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Pacific Region

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Science Response 2018/042

INDIRECT EFFECTS OF BOTTOM-CONTACT FISHING ACTIVITIES (BY TRAP GEAR) ON SPONGE REEFS IN THE STRAIT OF GEORGIA AND HOWE SOUND

Context

Glass sponge reefs have intrinsic, ecological, and economic value. They provide a link between benthic and pelagic environments, play an important role in carbon and nitrogen processing, and act as a silica sink. Nine glass sponge reef complexes have been mapped by the Canadian Hydrographic Service and Natural Resources Canada in the Strait of Georgia and Howe Sound. The protection of sponge reefs is a key component to a number of international commitments made by Canada through the United Nations Convention on Biological Diversity and the United Nations Food and Agriculture Organization (FAO) Code of Conduct for Responsible Fisheries.

In 2015, DFO protected these nine complexes via formal bottom-contact fishing closures extending 150 m beyond simplified polygons delineating the reef footprints. There is evidence that sediment deposition (following re-suspension from human activities) impacts sponge reef communities, including glass sponges (Leys 2013; Conway et al. 2001; Whitney et al. 2005; Conway et al. 2007; Yahel et al. 2007; Tompkins-MacDonald and Leys 2008). DFO Science has been asked to determine the risk of exposure to each of the presently protected nine sponge reef complexes in the Strait of Georgia and Howe Sound to the remobilized sediment from bottom-contact fishing activities (such as prawn and crab by trap) following the methods used to assess fisheries-induced re-suspended sediment impacts on Hecate Strait glass sponge reefs from bottom-contact trawl fishing (Boutillier et al. 2013).

This Science Response Report results from the Science Response Process March 2018 on the Review of the Indirect effects of bottom-contact fishing activities (by trap gear) on sponge reefs in the Strait of Georgia and Howe Sound.

Background

There are nine sponge reef complexes in the Strait of Georgia (Figure 1); Gabriola Island, Foreslope Hills, and Sechelt each consist of one reef while the others include multiple sponge reefs (Table 1). The indirect effects of bottom-contact fishing activities refer to the deposition of bottom sediments on the sponge reef. This can occur when fishing activity disturbs the sediments on the sea floor causing them to be re-suspended and then transported by ocean currents to ultimately settle on the sponge reef.

Following Boutillier et al. 2013 the method to assess the effects of bottom-contact fishing activities on sponge reefs is to estimate the footprint of the remobilized sediment. This requires the following information:

1. The type of fishing activity. This will determine the height above the sea floor to which the bottom sediment is disturbed.
2. The characteristics of the bottom sediment, in particular the settling rate of the sediment that provides the vertical component to the trajectory of the disturbed sediment.

3. The ocean currents that transport the sediments horizontally.

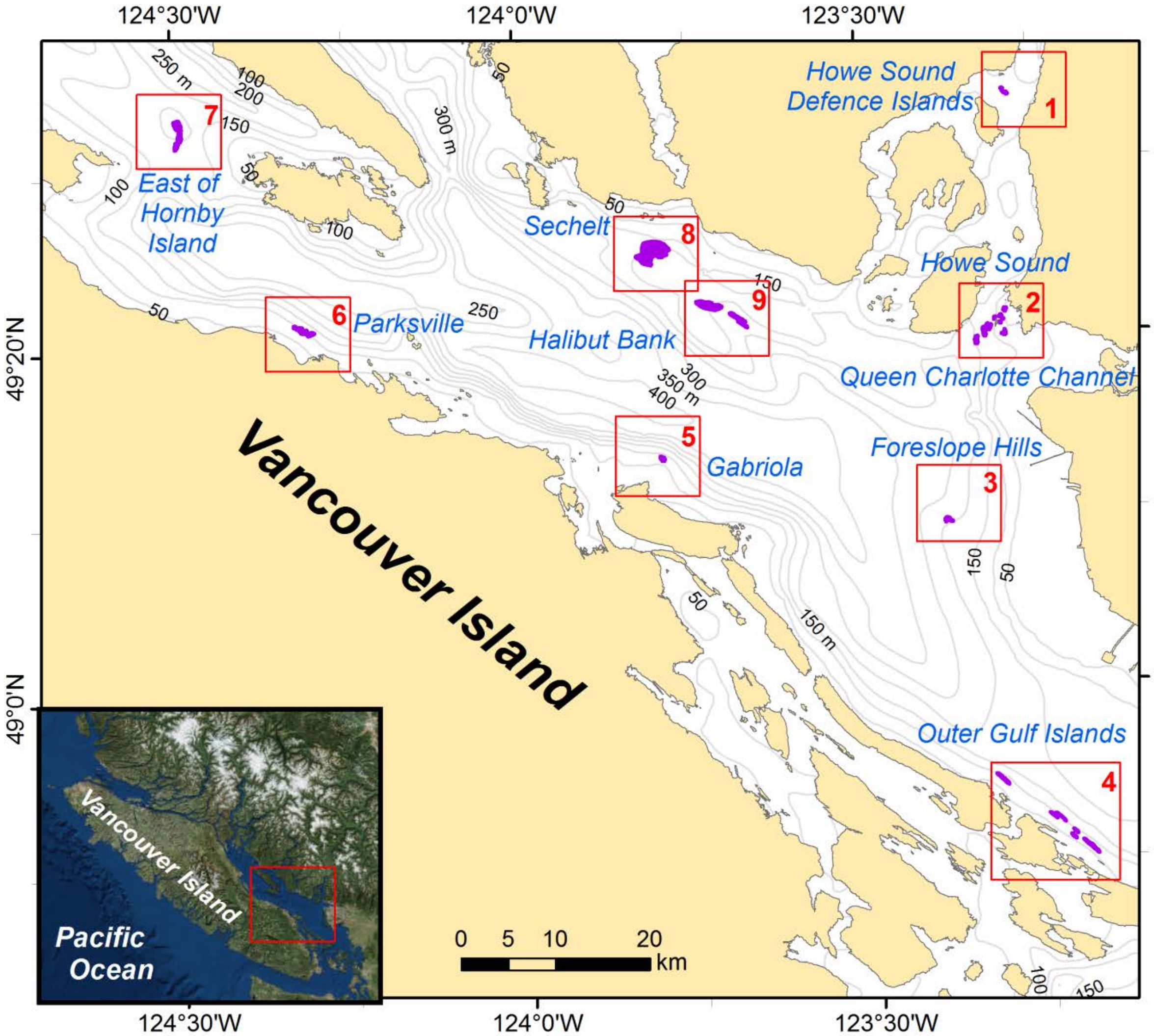

Figure 1. Map of central Strait of Georgia and Howe Sound, located in British Columbia, Canada, showing the locations and names of the nine sponge reef complexes.

Bottom-contact Fishing Activities

The types of fishing activity assessed in this report are those that use bottom-contact trap gear. Typically this involves stationary fixed gear set along the seafloor attached to a longline which is anchored at both ends, and the area of the seafloor sediments disturbed is equivalent to the size of the gear. This can vary depending on the weather at the time of retrieval and if the gear gets snagged on the bottom (DFO 2010).

Table 1. The area and identifier of the nine sponge reef complexes in the Strait of Georgia and Howe Sound as described in Dunham et al. 2018 and DFO Fishery Notice FN0415 (DFO 2016). Footprint areas of the reefs were calculated using the sponge reef footprint shapefiles provided by the Geological Survey of Canada and the Canadian Hydrographic Service in the Strait of Georgia and Howe Sound using multibeam swath bathymetry imagery (Conway et al. 2004, Conway et al. 2005, Conway et al. 2007).

Sponge Reef Complex	Sponge Reef Number	Area of Sponge Reef [m^2]
Howe Sound Defence Islands	1A	20,919
	1B	78,875
Howe Sound Queen Charlotte Islands Total area 0.89 km^2	2A	73,342
	2B	30,931
	2C	55,564
	2D	22,425
	2E	20,639
	2F	125,829
	2G	198,790
	2H	118,774
	2I	98,687
	2J.	13,642
	2K	34,604
	2L	81,599
	2M	19,960
Foreslope Hills	3A	176,761
Outer Gulf Islands Total Area 0.86 km^2	4A	261,196
	4B	99,977
	4C	101,063
	4D	45,333
	4E	70,077
	4F	281,401
Gabriola Island	5A	168,114
Parksville Total area 0.61 km^2	6A	52,774
	6B	5,128
	6C	353,535
	6D	202,803
East of Hornby Island	7A	925,460
	7B	172,235
Sechelt	8A	4,999,438
Halibut Bank Total area 2.00 km^2	9A	1,462,331
	9B	379,300
	9C	163,335

Seafloor Sediments in the Strait of Georgia

The risk of exposure to re-mobilized sediment from bottom-contact fishing activities around or near the reefs will vary depending on the type of sediment that is re-mobilized. Bottom sediments can be categorized by their size giving three general classifications: clay (up to 3.9 µm), silt (3.9 to 63 µm), and sand (larger than 63 µm). The time it takes for disturbed sediment to settle to the seafloor is a function of the particle size, with larger particles settling faster. The settling rate of predominantly sandy sediments will be faster than that of silty sediments, which will fall faster than clay sediments.

The seafloor sediments at most locations in the Strait of Georgia and Howe Sound are comprised of a combination of sand, silt and clay. The settling velocity of these sediments will vary depending on the proportion of sand, silt and clay. For example, the bottom sediment found in the central Strait of Georgia is significantly influenced by silt deposition from the Fraser River plume. The shallow coastal plain along eastern Vancouver Island consists largely of low-gradient broad sand and gravel beaches. To further complicate the issue the settling velocities of bottom sediments will be affected if the particles flocculate, and if there is turbulence in the bottom currents.

A sediment type representative of those around sponge reefs in the Strait of Georgia and Howe Sound has been assumed to be similar to those around sponge reefs in the Hecate Strait (comprised of 30% clay, 55% silt, and 15% sand, with 20 µm as the median diameter and a settling velocity of 0.2 mms-1, Boutillier et al. 2013). The high proportion of clay-silt sediments typically results in an overall equivalent spherical particle diameter of a floc above 20 µm and a faster settling rate (Lintern 2003).

Hydrodynamic Model

Following the re-suspension of the seafloor sediments the ocean currents in the area will transport the sediments horizontally as they fall to the seafloor. There are few empirical measurements of near-bottom currents in the Strait of Georgia but a hydrodynamic model has been developed for the region (Masson and Fine 2012).

The hydrodynamic model used is based on an implementation of version 3.5 of the Regional Ocean Modeling System (ROMS) (Haidvogel et al. 2008) similar to that used to estimate the extent of re-mobilized sediment near the Hecate Strait sponge reefs (Boutillier et al. 2013). The model domain (Figure 2) includes over 67,000 elements encompassing the Strait of Georgia, Puget Sound, Juan de Fuca Strait and adjacent inlets; the open boundaries are at the mouth of Juan de Fuca Strait and the northern end of the Strait of Georgia (Peña et al. 2016).

The model grid has a horizontal resolution of 1 km. Given that the areas of the sponge reefs (Table 1) are generally less than 1 km^2, the horizontal forcing of the re-suspended sediment is derived primarily from the grid elements in the immediate vicinity of the sponge reef. The model has 31 vertical layers and the thickness of each layer varies with the overall water depth such that only the current velocities in the bottom-most layer of the model are used for modelling the sediment transport.

The purpose of the hydrodynamic model is to simulate the currents around the sponge reefs and use them to determine whether the sediments re-mobilized from bottom-contact trap fishing activities will impact the reefs when they settle back to the seafloor. The currents in the Strait of Georgia and Howe Sound are primarily influenced by three driving forces: tides, winds, and rivers. The rivers contribute to the water circulation both through direct momentum and density gradients. For each time step in the computer simulation the model output includes velocity, temperature and salinity at every grid element, at every depth.

Observations are used to establish the initial conditions in the model, and to force the model during the simulation. The model establishes the initial density structure of the water using a multi-year dataset of salinity and temperature profiles collected at about 80 locations in the Salish Sea (Chandler et al. 2017). Tidal forcing is derived from the eight most significant tidal constituents (K_2, N_2, S_2, M_2, Q_1, P_1, O_1 and K_1) taken from the Northeast Pacific tidal model (Foreman et al., 2000). Wind data from 21 weather stations and lighthouses within the model domain are used to define the hourly wind forcing. Freshwater forcing is applied at 20 locations using daily discharge data from rivers and model data from Morrison et al. 2012.

The hydrodynamic model was run to simulate conditions in 2007 as the most comprehensive datasets to initialize and force the model were available for this time period. The horizontal velocity used to simulate the movement of sediment was re-constructed from two components in the velocity field; the mean flow and the tidal flow. The mean flow at each grid point was calculated as the average velocity over 5-day intervals for the 2007 simulation year using all the forcing described above. To determine the tidal component of the flow field a separate model simulation, with forcing from eight tidal constituents, was run for three months with output at three hour intervals. Tidal analysis was then applied to provide the tidal currents at each grid point for the entire year. These two components were combined and then interpolated to generate a time series of horizontal velocity at each grid point at 30 minute intervals for the simulation year 2007.

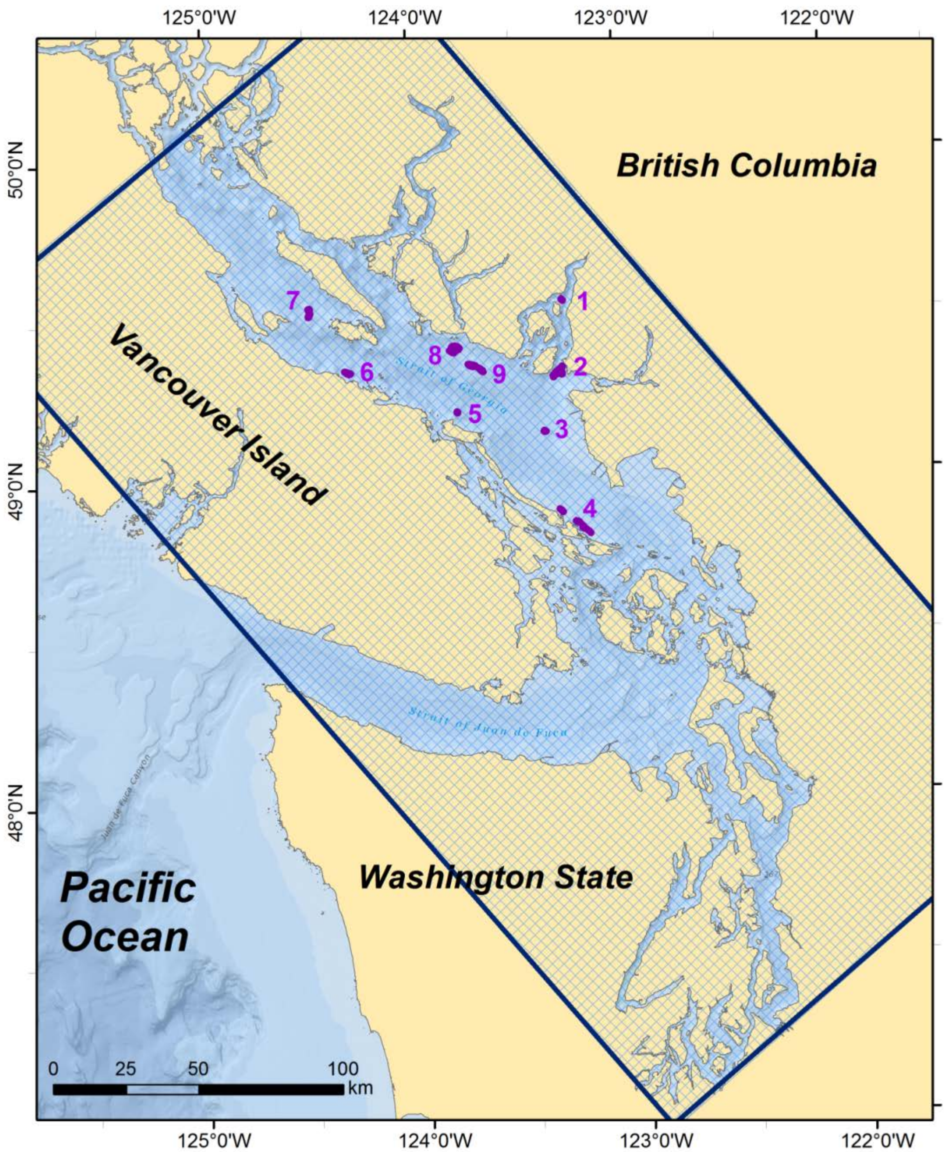

Figure 2. The ROMS model domain for the Salish Sea. The nine Strait of Georgia and Howe Sound sponge reef complexes are shown in purple.

Particle Trajectory Model

Following Boutillier et al. 2013 the distribution of re-mobilized sediment was modelled using a disturbance height consistent with bottom-contact trap fishing activity. Sediments are assumed to move as passive particles, horizontally with the ocean currents and vertically based on its settling velocity. The relationship between the settling velocity of the sediment with the disturbance height above the seafloor provides a time scale of suspension during which the particle is transported by the model currents. For bottom-contact trap fishing in the Strait of Georgia and Howe Sound this time period is 1.5 hours (Isaak Fine, Institute of Ocean Sciences contractor, Sidney, BC, pers.comm.).

Equation 1. The relationship between settling time, settling velocity, and disturbance height above the seafloor.

$$time\ scale = \frac{release\ height}{settling\ velocity}$$

Figure 3 shows the relationship in Equation 1 for disturbance heights up to 5 m from the sea floor, and settling velocities applicable to bottom-contact trap fishing activities and the sediments around the sponge reefs in the Strait of Georgia and Howe Sound.

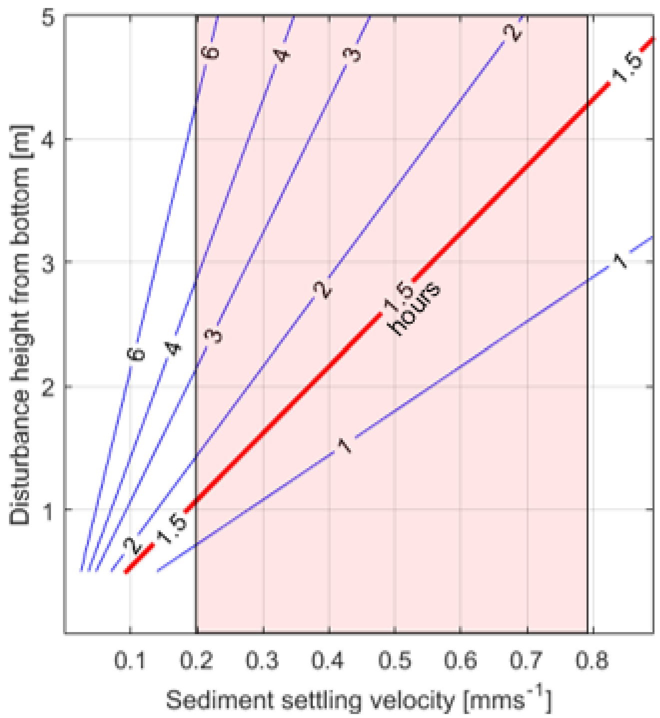

Figure 3. The settling time in hours based on disturbance height and settling velocity. The shaded area represents silty material ranging in size from 20 – 50 µm.

The simplified reef polygon is defined as a simple polygon enclosing the reef footprint delineated by NRCan using multibeam swath bathymetry imagery collected between 2002 and 2010. The glass sponge reef fishing closure defined in DFO Fishery Notice FN0415 (DFO 2016) extends 150 m beyond this simplified reef polygon. Where multiple sponge reefs are co-located a simplified reef polygon enclosing several sponge reefs has been applied (Figure 4).

The objective of the trajectory modelling is to identify the risk of exposure to the sponge reef by re-mobilized sediment from bottom-contact trap fishing activities around or near the reefs. This is done by determining a risk boundary around each sponge reef based on the particle trajectory model results. The risk boundary is associated with a probability that re-mobilized sediment will settle on the sponge reef. The zero probability contour refers to the distance from the reef that no re-mobilized sediment will reach the simplified reef polygon. Following Boutillier et al. 2013 two levels of risk are examined; one where 5% of the passive tracers settle within the simplified reef polygon and the other where 20% of the particles settle within the simplified reef polygon (Figure 5).

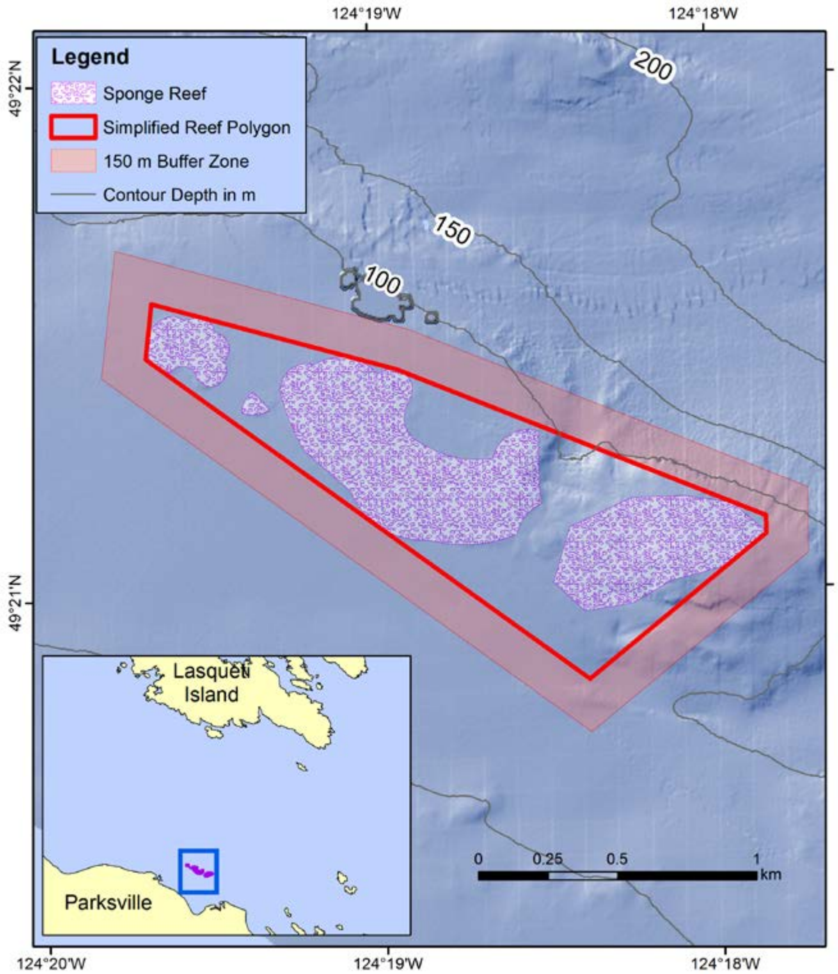

Figure 4. Map of the Parksville sponge reef complex showing the sponge reef footprints (purple), the simplified reef polygon (red line), and the 150 m buffer zone used to define the glass sponge reef fishing closure buffer zone.

To represent the location of the initial disturbances caused by fishing activity a grid of particle release points spaced every 200 m is generated extending five km beyond the simplified reef polygon. At each location a particle is released for every hour of the year (a total of 8760 particles). The particle tracking method uses the times series of bottom currents generated by the hydrodynamic model at the release point to update the horizontal position of the sediment particle at 30 minute intervals. After 1.5 hours the location of the particle is calculated and stored as an end-point, together with the end-points of the 8759 other particles released from the same location.

The distribution of end-points represents the spatial extent of sediment that had been disturbed at the common release point. The number of end-points that fall within the simplified reef polygon can be calculated and expressed as a proportion of the number of particles released. For example, if 876 end-points landed within the simplified reef polygon then the release point represents a location where there is a 0.1 probability of sediment settling within the simplified reef polygon (876 divided by the 8760 particles released). If one was interested in the 10% risk boundary then this release point would be right on it.

Extending this method provides a risk probability assigned to each of the release points in the 200 m grid. Interpolating the probabilities at each of these points allows contours to be drawn at 0.05 and 0.20 levels which correspond to the 5 and 20 percent risks of exposure of sediment settling within the simplified reef polygon. For each sponge reef analysis it was confirmed that the zero probability contour (the grid points from which no particles reached the simplified reef polygon) was within the grid of release points that extended 5 km from the reef complex. Figure 5 shows an example of how the risk lines are mapped.

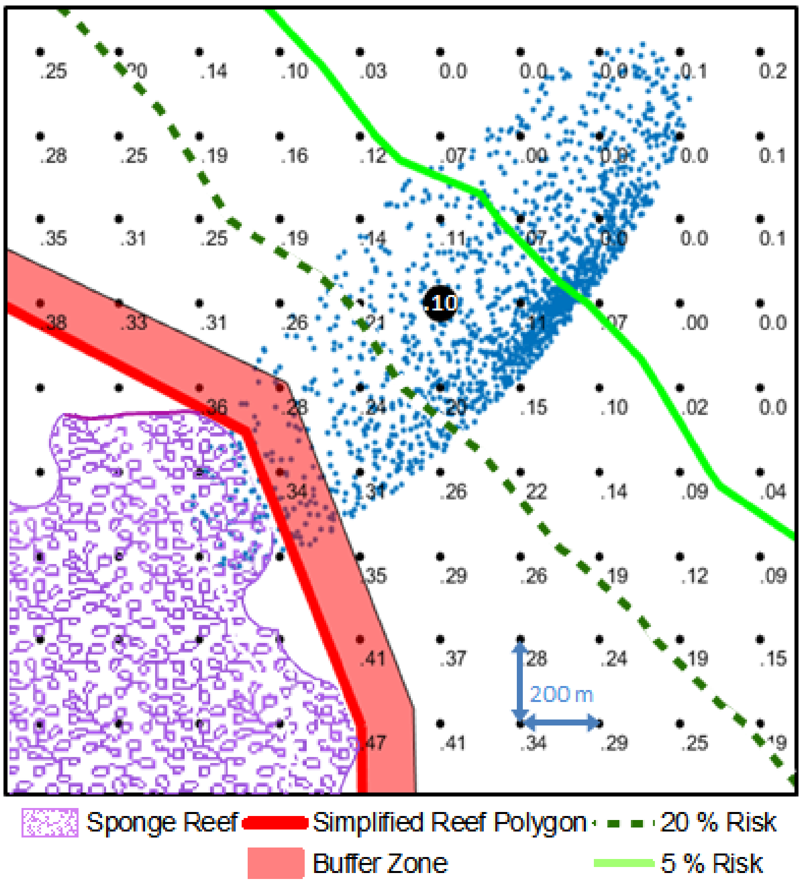

Figure 5. Example of model generated risk contours. The red line represents the boundary of the simplified reef polygon, the black dots the release points spaced every 200 m. For every release point outside the simplified reef polygon the model releases 8760 particles and determines their settling point. The release point is assigned a value that corresponds to the proportion of particles landing within the simplified reef polygon. In this example the large black dot in the centre of the plot is the release point and the end-points are shown as a cloud of blue dots revealing a current pattern with a southwest/northeast tidal ellipse and a mean flow from the west. The value of 0.10 at the release point indicates that 10% of the particles settled within the simplified reef polygon. As in Figures 6 to 15 the 0.05 and 0.20 contours are shown as light green and dark green respectively.

Analysis and Response

For each of the nine sponge reef complexes a map has been generated showing the results of the sediment particle trajectory modeling using the horizontal currents generated by the ROMS hydrodynamic model (Figures 6 to 14). Table 2 provides a comparison of the areas enclosed by the simplified reef polygon, the 150 m buffer zone, and the five and 20 percent risk contours.

The risk probability maps do not consider the volume of bottom material disturbed by the fishing activity, and the contours represent potential for risk rather than the impact of the re-mobilized sediment.

The 20 percent risk contour defines a boundary on which 20 percent of any re-mobilized sediment can be expected to drift and settle within the simplified reef polygon. At release points closer to the reef than this boundary a greater percentage of particles will settle within the simplified reef polygon. The five percent risk contour identifies the line beyond which less than five percent of the re-mobilized sediment will settle within the simplified reef polygon, and the area between the five and 20 risk contours represent a 5-20% risk of sediment settling within the simplified reef polygon (Figures 6 to 14).

As shown in Table 2, a comparison of the area covered by the existing DFO delineated sponge reef fishing closure buffer zones (currently extending 150 m beyond the reef footprint as defined by a simplified reef polygon) and the five percent risk contour shows (with the exception of the Howe Sound Defence Islands reef complex) that the former provides a smaller protection area.

Around four of the nine sponge reef complexes (Howe Sound Defence Islands, Howe Sound Queen Charlotte Channel, Parksville, and Sechelt) the area of the DFO sponge reef fishing closure buffer zone is greater than the area associated with the 20 percent exposure risk contour.

The 20 percent exposure risk contour around Gabriola Sponge Reef, and the area of the DFO sponge reef fishing closure buffer zone are very similar (0.59 km^2 and 0.62 km^2, see Table 2), but the shapes are quite different (see Figure 10). The size and orientation of the risk contours suggest that the use of site specific physical information, in addition to the reef footprint, provides information that contributes to the evaluation of risk from bottom-contact trap fishing activities.

Table 2. The area of the features shown in the risk probability maps for nine sponge reef complexes in the Strait of Georgia and Howe Sound. Note: the area extending 150 m beyond Simplified Reef Polygon corresponds to the area of the glass sponge reef fishing closure buffer zone (DFO 2016).

Sponge Reef Complex	Area of Simplified Reef Polygon (km^2)	Area extending 150 m beyond Simplified Reef Polygon (km^2)	Area within 20% Risk Contour (km^2)	Area within 5% Risk Contour (km^2)
Howe Sound Defence Islands	0.25	0.68	0.43	0.57
Howe Sound Queen Charlotte Channel	2.19	4.48	4.06	5.39
Foreslope Hills	0.35	0.81	1.02	2.06
Outer Gulf Islands	1.56	4.21	6.55	13.28
Gabriola Island	0.22	0.59	0.60	1.19
Parksville	1.16	2.05	1.69	2.36
East of Hornby Island	2.03	3.20	3.50	5.47
Sechelt	5.93	7.61	7.53	9.53
Halibut Bank	3.29	5.43	7.43	9.21

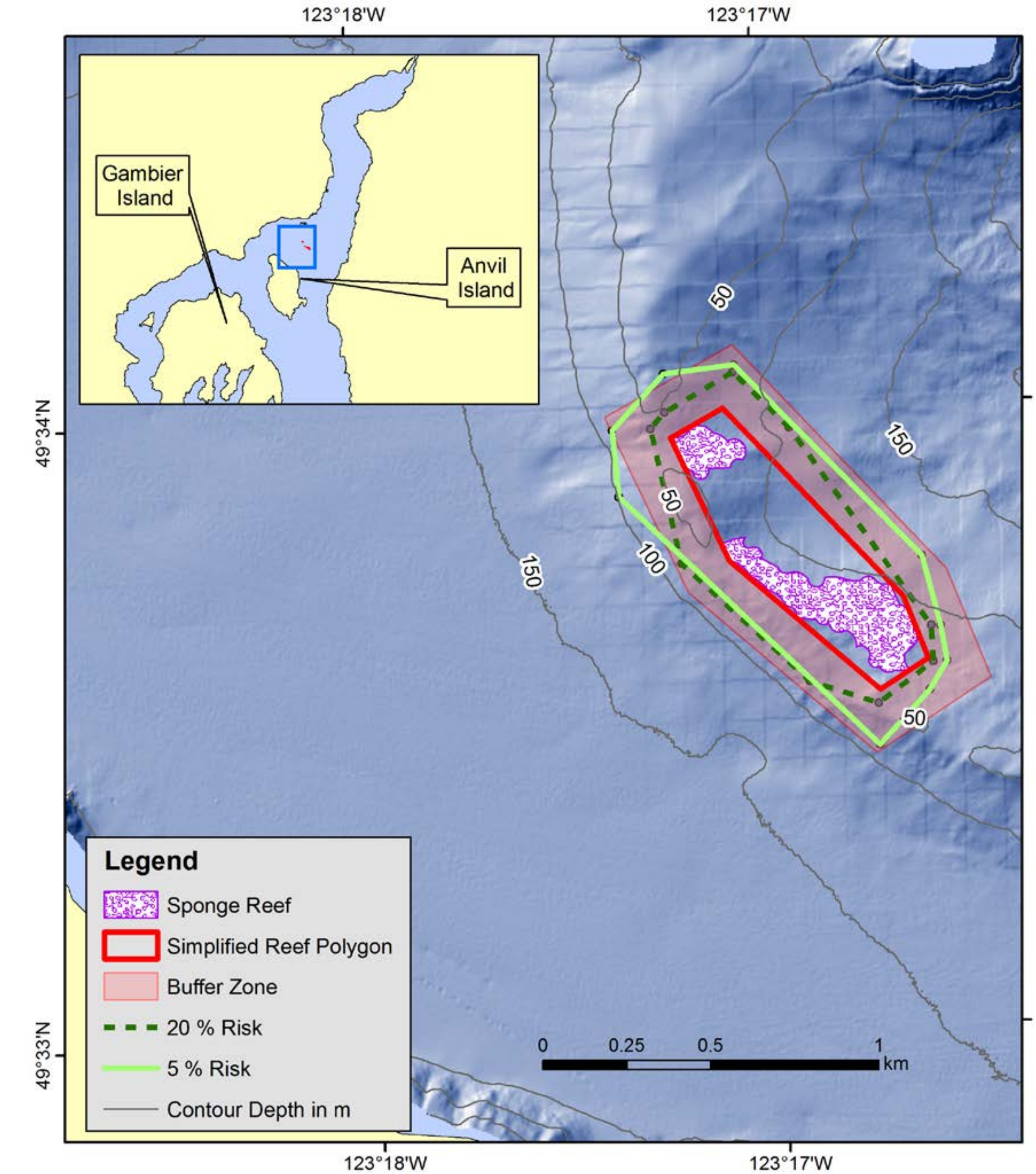

Figure 6. Map of the Howe Sound (Defence Islands) sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

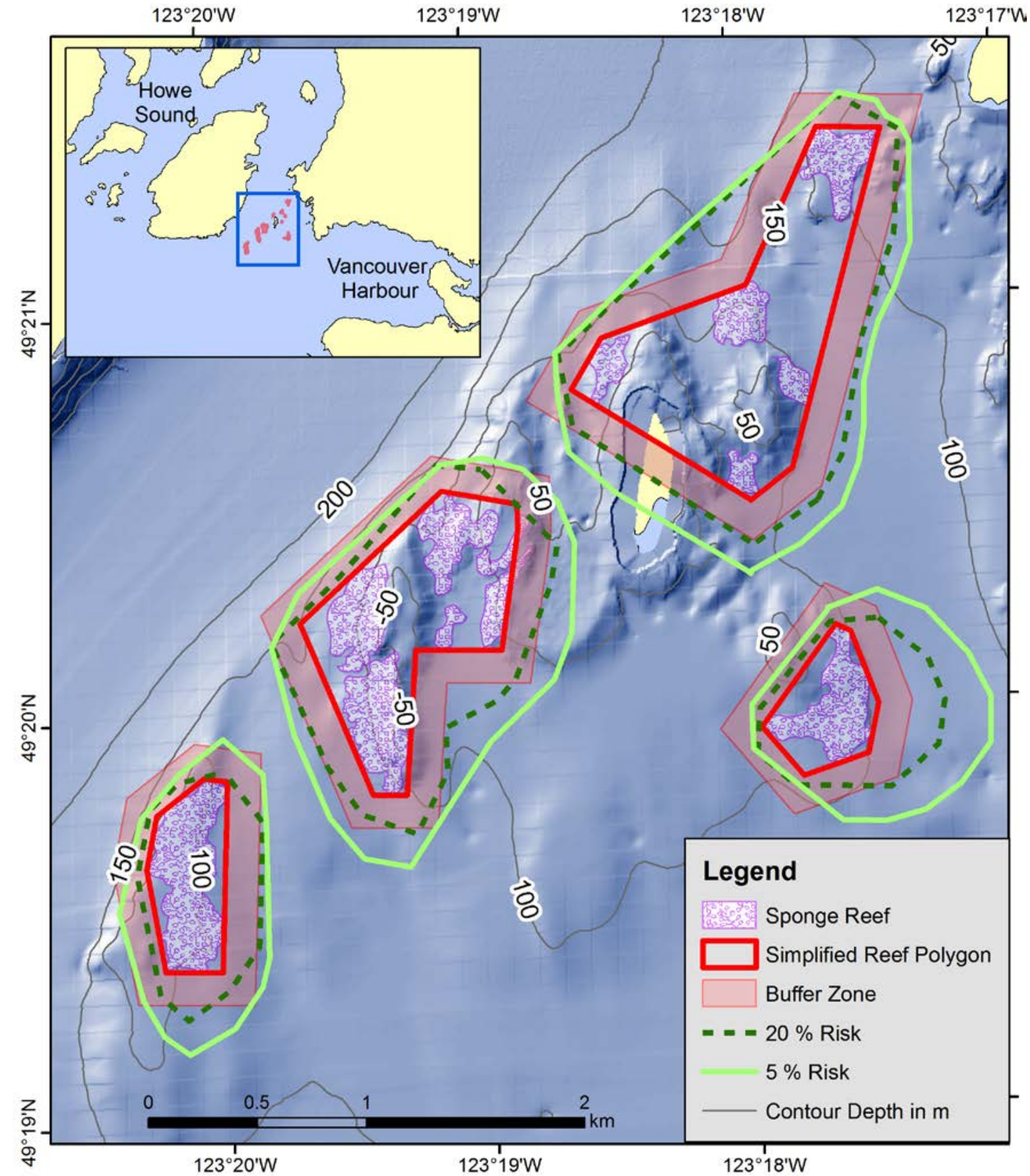

Figure 7. Map of the Howe Sound (Queen Charlotte Channel) sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

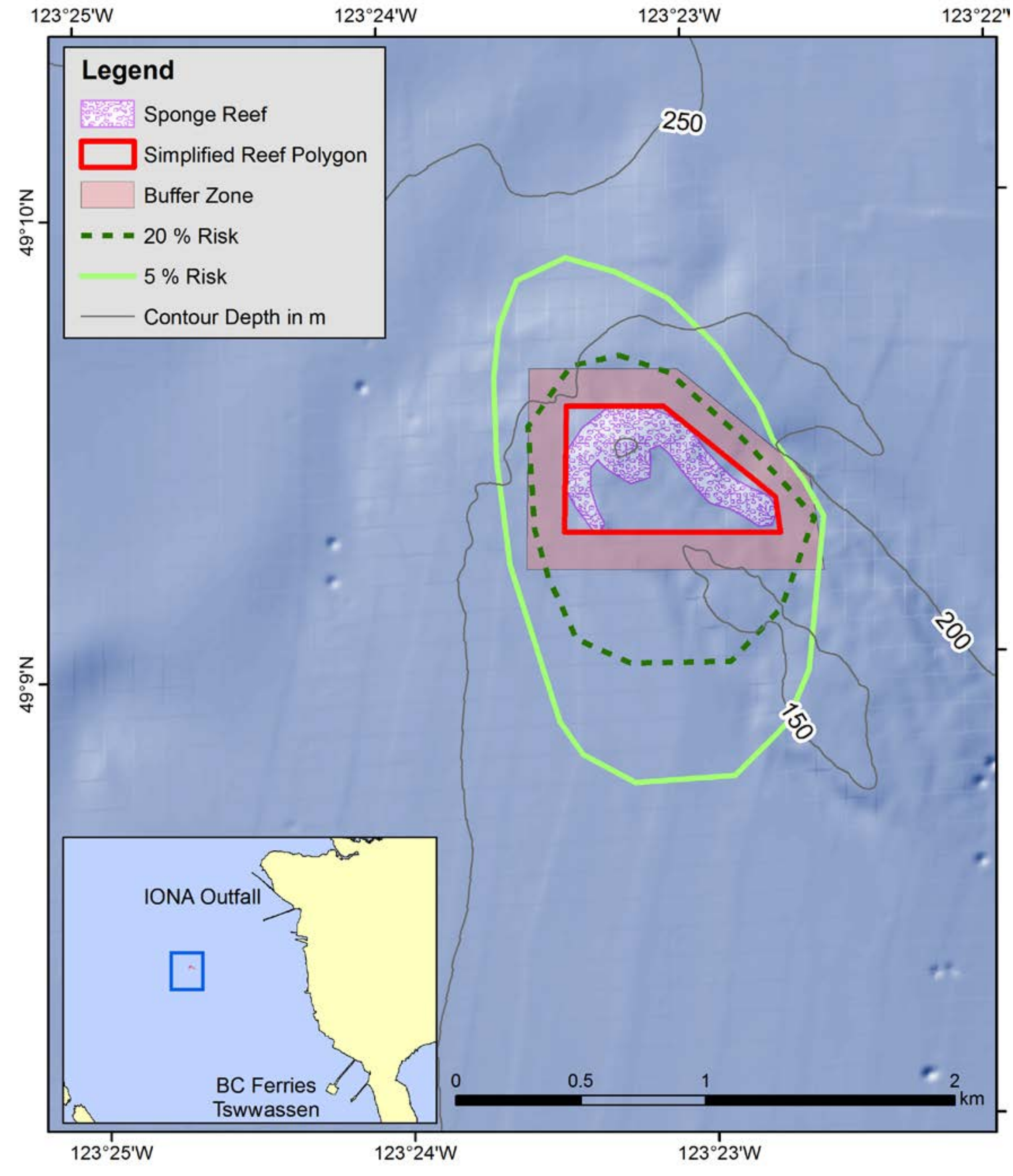

Figure 8. Map of the Foreslope Hills sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

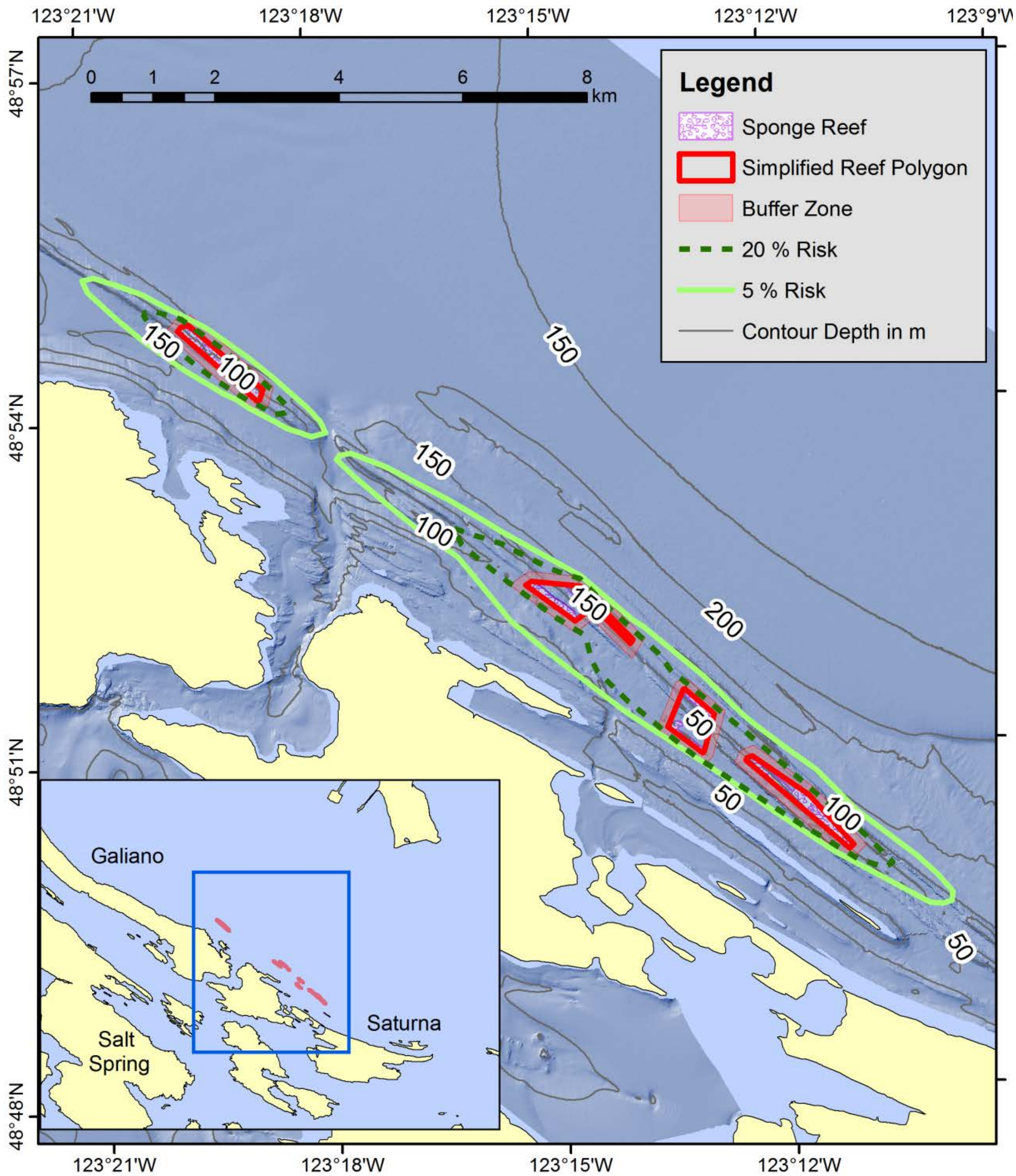

Figure 9. Map of the Outer Gulf Islands sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

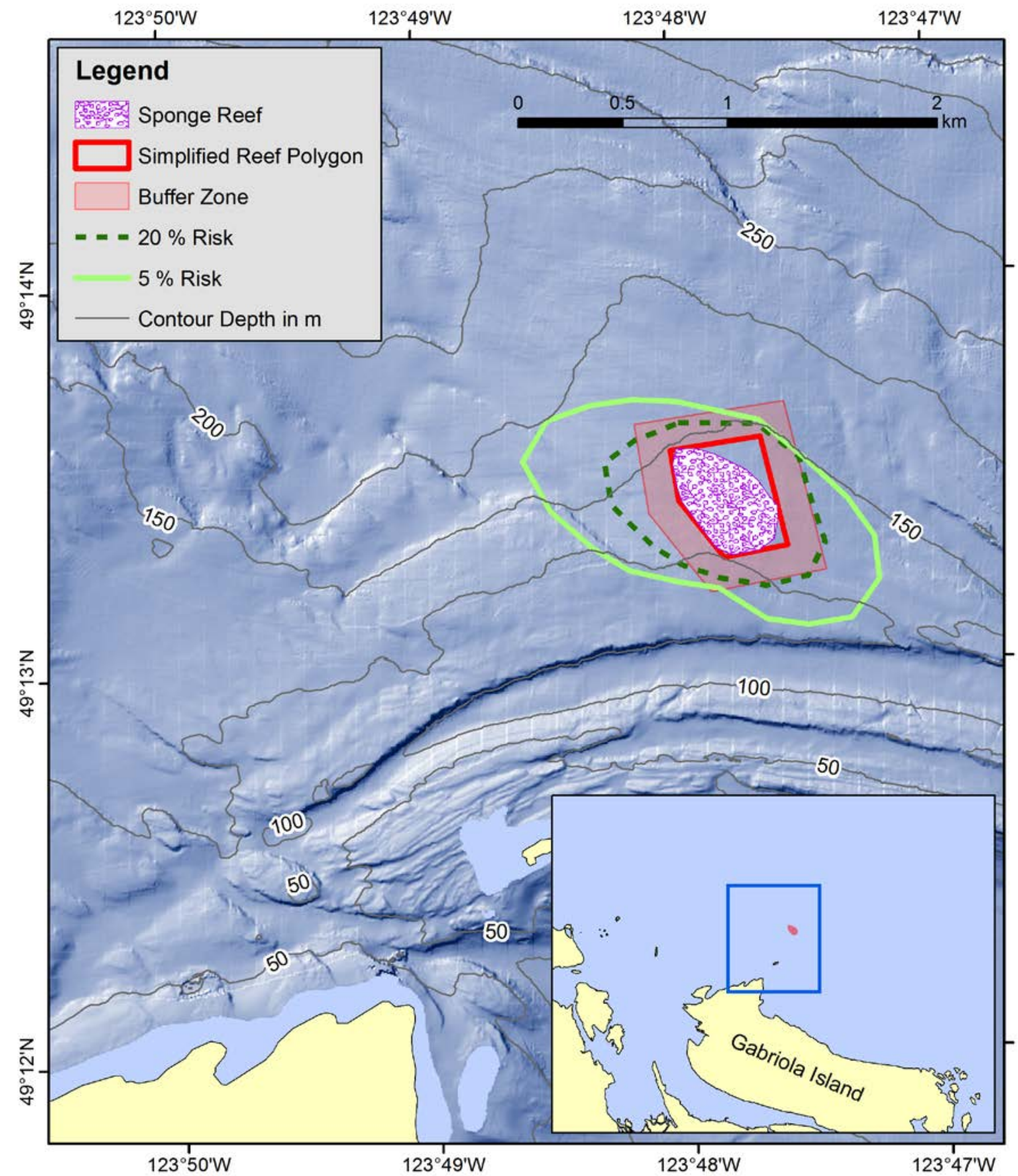

Figure 10. Map of the Gabriola Island sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

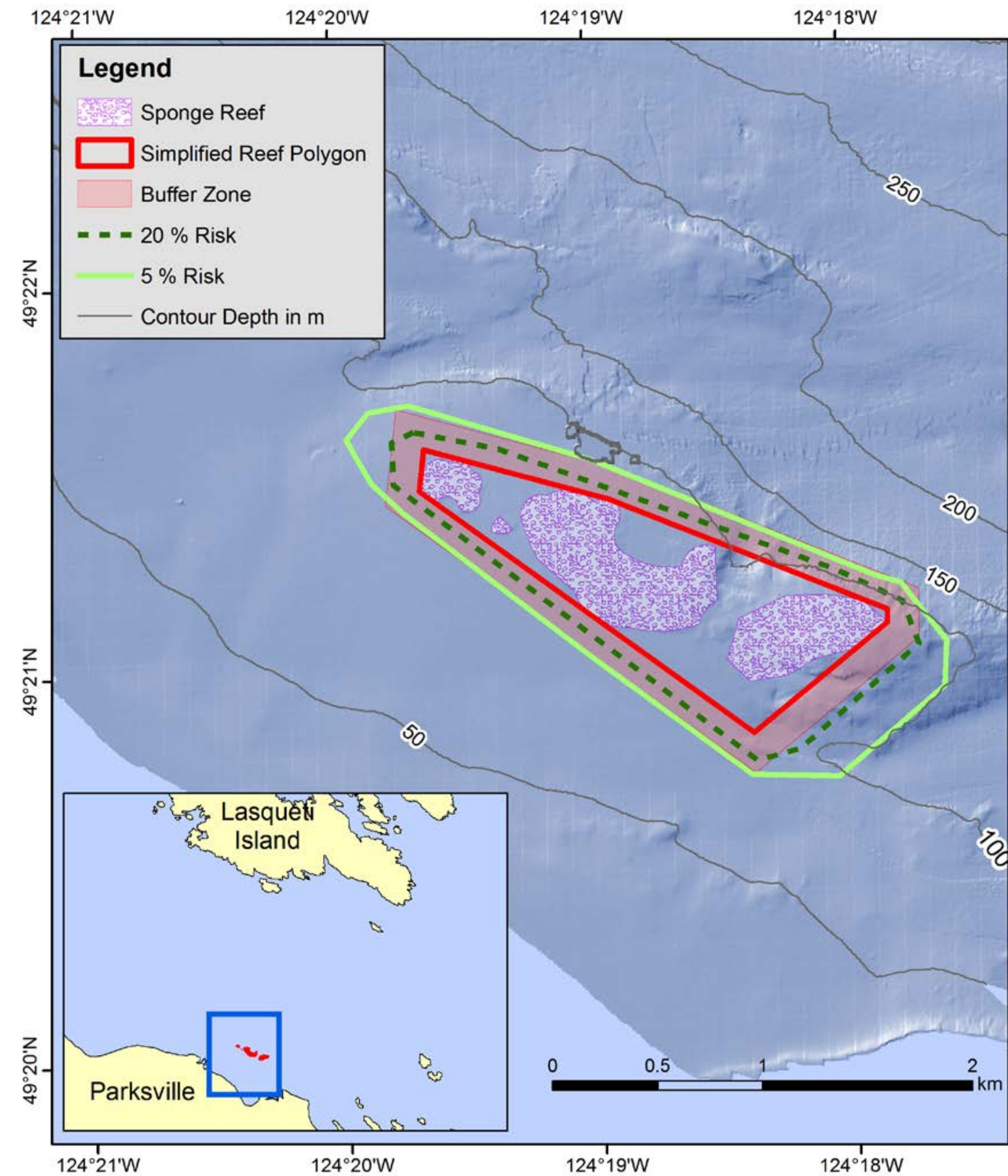

Figure 11. Map of the Parksville sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

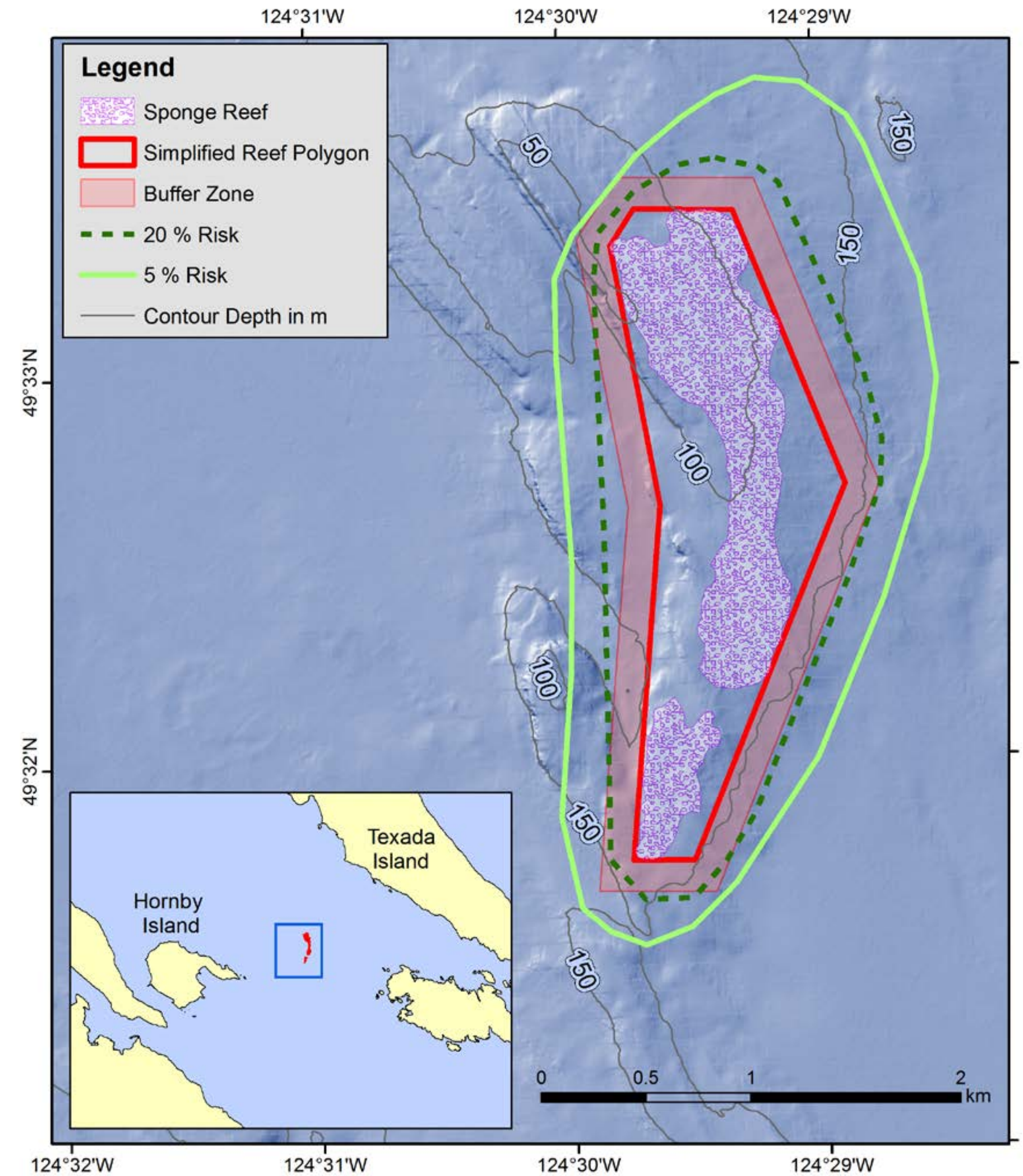

Figure 12. Map of the sponge reef complex (purple) East of Hornby Island showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

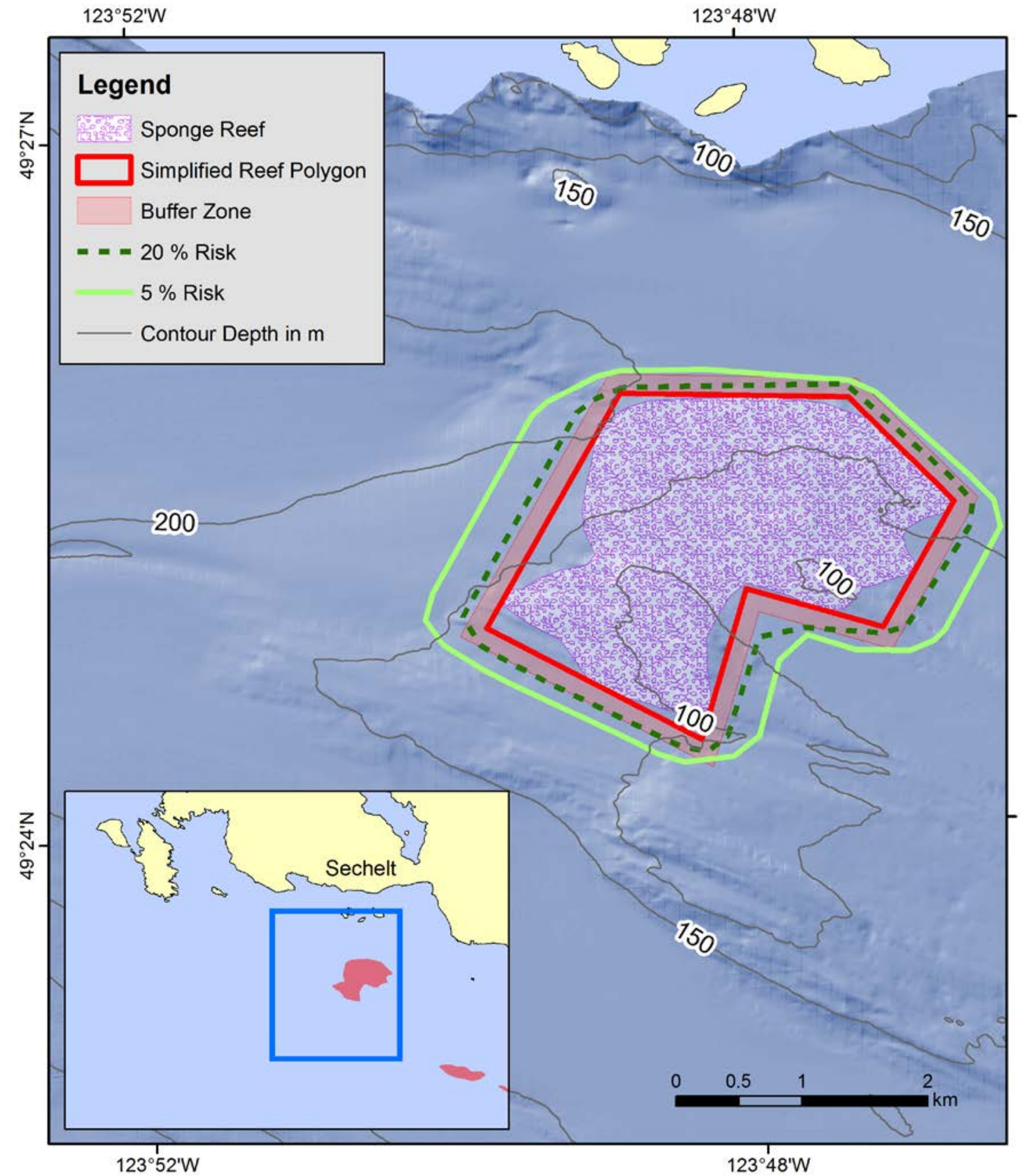

Figure 13. Map of the Sechelt sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

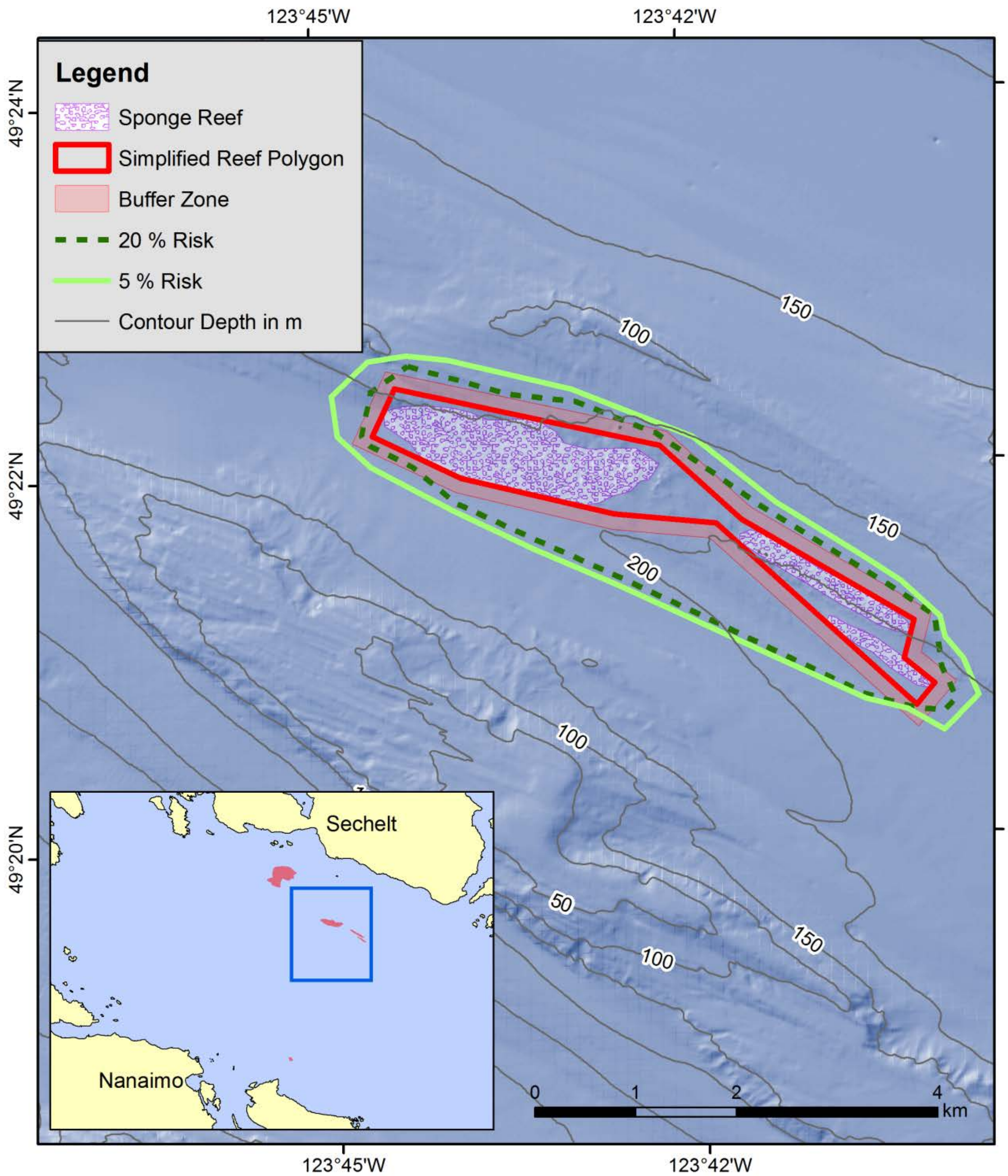

Figure 14. Map of the Halibut Bank sponge reef complex (purple) showing the Simplified Reef Polygon (red) and the DFO defined 150 m buffer zone. The green contours represent the model derived boundaries that delineate the risk of exposure of re-mobilized sediment settling within the Simplified Reef Polygon.

Uncertainties

The following limitations and uncertainties were noted during the completion of this study:

In Boutillier et al. 2013 the resettlement time was estimated using a fixed height of 10 m for remobilization of sediment with a grain size of 20 um. For bottom-contact trap fishing in the Strait of Georgia the disturbance height of sediment with a similar grain size has been assumed to be about 3.0 m above the sea floor, which is based on the assumption that a 1.5 hour settling time is reasonable (Isaak Fine, Institute of Ocean Sciences contractor, Sidney, BC, pers.comm.). There is no empirical evidence to quantify the accuracy of these assumptions. A greater disturbance height or settling time leads to the sediment being suspended for longer and likely travelling further away from the release point.

The single settling rate used to represent the composite sediments such as those found around the sponge reefs does not account for the flocculation and aggregation of the mineral and biological components of the seafloor material. A higher proportion of finer bottom sediments will reduce the settling time than that used in the particle tracking model which will expand the area of the risk contours. Sediment that is highly aggregated will settle more quickly than individual particles and may reduce the area of the risk contours.

The spatial and temporal resolution of the horizontal velocities from the ROMS hydrodynamic model has not undergone a sensitivity analysis to determine the confidence limits associated with these results. The 1 km grid provides current information at a distance interval that exceeds the length scale of some of the sponge reefs. In these cases only one model grid point is used to define the current flow. The vertical resolution of the model defines a bottom layer that extends more than 10 m from the seafloor, such that the velocity from only one depth layer is used in the trajectory modelling. The 30 minute time interval of the model output, and the 1.5 hour settling time, provides only three velocity vectors for each particle trajectory. Hydrodynamic model output with finer spatial (horizontal and vertical) and temporal resolution will likely provide greater detail to the distribution of disturbed sediment, but a sensitivity analysis will reveal if this greater detail provides more relevant information.

Conclusions

The application of a ROMS hydrodynamic model and a particle trajectory model has been used to generate risk probability maps of the indirect effects of bottom-contact fishing activities by trap gear on the nine sponge reefs in the Strait of Georgia following the method used in Boutillier et al. 2013.

A comparison of the model generated risk contours based on site-specific current information with the DFO buffer zones based on the reef footprint reveals noticeable differences. In areas where bottom currents have a strong directional orientation, such as around the Outer Gulf Islands reef complex, the model identifies contours of risk that match the 150 m buffer zone in some directions, and extend well beyond them in others. The risk contours generated for other reef complexes, such as Foreslope Hills and Gabriola, similarly indicate a drift pattern of re-mobilized sediment that is not related to the shape of the sponge reef which defines the DFO buffer zone. The Howe Sound (Defence Islands) and Outer Gulf Islands are the only sponge reef complexes where the DFO buffer zone is entirely within the 20 percent risk contour. For the remaining sponge reef complexes there are areas within the DFO buffer zone where the risk of re-mobilized sediment settling on the sponge reef is greater than 20 percent.

As discussed in the previous section there are a number of assumptions made in the specification of the sediment characteristics and the hydrodynamic modelling that introduce uncertainties in the results. Recommendations for future work to reduce these uncertainties include:

1. Comparing the results of the particle tracking forced by the ROMS hydrodynamic model with those forced by observed bottom currents from the Strait of Georgia, such as the two-year dataset from a 1996-98 mooring off Saturna Island.
2. Carrying out additional ROMS model simulations to determine the sensitivity of the horizontal velocities in the bottom layer to changes in temporal and spatial resolution. Sensitivity analyses will assist in quantifying the confidence limits of the model results, and provide worthwhile suggestions for future modelling efforts.
3. Collecting and analyzing bottom sediment samples in the vicinity of the sponge reefs to determine whether a more accurate representation of the sediment composition and the settling velocities will alter the risk probability contours.
4. Observing (by camera or by submarine) bottom-contact trap fishing activity in the areas of interest to determine the range of appropriate disturbance heights.
5. Monitoring of the sponge reefs to determine if re-mobilized bottom sediments is settling within the simplified reef polygons, and evidence of the likely cause.

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Sources of information

Boutillier, J., Masson, D., Fain, I., Conway, K., Lintern, G, O, M., Davies, S., Mahaux, P., Olsen, N., Nguyen, H. and Rutherford, K. 2013. The extent and nature of exposure to fishery induced remobilized sediment on the Hecate Strait and Queen Charlotte Sound glass sponge reef. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/075. viii + 76 p.

Chandler, P.C., King, S.A., and Boldt, J. (Eds.). 2017. State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2016. Can. Tech. Rep. Fish. Aquat. Sci. 3225: 243 + vi p.

Conway, K.W., Barrie, J.V., Hill, P.R., Austin, W.C., Picard, K., 2007. Mapping sensitive benthic habitats in the Strait of Georgia, coastal British Columbia: deep-water sponge and coral reefs. Geological Survey of Canada. Current Research. 2007-A2. 6pp.

Conway, K.W., Barrie, J.V., Krautter, M., 2004. Modern siliceous sponge reefs in a turbid siliciclastic setting: Fraser River delta, British Columbia, Canada. Neues Jahrbuch für Geologie und Paläontologie. 2004: 335-350.

Conway, K.W., Barrie, J.V., Krautter, M., 2005. Geomorphology of unique reefs on the western Canadian shelf: sponge reefs mapped by multibeam bathymetry. Geo-Marine Letters. 25: 205-213.

Conway, K., Krautter, M., Barrie, J.V. and Neuweiler, M. 2001. "Hexactinellid Sponge Reefs on the Canadian Continental Shelf: A Unique "Living Fossil"." Geoscience Canada 28(2): 71-78.

DFO. 2016. DFO Fishery Notice FN0415 (accessed on April 6, 2018)

DFO. 2010. Potential impacts of fishing gears (excluding mobile bottom-contacting gears) on marine habitats and communities. DFO Can. Sci. Advis. Sec.Sci. Advis. Rep. 2010/03.

Dunham, A., Mossman J., Archer S., Davies S., Pegg J, Archer E. 2018. Glass Sponge Reefs in the Strait of Georgia and Howe Sound: Status assessment and ecological monitoring advice. DFO Can. Sci. Advis. Sec.Res. Doc. 2018/10. In press.

Foreman, M. G. G., Crawford, W. R., Cherniawsky, J. Y., Henry, R. F. and Tarbotton, M. (2000). A high-resolution assimilating tidal model for the Northeast Pacific Ocean. J. Geophys. Res., 105, 28629–51.

Haidvogel,D.B., H. Arango, W.P. Budgell, B.D. Cornuelle, E. Curchitser, E. Di Lorenzo, K. Fennel, W.R. Geyer, A.J. Hermann, L. Lanerolle, J. Levin, J.C. McWilliams, A.J. Miller, A.M. Moore, T.M. Powell, A.F. Shchepetkin, C.R. Sherwood, R.P. Signell, J.C. Warner, J. Wilkin, 2008. Ocean forecasting in terrain-following coordinates: formulation and skill assessment of the Regional Ocean Modeling System. Journal of Computational Physics, 227,3595-3624.

Leys, S.P. 2013. Effects of Sediment on Glass Sponges (Porifera,Hexactinellida) and projected effects on Glass Sponge Reefs. DFO Can. Sci. Advis. Sec. Res. Doc. 2013/074. vi + 23 p.

Lintern, D.G. 2003. Influences of flocculation on bed properties for fine-grained cohesive sediment. . Oxford, U.K., Oxford University. Doctor of Philosophy Thesis: 226 p.

Masson, D. and I. Fine, 2012. Modeling seasonal to interannual ocean variability of coastal British Columbia. J. Geophys. Res 117. Journal of Geophysical Research, 117 (2012), Article C10019, 10.1029/2012JC008151

Morrison, J., M. G. G. Foreman, and D. Masson, 2012: A Method for Estimating Monthly Freshwater Discharge Affecting British Columbia Coastal Waters. *Atmosphere-Ocean*, 50, 1–8, doi:10.1080/07055900.2011.637667.

Peña, M. A., D. Masson, and W. Callendar, 2016: Annual plankton dynamics in a coupled physical–biological model of the Strait of Georgia, British Columbia. Prog. Oceanogr., 146, 58–74, doi:10.1016/j.pocean.2016.06.002.

Tompkins-MacDonald, G.J and Leys, S.P. 2008. Glass sponges arrest pumping in response to sediment: implications for the physiology of the hexactinellid conduction system. Marine Biology 154:973-984.

Whitney, F., Conway, K., Thomson, R., Barrie, V., Krautter, M., and Mungov, G. 2005. Oceanographic habitat of sponge reefs on the Western Canadian Continental Shelf. Continental Shelf Research. 25: 211-226.

Yahel, G., Whitney, F., Reiswig, H.M., Eerkes-Medrano, D.I., and Leys, S.P. 2007. In situ feeding and metabolism of glass sponges (Hexactinellida, Porifera) studied in a deep temperate fjord with a remotely operated submersible. Limnol. Oceanogr. 52(1): 428-440.

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