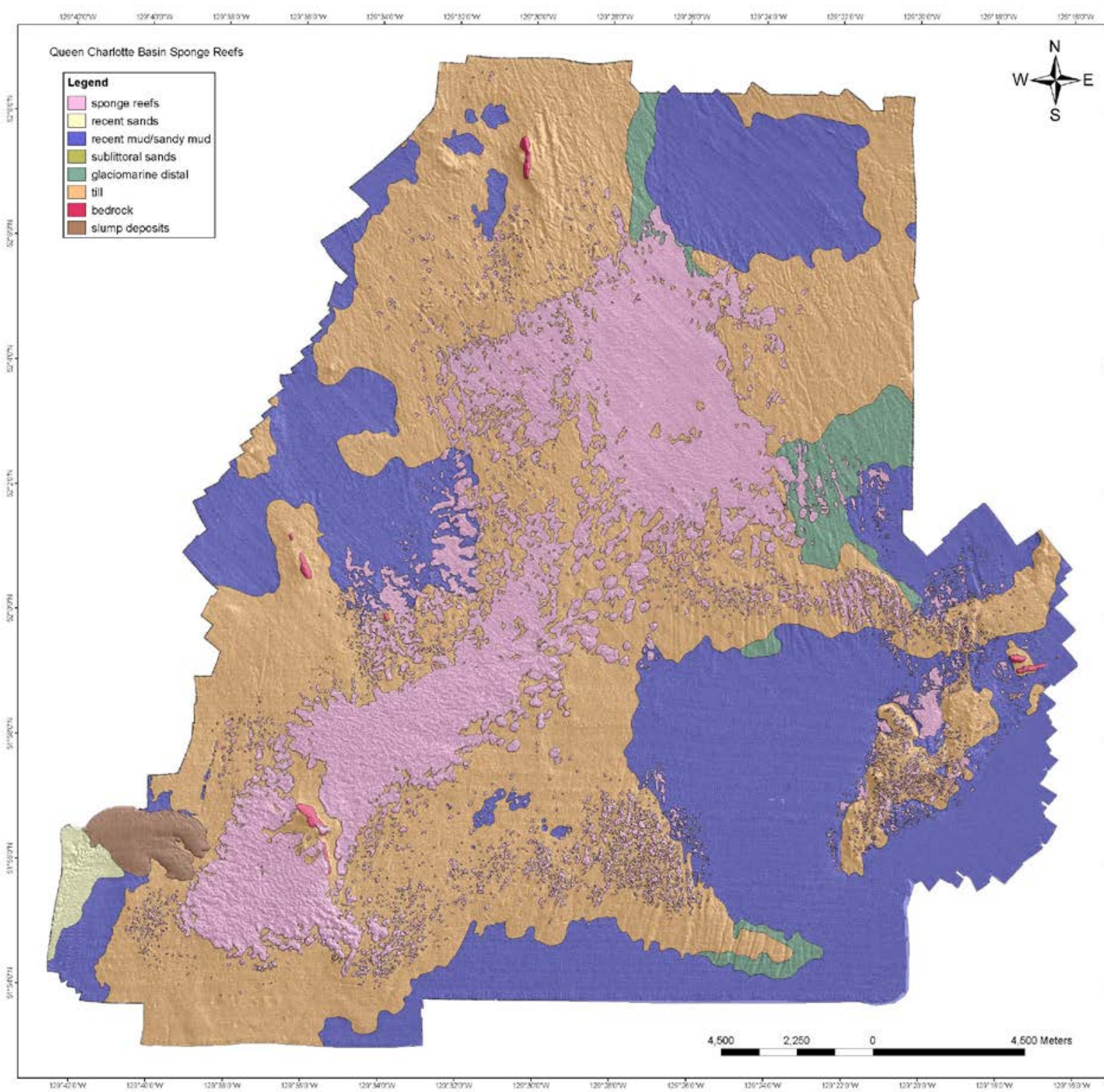
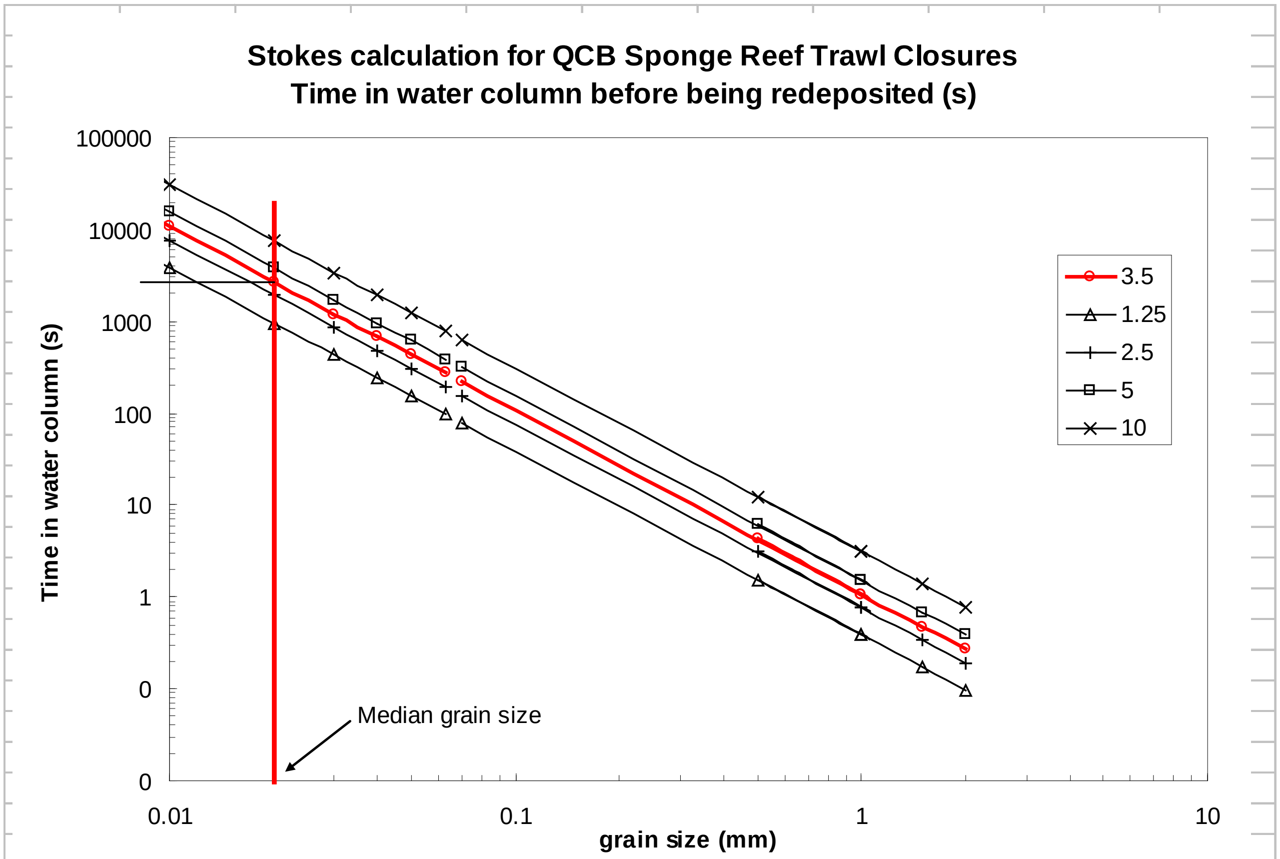


Figure 15 Sediment map of the Southern Sponge Reef Complex.



Current flows at 0.35m/s for 3 hours before switching direction.

3 hours = 10800 seconds

Anything below 10800 seconds will be deposited in a single tide

Figure 16 Grain size versus time in water column before re-settling to bottom. The different lines show different ejection heights (m) into the water column.

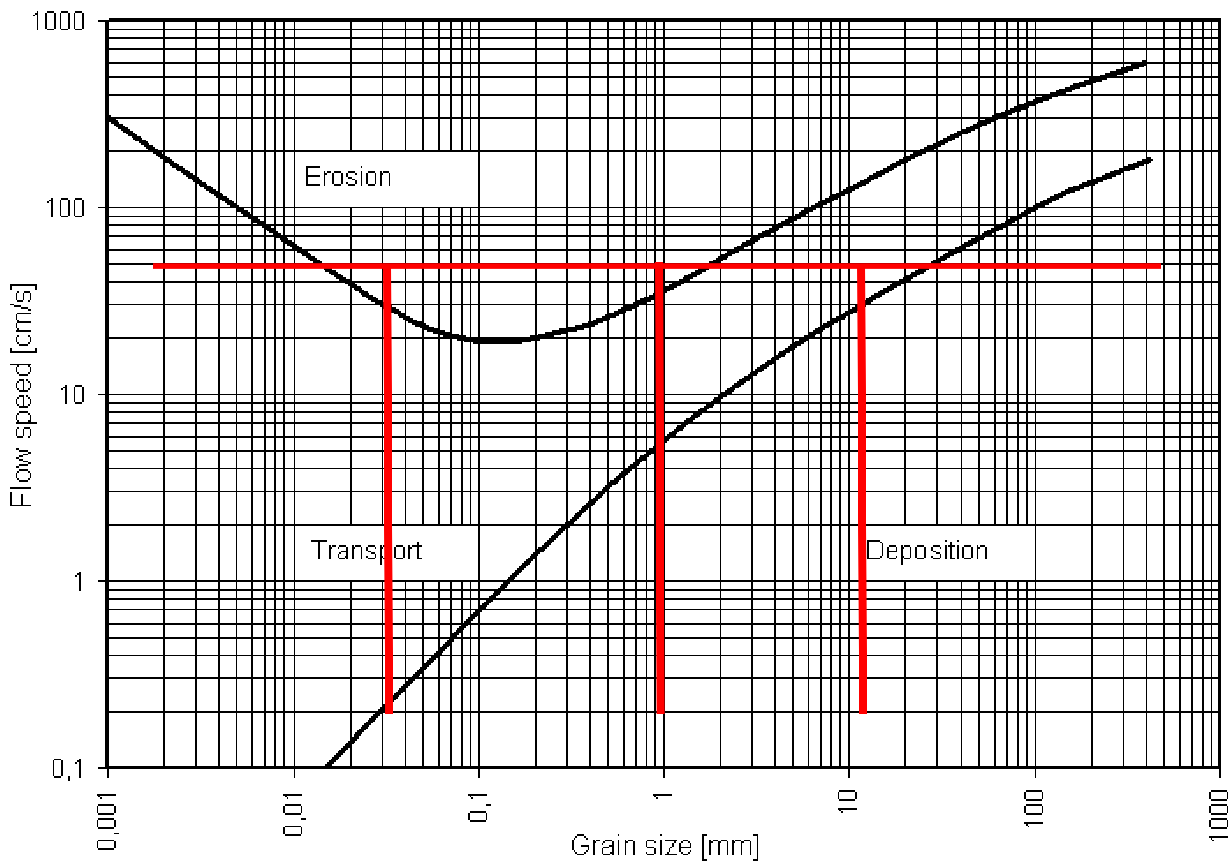


Figure 17 Hjulström curve.

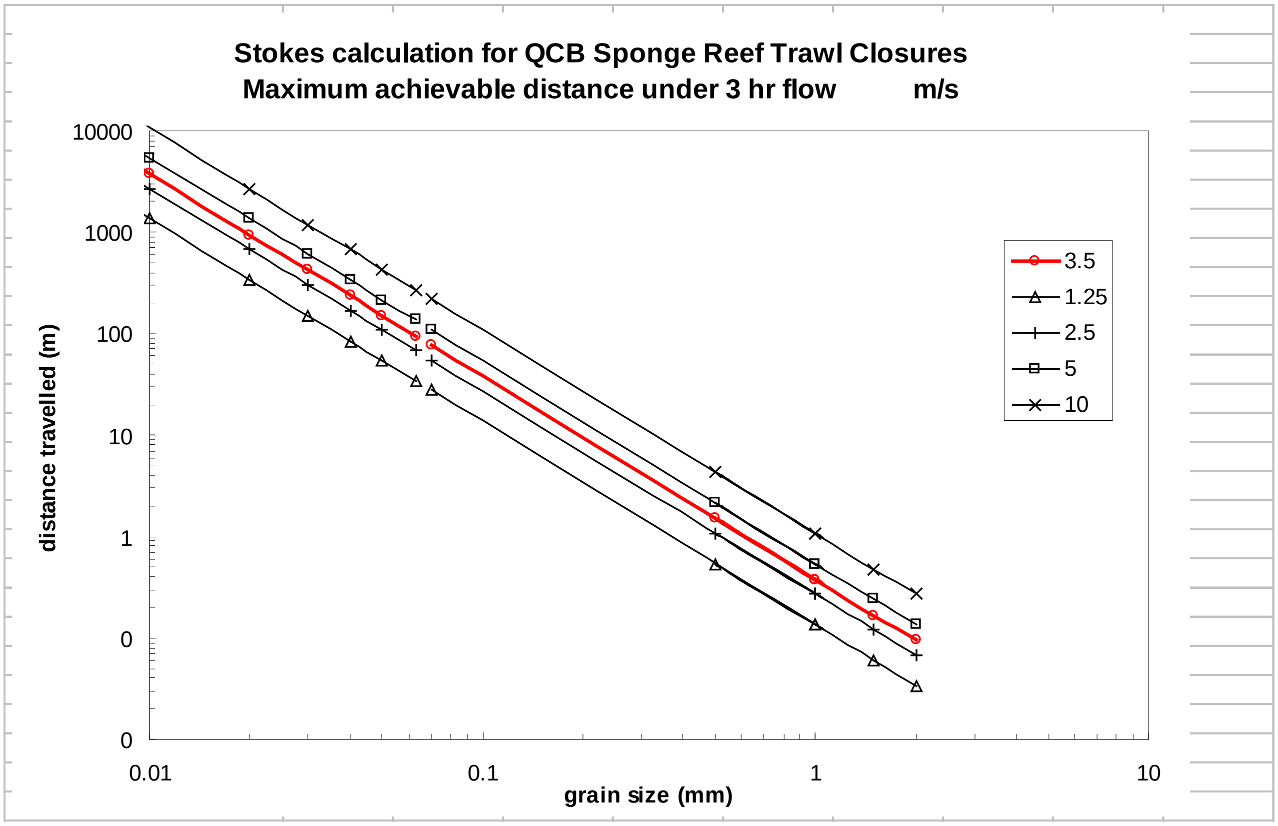


Figure 18 Maximum achievable distance under steady flow of 0.35m/s.

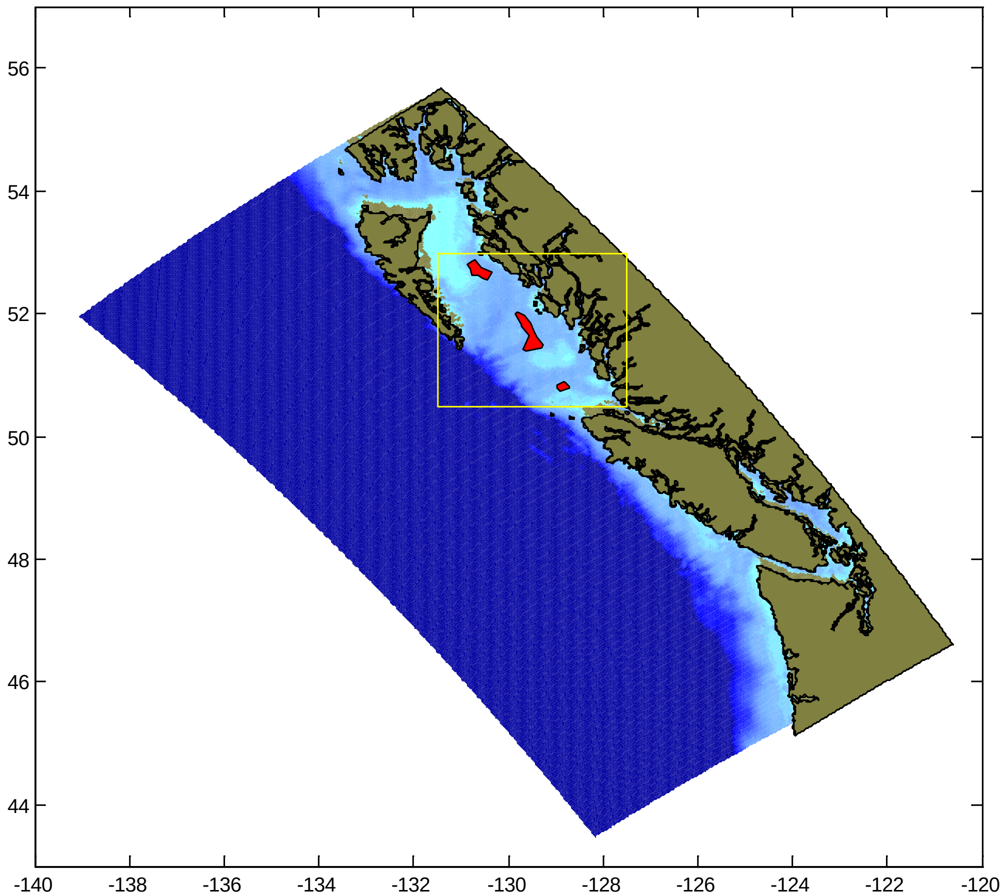


Figure 19 BC ROMS model domain. Domain contains all BC coastal areas with approximately 3 km horizontal resolution and 30 vertical layers. The location of the glass sponge reefs is shown in the yellow rectangle References.

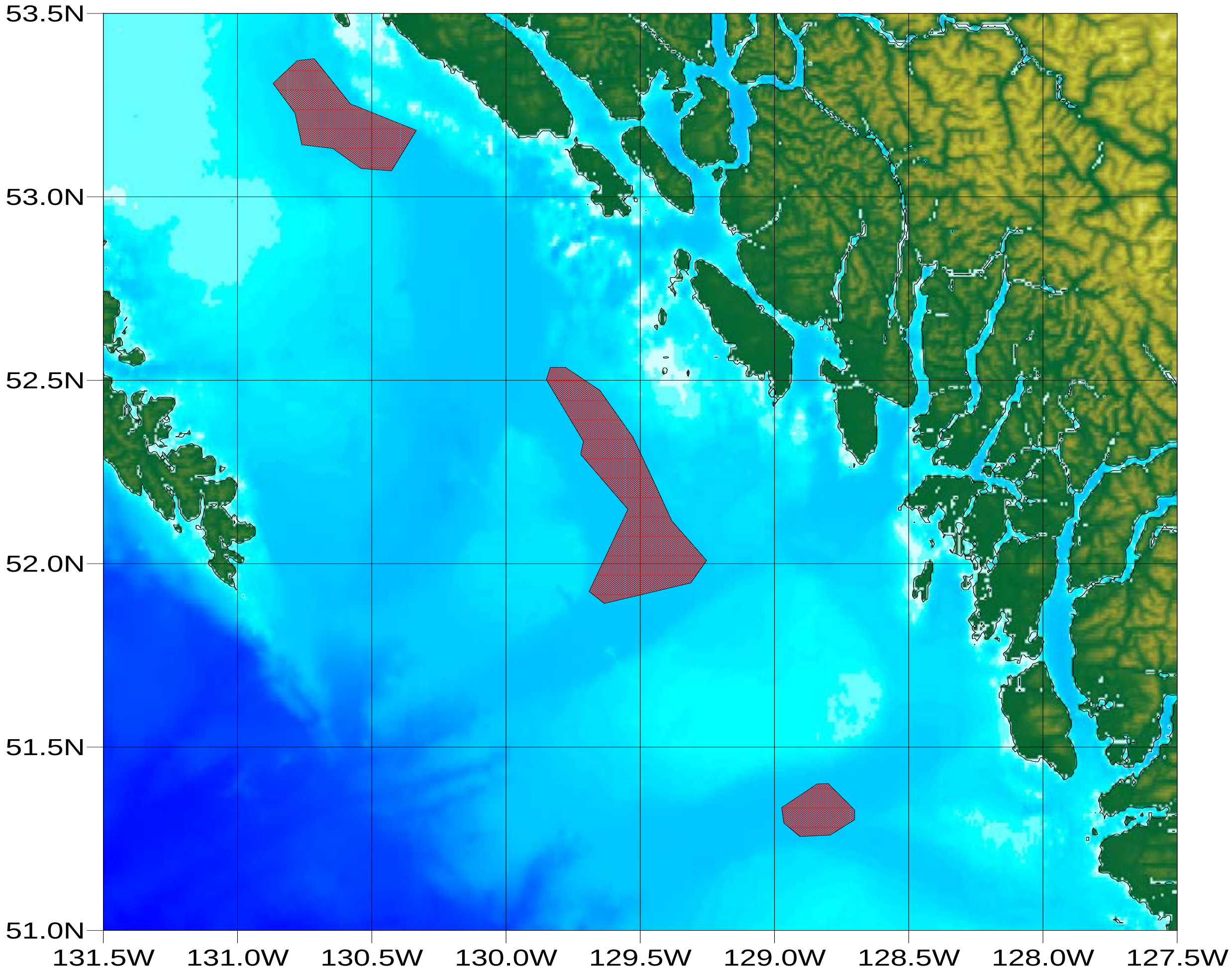


Figure 20 Current bottom trawl fishery closures encompassing the glass sponge reefs.

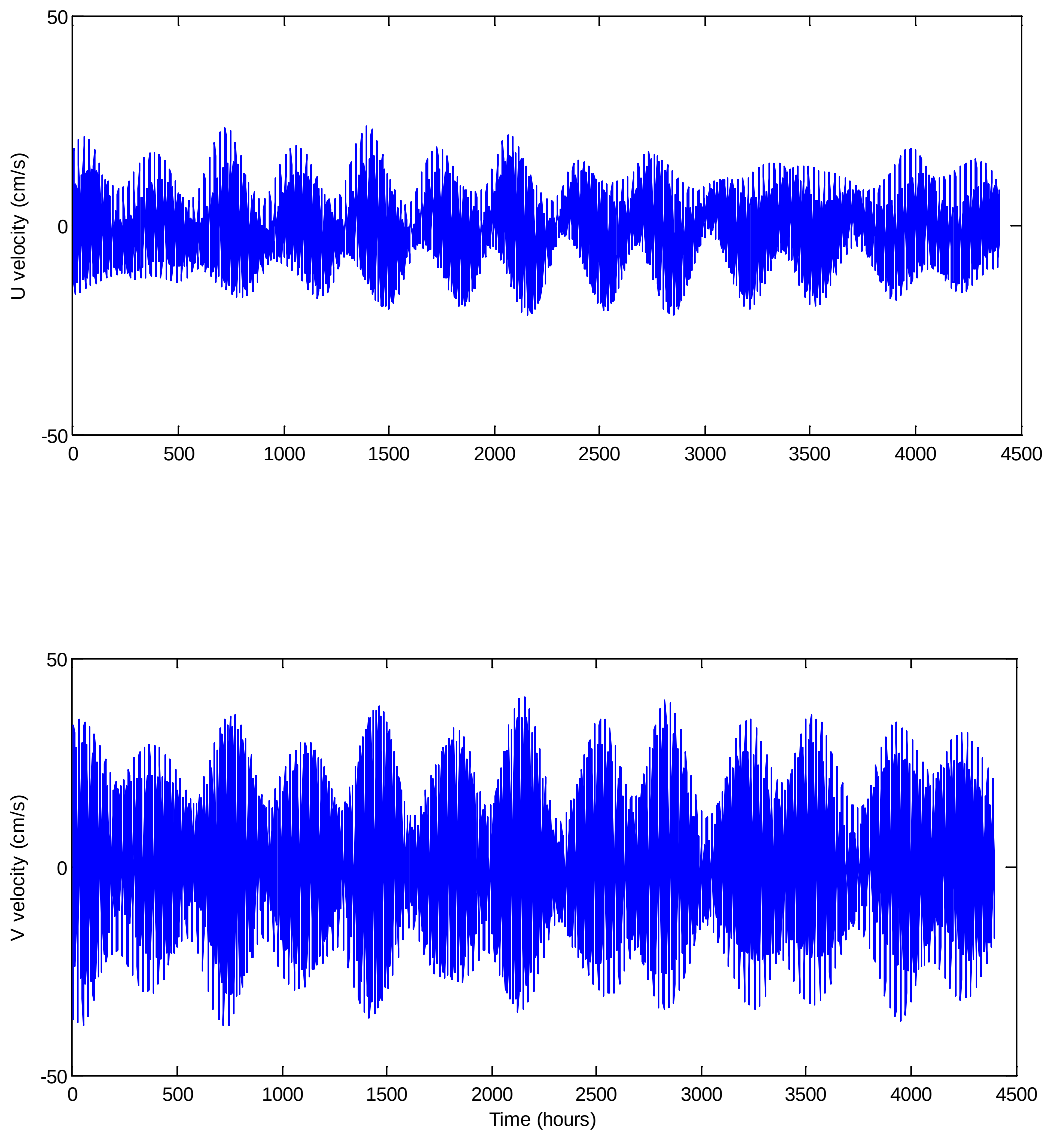


Figure 21 Near-bottom tidal current in northernmost point of the northern closure, where U represents East-West currents and V represents North-South currents.

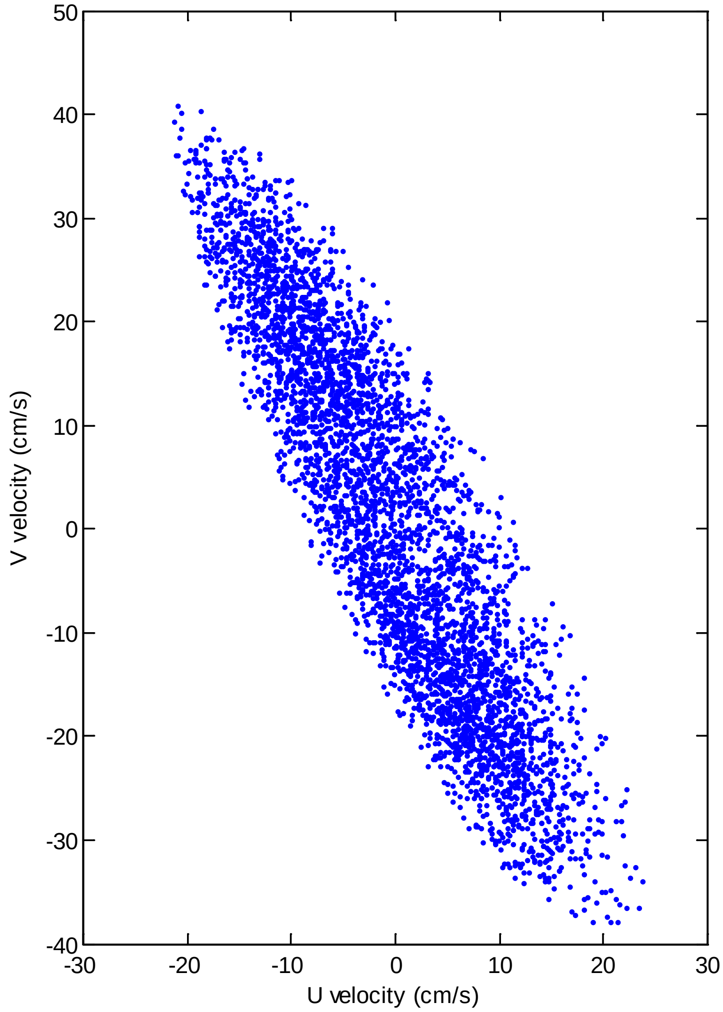


Figure 22 Ellipse depicting near-bottom tidal current at the northernmost point of the northern closure, plotted by U-V coordinates where U represents East-West currents and V represents North-South currents.

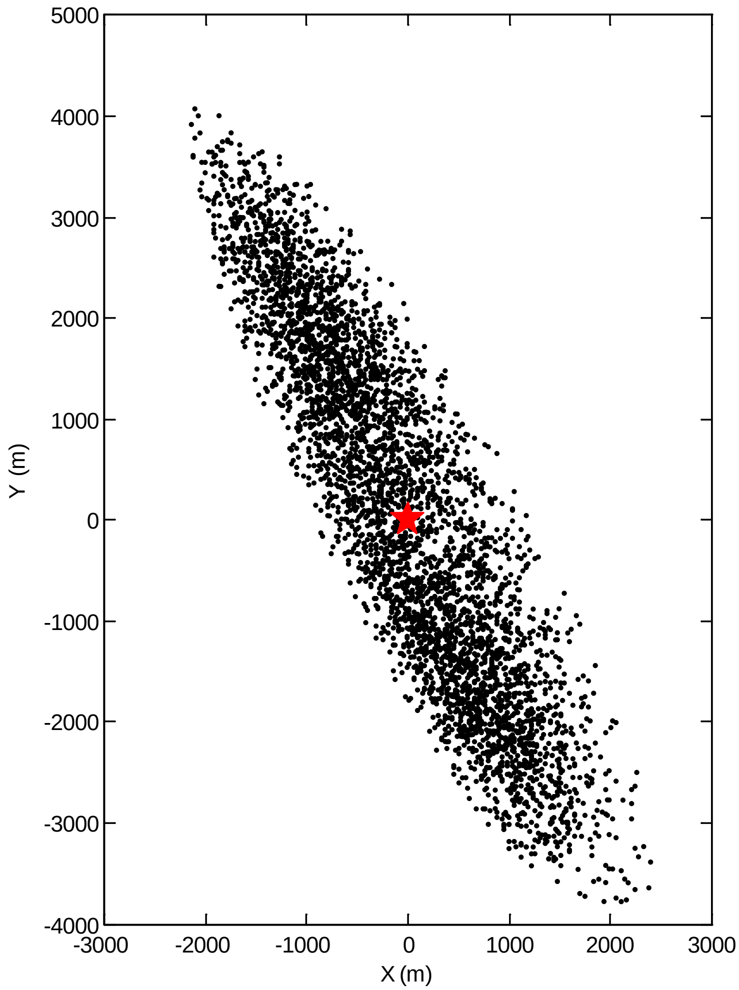


Figure 23 Three-hour excursion of a near-bottom particle dropped at the origin coordinate (0,0 – marked by red star) for the northernmost point of the northern closure.

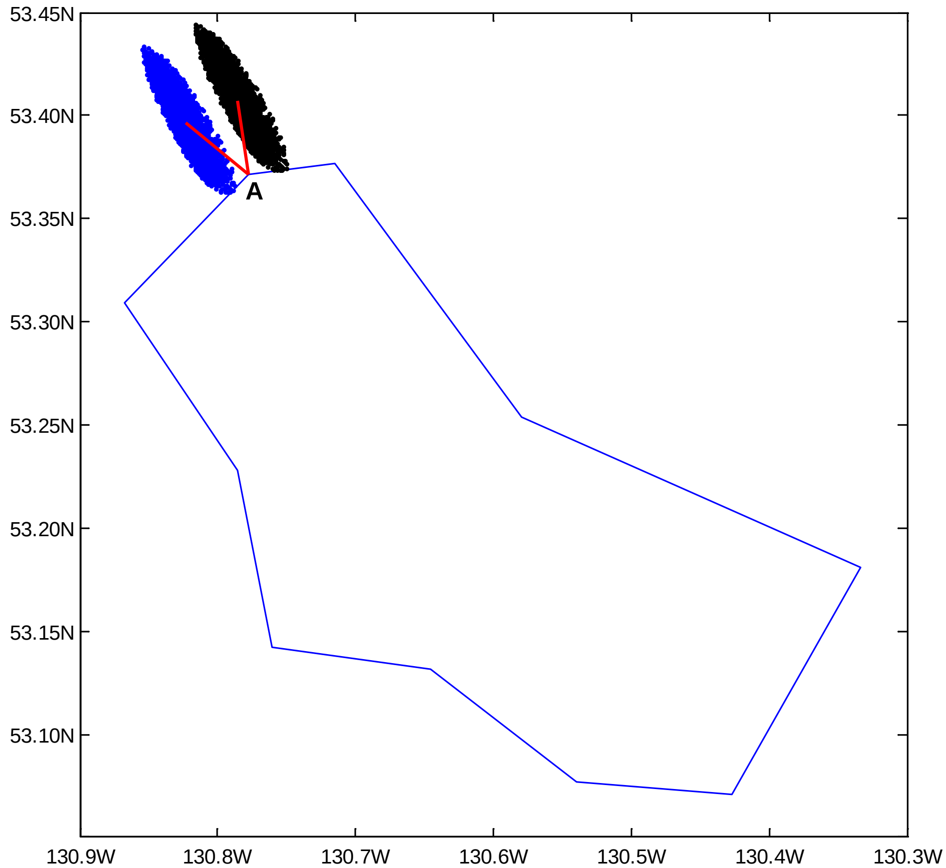


Figure 24 Example of the determination of the width of the buffer zone using the tidal excursion clouds for the most northern point, A, of the northern fishery closure.

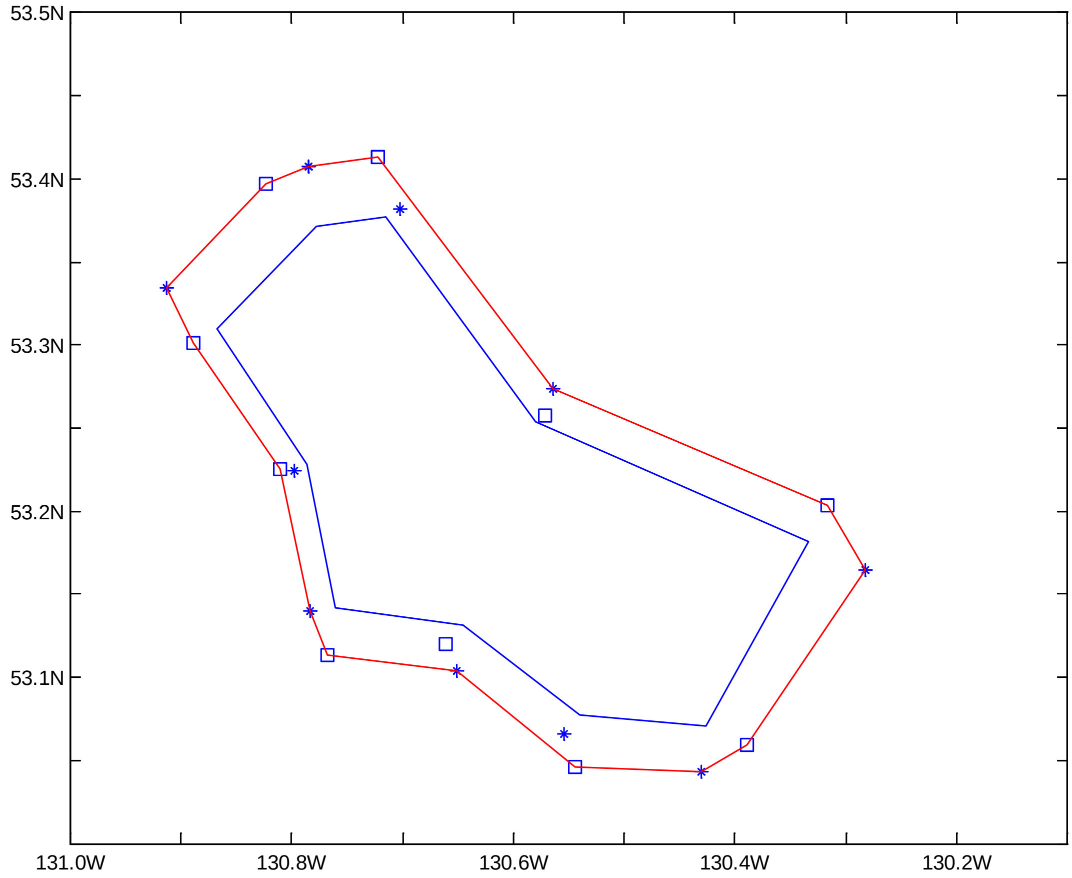


Figure 25 Extent of the sediment transport buffer zone for the northern reef complex. The blue line shows the boundary of the CMZ, while the red line shows the boundary of the models total exclusion zone. Stars and squares show positions of the computed points of origin of each ellipse, as described in the previous figure.

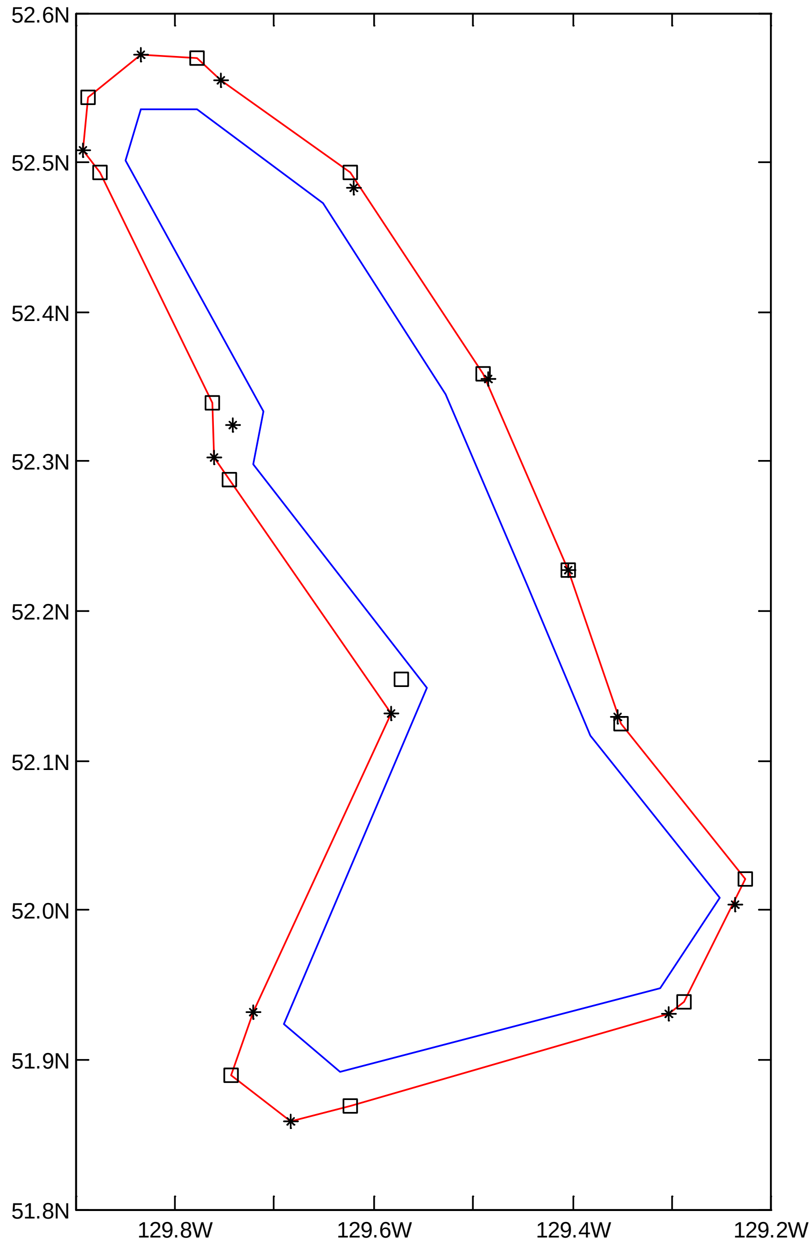


Figure 26 Extent of the sediment transport buffer zone for the central reef complex. The blue line shows the boundary of the CMZ, while the red line shows the boundary model total sediment exclusion zone. Stars and squares show positions of the computed points of origin as described in the previous figure.

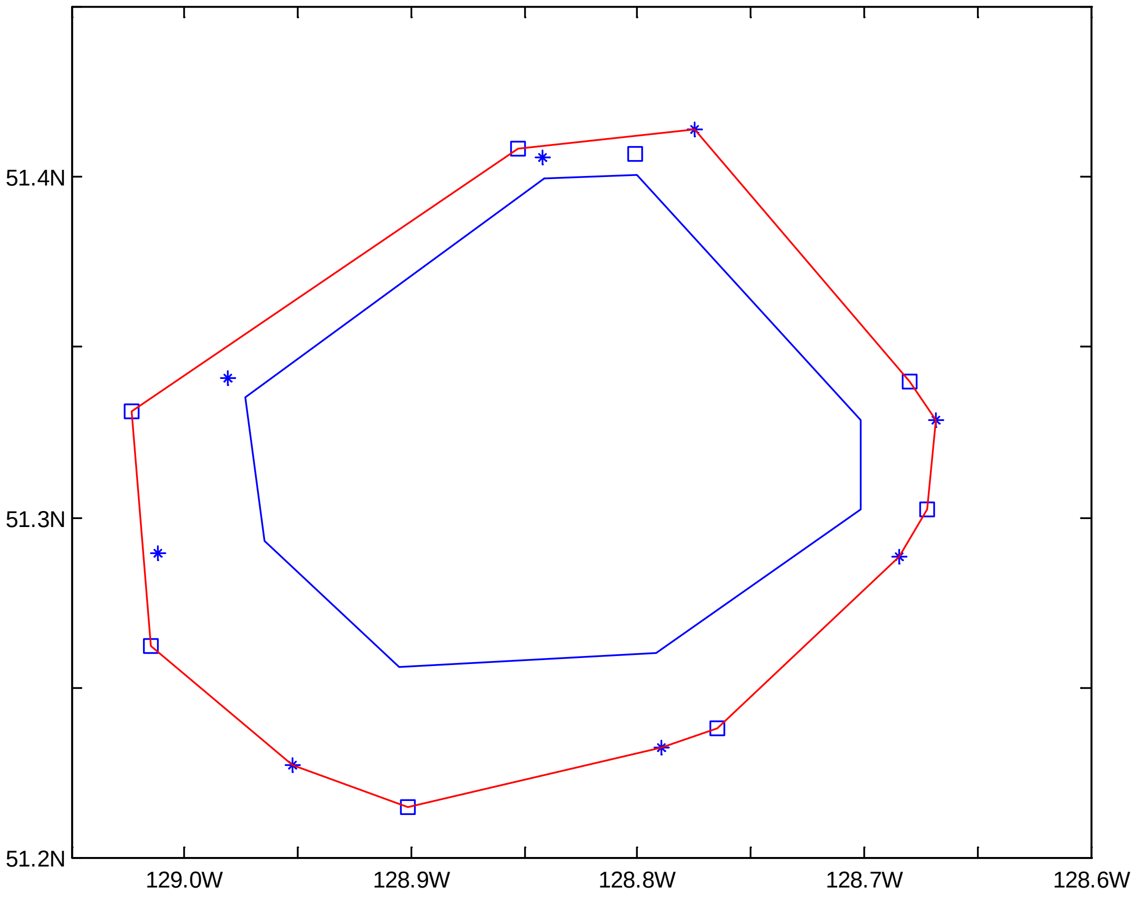


Figure 27 Extent of the sediment transport buffer zone for the southern reef complex. The blue line shows the boundary of the CMZ, while the red line shows the boundary of model total sediment exclusion zone. Stars and squares show positions of the computed points of origin of each ellipse as described in the previous 2 figures.

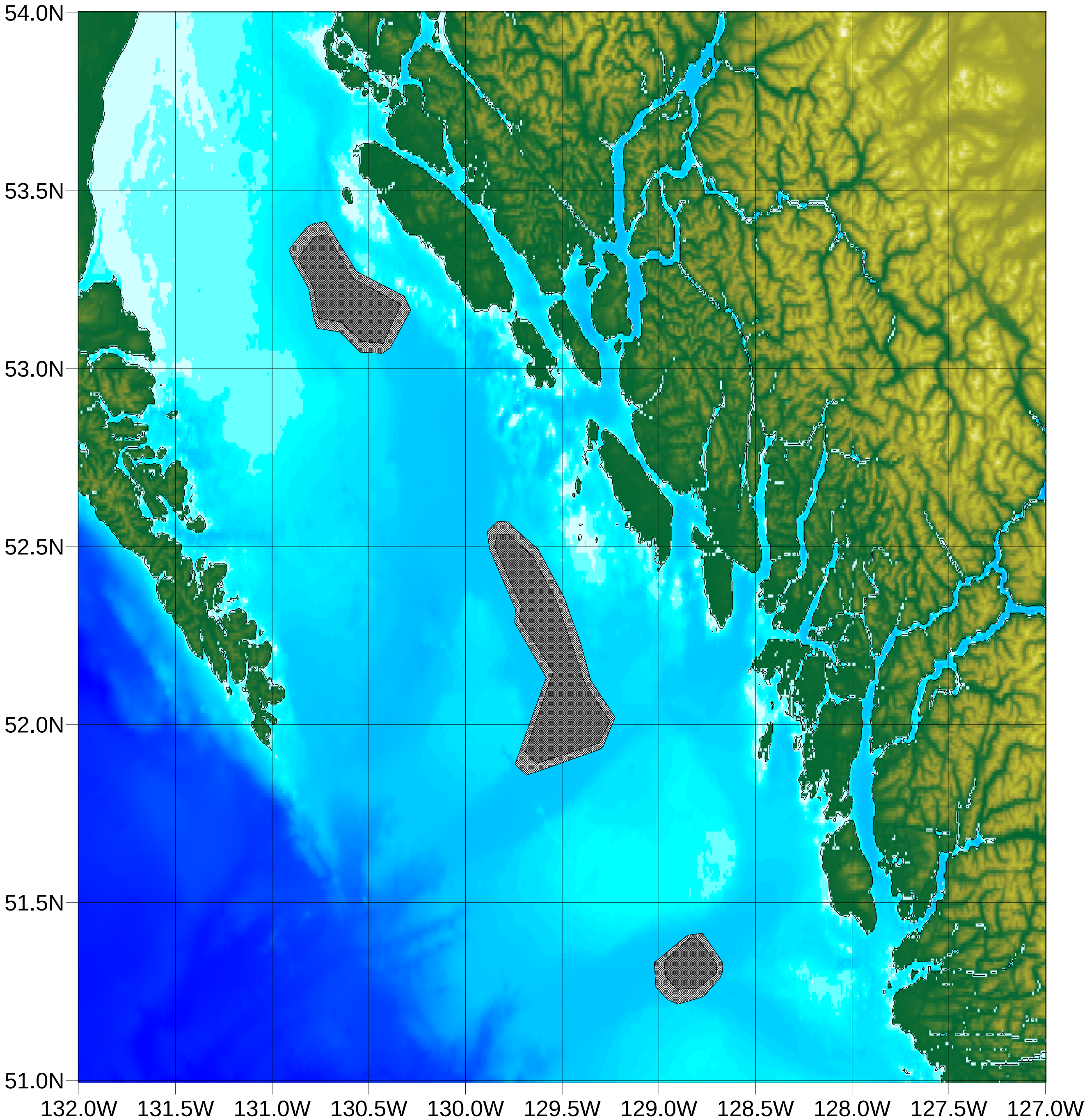


Figure 28 Overview map depicting fishery closures around each reef (grey hatched area) and sediment transport buffer zones (white hatched area).

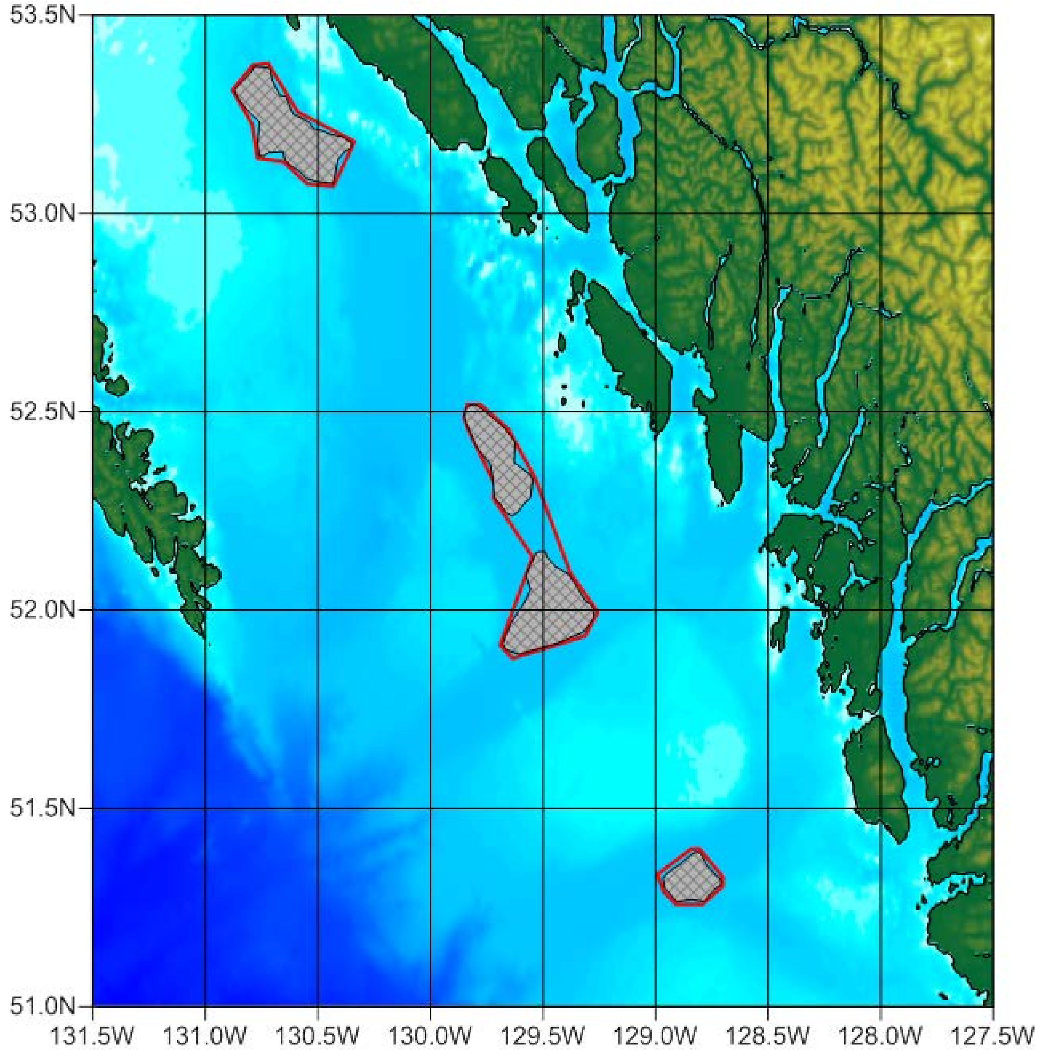


Figure 29 200 m zones (shadow) and current fishery closures (red lines) encompassing the glass sponge reefs.

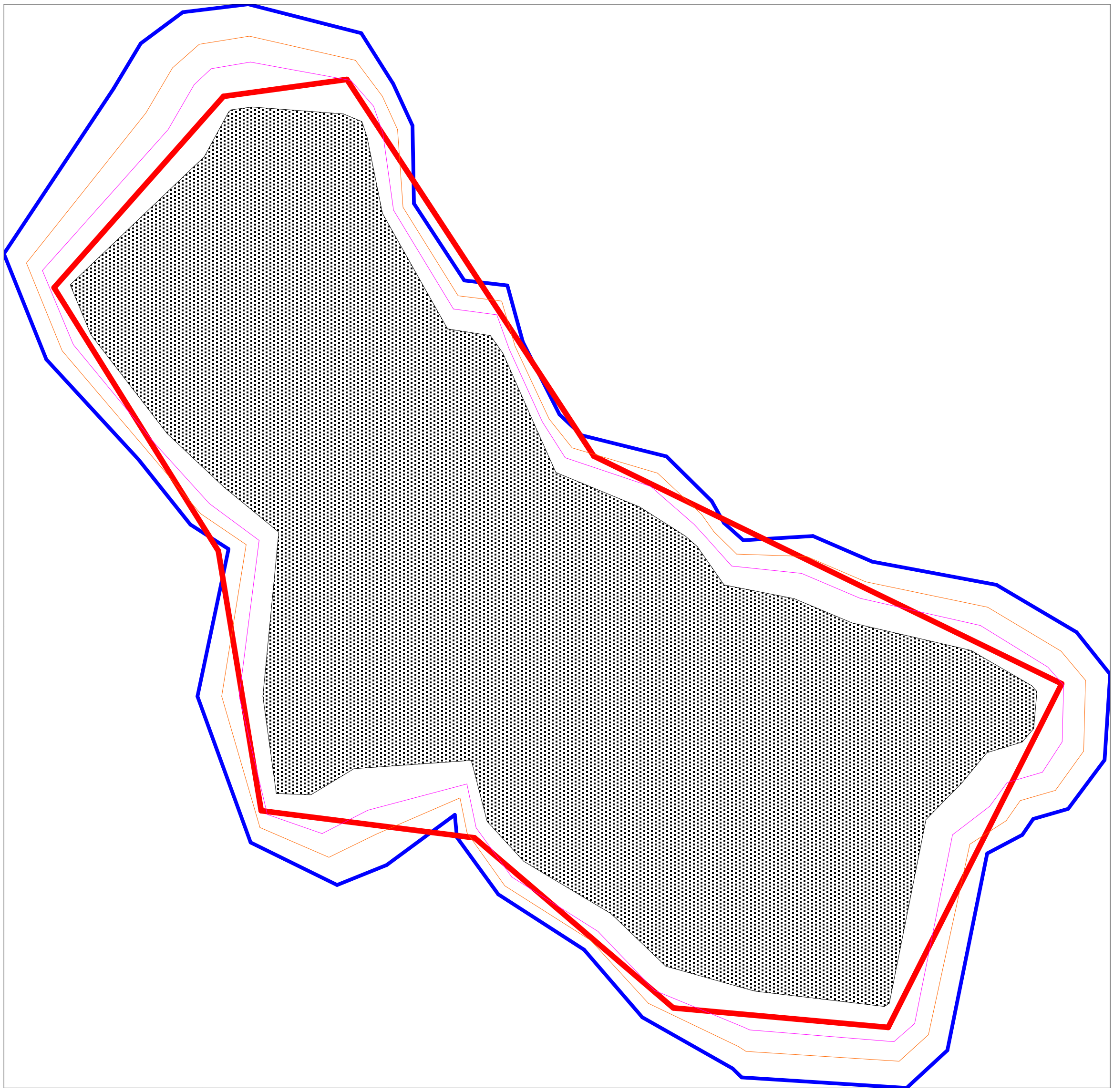


Figure 30. Trawl fisheries closure area boundary (red line) within the AMZ and proposed AOI boundary (blue line) for the Northern zone. Showed the lines where in 5% of the cases the sediments will deposit in the 200m zone (orange line) and the line where in 20% of the cases the sediments will deposit in the CMZ (purple line). The CMZ is shadowed.

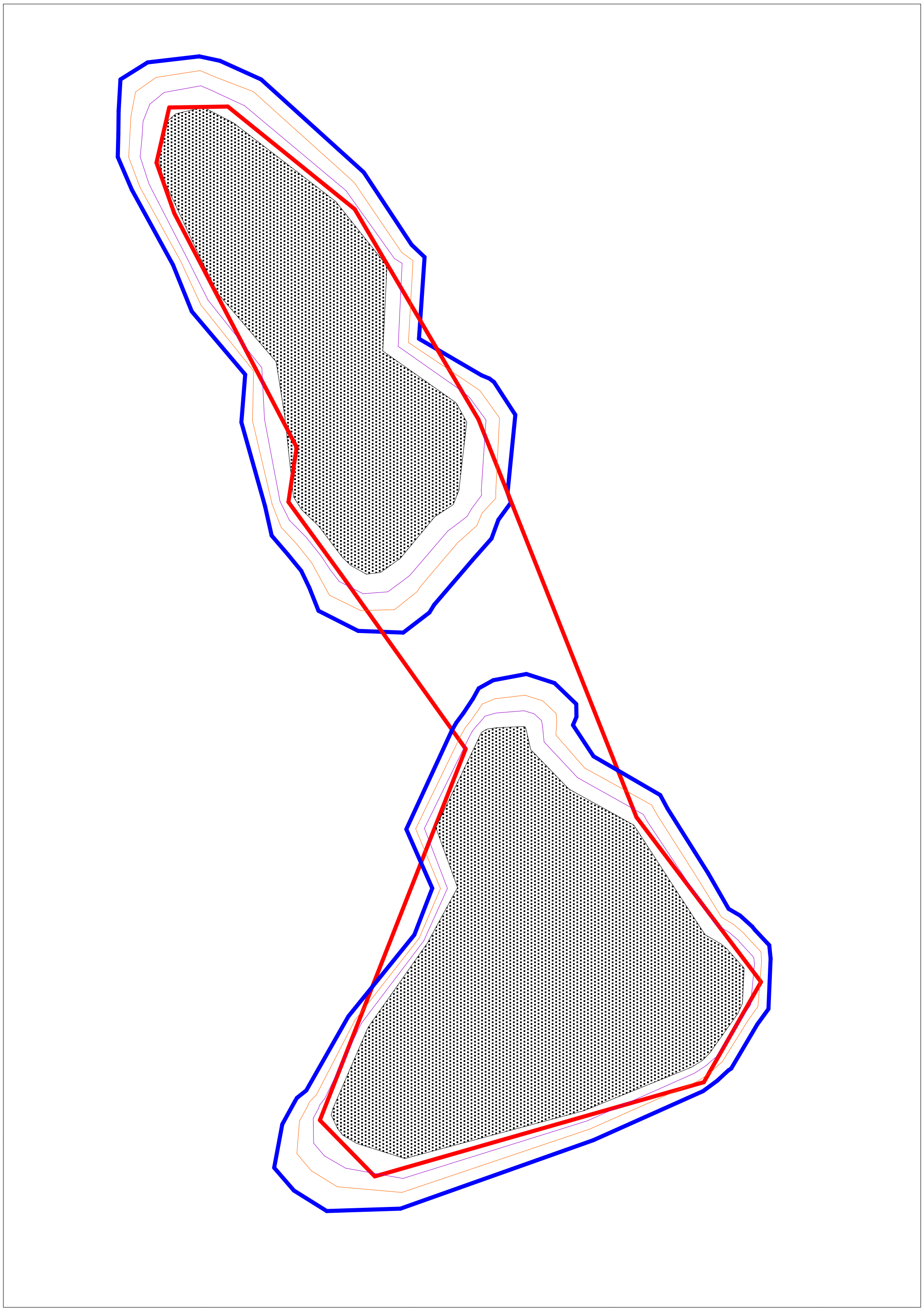


Figure 31 The same as at the Figure 17,a for the Central Reef complex, divided into Northern Compartment and Southern Compartment.

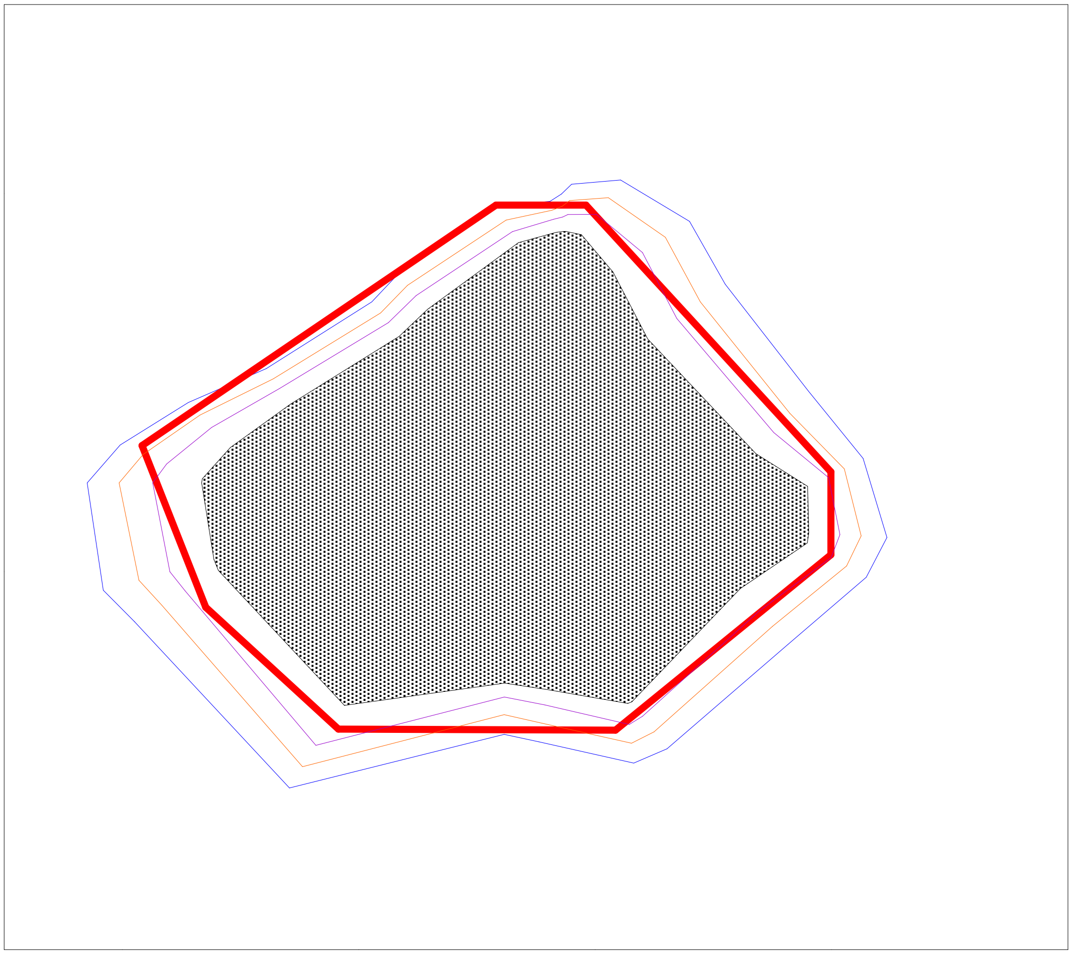


Figure 32 The same as at the Figure 17,for the Southern Sponge Reef Complex.

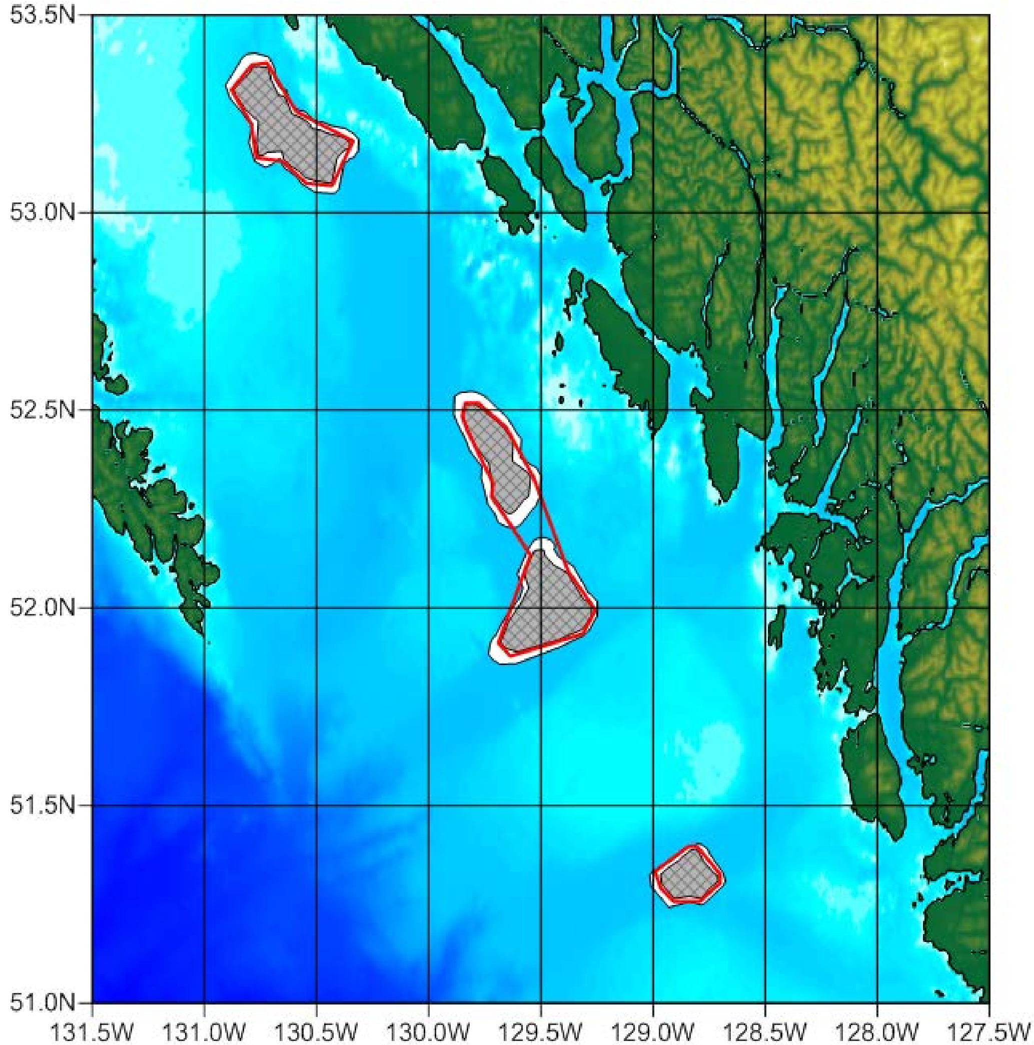


Figure 33 Overview map depicting proposed fishery closures around each reef (grey hatched area) and sediment transport buffer zones (white area).Existing fisheries closure showed in red lines.

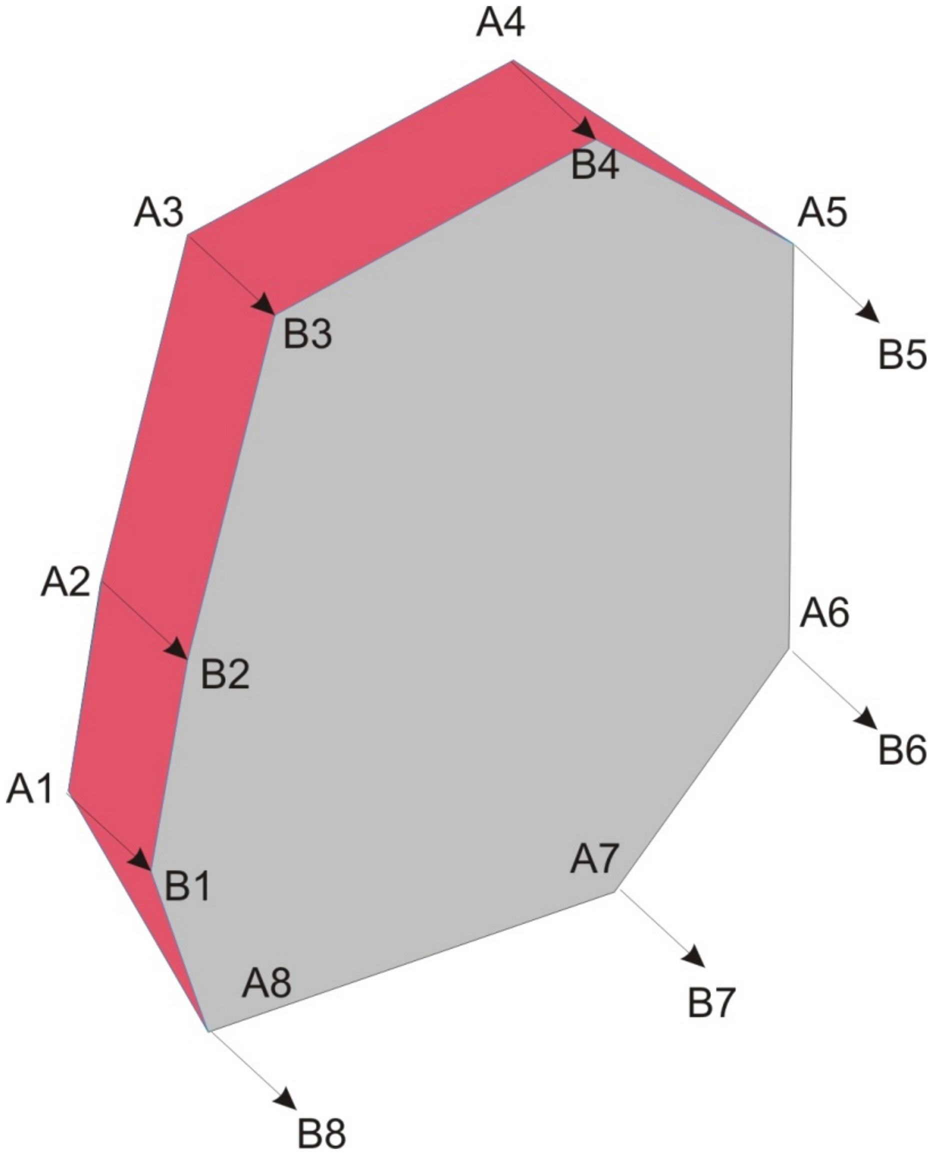


Figure 34 Sketch showing the method use to estimate the area of the CMZ impacted by trawling at the CMZ boundary.

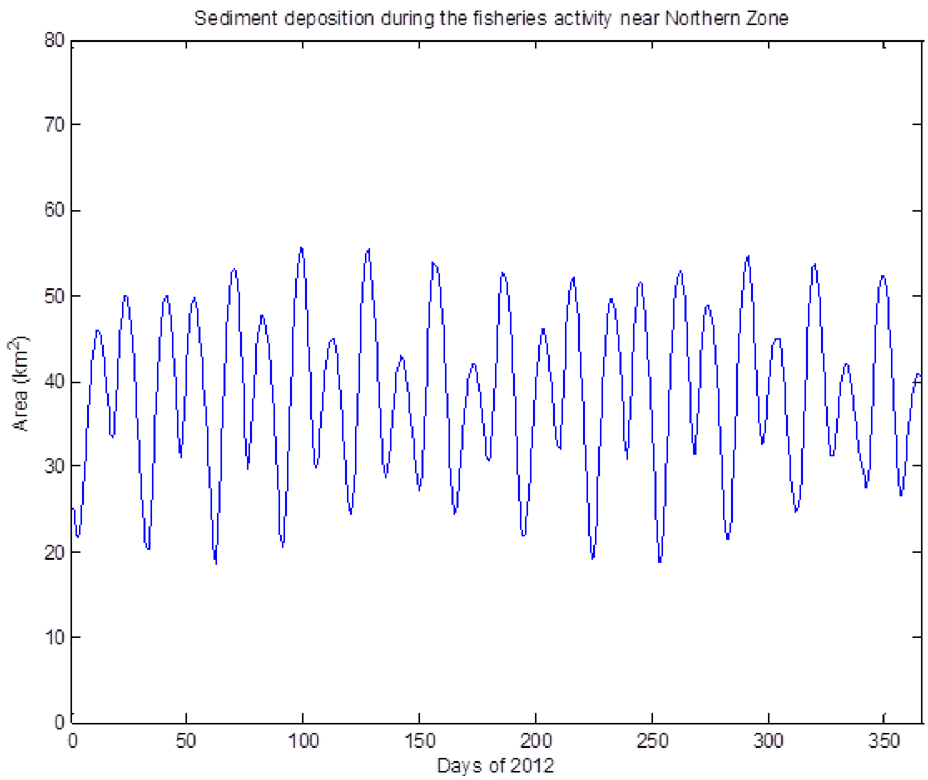


Figure 35 The Area of potential sediment deposition from trawl fisheries activity on the Northern Reef CMZ boundaries at different days of the year 2012 (in km2).

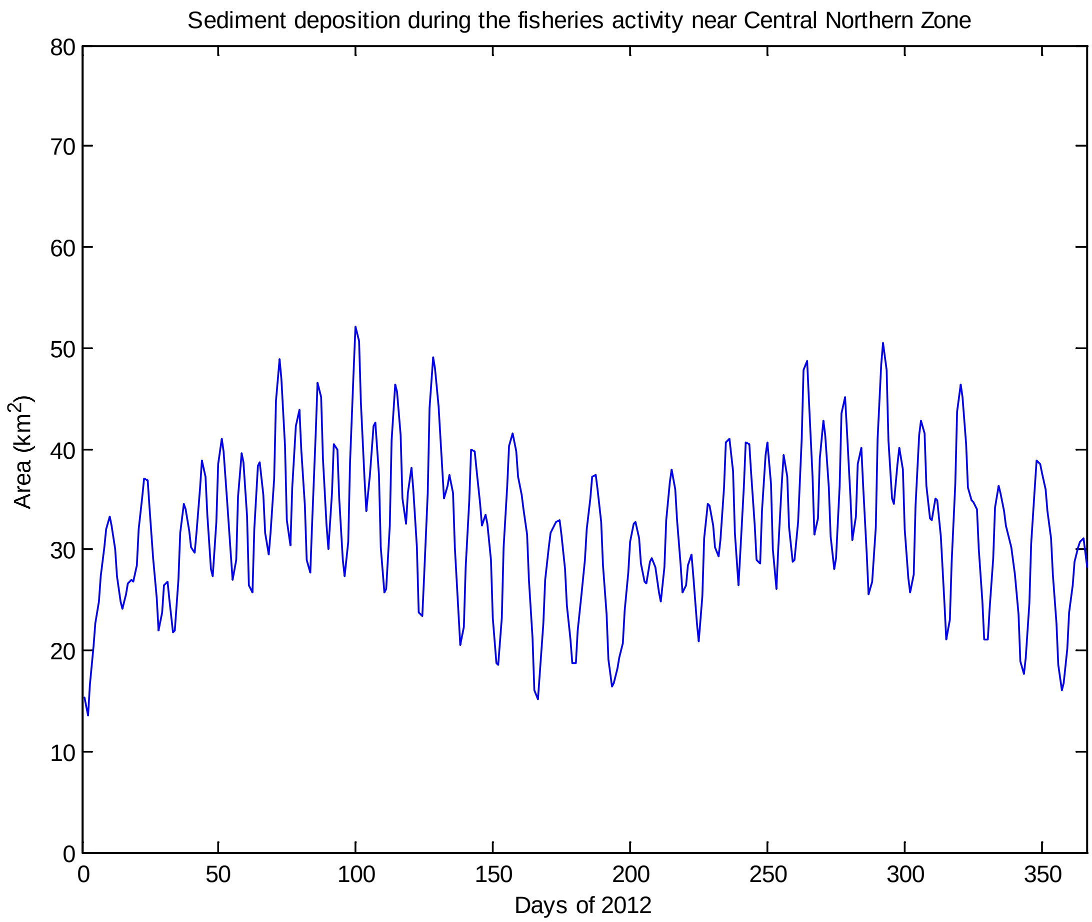


Figure 36 The Area of potential sediment deposition from trawl fisheries activity on the Northern portion of the Central Reef CMZ boundaries at different days of the year 2012 (in km2).

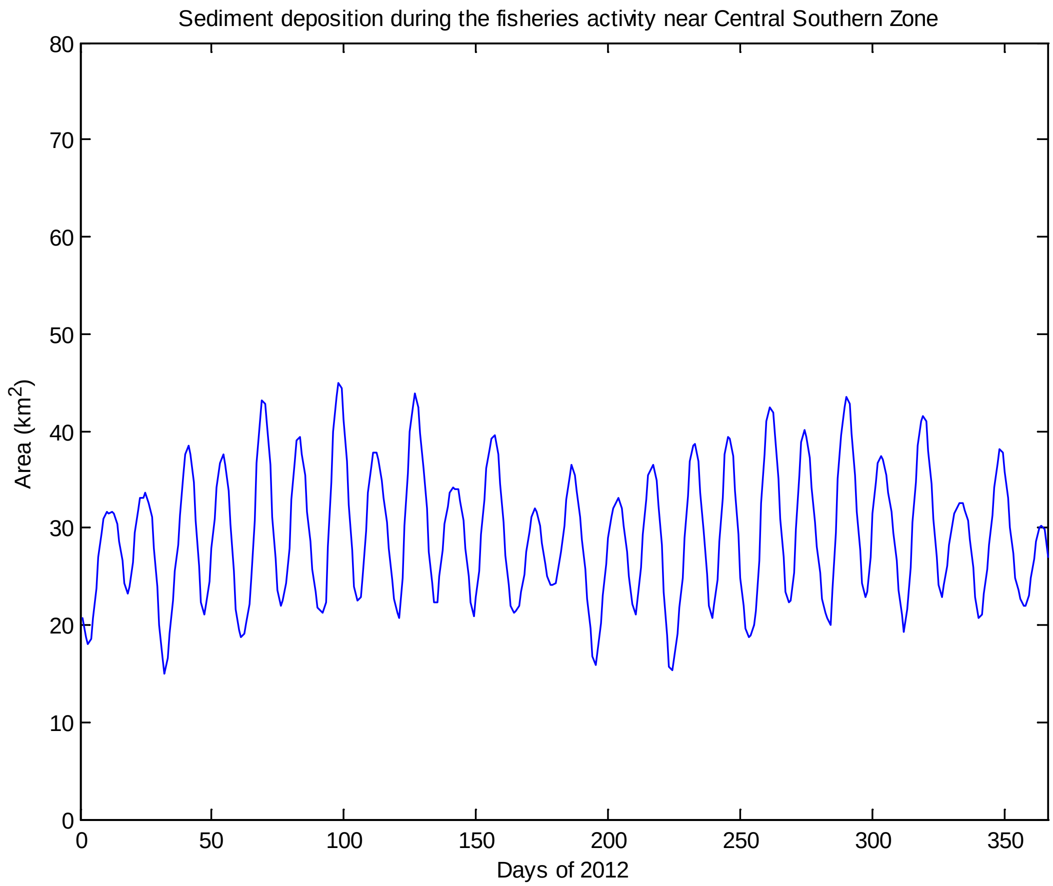


Figure 37 The Area of potential sediment deposition from trawl fisheries activity on the Southern portion of the Central Reef CMZ boundaries at different days of the year 2012 (in km2).

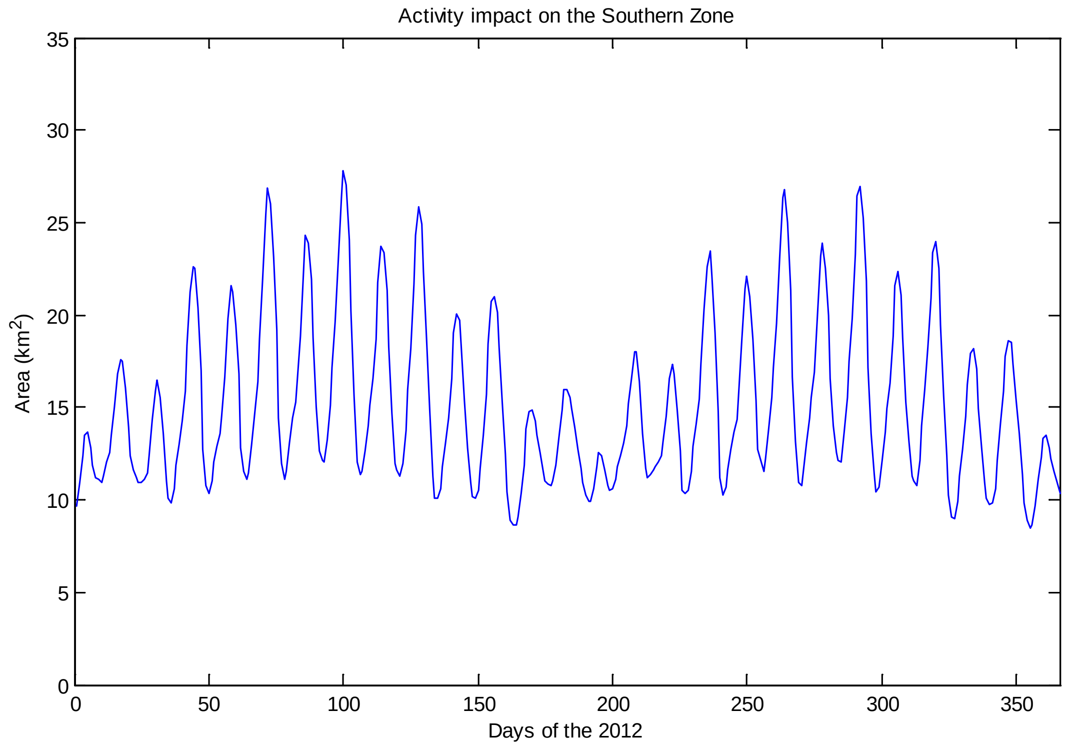


Figure 38 The Area of potential sediment deposition from trawl fisheries activity on the Southern Reef CMZ boundaries at different days of the year 2012 (in km2)..