IDENTIFICATION AND EVALUATION OF BIOLOGICAL EFFECTS AND IMPACTS OF SEDIMENT TO SPONGE COMMUNITIES IN HECATE STRAIT

Figure 1 Overview of the Hecate Strait and Queen Charlotte Sound Sponge Reef Area of Interest and the proposed Adaptive Management Zones

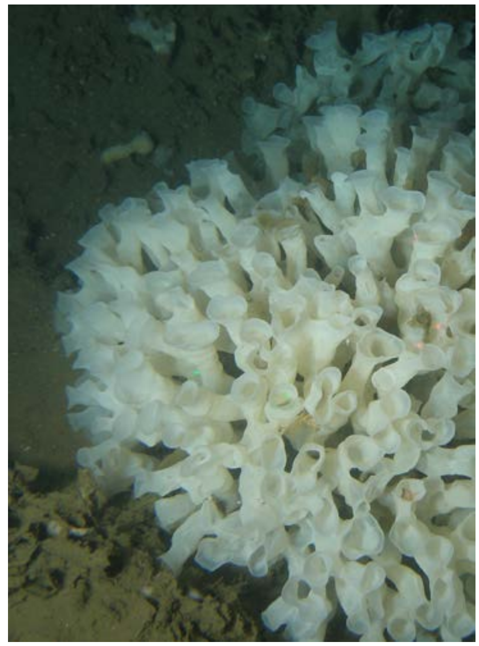

Figure 2: Farrea occa a species of reef-forming glass sponge found in Hecate Strait.

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 uniqueness (Conway et al. 1991, Conway et al. 2001 & Krautter et al. 2001),

Indirect effects due to resuspension of sediment from human activities have been documented to affect sponge communities including hexactinellid 'glass' sponges, however, the nature and extent of these effects in Hecate Strait Sponge Reefs are unclear. Fishing activities that re-suspend sediment, due to contact with the bottom, occur in the Adaptive Management Zone (AMZ).

DFO Ecosystem Management Branch Pacific Region 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 a range of mitigation options to reduce these effects.

This Science Advisory Report is from the Identification and Evaluation of Biological Effects and Impacts of Sediment to Sponge Communities in Hecate Strait, Canadian Science Advisory Secretariat, Regional Peer Review meeting held October 23 to 25th, 2012. Additional publications from this meeting will be posted Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Glass sponges are animals with tissues and sensory systems, but they are non-motile due to the absence of any muscle. Therefore, they are dependent on underwater currents for delivery of food. The few places where glass sponges occur in high densities exhibit a balance between high turbidity (natural fallout that delivers nutrients) and sufficient current to prevent accumulation of sediment and smothering.
- Sponges feed by filtering water for digestible organic material, largely bacteria. Exposure to suspended sediment (above background levels) causes arrest of the feeding current through the sponge. Prolonged exposure (>40min) causes clogging of the sponge filter and a reduction in the volume of water processed and in nutrient uptake. For reef building glass sponges, loss of energy supplies during summer periods of peak feeding could compromise growth and future reproductive ability.
- Indirect effects due to resuspension of sediment from human activities have been documented to affect sponge communities including hexactinellid 'glass' sponges. Fishing activities that re-suspend sediment, due to contact with the bottom, have historically occurred, and continue to occur, in the Adaptive Management Zone (AMZ) of the proposed Hecate Strait and Queen Charlotte Sound Area of Interest (AOI).
- This assessment did not consider the risk to the ecosystem from impacts to sponge reefs. In the absence of a detailed understanding of the ecosystem consequences of exposure to sponge reef communities, a precautionary approach is recommended considering the mitigation scenarios that reduce the risk of exposure.
- An assessment was conducted of the risks to sponge reefs associated with remobilization of sediment from fishing activities. The assessment considered both the physiological consequences of sediment on glass sponges and sponge reefs and the level of exposure or the impact of remobilized sediment from various types of fishing, which have historically occurred in the Adaptive Management Zone (AMZ) of the Hecate Strait and Queen Charlotte Sound Sponge Reefs.
- The assessment found that the risk associated with fixed and mobile fishing gear caused by remobilization of sediment is "high", and may cause deleterious effects on sponge reef organisms. As a result, a higher level of scrutiny and potential management action are recommended.
- A number of factors related to the potential level of exposure were explored quantitatively. Factors that affect the rate and range of exposure of sponge reefs to re-suspended sediment were identified to include: the interaction of fishing gear with the bottom, which determines the height to which sediment is ejected in the water column; sediment composition, which determines the length of time sediment is suspended in the water column; and, current speed, which determines the distance and direction over which sediment is carried in relation to the location of the fishing event.
- Exposure was assessed using data and models to understand: the level of interaction of fishing activities with benthic sediments; the historic locations and timing of fishery activities in the AMZ; the sediment types surrounding each reef complex; and, the factors that affect the resettlement rates of the remobilized sediment.
- The findings of the sediment dispersion models were used to identify the risk of exposure to the sponge reef from remobilized sediment under six mitigation scenarios, and are presented for management consideration.

INTRODUCTION

The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs (Figure 1) have been identified as ecologically and biologically significant areas. They are globally unique, particularly vulnerable to damage and disturbance, and provide important habitat for invertebrate and vertebrate animals including corals, tubeworms, shrimp, crabs, and fish species. The existence and formation of the reefs requires a combination of unique geological conditions combined with the occurrence of reef-forming species of hexactinellid (glass) sponges.

The reefs occur in four complexes with large, steep reef mounds and ridges covering a discontinuous area of 1,000 square kilometres. They are located in glacial troughs at depths between 140m and 240m. Small patches of reef grow over time and coalesce to form large, irregular structures extending to 25m in height and several kilometres wide. Although the glass sponge reefs date back about 9,000 years, the live sponges are up to 450 years old. They are fragile and particularly vulnerable to damage and disturbance. Recovery of a destroyed reef surface is uncertain, but was it to occur, it would likely take several tens to several hundreds of years.

The Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs (Figure 1) are currently in the process of being designated collectively as an *Oceans Act* Marine Protected Area (MPA), as part of Fisheries and Oceans Canada’s Health of the Oceans Initiative. They have been identified as an Area of Interest (AOI) for application of an ecosystem-based management (EBM) approach, as part of the Pacific North Coast Integrated Management Area (PNCIMA).

Sponges are suspension-feeding animals. They feed by filtering digestible particles, mostly bacteria (0.2-1µm) and picoplankton (0.2-10µm) (e.g. unicellular algae) from the water column. They draw water through pores in their surface tissues, to chambers of choanocytes where food is captured on filters of less than 0.1µm mesh size.

Resuspension of sediment from human activities has been shown to affect sponge communities, including hexactinellid ‘glass’ sponges. In Hecate Strait, remobilized sediments could have a variety of effects on sponges depending on the extent and duration of re-suspension events. These include clogging of the filter and smothering of the inhalant pores.

This review examined only sediment resuspension from fishing activities, as these are the only known activities, with the potential to create resuspension, currently in the area.

ASSESSMENT

Two research documents were prepared and reviewed for this assessment. One concentrated on the physiological **consequences** of sediment on glass sponges and sponge reefs, and the other addressed the level of **exposure** and the **impact** of remobilized sediment from the various types of fishing, which have historically occurred in the AMZ of the Hecate Strait and Queen Charlotte Sound Sponge Reefs.

To assess the **consequences** of sediment on sponges, with a particular focus on glass (hexactinellid) sponges and sponge reefs, research findings from physiological and filtration experiments conducted on several different species of sponges including glass sponges were reviewed and synthesized. These studies were conducted both *in situ* and in laboratory settings.

The theoretical information needed for calculating the **exposure** term of an ecological risk analysis was presented. Further, a hypothetical evaluation of how the level of **exposure** might vary under different mitigation options was provided.

Inputs to the exposure term were:

1. A summary of the fishing patterns by gear type in the AMZ over from 2007 – 2011.
2. A description of the substrate and sediment types in each reef complex.
3. Estimates of the potential area of impact from remobilized sediment. This was calculated with inputs from the following models:
    - A sediment re-settlement rate model based on sediment type and the height of the sediment cloud; and,
    - A sediment dispersion model using the estimated re-settlement rates calculated in the first model, and a calculation of the effective area of dispersion of the remobilized sediment. This later calculation was made using fine scale regional oceanographic models.

    Three scenarios were modeled:

    - The first scenario calculated the maximum tidal excursion and sediment transport around the AOI.
    - The second scenario calculated the potential area of impact based on historic fishing patterns.
    - The third scenario calculated the potential area of impact by only allowing fishing on days with the lowest tide cycles.

    The findings of the sediment dispersion models were then used to estimate the area of exposure under six mitigation scenarios.

Results

Effect on sponges

Sponges are suspension-feeding animals. They feed by filtering digestible particles, mostly bacteria (0.2-1µm) and picoplankton (0.2-10µm) (e.g. unicellular algae) from the water column. To do this they draw water through pores in their surface tissues, into canals that carry the water to chambers of choanocytes where food is captured. Sponges and other benthic suspension feeding invertebrates can live in areas of high turbidity if there is little accumulation of silt. Where silt deposition is high, fewer sponges are found. In experimental manipulations in their natural environment, sponges generally die when covered by silt.

In British Columbia, glass sponges are most common on rock walls and on raised topography on the seafloor where accelerated water enhances flow over the sponge at flood and ebb tides. Glass sponges appear to have evolved to take advantage of a process called passive flow, whereby currents are induced through their tissues when there is accelerated flow over them. By using passive flow, they process more water and filter more bacteria without expending additional energy by pumping. The morphology and physiology of the sponge that allows it to make use of passive flow is expected to be an adaptation to food-poor habitats. The corollary is that if pumping becomes costly, or if passive flow is reduced, for example due to increased resistance through the sponge body due to clogging, the sponge would not meet its energetic requirements.

Sponges are sensitive to total suspended solids (TSS) of >10mg/L. Turbid water may consist of organic and inorganic matter, some of which may accumulate on surfaces, and other parts may be consumed or removed by processes prior to settlement. Prolonged sediment exposure causes arrest in flow and clogging in glass sponges. No experiments have tested long-term effects of smothering of glass sponges by sediment in their natural environment because these animals are difficult to maintain for long periods in laboratory settings and because experiments in their natural setting are not logistically possible given the depths at which these animals live. However, the experiments that have been undertaken in the laboratory demonstrate that continued presence of >15-35 mg/mL of sediment (grain size <25µm) caused complete and continued arrest of glass sponge pumping and filtration. Longer than 40 minutes exposure to 15-35 mg/L sediment caused clogging of sponge feeding tissues. Clogging alone reduced the volume filtered by 50% of maximum filtration rates, amounting to a reduction of approximately 30% of daily food intake. For reef building glass sponges, loss of 30% of the energy supplies during summer periods of peak feeding could compromise growth and future reproductive ability.

Fishing (by gear type) that occurs in the area

For the purposes of this risk assessment an analysis of the groundfish bottom trawl, groundfish midwater trawl, groundfish longline, and prawn by trap activities was conducted for the period 2007-2011.

Bottom trawling interacts with the seafloor as part of normal operations, and the area of potential impact is significantly larger than the relative size of the gear.

Midwater trawling is typically operated in a manner to avoid gear contact with the bottom, however, contact with the bottom during fishing operations can occur and other jurisdictions that report incidents of bottom contact have taken to managing these activities in areas that contain vulnerable and sensitive benthic organisms and habitats (NMFS, 2005) A review of the catch data from the AMZ area revealed that a number of “midwater” tows reported flatfish species in the catch which would indicate contact with the bottom.

Stationary fixed gear on the bottom typically impacts the benthic substrate within an area equivalent to the relative size of the gear, typically described as the “footprint”. Groundfish longline gear is a stationary fixed gear, whereby a ground line, with hooks attached at regular intervals, is deployed and anchored at both ends. Under best case conditions, the gear can be retrieved so that the area of impact is no greater than the footprint of gear, however, the area of impact can potentially increase during inclement weather or if the gear gets snagged on the bottom.

Prawn traps are also a stationary fixed gear set along the seafloor attached to a longline that is anchored at both ends. On average, there are 50 prawn traps that are up to 1-meter diameter in size and are each snapped onto the longline at 10 m intervals. However, the same weather and effects caveat outlined for groundfish longline apply.

Sediment at reef

The surface sediments and shallow subsurface geology of the seabed adjacent to the sponge reef complexes on the western Canadian shelf are composed of glacially derived gravel and till and a variety of glacio-marine sediments. No reefs develop where glacial deposits are thickly

(>50 cm) buried by subsequent finer sedimentation of sand, silt and clay. Where the reefs occur, the surficial seabed includes gravel to which sponges can attach and grow. The sediments adjacent to the reefs are variable and depend on the age and genesis of the geological unit.

Estimates of the potential area of impact from remobilized sediment

Sediment Settlement Modeling

For this assessment, the settlement rates for remobilized sediment was based on a maximum tidal current velocity = 0.35 m/s and a clay-silt cohesive floc sediment composed of: 55% silt (3.9 to 63µm), 30% clay (0 to 3.9µm) and 15% sand (63µm+) with an average grain size of D50 = 20µm. This sediment is similar in composition to many of the silt-clay-sand sediments found around the sponge reefs.

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 and would have a much higher settling velocity than non-cohesive individual particles.

The model demonstrated that if an area with this type of sediment were trawled, under maximum current flow 0.35m/s and with a median particle size of 20µm, the settling velocities of the clay-silt cohesive floc would be such that in 3 hours, sediment that had been ejected 3.5m up into the water column would be dispersed to settle and reform with the bottom at a distance of no more than 2 to 3 km away, while sediment ejected higher than this (up to 10m) could travel as far as 7-8 km. Thus the estimates for settling time and distance traveled double as the ejection height doubles

In general, 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, assuming they are ejected 10m into the water column. Similarly, smaller particles (<20um) will travel farther than the modeled median particle size.

Sediment dispersion models

The sediment dispersion models used the estimated re-settlement rates calculated in the first model, and inputs from fine scale regional oceanographic models, to calculate the effective area of dispersion of the remobilized sediment. These models were:

1. Maximum tidal excursion and sediment transport around Glass Sponge reef complexes

This model was used to estimate the size of the AMZ needed around each reef complex to reduce the likelihood of resuspended sediment settling on the reefs.

Table 1. Area (in square km) of the AMZ for each reef complex

	Total Area (km^2)
Northern Reef	877
Central Reefs	1526
Southern Reef	378
Total	2780

2. Potential area of impact from the bottom trawl fishery with historic restrictions.

In this model, the efficacy of the existing bottom trawl fishing closure in terms of deposit of remobilized sediment resulting from the fishery were examined. The results demonstrated that the existing Fishery Closure Areas for bottom trawling are inadequate and that re-suspended sediment is carried over the reef complexes.

3. Potential area of impact from the bottom trawl fishery with fishing days allowed only at the lowest tide cycles as a mitigation measure

In this model the effect of reduced fishing days by tidal cycle could reduce the sediment loading by as much as 20% assuming historic levels of fishing.

Risk Assessment

In addition to the quantitative assessment of exposure, a second type of ecological risk assessment (ERA) was carried out. This was a qualitative ERA based on the National Sustainable Fisheries Framework (SFF) and a broader ERA Framework that is in development for Ecosystem-based Oceans Management in the Pacific Region (EOM-ERAF). The ERA assessed the likelihood and consequences of gear contacting the bottom, which is the specific stressor or activity of concern with respect to re-suspension of sediment. The result was that a level of high risk was identified for all the mobile and fixed fishing gear. The EOM-ERAF specifies that a moderate to high level of risk indicates that a higher level of scrutiny is needed and management actions will be required to reduce the risks.

To address the need for management actions, the findings of the sediment dispersion models were then used to explore the results of six mitigation scenarios. The intent of these scenarios was to demonstrate a range of mitigation options that could be quantitatively assessed in greater detail. Specifically, the scenarios evaluated were;

1. No additional mitigation measures. This scenario applies no input controls on fishing gear types, nor on the level of effort or on the area of effort in the AMZ. This scenario leaves the greatest uncertainty with respect to exposure and could ultimately provide the highest risk to the AMZ.
2. Restrict fishing to historic levels of effort, timing and areas. At best, this would be exposing the reef complexes to the same level of exposure that they have been subject to over the period from 2007-2011.
3. Restrict the fishing days to those with the smallest tidal change. This scenario could partially reduce the level of exposure but the benefits would only be realized if it were combined with Scenario 2 - Restrict the fishing on a daily basis to a time/area in which the remobilized sediment will flow away from the reef complex. Under this scenario, all fishing operations when the gear is mobile (i.e. all trawling activities and the setting and recovery of fixed longline and prawn trap gear) would be restricted by area and time of day to those situations when the remobilized sediment would drift away from the AMZ.
4. Restrict the height from the bottom for midwater trawling. This scenario only applies to the midwater trawl fishery and would restrict the depth that trawling could take place such that bottom contact within the AMZ would not occur. If this scenario were combined with Scenario 2 and or 3, this would also reduce the cumulative effect of exposure in areas where other fisheries occurred

5. Exclude certain types of gear from the area completely. In this scenario, all fishing activities for which mitigation measures do not eliminate the exposure, would not be allowed within the outer boundary of the AMZ

Sources of Uncertainties

Several knowledge gaps were identified that contribute to some uncertainty in this assessment. These included incomplete knowledge about the intensity of gear effects that result in remobilization of sediment, which will occur as a result of the manner in which the gear is fished which is related to individual fishermen's experience and the vagaries of each situation, including weather and bottom topography. The analysis did not consider the effect of the volume of disturbed sediment in the estimation of area of impact. It could be useful to develop estimates of volume, as this could improve estimates of the extent of the area of reef that would be affected by sediment disturbance.

With regard to the effects of long-term exposure to sediment on glass sponges, these have not been studied in the wild or in tanks due to inaccessibility of reefs and the difficulty of maintaining these deep water animals in aquaria for long periods. Long-term effects on glass sponges have therefore been estimated with assumptions from known effects of long-term exposure to sediment on other types of sponges and from extrapolation from short-term experiments on glass sponges. Finally, there is an incomplete understanding of the extent of acute and chronic effects to sponges from a single versus repeat exposure to remobilized sediment. Although even short-term continuous exposure reduces and abolishes filtration by the sponges, it is not known at what point mortality occurs. It is also not known what effect sediment resuspension and redeposition has on larval settlement and recruitment.

Ecosystem Considerations

This assessment addressed risks from remobilized sediment pose to the glass sponges that make up the sponge reefs. However, the assessment did not consider the risk to the ecosystem from impacts to sponge reefs. Glass sponges play a key role in the recycling of nutrients and energy derived from bacteria within an ecosystem. They also provide habitat and shelter from predation and provide unique feeding opportunities and resting areas for a number of commercial species and the community that supports those species. This review has started the process to quantify the consequence of remobilized sediment on the glass sponges themselves, but there is a great deal of work that needs to be done to quantify the effects on ecosystem functioning and the resulting effects on the production characteristics of commercial fish populations that utilize the area.

CONCLUSIONS

- Suspended sediment above ambient levels causes clogging of the sponge filter. Since reef sponges feed continually, reduced feeding due to clogging may cause the sponge to intake less than necessary to meet its energetic requirements, which would have the potential to compromise growth and future reproductive ability.
- Current fishing gear and activities that can resuspend sediment in the AMZ are bottom trawling, mid-water trawling, longlining and trap fishing.
- The assessment found that the risk associated with fixed and mobile fishing gear to cause remobilization of sediment is "high" and may cause deleterious effects on sponge reef

organisms. As a result a higher level of scrutiny and potential management action is recommended.

- This assessment did not consider the risk to the ecosystem from impacts to sponge reefs. In the absence of a detailed understanding of the ecosystem consequences of exposure to sponge reef communities, a precautionary approach is recommended considering the mitigation scenarios that reduce the risk of exposure.
- Use of quantitative assessments, incorporating sediment resettlement rate models and dispersion models were developed and provide a suite of tools with which to assess risks of exposure from sediment remobilized by fishing activities to sensitive and vulnerable benthic communities like glass sponge reefs.
- An evaluation of a range of possible mitigation scenarios that provide examples for management actions that might be considered based on the current gear technologies and fishing techniques was completed.
- A future improvement to the sediment dispersion model would be to include a range of sediment sizes instead of an average particle size. This would refine the estimate of dispersal and area of impact.
- A comprehensive quantitative risk assessment requires detailed information on the factors controlling the extent of exposure to the stressor. Such an assessment would likely consider in more detail the temporal and spatial distribution of fishing events, the site-specific sediment characteristics, and the gear-specific estimations of the duration and area of gear interaction with the bottom (i.e. to better estimate plume height).
- Further modeling should be done to investigate and evaluate the mitigation scenario that restricts fishing by time and area according to daily tidal cycles.
- Although a range of mitigation scenarios were presented, in future the fishing industry should also be consulted to assist in developing realistic and practical options for mitigation.
- This modelling and assessment project focussed on effects of sediment resuspension from fishing activities, but the approach has broader applicability and could be implemented to examine effects from other activities (coastal development, drilling, ocean dumping, etc.).

OTHER CONSIDERATIONS

- Climate change impacts that may alter not only glass sponge habitat but also fish habitat and hence management options for fishing activity in the vicinity of the glass sponge reef complexes include coastal erosion (and therefore increased sedimentation) due to sea level rise, ocean acidification, warming and declines in levels of dissolved oxygen. This analysis did not consider the effect of these interacting factors.
- This assessment did not include any consideration of the effects on sponge reef communities from the release of toxic pollutants from disturbed sediment. There are no known point sources of pollution in proximity to the area of concern.

SOURCES OF INFORMATION

This Science Advisory Report is from the Identification and Evaluation of Biological Effects and Impacts of Sediment to Sponge Communities in Hecate Strait, Canadian Science Advisory Secretariat, Regional Peer Review meeting held October 23 to 25th, 2012. Additional publications from this meeting will be posted *Fisheries and Oceans Canada (DFO) Science Advisory Schedule* as they become available.

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