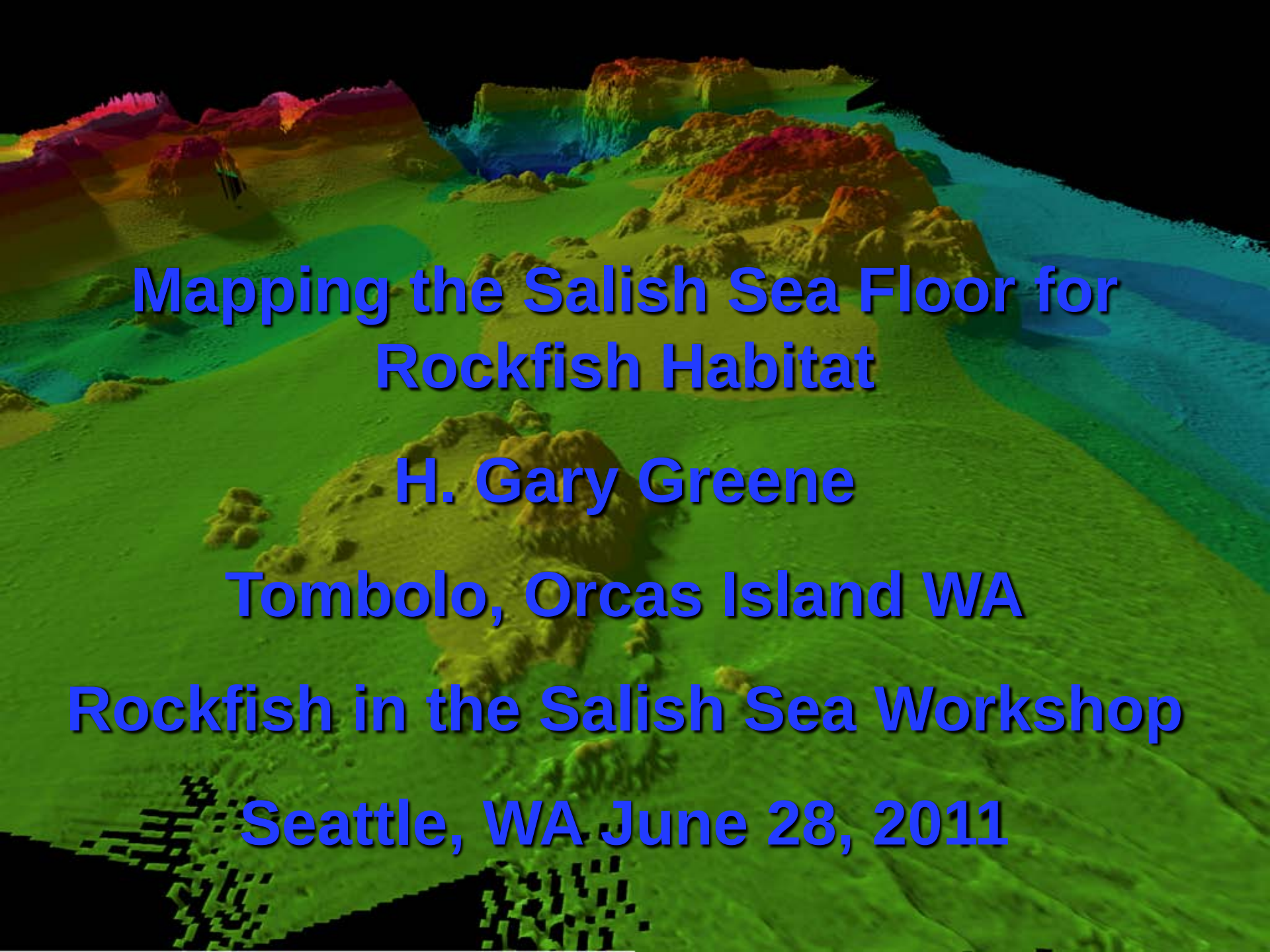


Mapping the Salish Sea Floor for Rockfish Habitat

H. Gary Greene

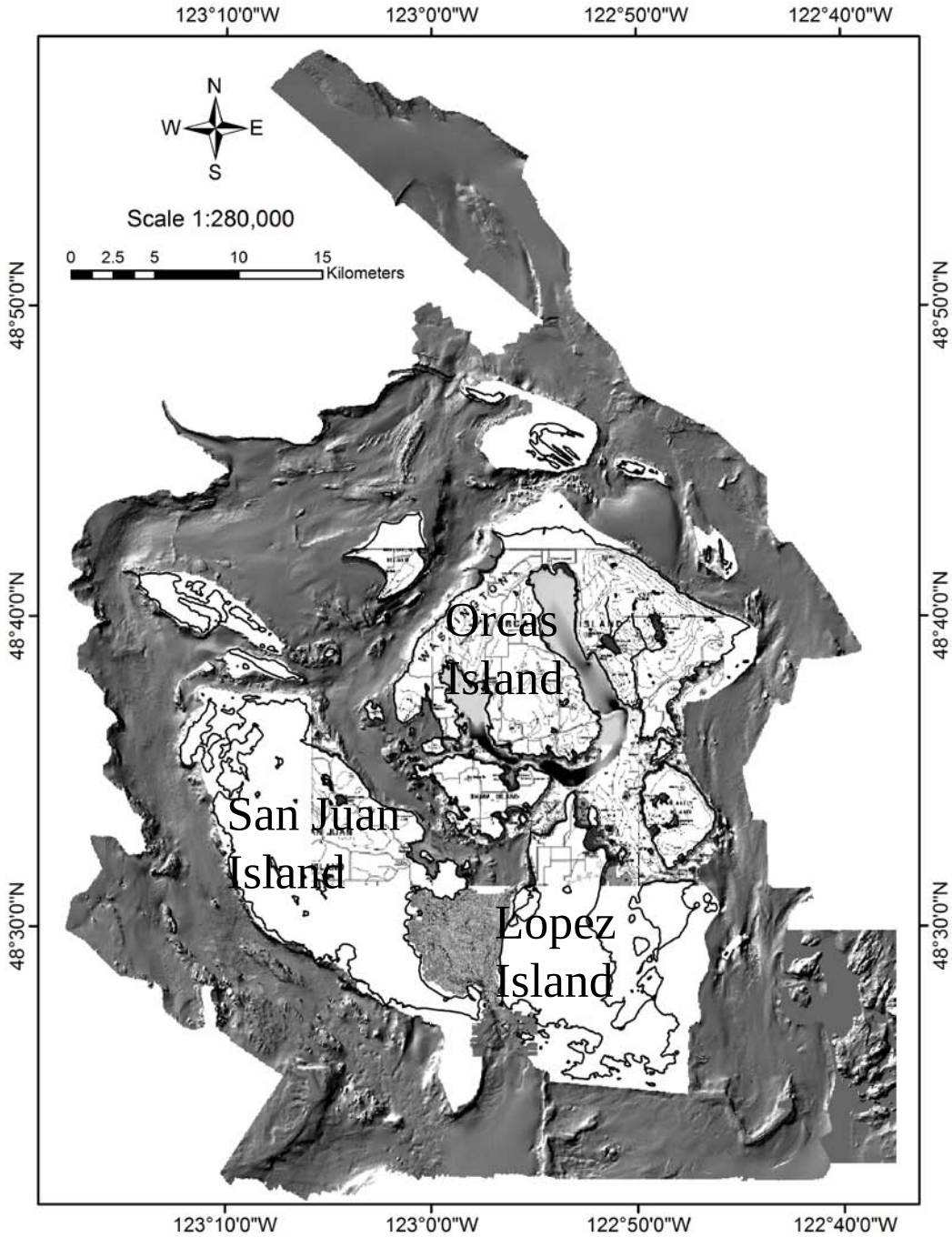
Tombolo, Orcas Island WA

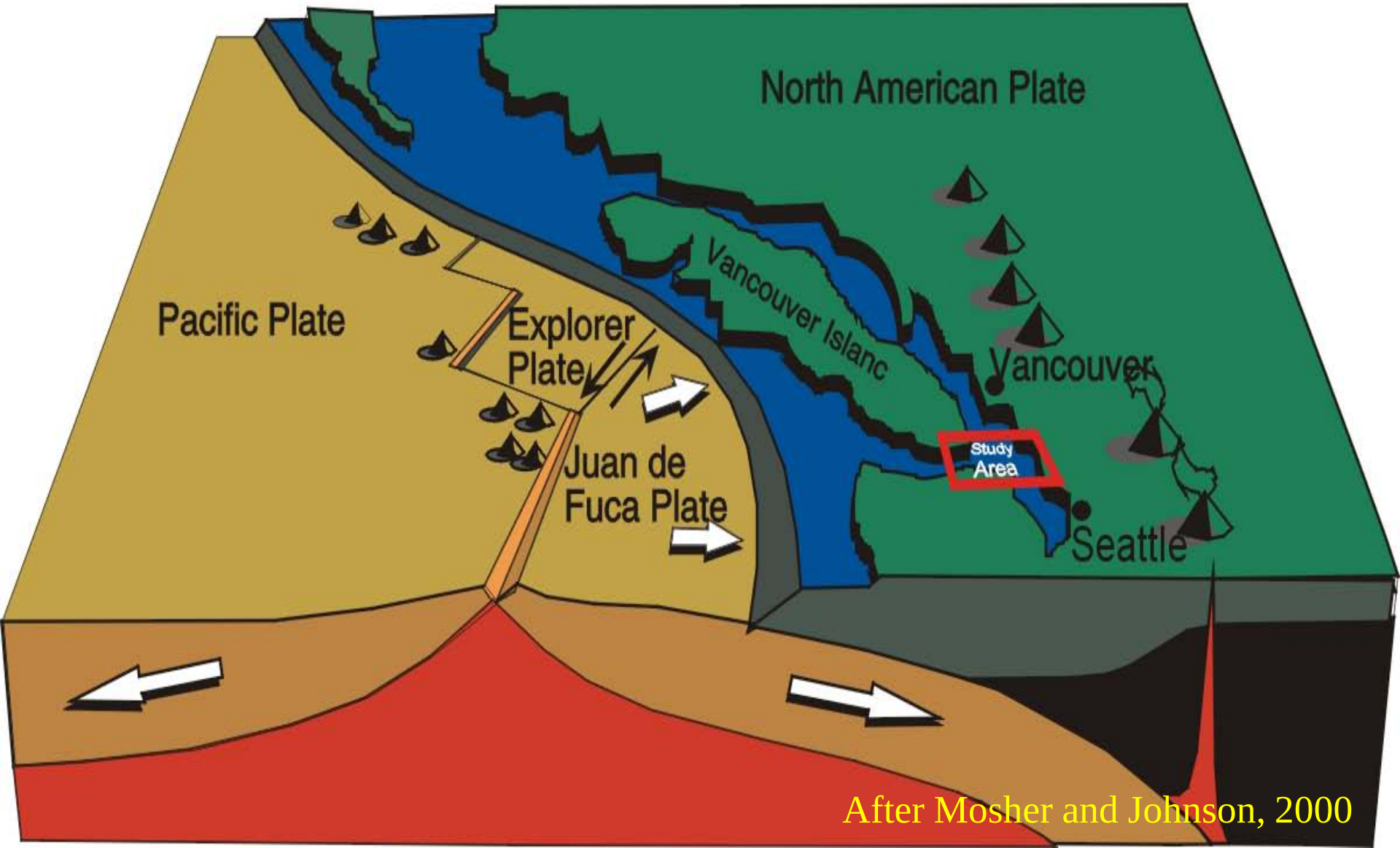
Rockfish in the Salish Sea Workshop

Seattle, WA June 28, 2011

A Geologist

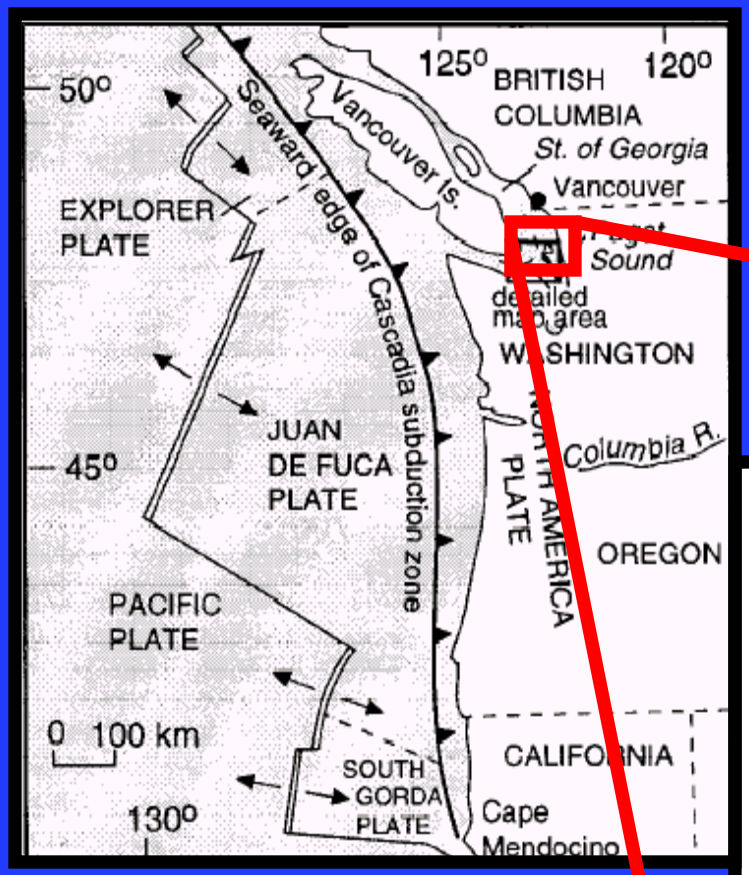
Multibeam Data Coverage 2000 to present

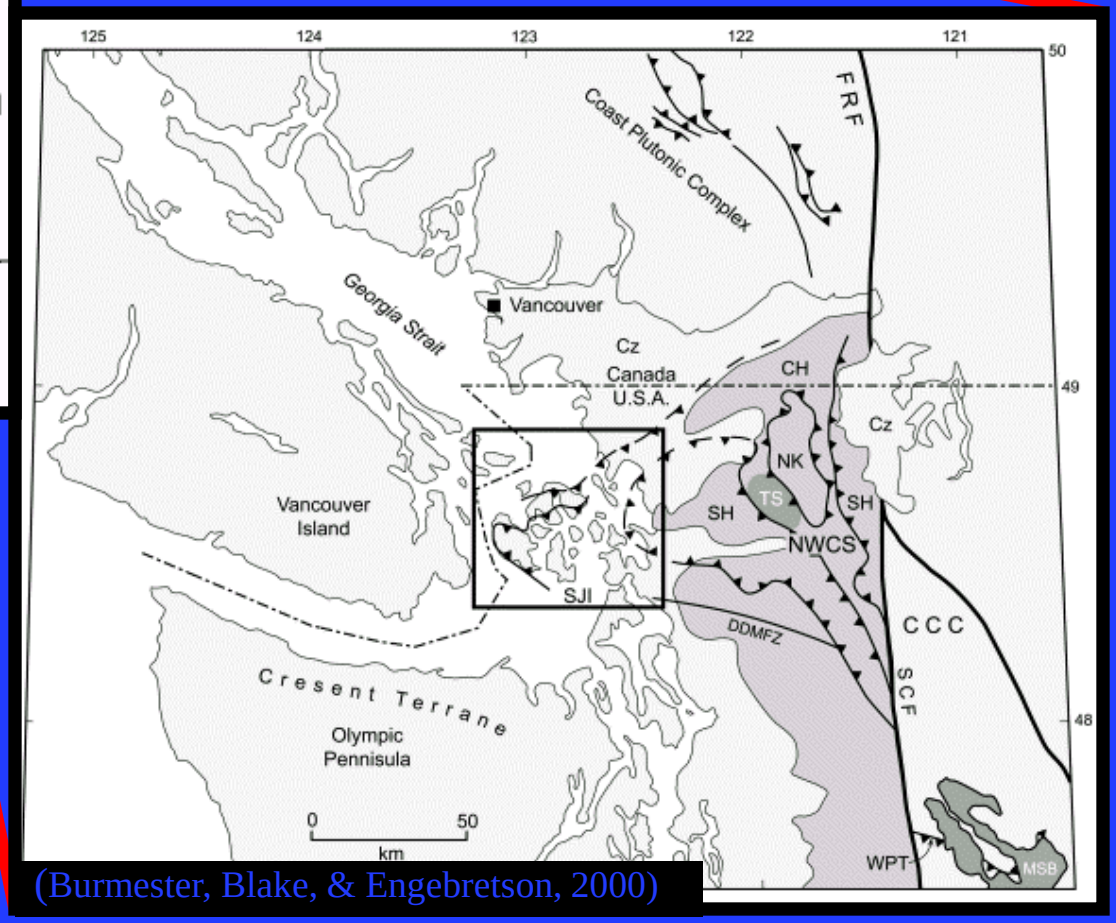




After Mosher and Johnson, 2000

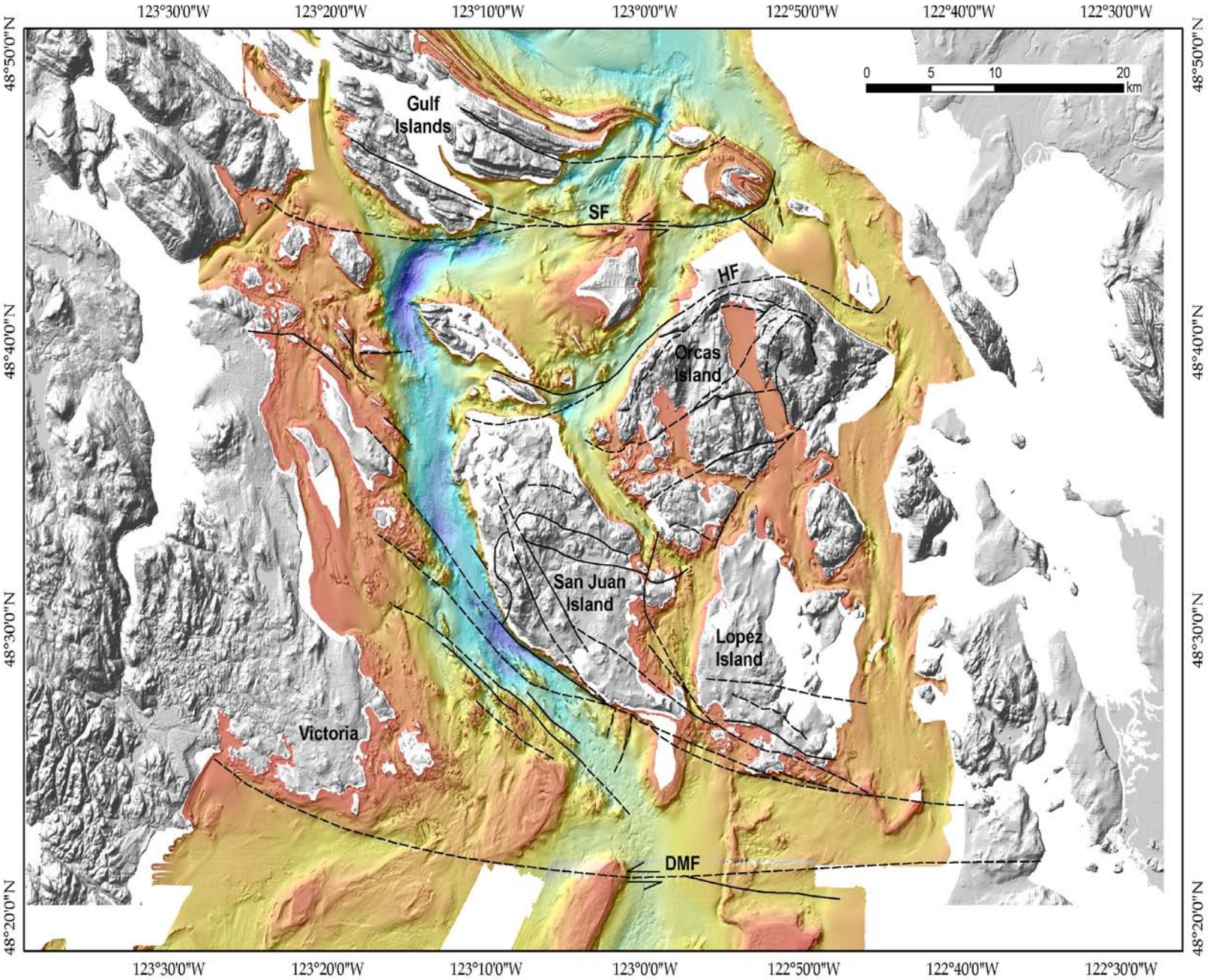
Geologic Setting





(Burmester, Blake, & Engebretson, 2000)

Numerous episodes of uplift & subsidence associated with tectonics and glacial cycles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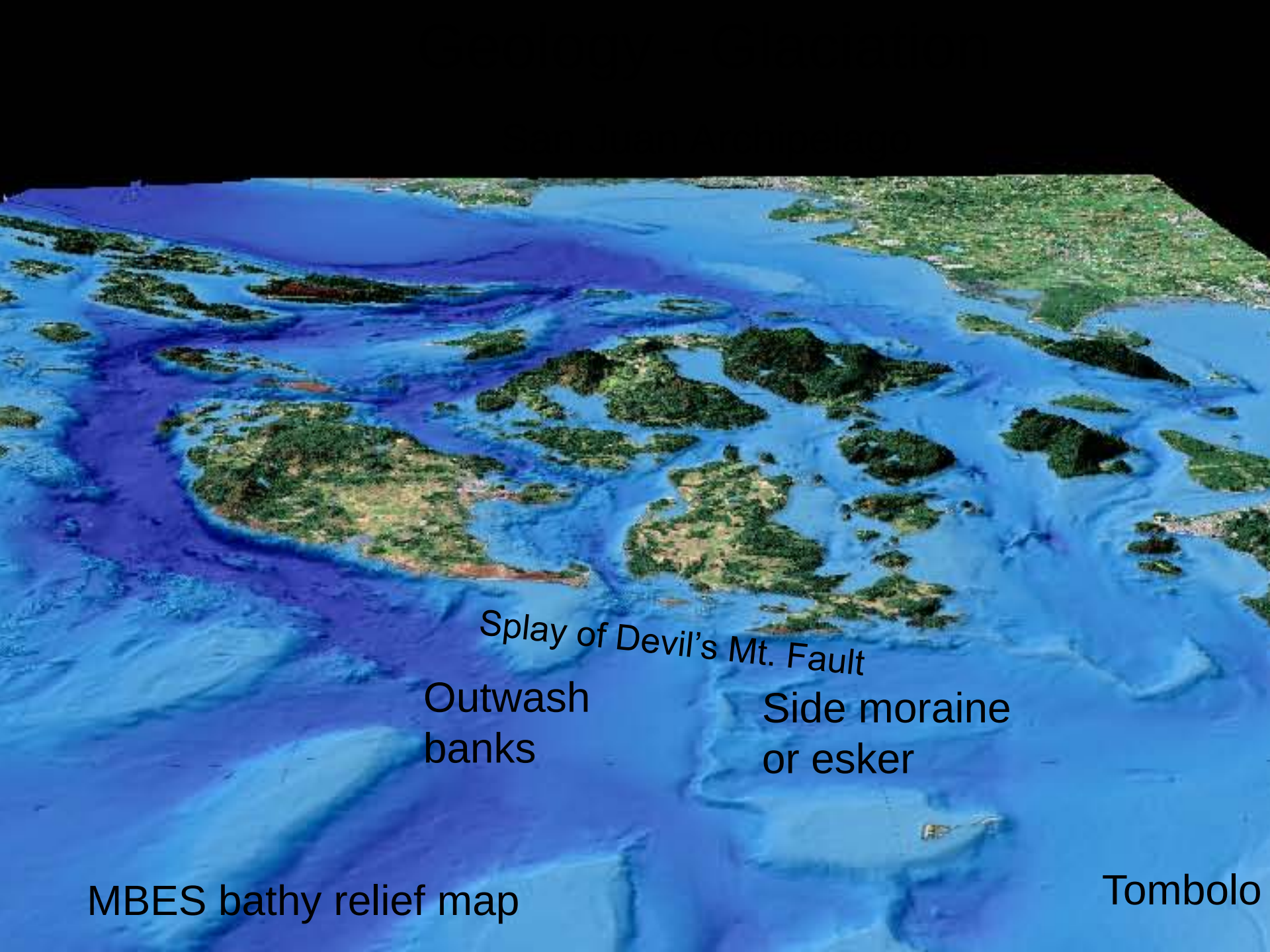
Orcas Island
San Juan Island
Lopez Island
Victoria
DMF


Splay of Devil's Mt. Fault
Outwash banks
Side moraine or esker
MBES bathy relief map
Tombolo

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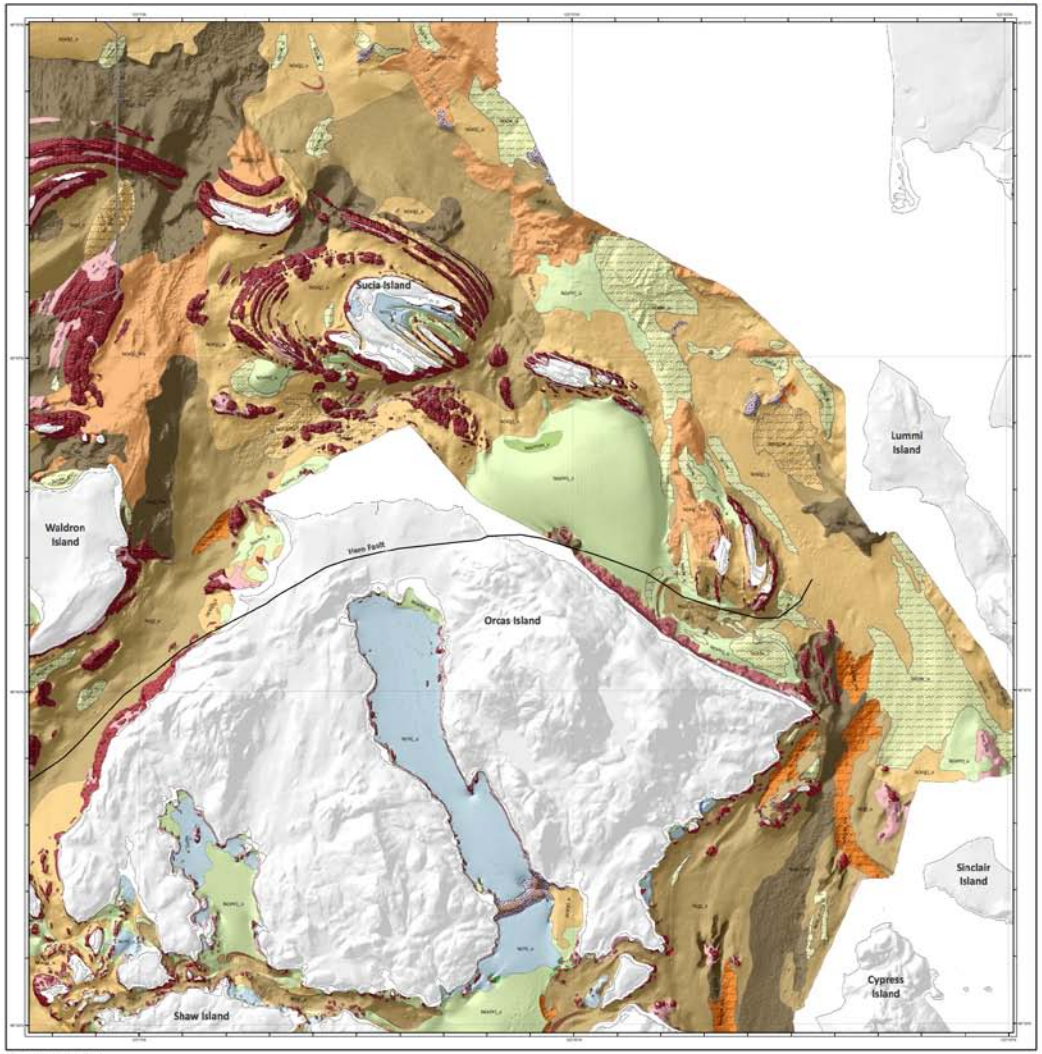

OPEN FILE 6625

POTENTIAL MARINE BENTHIC HABITATS AND SHADED SEAFLOOR RELIEF

SOUTHERN GULF ISLANDS AND SAN JUAN ARCHIPELAGO

CANADA AND U.S.A.

Sheet 3: Orcas Island

Scale 1:50 000/Échelle 1:50 000

DESCRIPTIVE NOTES

The Sain Juan Archipelago-Southern Gulf Islands seafloor mapping effort is an ongoing mapping program focused on the characterization of marine benthic habitats and the mapping of geology within the Salish Sea. The Salish Sea has suffered a severe decline in several species of bottom fish over the past several decades, likely due to environmental degradation and overfishing (Puget Sound Ambient Monitoring Program, 2002; Fisheries and Oceans Canada, Pacific Biological Station, 2004; Levin et al., 2009). Habitat loss has been a factor in the decline of potential marine benthic habitats and geology. The final product includes interactive maps that can be used to identify habitat (because as a habitat, which then can be used by both Canada and the US to manage, conserve and sustain economically significant fisheries (commercial and recreational) in the Transboundary region. A mechanism that has been developed to address the decline of marine benthic habitat is the creation of marine protected areas (MPAs) (mandatory and voluntary or mandatory no-take zones where extraction is a benthic habitat can be done using potential habitat maps. Therefore, a secondary objective of this mapping effort is to provide aids where assessment and if necessary modification, of established MPAs, and the establishment of new MPAs, can be made. Additional mapping objectives that evolved from this project include the identification of specific deep-water fragile habitats such as dynamic sediments that harbor sand lance (Ammodytes hexapterus) and patterns of kelp sponge reefs (Hexactinellida, Porifera) and other, specifically identified in the maps as characterization of these specific habitat types is continuing.

The Sain Juan Archipelago-Georgia Basin region is an active tectonic province where photography and geomorphology reflect both Neocene to Eocene convergent transpressional tectonics and Pleistocene glacial processes (Clague et al., 1980; Monger and Journeay, 1994). These processes have juxtaposed and sediment Jurassic-Cretaceous metamorphic rocks with Tertiary-Quaternary sedimentary rocks producing a complex of (rocks, gravel and polished bedrock outcrops, and erratic boulders and moraines. Items of fill and glacial advance subsaint deposits have also formed and contribute to the variety of relief within the region. Present day tidal action has flattened much of the rocky glacial-marine sediments into dynamic seafloors consisting of sand and gravel waves and dune fields. Modern day sedimentary processes are active in the region and represent material being supplied to the region by the Fraser River of British Columbia, Canada.

The tectonic province can be divided into two distinct zones based on bedrock types: a northern sedimentary bedrock zone and a southern metamorphic rock zone separated by the Haro Fault (Mustard, 1994; Mustard et al., 1994). The northern zone is characterized by Cretaceous-Tertiary sedimentary rock type in differentiating exudes (high forming ridges and overhangs) while the metamorphic bedrock are highly fractured and faulted forming cracks, crevices, and blocky boulder aprons. The severity and variety of tectonic, geologic and physical processes active in the province are directly responsible for forming the large variety of potential marine benthic habitat types mapped in the region.

The habitat classification was done following an existing habitat classification code, which was established to distinguish habitat types for species of interest and to facilitate ease of use and queries in GIS and other database programs. The code used in this map is modified from the scheme developed by Greene et al. (1999, 2007) for deep-water habitat characterization.

The seafloor imagery interpretation and habitat type delineation were based on knowledge of the geology of the seafloor and seafloor processes in the study area (Thompson, 1981; Mosher et al., 2006; Barrie et al., 2005, 2009). Geological processes, structure and morphology described in the imagery were used to delineate distinct potential habitat types. Resolution of the seafloor interpretation varied with the type of MBES systems that were used in the various surveys. Generally, the finer the resolution, the smaller the features that could be identified (e.g., bedrock, metamorphic, volcanic and granitic rocks), structures (e.g., faults, folds, scours, and landslides), and bedforms of unconsolidated sediments were easily distinguished. To differentiate cobbles and/or boulders (>0.5m) habitat from simple bedrock habitat a specific rule was assigned where any known bedrock polygons with a surface area smaller than 500 m² became identified with "Attribute".

The Transboundary region covered by the map sheet was been divided into four quadrants and the sheet (Sheet 1 of 4, main Sicia) covers most of Haro Strait located between southern Vancouver Island (Victoria), B.C. Canada and San Juan Island, WA USA and part of north center Straits of Juan de Fuca. Habitat types here are predominantly composed of hard bedrock and fractured metamorphic rocks, boulders and dynamic seafloors. Strong currents in Haro Strait sweep the bedrock clean and produce sediment waves and dune fields.

* "Potential" is used here to indicate that the habitat mapped on the basis of morphology and substrate type may not have a known species or assemblage of organisms that are identified to use the habitat.

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KEY TO HABITAT TYPES

Not all units may appear on this map sheet

Unconsolidated substrate (mud)

la(m)_u	Unconsolidated sediments
la(m)_a	Unconsolidated sediment terrace
la(m)_hu	Hummocky unconsolidated sediments
la(m)m_u	Mound
la(m)h_a/u	Pockmark
la(m)h_a/u	Scour depression
la(m)_hla-dd/u	Hummocky dredge or anchor disturbances
la(m)g_a-dg/u	Dredge channel
la(m)t_hla/u	Seacuit terrace

Unconsolidated substrate (sand / mud)

la(sm)_u	Unconsolidated sediments
la(sm)_hu	Hummocky unconsolidated sediments
la(sm)vt_u	Vegetative unconsolidated sediment furrows
la(sm)m_u	Linear ridge
la(sm)m_u	Ice-formed mound
la(sm)h_u	Depression
la(sm)h_a/u	Scour depression
la(sm)g_a/u	Scour gully
la(sm)g/e_a/u	Scour gully with sediment bedforms
la(sm)s_a/u	Current-scoured swale
la(sm)s_u	Swell
la(sm)_hla-dd/u	Hummocky dredge or anchor disturbances

Unconsolidated substrate (sand / gravel)

la(sg)_u	Unconsolidated sediments
la(sg)_hu	Hummocky unconsolidated sediments
la(sg)e_u	Sediment bedforms
la(sg)e_a/u	Current-scoured sediment bedforms
la(sg)m_u	Mound or linear ridge
la(sg)m_u	Ice-formed mound, water or moraine
la(sg)m_hu	Hummocky ice-formed mound
la(sg)h_u	Depression
la(sg)h_a/u	Depression depression
la(sg)h_a/u	Scour depression
la(sg)g_a/u	Scour gully
la(sg)l_hlu	Hummocky landslide deposit
la(sg)s_a/u	Current-scoured swale
la(sg)_a-dm/u	Dredge disposal
la(sg)_hla-dd/u	Hummocky dredge or anchor disturbances
la(sg)g_a-dg/u	Dredge channel
la(w)_hla-f/u	Ferry wash swale

Unconsolidated substrate (sand)

la(s)_u	Unconsolidated sediments
la(s)_u	Unconsolidated sediment terrace
la(s)e_u	Sediment bedforms
la(s)m_u	Mound or Linear ridge
la(s)m_a/u	Scour ridge
la(s)h_a/u	Scour depression

Unconsolidated substrate (gravel)

la(g)_u	Unconsolidated sediments
la(g)_hu	Hummocky unconsolidated sediments
la(g)m_u	Mound or linear ridge
la(g)_mu	Ice-formed mound or moraine
la(g)h_a/u	Scour depression
la(g)s_a/u	Current-scoured swale

Unconsolidated substrate (boulders)

la(b)m_u	Moraine

Sediment covered bedrock

frs_c/u	Sediment covered bedrock

Hard substrate

hy	Rock fall
hy(p)	Pinnacle or boulder
frs_f/u	Fractured bedrock
frs_g/b	Granitic bedrock
frs(_d/b	Sedimentary bedrock
h_a-e	Anthropogenic structure - Shipwreck
h_a-p	Anthropogenic structure - Buoyants
h_a-a	Anthropogenic structure - Pilasters
h_a-g	Anthropogenic structure - Former vessel mooring facility, jetty or ramp

AUTHORS: C. Enslin, K. Picard, H.G. Greene, and J.V. Barrie

Compilation by C. Enslin and K. Picard

Edited by H.G. Greene and J.V. Barrie

ACKNOWLEDGEMENTS: Canadian Hydrographic Service participants R. Hare, K. Crozier, G. Sargent, P. Minor, J. Gapra, C. Lawson, D. Cartwright, K. Lyngberg, and Canadian Coast Guard participants S. Allison and R. Kwiek.

This map was produced by the Center for Habitat Studies at Moss Landing Marine Laboratories in cooperation with Terrabotic, the GeoDisc Society, Natural Resources Canada and the Canadian Hydrographic Service.

Digital Cartography by C. Enslin, Center for Habitat Studies

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2010

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SHEET 3 OF 4
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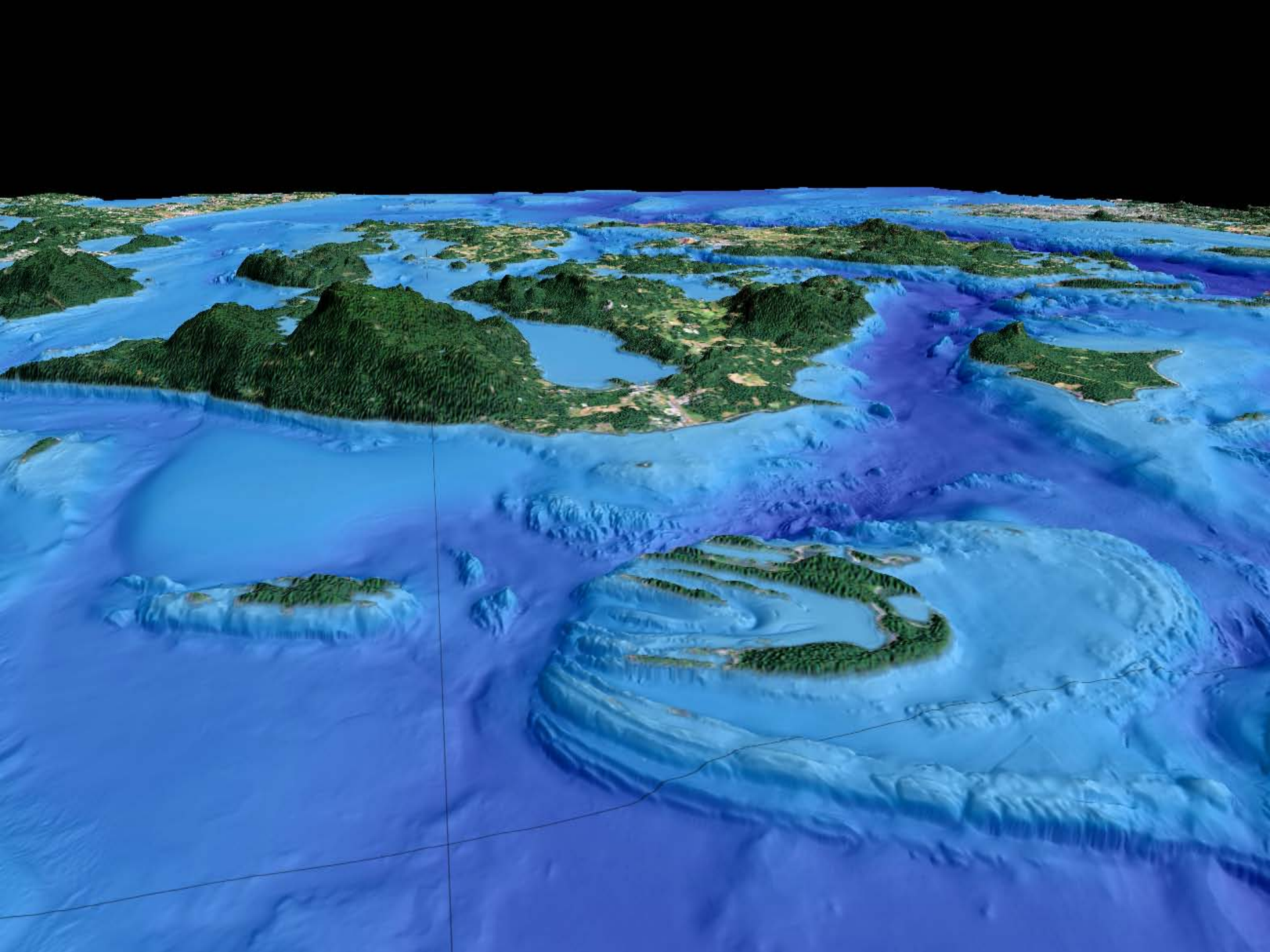
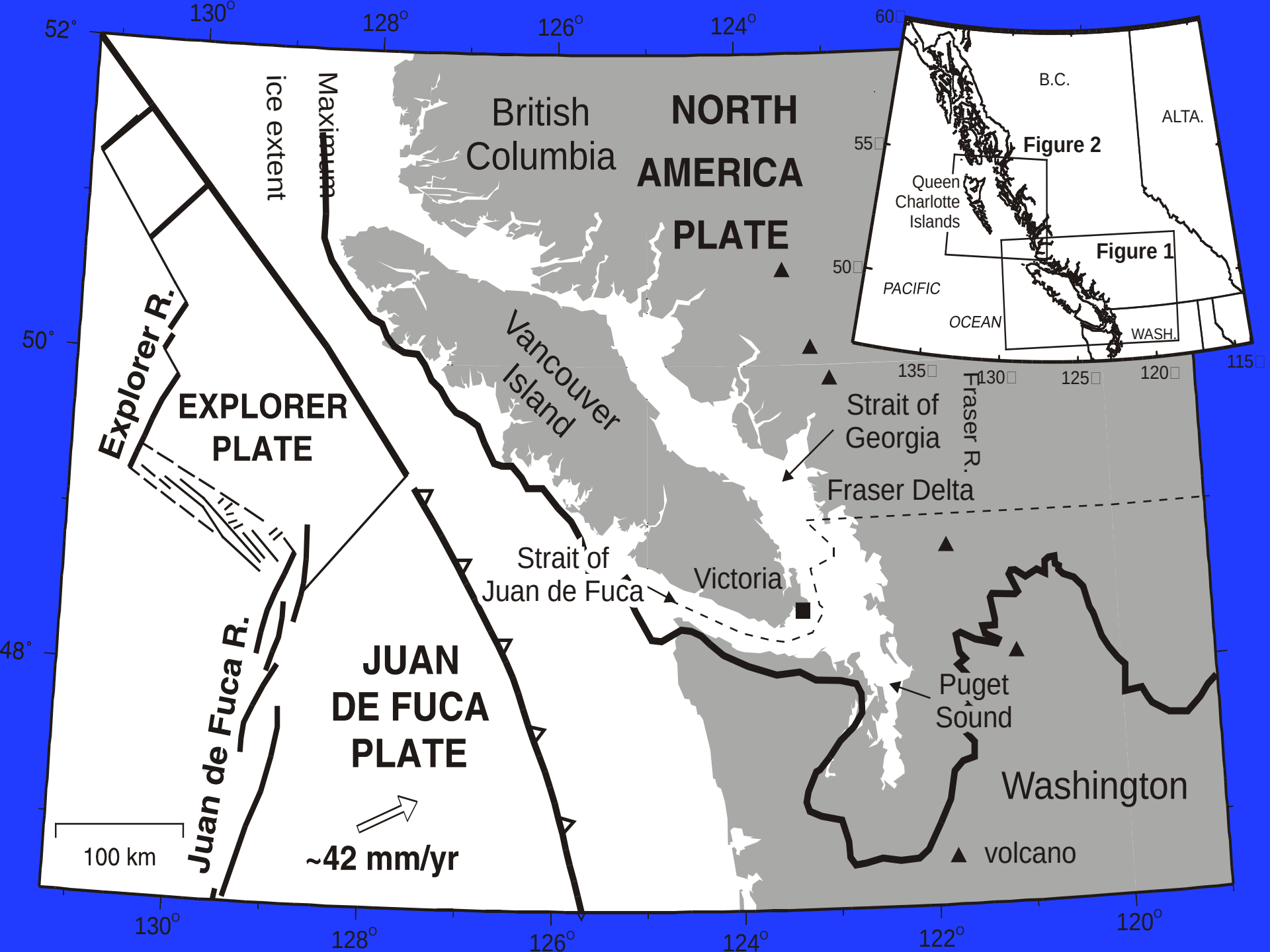
Sheet 3 of 4, Orcas Island

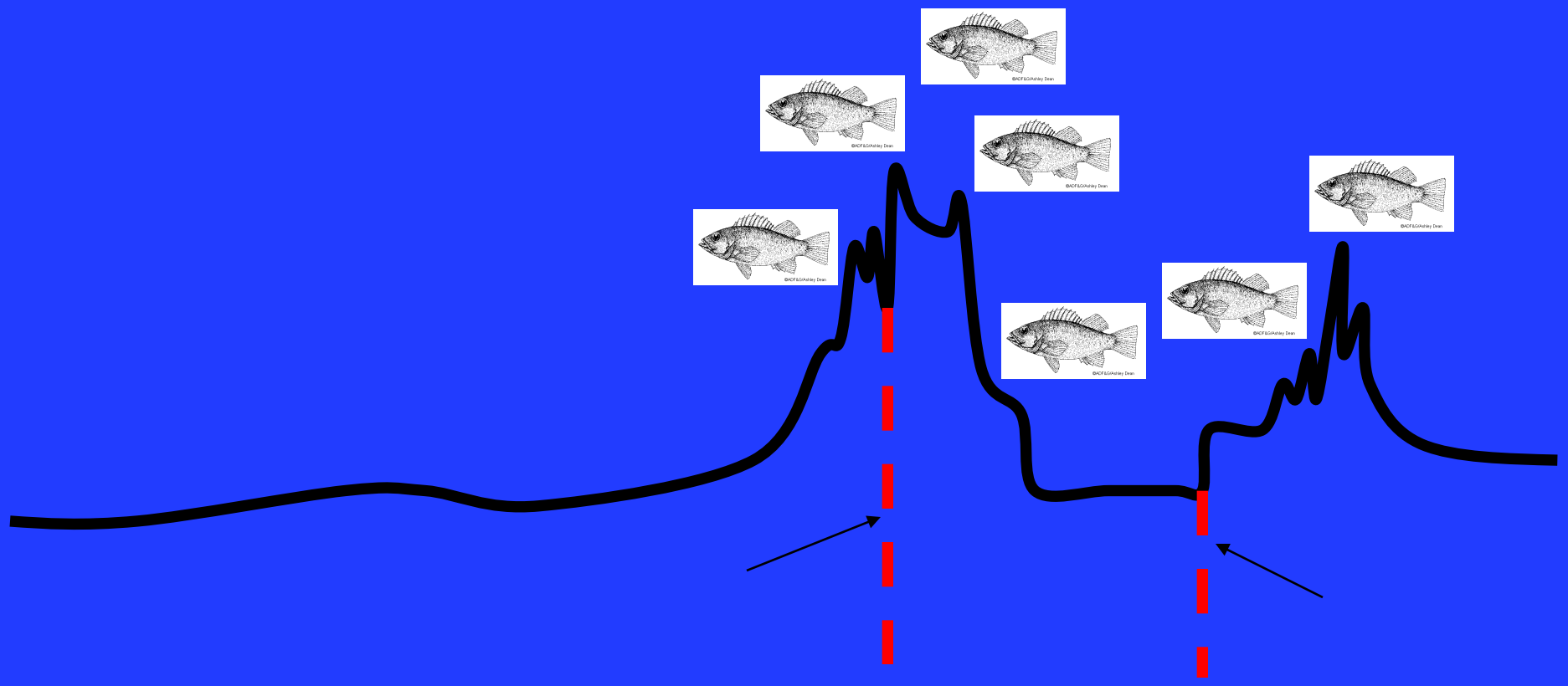
Recommended citation:
Enslin, C., Picard, K., Greene, H.G., and Barrie, J.V., 2010. Potential marine benthic habitats and shaded seafloor relief, Southern Gulf Islands and San Juan Archipelago, Canada and U.S.A., Geological Survey of Canada, Open File 6625, scale 1:50 000.

Canada




52°
130°
128°
126°
124°
122°
120°
50°
48°
Maximum ice extent
British Columbia
NORTH AMERICA PLATE
Vancouver Island
Strait of Georgia
Fraser R.
Fraser Delta
Strait of Juan de Fuca
Victoria
Puget Sound
Washington
volcano
Explorer R.
EXPLORER PLATE
Juan de Fuca R.
JUAN DE FUCA PLATE
~42 mm/yr
100 km
B.C.
ALTA.
Figure 2
Queen Charlotte Islands
Figure 1
PACIFIC
OCEAN
WASH.
60
55
50
135
130
125
120
115

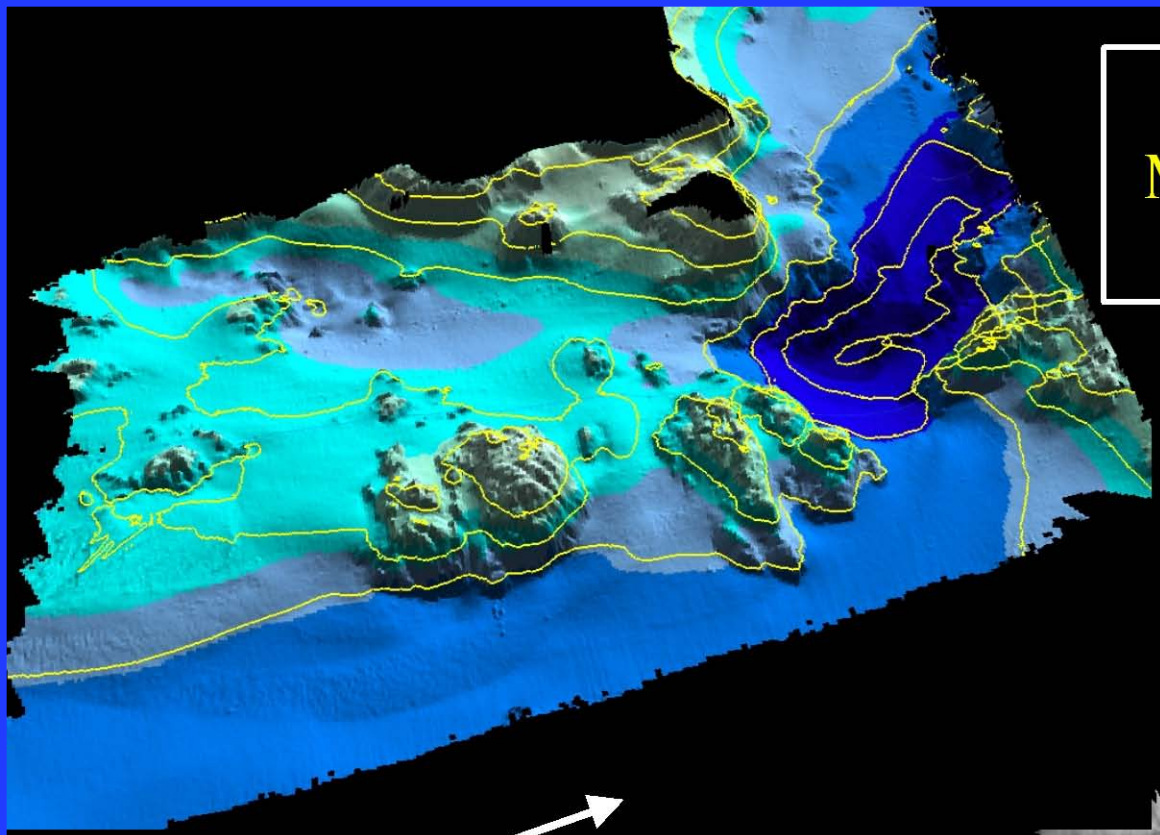
Geology = Habitat



* Rockfish sketch provided by ADFG website

Image courtesy of Alaska Fish & Game

Friday Harbor Processed Multibeam/Backscatter Data in 3D



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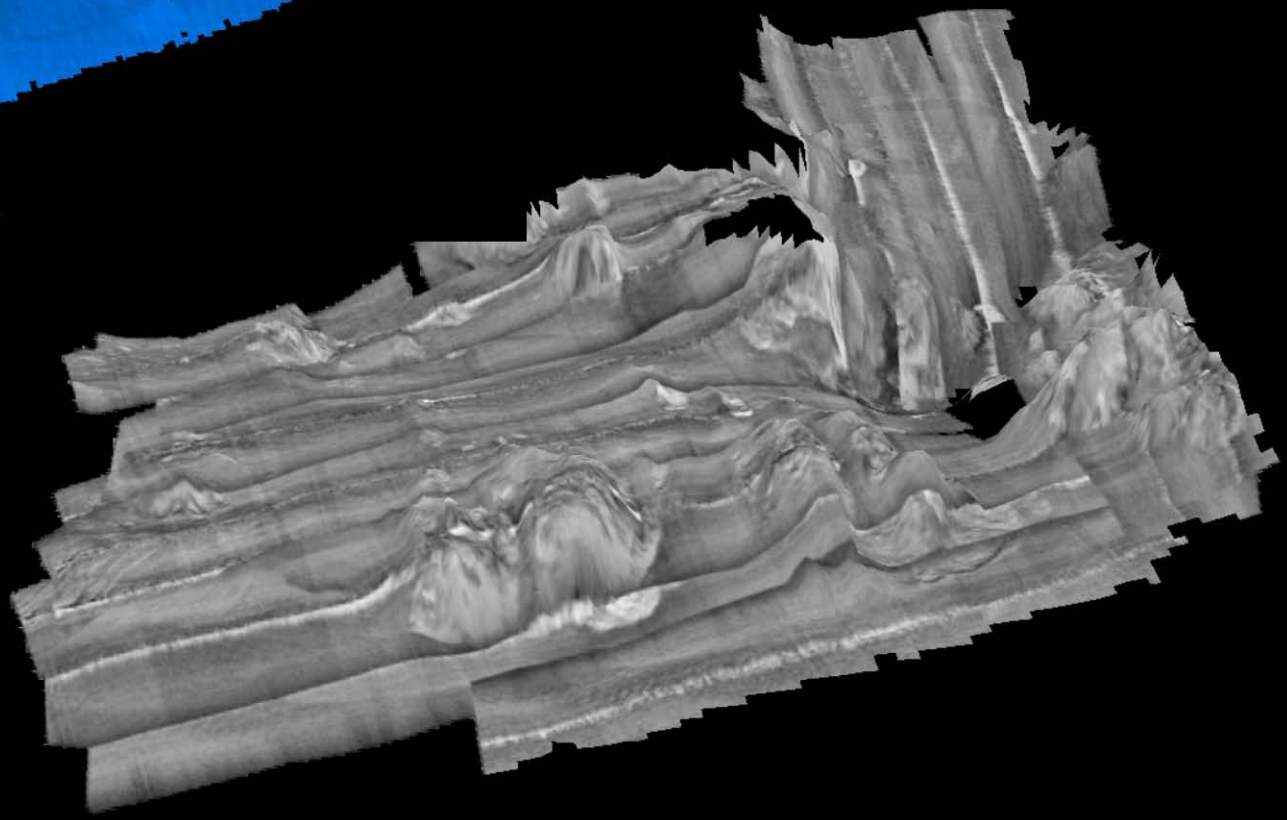

Natural Resources Canada / Ressources naturelles Canada

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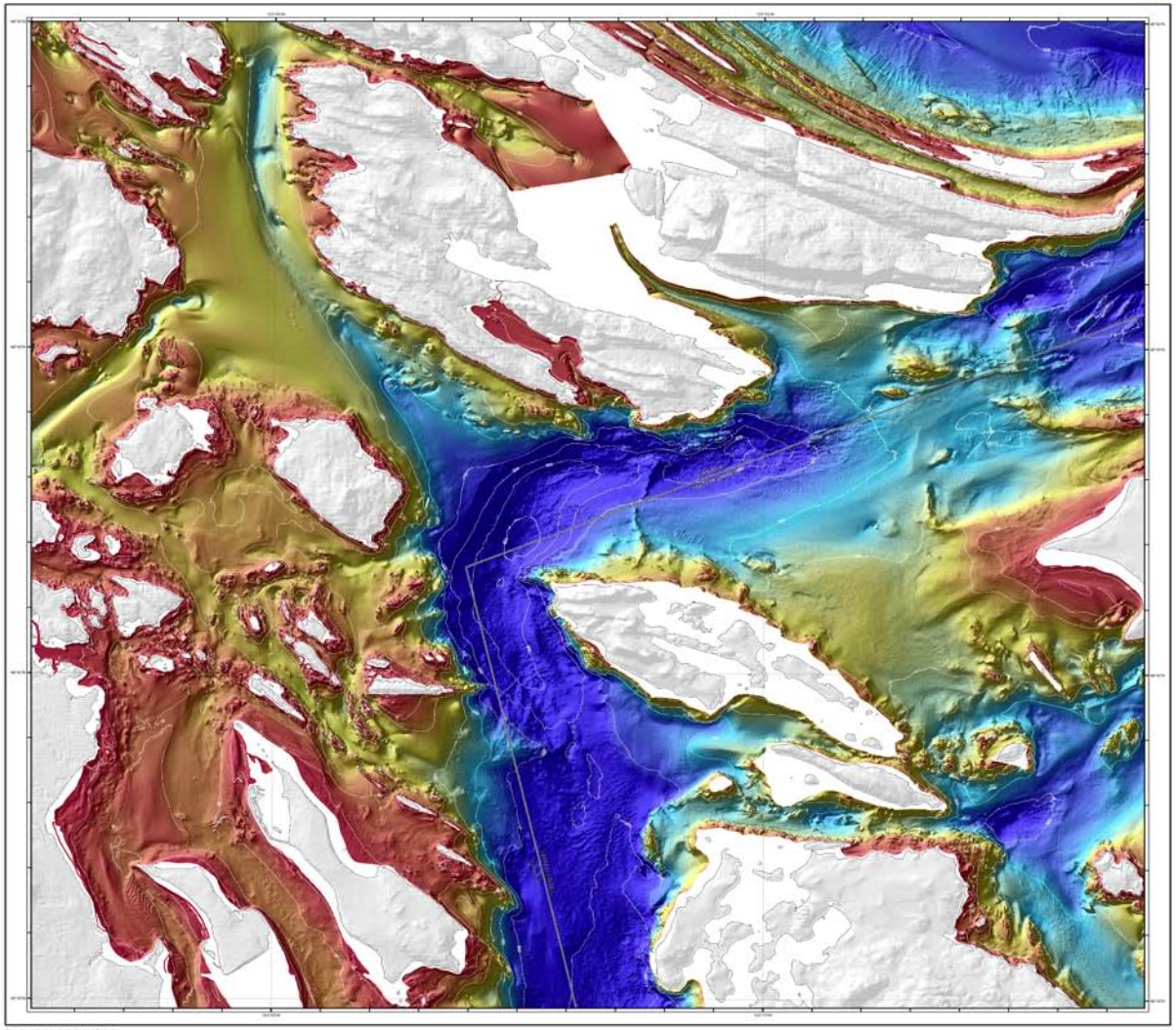


OPEN FILE 6627

SHADED SEAFLOOR RELIEF

SOUTHERN GULF ISLANDS AND SAN JUAN ARCHIPELAGO

CANADA AND U.S.A.

Sheet 2: southern Gulf Islands

Scale 1:50 000/Échelle 1/50 000

Kilometres 1 0 1 2 3 4 Kilomètres

Universal Transverse Mercator Projection, Zone 10 North
North American Datum 1983
© Her Majesty the Queen in Right of Canada 2010
This map is not to be used for navigational purposes

Projection transverse universelle de Mercator
Système nord-américain de référence de 1983
© Sa Majesté la Reine du chef du Canada 2010
Cette carte ne doit pas être utilisée aux fins de navigation

Map Index

Canada

DESCRIPTIVE NOTES

A pilot mapping project was undertaken in 2003 using a pole-mounted Reson 8101 SeaBat (240 kHz) swath (100 swath coverage) multibeam echosounder (MBES) system mounted aboard the R/V MacDonald, with the data collected under contract with the Seafloor Mapping Lab of California State University Monterey Bay through the Center for Habitat Studies, Moss Landing Marine Laboratories. Four areas in the southern Gulf Islands (Ganges, Sidney, Trincomali, and Plumper), Haro Point, Pile Point, Turn Island, and Lawson Reef areas within the San Juan Archipelago were mapped and the boat was positioned using a differential global positioning system (DGPS). Attitude information such as heave, pitch, and roll, were recorded using a heading motion sensor (HDMS), with the data logged and integrated using Triton Elics International ISIS and Coastal Oceanographic Hypack software. Water column sound velocity profiles were collected daily at each site using an AML SV+ sound velocity profiler. In addition, tide information was obtained from local tide stations. Data acquisition was maximized for collection of accurate bathymetry rather than backscatter data. Consequently, the quality of the backscatter data was substandard and unusable.

For the pilot project the bathymetric data were processed using CARIS HIPS hydrographic data cleaning software. Soundings were corrected for vessel motion and water column sound velocity and adjusted to mean lower low water (MLLW) using predicted tides for the San Juan Islands. Erroneous soundings were removed in CARIS HIPS through both automated filtering and manual editing. After processing of all lines for each of the five survey areas, the data were exported from CARIS as a geo-referenced, artifactly thumbnailed (from NW) image, and as a binned (2 m LASCI Neil Dyer) ha. A 2m Archive ASCII raster (.asc) grids were created from the xyz data using Fledermaus a 3D imaging software.

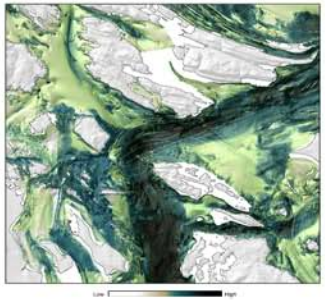
From 2001 through 2009 the Canadian Coast Guard vessels *Otter Bay*, *Revelstoke*, R.B. Young and *Medan*, and under the direction of the Canadian Hydrographic Service (CHS) in cooperation with the Geological Survey of Canada (GSC) and NOAA's Center for Habitat Studies/Tomlinson/Beaches Society, acquired extensive high resolution bathymetric datasets of the waterways surrounding the Southern Gulf Islands and the San Juan Archipelago.

The MBES, Simrad EM 1002 (95kHz frequency) and EM 3000-3002 (300 kHz frequency) systems were used for deep (>50 m) and shallow (<50 m) waters respectively. The dataset resolutions were 5 and 2 m respectively. In most of the areas, the tracks were positioned so as to mainly 100% of the seafloor with a 100% overlap, providing 200% coverage. Positioning was accomplished using a wide-band Differential Global Positioning System (DGPS) and MBES data were corrected for sound speed variations in the stratified water column using frequent sound speed casts.

The bathymetric data were carefully processed by CHS with CARIS Hydrographic Information Processing Software (HIPS). The outlying navigation and attitude sensor data were exported, the gaps restored using linear interpolation, and the filtered data were then merged with DGPS and POS/MV input. Subsequently, automatic coarse filters were applied to swath data (+/- 60° swath angle). Spurious data points were removed manually in the SwathEdit module of HIPS on a cross-track basis, and lost soundings were spotted (predicted or observed, if available). After surging the data (depth-dependent, variable-radius median filter) to compensate for depth-dependent data density, grids were generated and the gridded data were exported to an ASCII format as XYZ triplets and transferred to the GSC for further processing.

The Theatre boundary region covered by this map series has been divided into four quadrants and this sheet (Sheet 1 of 4, Haro Strait area) covers most of the Haro Strait located between southern Vancouver Island (Victoria), B.C. Canada and San Juan Island, WA USA and part of north central Strait of Juan de Fuca.

Sun-Illuminated Bathymetry



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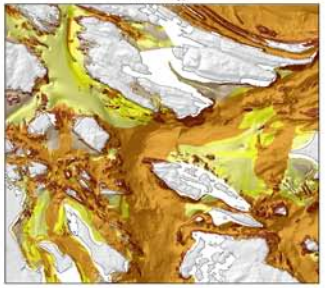

AUTHORS: C. Endris, K. Picard, H.G. Greene, and J.V. Barrie

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Edited by H.G. Greene and J.V. Barrie

ACKNOWLEDGEMENTS: Canadian Hydrographic Service participants R. Hare, K. Cantlon, E. Surgent, P. Milner, J. Gagne, C. Lacoste, G. Cartwright, K. Lyngberg, and Canadian Coast Guard participants G. Allison and K. Keane

This map was produced by the Center for Habitat Studies at Moss Landing Marine Laboratories in cooperation with Tombolo, the Beaches Society, Natural Resources Canada, and the Canadian Hydrographic Service

Digital Cartography by C. Endris, Center for Habitat Studies

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2010

SHEET 2 OF 4
FEUILLET 2 DE 4

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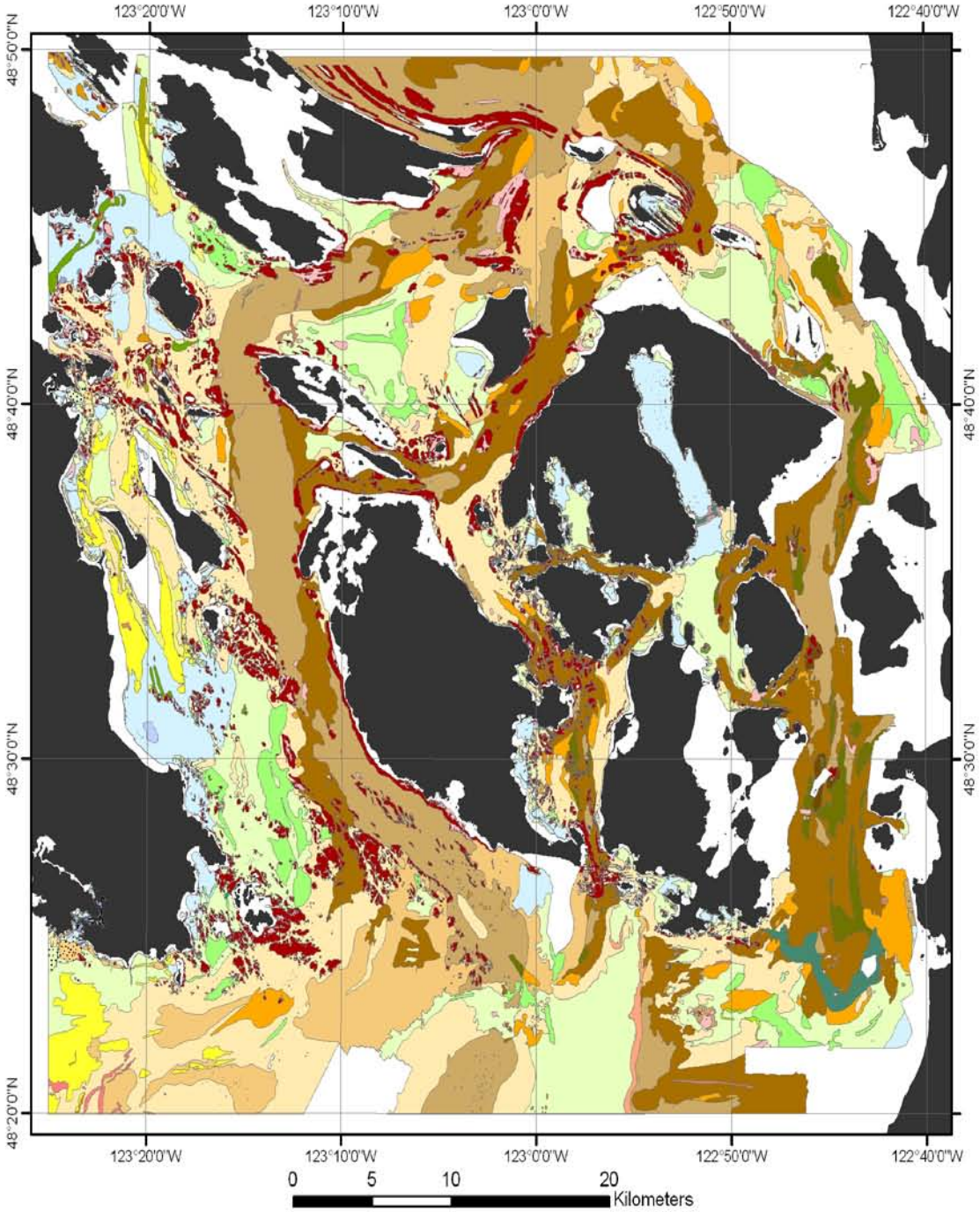
Sheet 2 of 4, southern Gulf Islands

Recommended citation:
Endris, C., Picard, K., Greene, H.G., and Barrie, J.V., 2010. Shaded seafloor relief, southern Gulf Islands and San Juan Archipelago, Canada and U.S.A.: Geological Survey of Canada, Open File 6627, scale 1:50 000.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123°10'0"W
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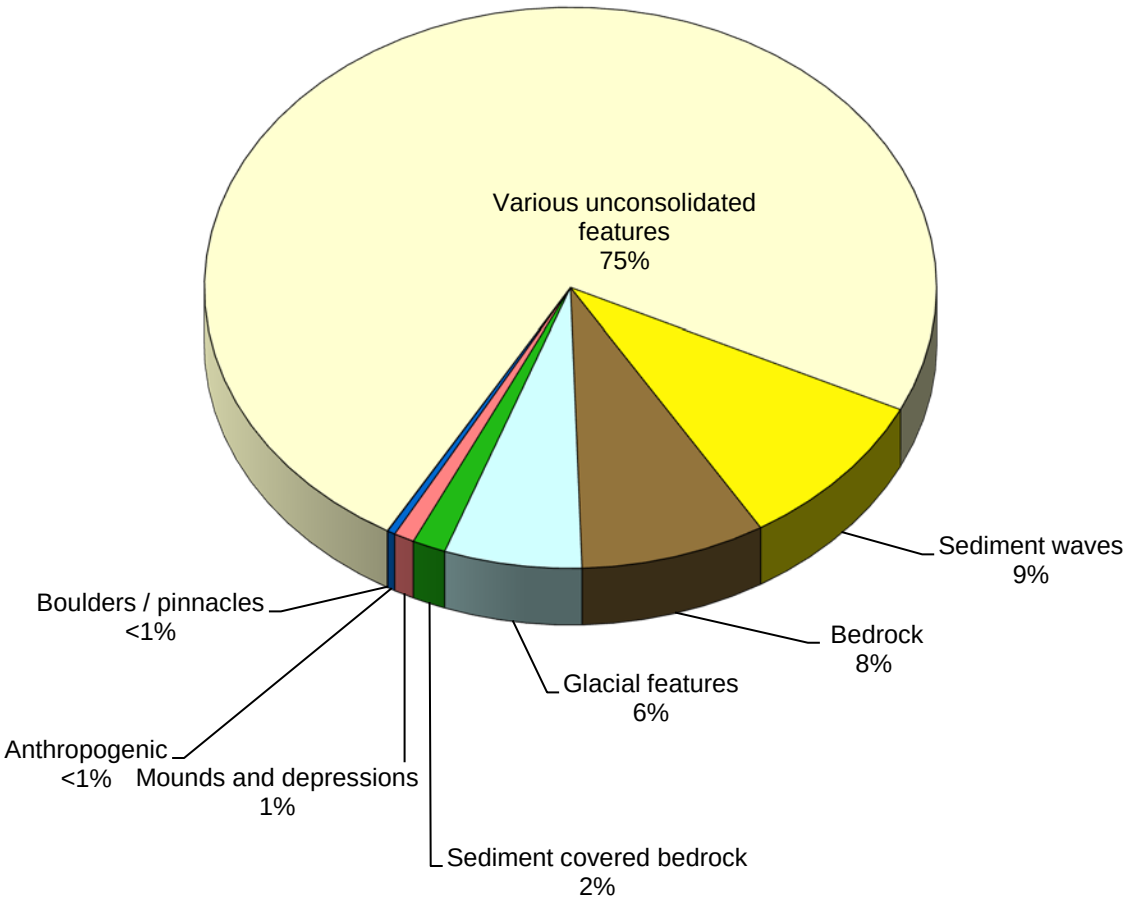
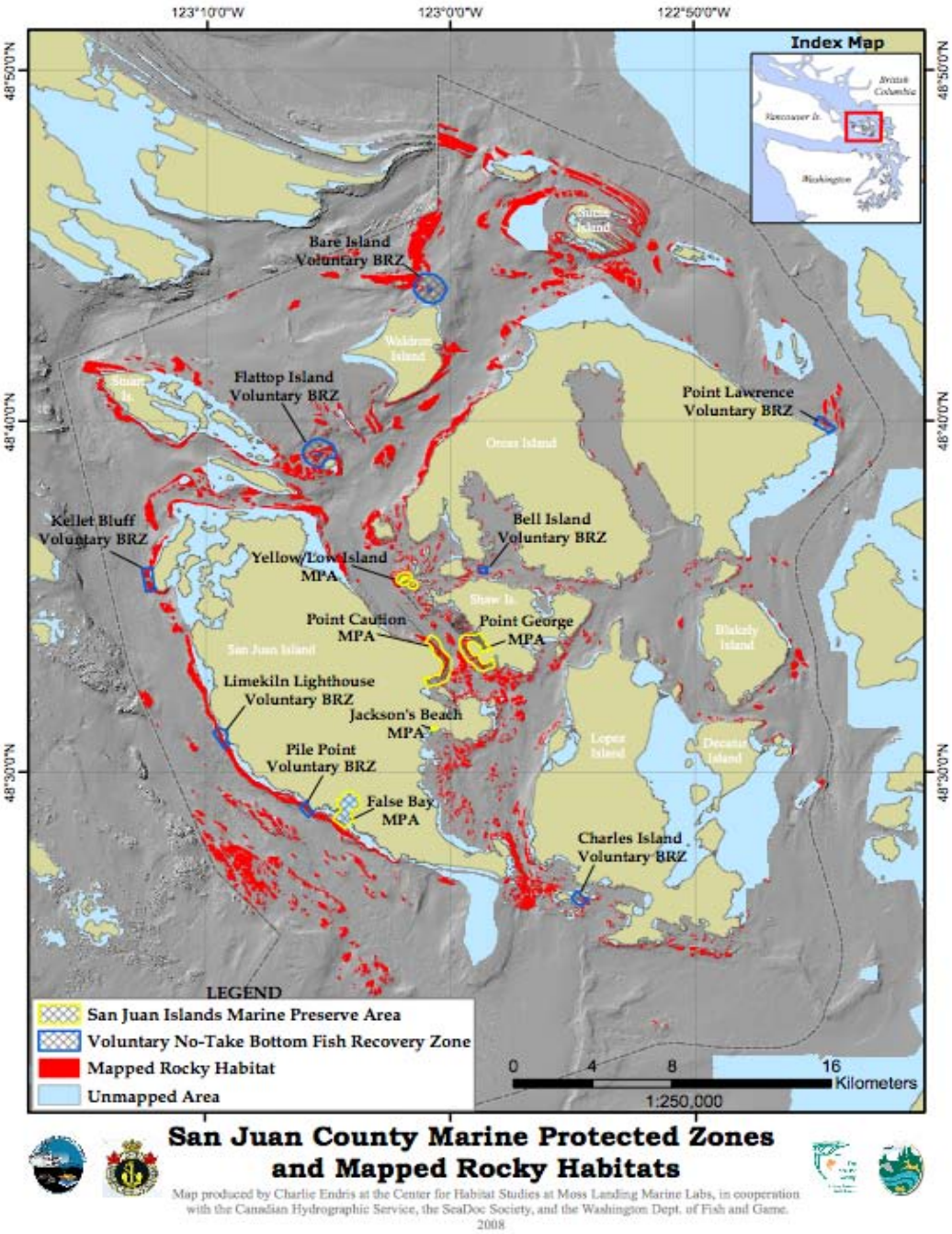
122°50'0"W
122°40'0"W
48°50'0"N
48°40'0"N
48°30'0"N
48°20'0"N
0
5
10
20
Kilometers

San Juan Archipelago Habitats





Habitat Mapping - Ecosystem Management

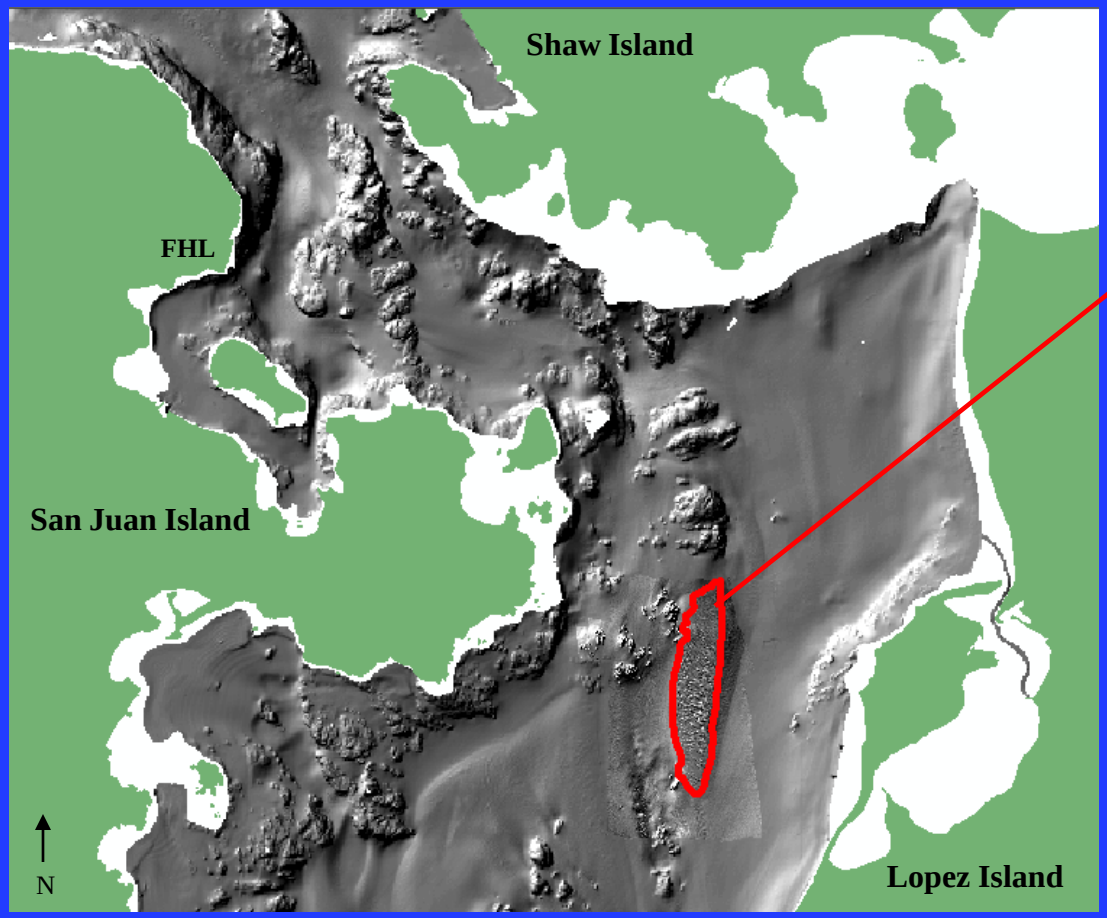
Potential Rockfish Habita
(Red areas)

Salish Sea Mapping Effort
MBES Bathymetry
(EM 3000 & 3002)

Tombolo

Foraging Habitats

Sandwave Field



Abundance in Sandwave Field

- If avg. density = 84 fish/m^2:

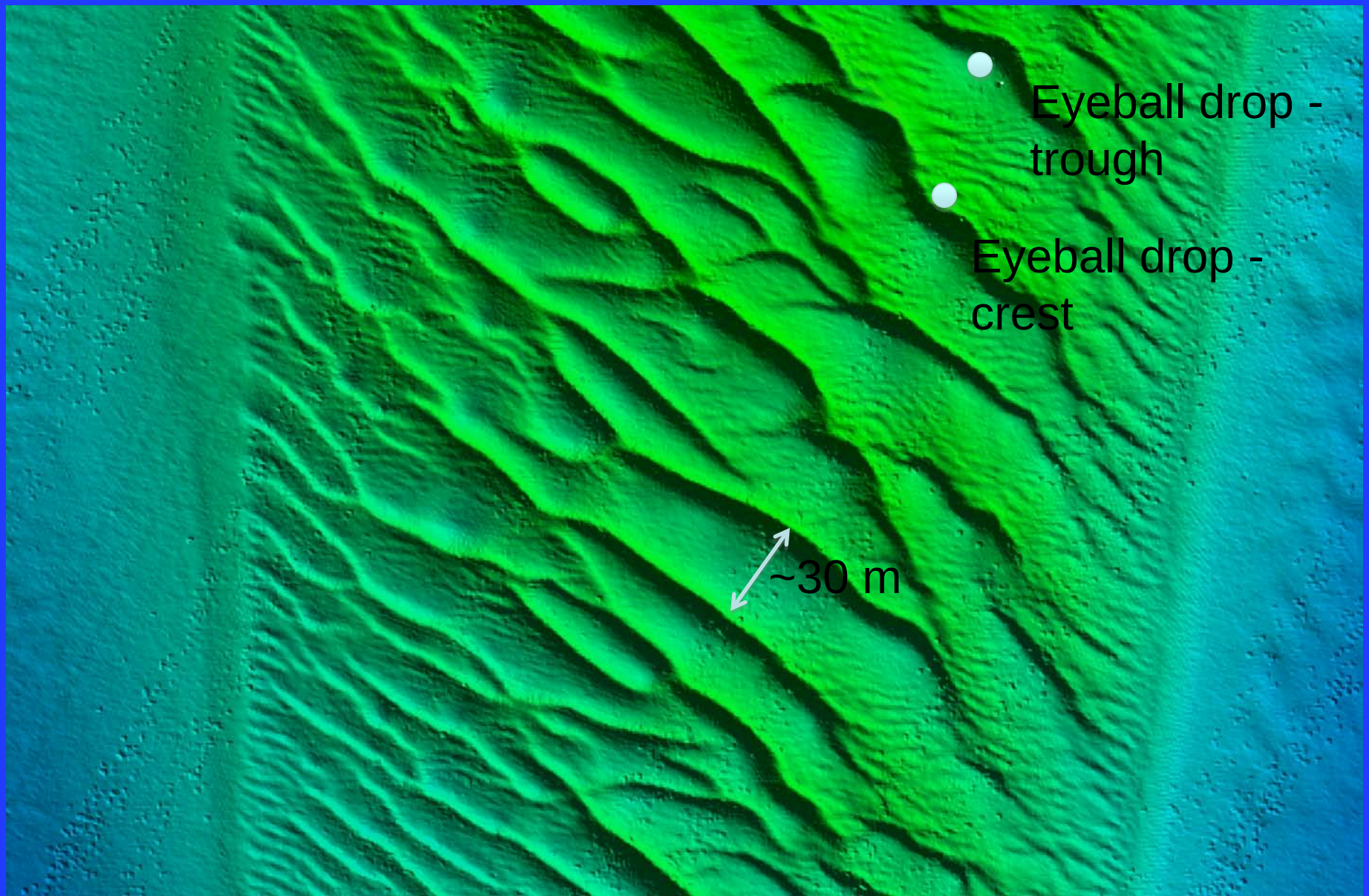
  44,556,805 fish

- If light density = 120 fish/m^2:

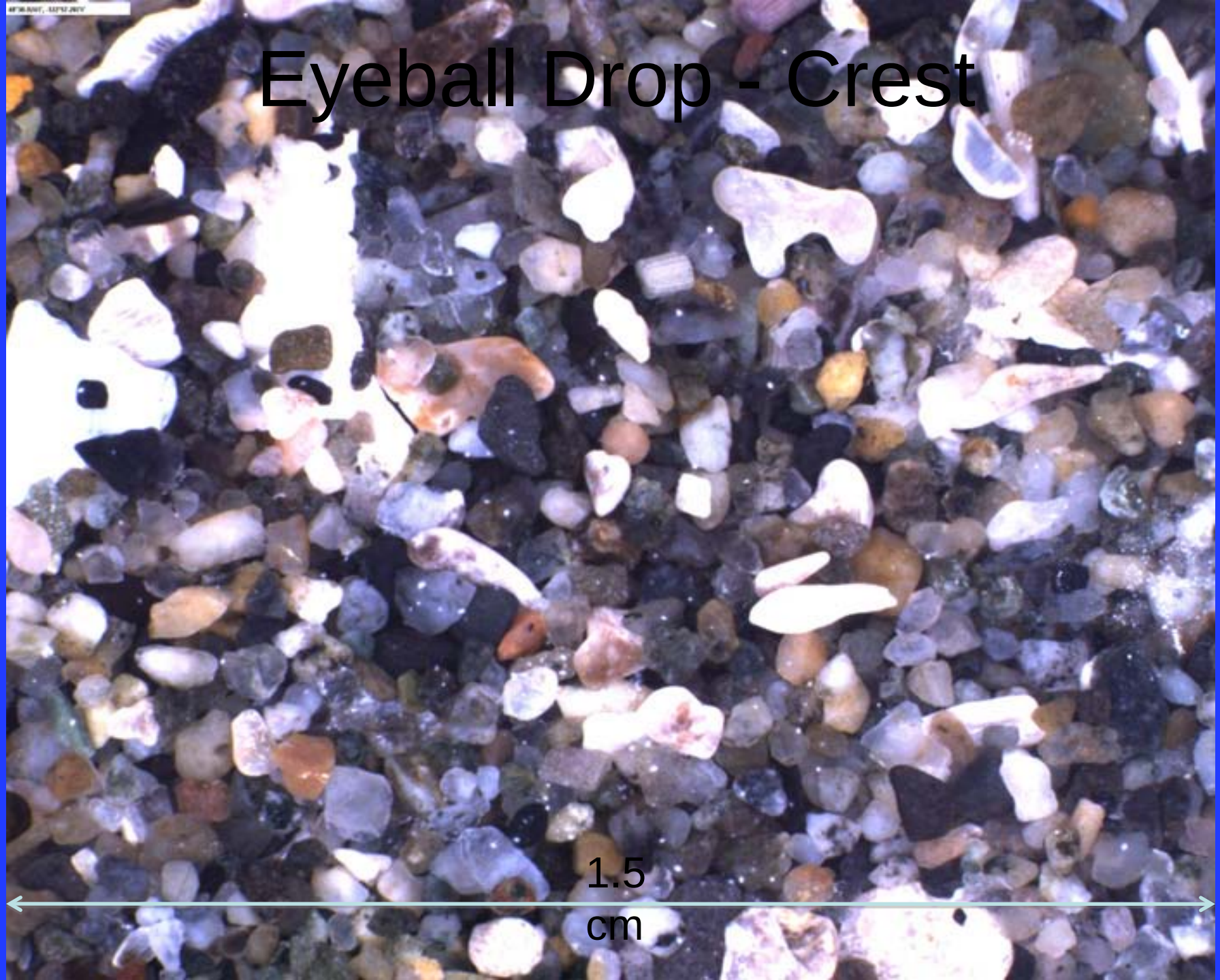
  63,742,733 fish

USGS eyeball
Sediment camera
USGS Video
Camera

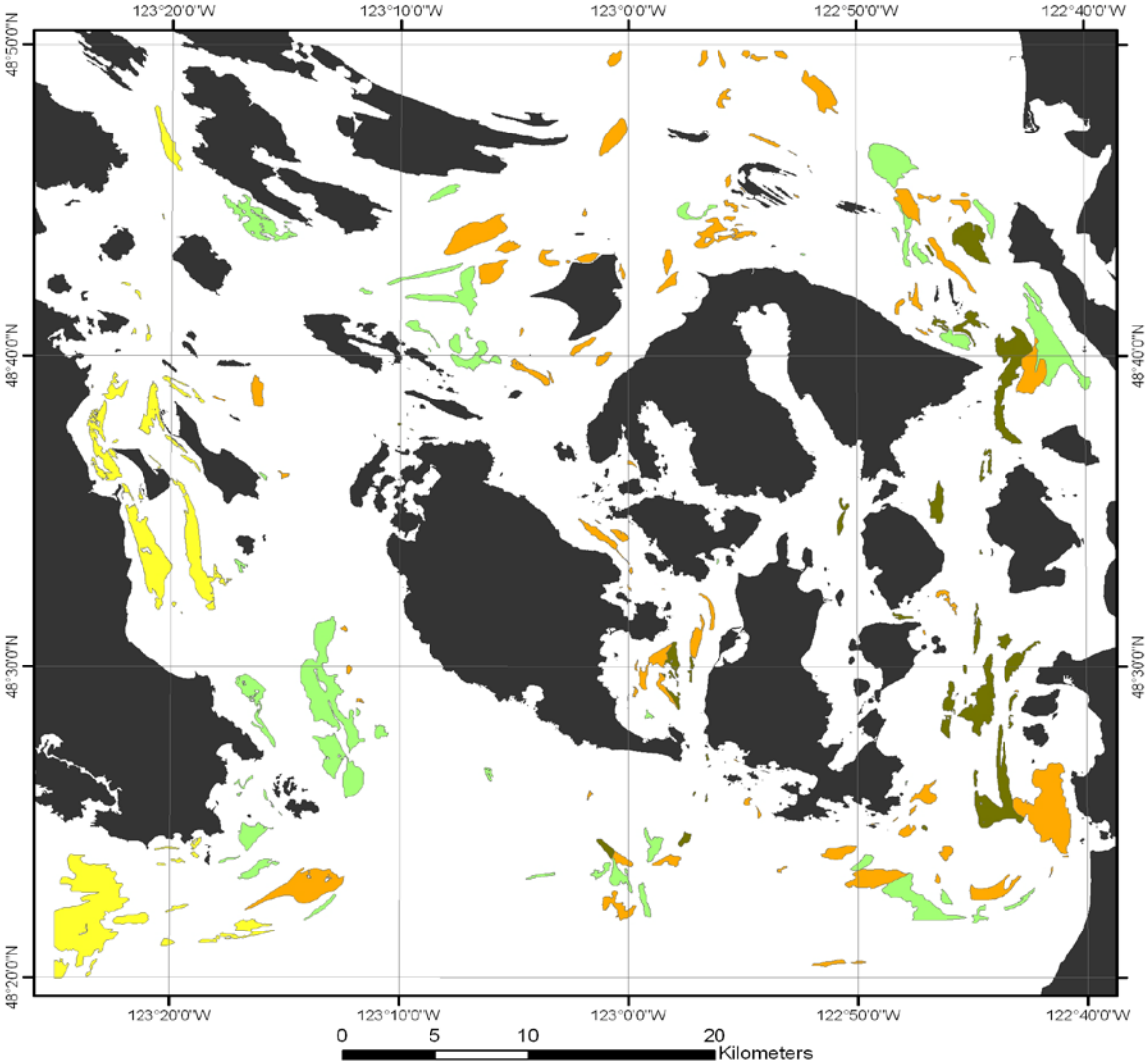
San Juan Channel Sand Waves



Eyeball Drop - Crest

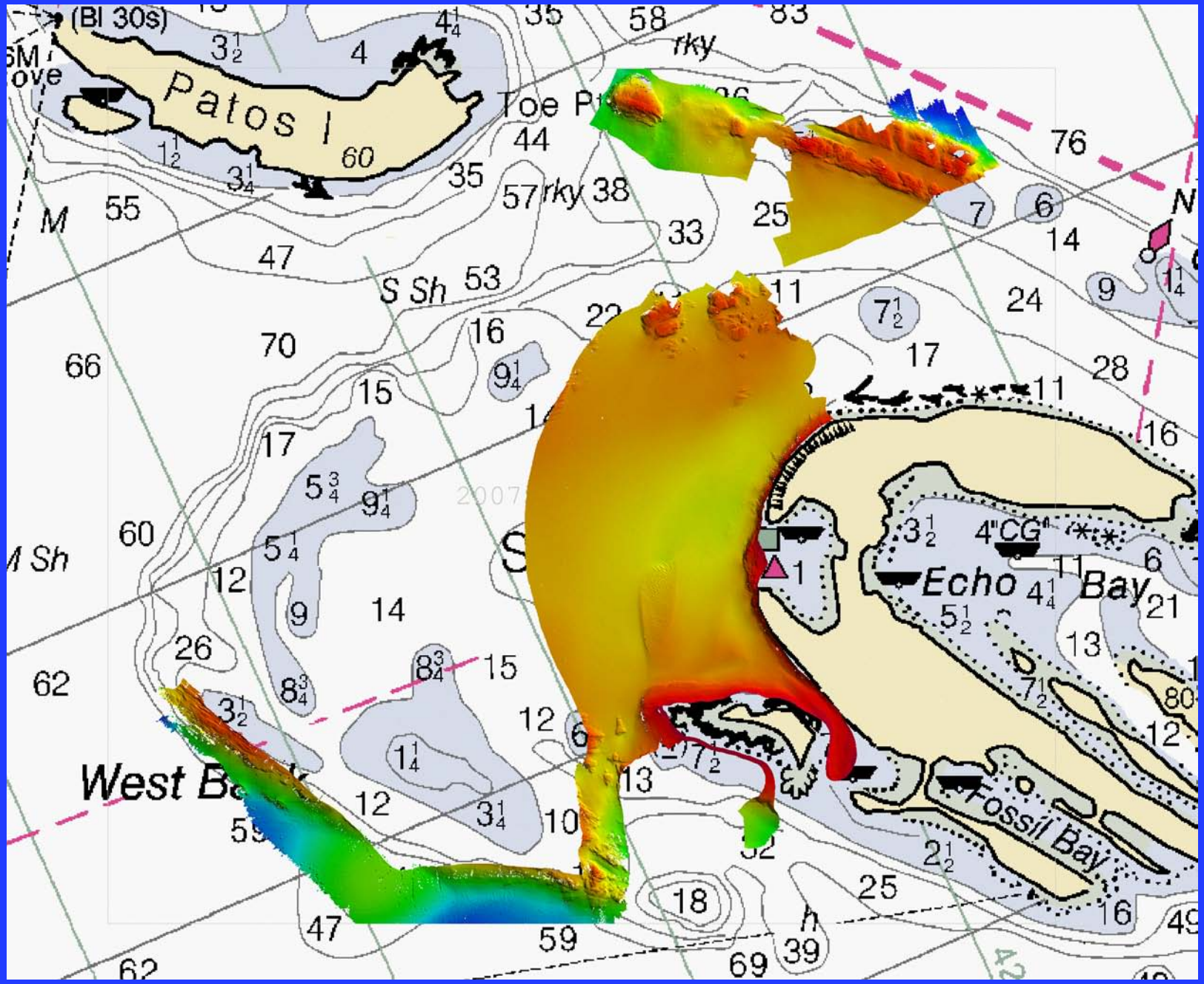


Eyeball Drop - Trough

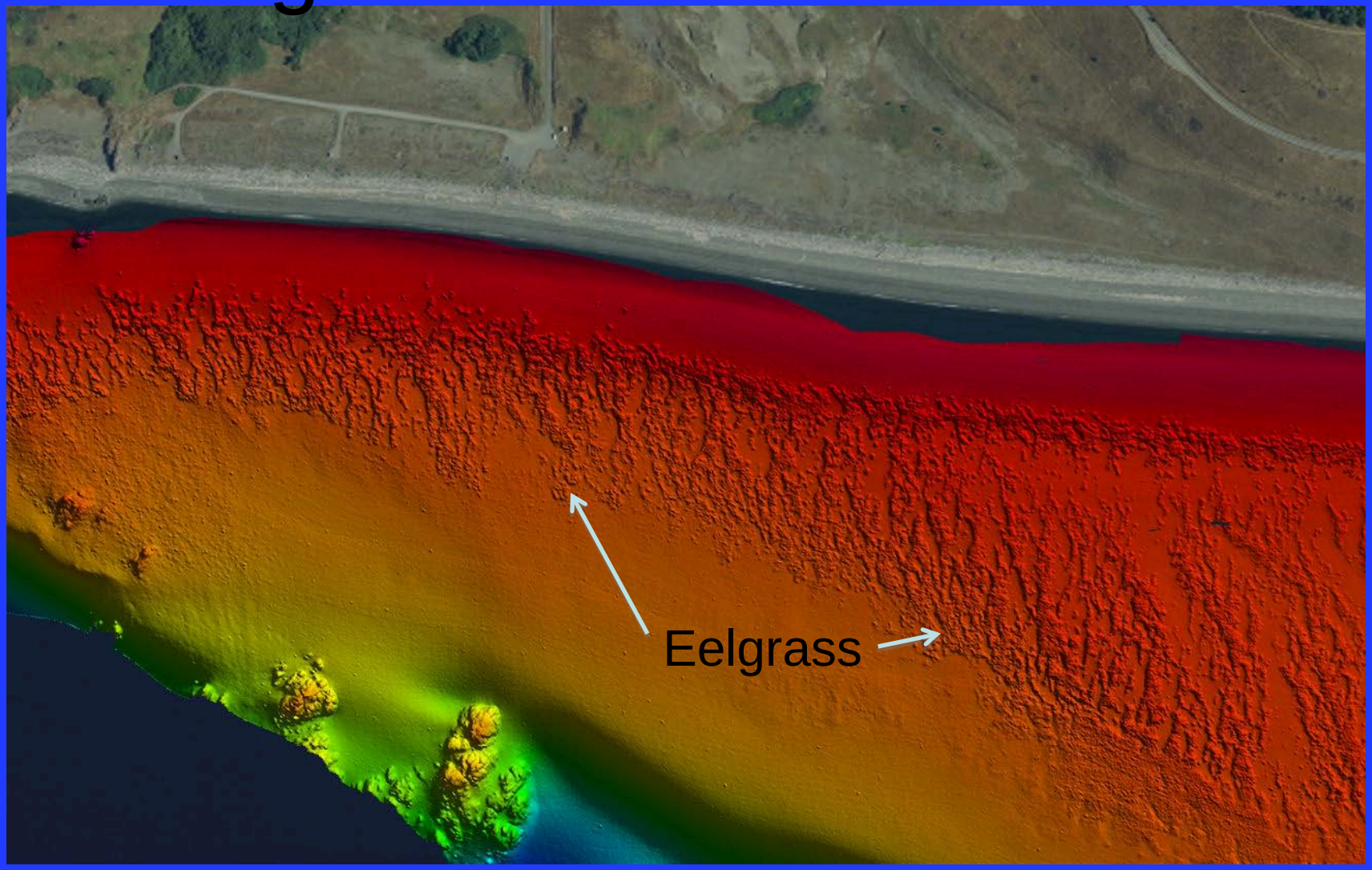


Sand wave fields

Induration	Count
sand/mud	52
sand	41
sand/gravel	97
gravel	45


(Bl 30s)
Patos I
Toe Pt
rky
S Sh
M Sh
Echo Bay
Fossil Bay
West Ba
4"CG"

Eelgrass on Salmon Bank



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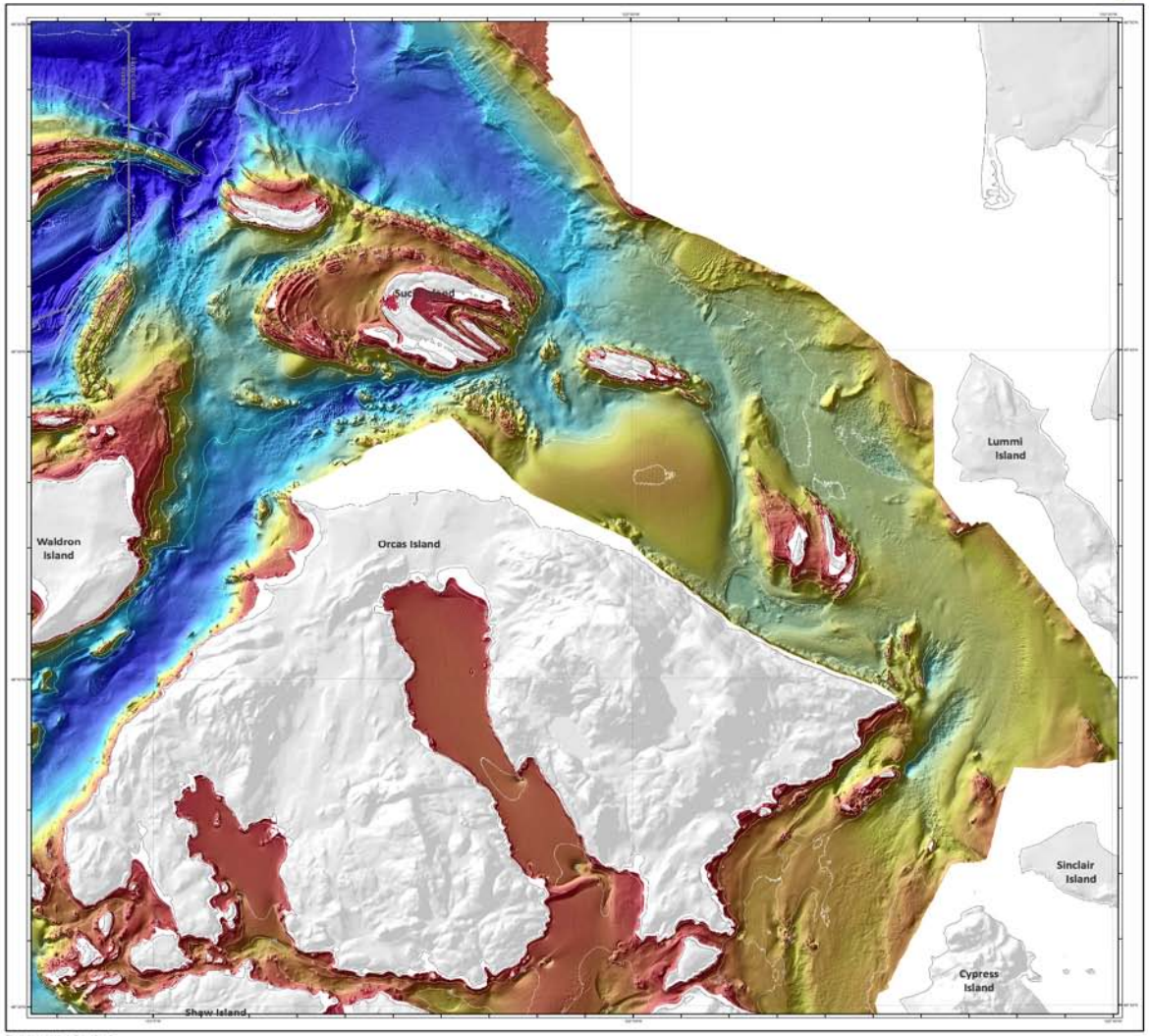


DESCRIPTIVE NOTES

A pilot mapping project was undertaken in 2001 using a pole-mounted Reson 8101 SeaBat (240 kHz) swath (150 swath coverage) multibeam echosounder (MBES) system mounted aboard the R/V MacGinitie, with the data collected under contract with the Seafloor Mapping Lab of California State University Monterey Bay through the Center for Habitat Studies, Moss Landing Marine Laboratories, in cooperation with the Canadian Hydrographic Service. Four sites, Cattle Pass, Neck Point, Pile Point, Turn Island, and Lawson Reef, were within the San Juan Archipelago were mapped and the field was positioned using a differential global positioning system (DGPS). Attitude information such as heave, pitch, and roll, were received using a heading motion sensor (HDRS) with the data logged and integrated using Triton Elics International ISIS and Coastal Oceanographic Hypack software. Water column sound velocity profiles were collected daily at each site using an AML SVP sound velocity profiler. In addition, tidal information was obtained from local tide stations. Data acquisition was maximized for collection of accurate bathymetry rather than backscatter data. Consequently, the quality of the backscatter data was substandard and unusable.

For the pilot project the bathymetric data were processed using CARIS HIPS hydrographic data cleaning software. Soundings were corrected for vessel motion and water column sound velocity and adjusted to mean lower low water (MLLW) using predicted tides for the San Juan Islands. Erroneous soundings were removed in CARIS HIPS through both automated filtering and manual editing. After processing of all lines for each of the five survey sites, the data were exported from CARIS as a geo-referenced, artifically illuminated (from NW) image, and as a binned (2 m) ASCII text (xyz). The .4.2m Archive ASCII raster (.asc) grids were created from the xyz data using Fledermaus v.6.30 imaging software.

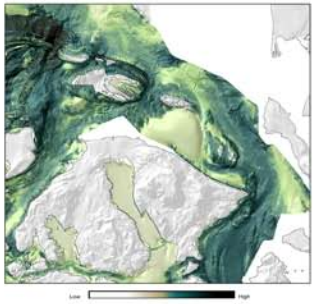
From 2001 through 2008 the Canadian Coast Guard vessels Otter Bay, Revolver, R.B. Young and Vector, and under the direction of the Canadian Hydrographic Service (CHS) in cooperation with the Geological Survey of Canada (GSC) and MLML's Center for Habitat Studies/Trans-boundary Survey, acquired extensive high-resolution bathymetric datasets of the waterways surrounding the Southern Gulf Islands and the San Juan Archipelago.

The MBES Simrad EM 1002 (98kHz frequency) and EM 3000-3002 (300 kHz frequency) systems were used for deep (>50 m) and shallow (<50 m) waters respectively. The dataset resolutions were 5 and 2 m respectively. In most of the areas, the tracks were positioned so as to insuring 100% of the seafloor with a 100% overlap, providing 200% coverage. Positioning was accomplished using a broadcast Differential Global Positioning System (DGPS) and MBES data were corrected for sound speed variations in the stratified water column using frequent sound speed casts.

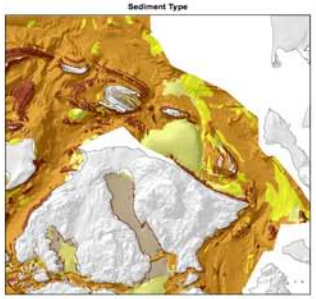
The bathymetric data were carefully processed by CHS with CARIS Hydrographic Information Processing Software (HIPS). The outlying navigation and attitude sensor data were rejected, the gaps restored using linear interpolation, and the filtered data were then merged with DGPS and POSMV input. Subsequently, automatic coarse filters were applied to swath data (+- 50° swath angle). Spurious data points were removed manually in the SwathEd module of HIPS on a line-by-line basis, and tidal corrections were applied (predicted, or observed, if available). After merging the data into a single hydrographic file, a sound velocity correction was applied, the aligned mean curve was then spline generalized and the gridded data were exported to an ASCII format as XYZ tripets and transferred to the GSC for further processing.

The Transboundary region covered by this map series has been divided into four quadrants and this sheet (Sheet 1 of 4, Haro Strait area) covers most of the Haro Strait located between southern Vancouver Island (Victoria), B.C. Canada and San Juan Island, WA USA and part of north-central Strait of Juan de Fuca.

Sun-Illuminated Bathymetry



Sediment Type



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This map was produced by the Center for Habitat Studies at Moss Landing Marine Laboratories in cooperation with Fondazione the Sea/Sea Society, Natural Resources Canada, and the Canadian Hydrographic Service

Digital Cartography by C. Enalra, Center for Habitat Studies

LOCATION MAP

OPEN FILE 6627

SHADED SEAFLOOR RELIEF

SOUTHERN GULF ISLANDS AND SAN JUAN ARCHIPELAGO

CANADA AND U.S.A.

Sheet 3: Orcas Island

Scale 1:50 000/Échelle 1:50 000

Kilometres 1 0 1 2 3 4 Kilomètres

Universal Transverse Mercator Projection, Zone 10 North
Projection transverse universelle de Mercator, Zone 10 Nord

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This map is not to be used for navigational purposes
Cette carte ne doit pas être utilisée aux fins de navigation

Map Index

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2010

Sheet 3 of 4, Orcas Island

Recommended citation:
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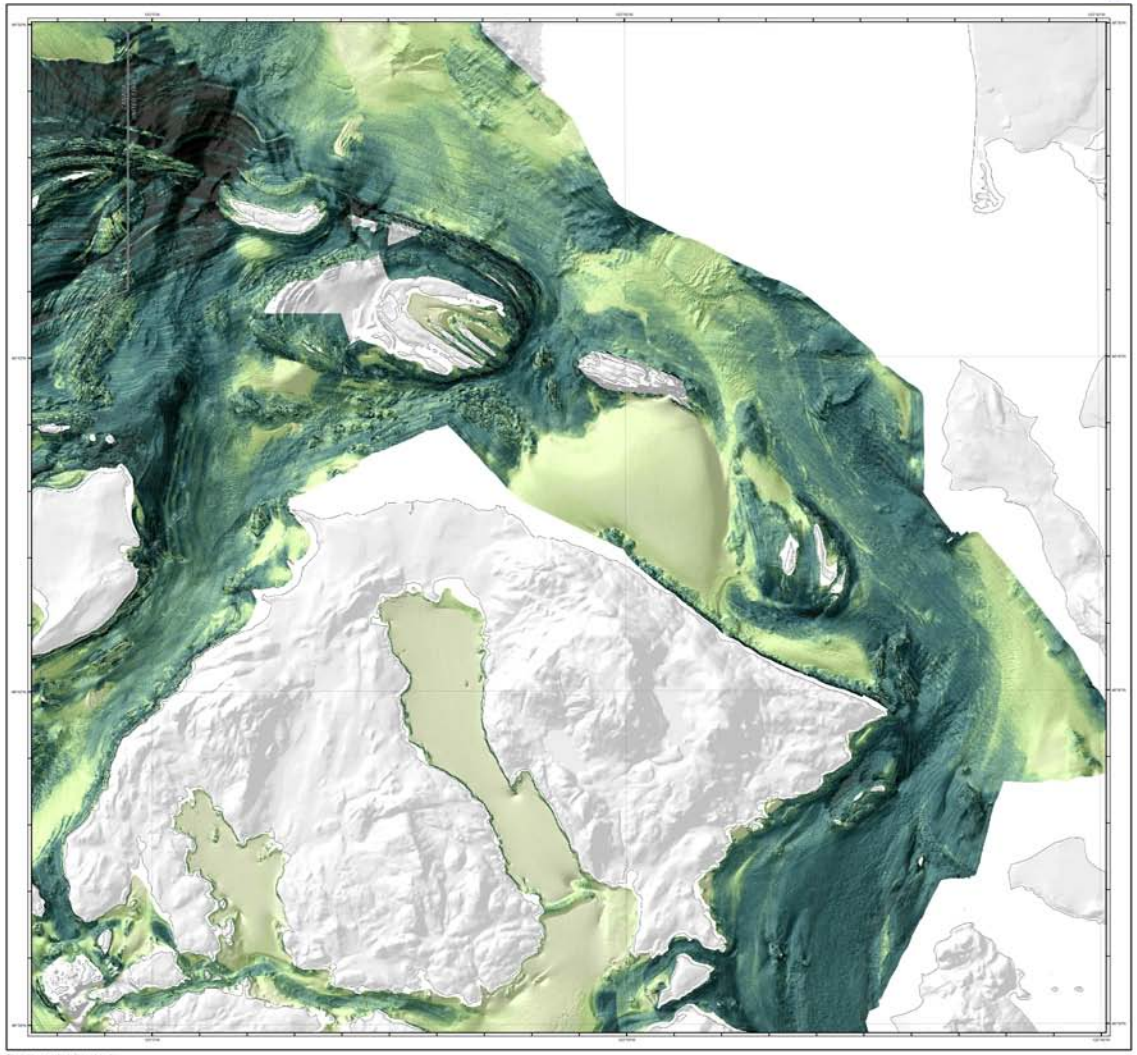


OPEN FILE 6626

BACKSCATTER STRENGTH AND SHADED SEAFLOOR RELIEF

SOUTHERN GULF ISLANDS AND SAN JUAN ARCHIPELAGO

CANADA AND U.S.A.

Sheet 3: Orcas Island

Scale 1:50 000/Échelle 1:50 000

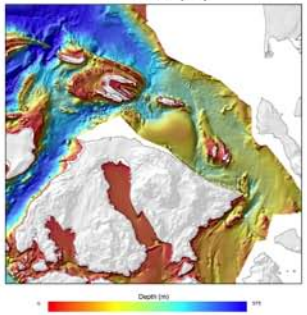
Map Index

DESCRIPTIVE NOTES

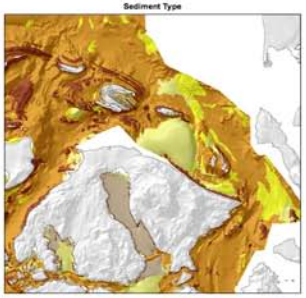
Backscatter intensity is a measure of sound that is scattered back toward the transmitter by acoustic reflection and scattering, both at the sediment-water interface and within the sediment (volume scattering). Many factors influence the intensity value, among them are: the angle of incidence of the beam, the volume scattered, the seabed slope and the surficial sediment type and roughness. With these factors in mind, backscatter strength datasets are used to determine seafloor sediment type, and to map the extent of various sediment types. Shaded relief images of seafloor topography are also in the best interpretation. Backscatter images are used in conjunction with other multibeam echosounder bathymetry derivative datasets, such as seafloor shaded relief, slope analysis and bathymetric contours. The multibeam echosounder bathymetry and backscatter raster datasets, as well as the bathy/ hatched layer were processed using ESRI ArcGIS tools.

The Transboundary region covered by this map series has been divided into four quadrants and the sheet (Sheet 1 of 4, Haro Strait area) covers most of the Haro Strait area located between southern Vancouver Island (Victoria, B.C. Canada and San Juan Island, WA USA and part of north-central Strait of Juan de Fuca. Backscatter intensities vary from high (darker areas in mosaic) representing hard rocks and coarse grain sediment (pebbles, cobbles, boulders) to low intensities representing fine-grain sediment (sand and mud). Bedrock is predominantly composed of metamorphic or volcanic bedrock or basement, while medium to low intensities of backscatter represent dynamic bedforms and other sediment deposits in the Haro and Juan de Fuca straits area.

Sun-Illuminated Bathymetry



Sediment Type



AUTHORS: K. Picard, C. Endris, H.G. Greene, and J.V. Barrie

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ACKNOWLEDGEMENTS: Canadian Hydrographic Service participants R. Hare, K. Cordle, K. Sargent, P. Milner, J. Dagne, C. Lassiter, D. Cartwright, K. Lyngberg, and Canadian Coast Guard participants S. Allison and A. Keane

This map was produced by the Center for Habitat Studies at Moss Landing Marine Laboratories in cooperation with Tombolo, the SeaDoc Society, Natural Resources Canada, and the Canadian Hydrographic Service

Digital Cartography by C. Endris, Center for Habitat Studies

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2010

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Sheet 3 of 4, Orcas Island

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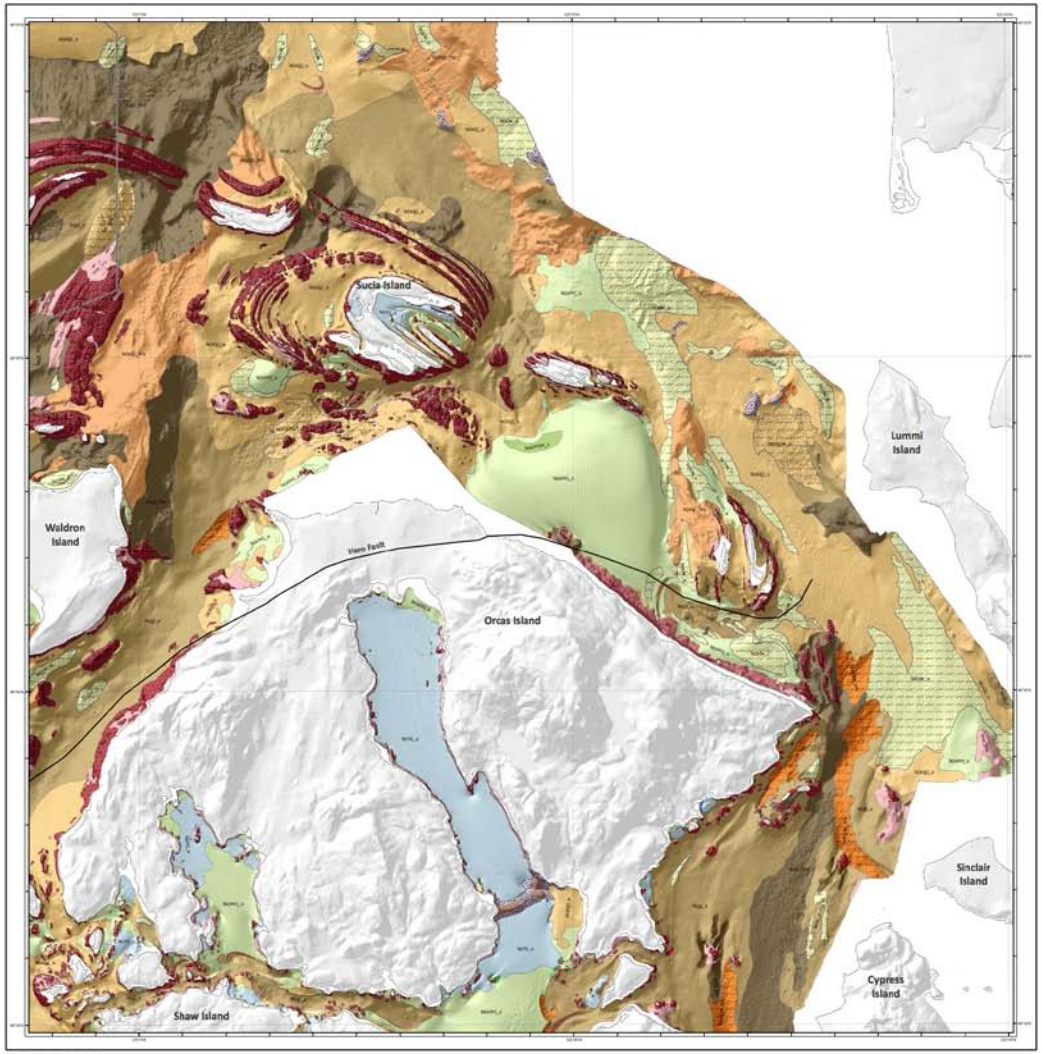

OPEN FILE 6625

POTENTIAL MARINE BENTHIC HABITATS AND SHADED SEAFLOOR RELIEF

SOUTHERN GULF ISLANDS AND SAN JUAN ARCHIPELAGO

CANADA AND U.S.A.

Sheet 3: Orcas Island

Scale 1:50 000/Échelle 1:50 000

DESCRIPTIVE NOTES

The Sain Juan Archipelago-Southern Gulf Islands seafloor mapping effort is an ongoing mapping program focused on the characterization of marine benthic habitats and the mapping of geology within the Salish Sea. The Salish Sea has suffered a severe decline in several species of bottom fish over the past several decades, likely due to environmental degradation and overfishing (Puget Sound Ambient Monitoring Program, 2002; Fisheries and Oceans Canada, Pacific Biological Station, 2004; Levin et al., 2009). Habitat loss has been a factor in the decline of potential marine benthic habitats and geology. The final product includes interactive maps that can be used to identify habitat (because as a habitat, which then can be used by both Canada and the US to manage, conserve and sustain economically significant fisheries (commercial and recreational) in the Transboundary region. A mechanism that has been developed to address the decline of marine benthic habitat is the creation of marine protected areas (MPAs) (mandatory and voluntary or mandatory no-take zones where extraction is a benthic habitat can be done using potential habitat maps. Therefore, a secondary objective of this mapping effort is to provide aids where assessment and if necessary modification, of established MPAs, and the establishment of new MPAs, can be made. Additional mapping objectives that evolved from this project include the identification of specific deep-water fragile habitats such as dynamic sediments that harbor sand lance (Ammodytes hexapterus) and patterns of kelp sponge reefs (Hexactinellida, Porifera) and other, specifically identified in the maps as characterization of these specific habitat types is continuing.

The Sain Juan Archipelago-Georgia Basin region is an active tectonic province where photography and geomorphology reflect both Neocene to Eocene convergent transpressional tectonics and Pleistocene glacial processes (Clague et al., 1980; Monger and Journeay, 1994). These processes have juxtaposed and sediment Jurassic-Cretaceous metamorphic rocks with Tertiary-Quaternary sedimentary rocks producing a complex of (rocks, gravel and polished bedrock outcrops, and erratic boulders and moraines. Items of fill and glacial advance subsaint deposits have also formed and contribute to the variety of relief within the region. Present day tidal action has flattened much of the rocky glacial-marine sediments into dynamic seafloors consisting of sand and gravel waves and dune fields. Modern day sedimentary processes are active in the region and represent material being supplied to the region by the Fraser River of British Columbia, Canada.

The tectonic province can be divided into two distinct zones based on bedrock types: a northern sedimentary bedrock zone and a southern metamorphic rock zone separated by the Haro Fault (Mustard, 1994; Mustard et al., 1994). The northern zone is characterized by Cretaceous-Tertiary sedimentary rock type in differentiating exudes (high forming ridges and overhangs) while the metamorphic bedrock are highly fractured and faulted forming cracks, crevices, and blocky boulder aprons. The severity and variety of tectonic, geologic and physical processes active in the province are directly responsible for forming the large variety of potential marine benthic habitat types mapped in the region.

The habitat classification was done following an existing habitat classification code, which was established to distinguish habitat types for species of interest and to facilitate ease of use and queries in GIS and other database programs. The code used in this map is modified from the scheme developed by Greene et al. (1999, 2007) for deep-water habitat characterization.

The seafloor imagery interpretation and habitat type delineation were based on knowledge of the geology of the seafloor and seafloor processes in the study area (Thompson, 1981; Mosher et al., 2006; Barrie et al., 2005, 2009). Geological processes, structure and morphology described in the imagery were used to delineate distinct potential habitat types. Resolution of the seafloor interpretation varied with the type of MBES systems that were used in the various surveys. Generally, the finer the resolution, the smaller the features that could be identified (e.g., bedrock, metamorphic, volcanic and granitic rocks), structures (e.g., faults, folds, scours, and landslides), and bedforms of unconsolidated sediments were easily distinguished. To differentiate cobbles and/or boulders (>0.5m) habitat from simple bedrock habitat a specific rule was assigned where any known bedrock polygons with a surface area smaller than 500 m² became identified with "Attribute".

The Transboundary region covered by the map sheet was been divided into four quadrants and the sheet (Sheet 1 of 4, main Sicia) covers most of Haro Strait located between southern Vancouver Island (Victoria), B.C. Canada and San Juan Island, WA USA and part of north center Straits of Juan de Fuca. Habitat types here are predominantly composed of hard bedrock and fractured metamorphic rocks, boulders and dynamic seafloors. Strong currents in Haro Strait sweep the bedrock clean and produce sediment waves and dune fields.

* "Potential" is used here to indicate that the habitat mapped on the basis of morphology and substrate type may not have a known species or assemblage of organisms that are identified to use the habitat.

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KEY TO HABITAT TYPES

Not all units may appear on this map sheet

Unconsolidated substrate (mud)

la(m)_u	Unconsolidated sediments
la(m)_a	Unconsolidated sediment terrace
la(m)_hu	Hummocky unconsolidated sediments
la(m)m_u	Mound
la(m)h_a/u	Pockmark
la(m)h_a/u	Scour depression
la(m)_hla-dd/u	Hummocky dredge or anchor disturbances
la(m)g_a-dg/u	Dredge channel
la(m)t_hla/u	Seacuit terrace

Unconsolidated substrate (sand / mud)

la(sm)_u	Unconsolidated sediments
la(sm)_hu	Hummocky unconsolidated sediments
la(sm)vt_u	Vegetative unconsolidated sediment furrows
la(sm)m_u	Linear ridge
la(sm)m_u	Ice-formed mound
la(sm)h_u	Depression
la(sm)h_a/u	Scour depression
la(sm)g_a/u	Scour gully
la(sm)g/e_a/u	Scour gully with sediment bedforms
la(sm)s_a/u	Current-scoured swale
la(sm)s_u	Swell
la(sm)_hla-dd/u	Hummocky dredge or anchor disturbances

Unconsolidated substrate (sand / gravel)

la(sg)_u	Unconsolidated sediments
la(sg)_hu	Hummocky unconsolidated sediments
la(sg)e_u	Sediment bedforms
la(sg)e_a/u	Current-scoured sediment bedforms
la(sg)m_u	Mound or linear ridge
la(sg)m_u	Ice-formed mound, water or moraine
la(sg)m_hu	Hummocky ice-formed mound
la(sg)h_u	Depression
la(sg)h_a/u	Depression depression
la(sg)h_a/u	Scour depression
la(sg)g_a/u	Scour gully
la(sg)l_hlu	Hummocky landslide deposit
la(sg)s_a/u	Current-scoured swale
la(sg)_a-dm/u	Dredge disposal
la(sg)_hla-dd/u	Hummocky dredge or anchor disturbances
la(sg)g_a-dg/u	Dredge channel
la(w)_hla-f/u	Ferry wash swale

Unconsolidated substrate (sand)

la(s)_u	Unconsolidated sediments
la(s)_u	Unconsolidated sediment terrace
la(s)e_u	Sediment bedforms
la(s)m_u	Mound or Linear ridge
la(s)m_a/u	Scour ridge
la(s)h_a/u	Scour depression

Unconsolidated substrate (gravel)

la(g)_u	Unconsolidated sediments
la(g)_hu	Hummocky unconsolidated sediments
la(g)m_u	Mound or linear ridge
la(g)_mu	Ice-formed mound or moraine
la(g)h_a/u	Scour depression
la(g)s_a/u	Current-scoured swale

Unconsolidated substrate (boulders)

la(b)m_u	Moraine

Sediment covered bedrock

frs_c/u	Sediment covered bedrock

Hard substrate

hy	Rock fall
hy(p)	Pinnacle or boulder
frs_f/u	Fractured bedrock
frs_g/b	Granitic bedrock
frs(_d/b	Sedimentary bedrock
h_a-e	Anthropogenic structure - Shipwreck
h_a-p	Anthropogenic structure - Buoyants
h_a-a	Anthropogenic structure - Pilasters
h_a-g	Anthropogenic structure - Former vessel mooring facility, jetty or ramp

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Digital Cartography by C. Enslin, Center for Habitat Studies

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FEUILLET 3 DE 4

Sheet 3 of 4, Orcas Island

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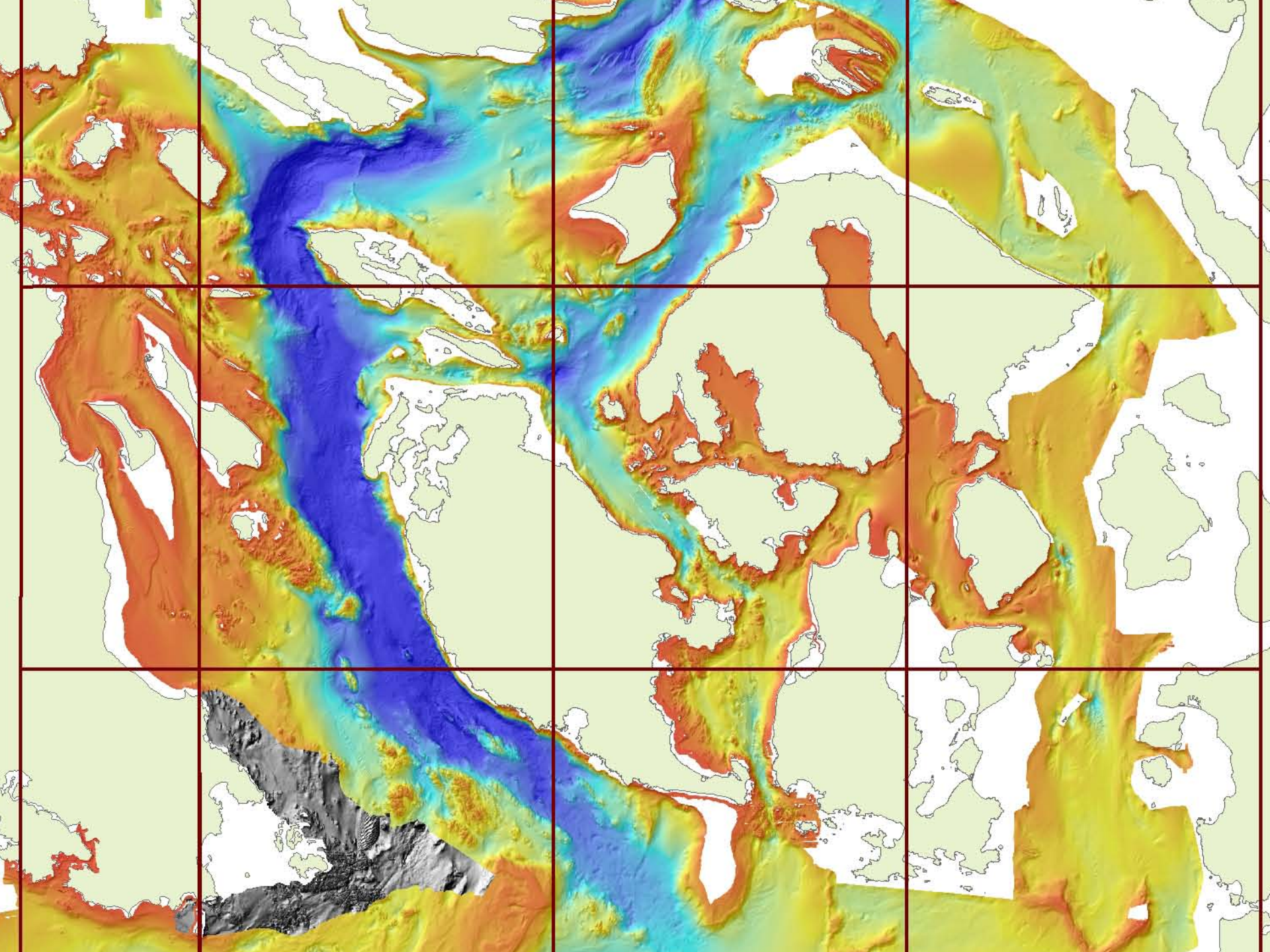
Canada



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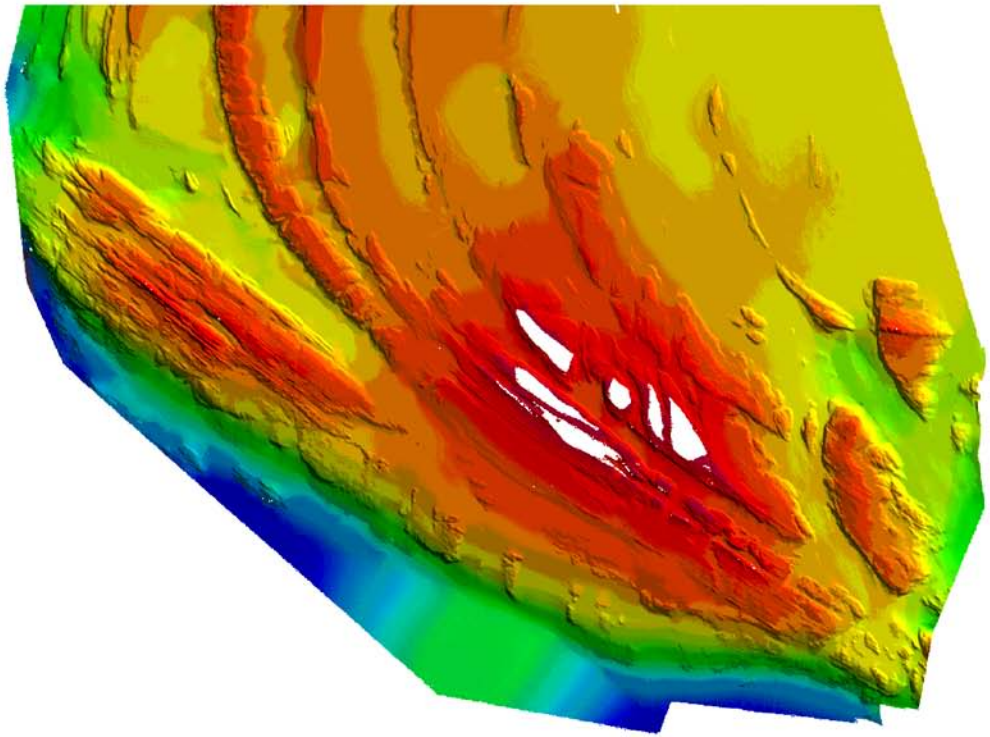

Conclusions

- Marine benthic habitat mapping in the San Juan Archipelago has progressed to the point where other thematic maps can be constructed
- Value added through focusing on rockfish and PSL sub-tidal habitats
- Shallow water mapping underway and “white zone” being addressed
- Eelgrass beds including abundances is being mapped