prepared by the Western and Northern Service Centre

The status of coastal health in the Gulf Islands National Park Reserve of Canada using eelgrass *(Zostera marina)* as a bio sentinel

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Canada

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WNSC RESOURCE CONSERVATION TECHNICAL REPORT

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Executive Summary

The Gulf Islands National Park Reserve of Canada (GINPRC) encompasses about 35 km^2 of marine ecosystems within its boundaries. There are many coastal ecosystems in GINPRC that will require monitoring to ensure conservation of nearshore ecological integrity. In this report, we characterize the status of environmental and fish diversity in what is arguably the most productive and sensitive (to human impacts) nearshore ecosystem, eelgrass (*Zostera marina*). Eelgrass is one of the few marine species that offers such a complete attribute package for acting as an indicator of coastal ecosystem health. The main objectives of the report were to 1) Review the status of eelgrass ecosystems in the southern Gulf Islands. 2) Report on an application of the coastal health assessment program to eelgrass meadows of Gulf Islands NPRC, including anthropogenic disturbance, environmental assessment, eelgrass health assessment, and fish assemblage assessment. And 3) make recommendations to GINPRC staff for future inventory, monitoring, and restoration of eelgrass ecosystems.

Acknowledgements

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1.0 INTRODUCTION

The Canada National Parks Act Sec 8(2) states that "Maintenance or restoration of ecological integrity, through the protection of natural resources and natural processes, shall be the first priority of the Minister when considering all aspects of the management of parks." Ecological Integrity (EI) means, with respect to a park, "a condition characteristic of its natural region and likely to persist, including abiotic components and the structure/function of biological communities". An objective science-based monitoring program will be required to assess and monitor for changes in EI in Canada's National Parks.

The Gulf Islands National Park Reserve of Canada (GINPRC) encompasses about 35 km^2 of marine ecosystems within its boundaries (*Figure 1*). There are many coastal ecosystems in GINPRC that will require monitoring to ensure conservation of nearshore ecological integrity. In this report, we characterize the status of environmental and fish diversity in what is arguably the most productive and sensitive (to human impacts) nearshore ecosystem, eelgrass (*Zostera marina*). Previous research conducted in other temperate areas has shown that eelgrass is a useful and meaningful indicator or bio-sentinel of ecosystem health such as water quality (Deegan 2002, Duffy 2006).

Eelgrass prefers clear, oligotrophic and oxygenated waters of the shallow subtidal and intertidal (+2 m to –5 m relative to Chart Datum). Eelgrass meadows are an important coastal ecosystem for several reasons. First, they directly support food chains through the secondary production of invertebrates associated with epiphytes (animals or algae growing on eelgrass blades). Second, eelgrass meadows indirectly support food chains through supplies of plant material to detrital pathways and adjacent ecosystems (e.g., mudflats). Third, eelgrass provides rearing and foraging habitat for invertebrates (e.g., Dungeness crabs), fishes and birds such as Great Blue herons. Finally, eelgrass meadows reduce impacts of shoreline erosion by waves and currents, help stabilize sediments, and act as an integral component of the shallow water nutrient recycling process.

Eelgrass meadows grow at the land-sea interface, and because of this they are considered a globally threatened marine ecosystem particularly vulnerable to effects of human activities such as habitat destruction, sedimentation or pollution (Orth et al. 2006). By monitoring these habitats, early detection of coastal environmental degradation can be made before irreparable losses occurs (Short et al. 2006). Further, eelgrass is useful in that it can respond rapidly to changing environmental conditions.

Some of the major factors causing seagrass declines worldwide are excess nutrients (eutrophication) or sediments, both of which ultimately reduce the amount of light available to meadows. For example, anthropogenic (human-caused) eutrophication typically leads to large and persistent blooms of macroalgae, epiphytes, or phytoplankton that shade and eventually displace seagrass (Kentula and Dewit 2003). The establishment of relationships between light availability, water quality, and depth distributions of seagrass has provided a valuable tool for establishing habitat requirements for the species.

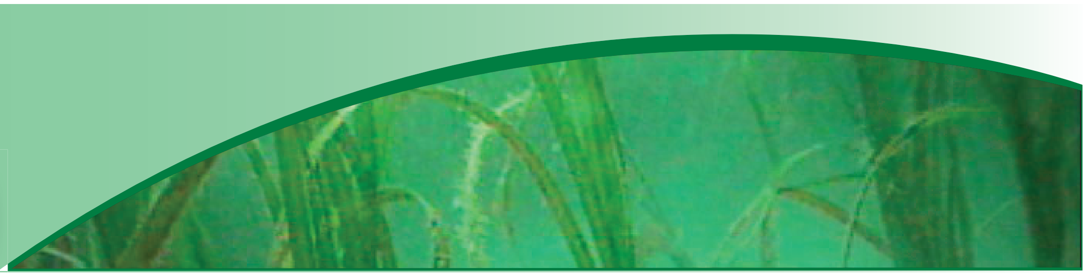
Anthropogenic nutrient enrichment not only causes a shift in primary producers but also alters the fish and invertebrate communities and food webs (Deegan 2002). For example, the competition from algae and elimination of seagrasses results in bare substrate that supports a much lower diversity and abundance of fish (Deegan et al. 1997). Conversion of seagrass meadows into seaweed-dominated ecosystems is equivalent to habitat loss. Eelgrass meadows are protected as important fish habitat including "no net loss" policies for these ecosystems under the Fisheries Act (Section 34) in which the definition of "fish habitat" fits well with the ecosystem role of meadows. As well, meadows could also be "residences" of listed species at risk warranting protection under the Species at Risk Act. Although eelgrass ecosystems are relatively small compared to other inshore ecosystems, they are a very important habitat for young fishes such as rockfish, many invertebrates and marine birds.

Eelgrass meadows meet most of the selection criteria developed for selecting indicator taxa for assessing ecosystem health (Hilty and Merenlender 2000). Their taxonomic status is clear, and there is one dominant species of eelgrass in nearshore coastal British Columbia (*Zostera marina*). There is a large and growing literature on the biology and life history of eelgrass, and tolerance limits to environmental conditions (e.g., temperature, salinity, light levels, etc) are well known. Eelgrass has a cosmopolitan distribution and has limited mobility (rhizomes can potentially spread 1-3 meters per year). There is plenty of evidence to indicate that eelgrass offers an early warning system in response to stress. For example, recent observations in the San Juan Islands (Wyllie-Echeverria et al. 2003) indicate that intertidal portions of many meadows were completely lost within two years. Eelgrass is easy to find because it is visible at low tide, and it occurs along 10-25% of the British Columbia coastline. Parks Canada is presently investigating relationships between changes in eelgrass and other ecosystem components (e.g., fish assemblages) and documenting the variability in population parameters. Overall, eelgrass is one of the few marine species that offers such a complete attribute package for acting as an indicator of coastal ecosystem health.

1.1 Objectives

The main objectives of this report were to:

1. Review the status of eelgrass ecosystems in the southern Gulf Islands.
2. Report on an application of the coastal health assessment program to eelgrass meadows of Gulf Islands NPRC, including: 1) anthropogenic disturbance, 2) environmental assessment, 3) eelgrass health assessment, and 4) fish assemblage assessment.
3. Make recommendations to GINPRC staff for future inventory, monitoring, and restoration of eelgrass ecosystems



2.0 OVERVIEW OF EELGRASS ECOSYSTEMS IN THE SOUTHERN GULF ISLANDS

Data used in this overview were taken from Parks Canada field sampling and from the Gulf Islands Atlas (http://www.shim.bc.ca/gulfislands/atlas.htm). Available information indicates that eelgrass covers approximately 30% of the park's shoreline, second to kelp (34% of coastline; *Table 1*). About 33% of the eelgrass meadows occupy bays or coves (flats) while the remaining meadows parallel the shoreline as fringes (*Table 1*). Eelgrass, in general, prefers low wave exposure levels. Most of the Southern Strait of Georgia NMCA region consists of low-energy shoreline (Coastal Ocean Resources Inc. 2005): 68% is classified as semi-protected exposure, 25% as protected and 3% as very protected exposures (*Figure 1*).

TABLE 1. Linear lengths (m) and number of eelgrass biobands along the coastline of the Gulf Islands National Park Reserve of Canada (GINPRC). Data extracted from the southern Gulf Islands Atlas (http://www.shim.bc.ca/gulfislands/atlas.htm)

GINPRC Site	Total Length of GINPRC shoreline (m)	Shoreline with Zostera [1]	Shoreline with kelp [2]	Shoreline with surfgrass [3]	No. of eelgrass bands	No. of eelgrass bands fringed [4]	No. of eelgrass meadows as flats	Eelgrass meadows sampled within GINPRC
Prevost Is	5,884	1,705	432	0	2	2	1	Selby Cove, James Bay
Bright Is	588	0	543	0	0	0	0	
Red Is	849	0	647	0	0	0	0	
Hawkins Is	768	0	737	0	0	0	0	
Channel Is	1,327	0	0	0	0	0	0	
Mayne Is	1,140	527	613	0	1	0	1	
Georgeson Is	1,190	254	936	0	1	1	0	Bennett Bay
SE of Georgeson Is	180	0	0	0	0	0	0	
Samuel Is	426	0	0	0	0	0	0	
Belle Chain Islets	5,263	0	1,779	0	0	0	0	
Saturna Is (incl. Boiling Reef)	11,705	1,747	4,607	0	7	5	2	Winter Cove, Narvaez
Java Is	982	0	982	0	0	0	0	
Cabbage Is	1,767	660	0	0	3	2	1	Cabbage Is
Tumbo Is	9,540	3,187	6,118	0	2	1	2	Tumbo
Pender Is	6,016	2,168	1,368	0	9	6	3	Ella Bay, Beaumont
Blunden Is	776	0	776	0	0	0	0	
Russell Is	2,160	0	1,099	0	0	0	0	
Portland Is	8,187	2,529	963	0	10	8	2	
Brackman Is	1,020	0	492	0	0	0	0	
Isabella Is	538	0	0	0	0	0	0	
Imrie Is	449	0	185	0	0	0	0	
Reay Is	1,085	0	1,085	0	0	0	0	
Greig Is	443	0	443	0	0	0	0	
SW of Passage Prevost	995	70	814	0	1	1	0	
Isle de Lis	949	0	949	0	0	0	0	
Dock Is	868	0	868	0	0	0	0	
Sidney Spit	13,660	12,102	0	0	6	4	2	Sidney Spit
Sallas Rocks	1,145	0	387	322	0	0	0	
D'Arcy Is + Unit Rocks	5,264	1,027	1,993	691	4	2	2	
TOTAL	**85,164**	**25,976**	**28,816**	**1,013**	**46**	**32**	**16**	**10**

NOTES: [1] includes *Zostera marina* and *Z. japonica*; [2] Most kelp appears to be *Nereocystis luetkeana*. There might be some *Agarum*; [3] Could be *Phyllospadix* or at times *Ulva*. Impossible to tell from photos; [4] Some bands have both fringe and flat elements, and were counted twice

FIGURE 1. Wave exposure estimated by Coastal and Ocean Resources Ltd and made from observations of key indicator species and assemblages (Coastal Ocean Resources Inc. 2005).

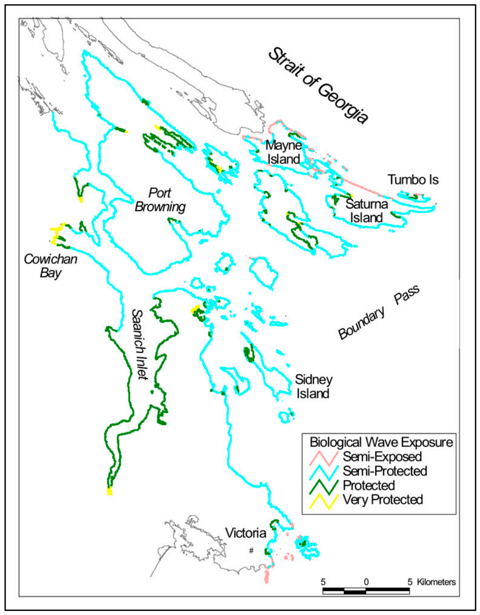
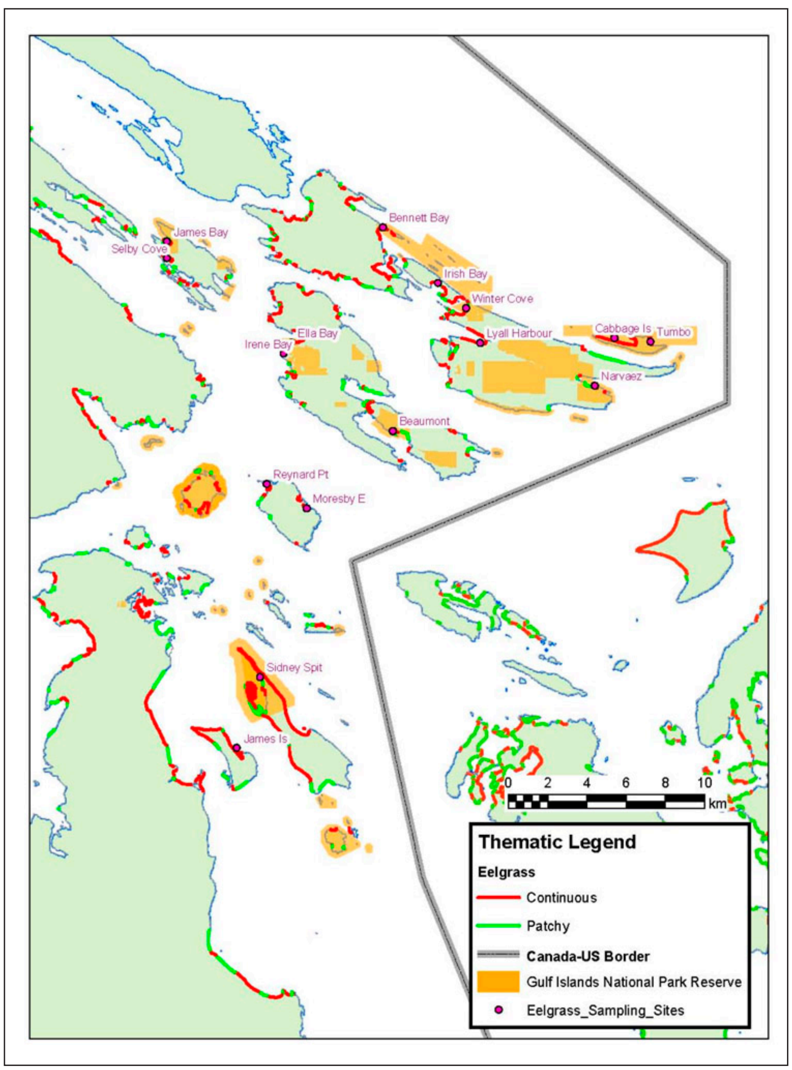


FIGURE 2. Approximate linear extent of eelgrass meadows along the coastline of the Gulf Islands National Park of Canada and adjacent areas (data based on southern gulf islands atlas; http://www.shim.bc.ca/gulfislands/atlas.htm). The locations of eelgrass meadows sampled in 2004, 2005 and 2006 are also shown.



Parks Canada field sampling of eelgrass was conducted during August of 2004, 2005 and 2006. Ten (10) meadows were sampled within the GINPRC boundaries and six (6) outside (*Figure 2*). Most of the meadows were subtidal. The eelgrass meadow areal extents were estimated from orthophotos on which the outward edges of the meadows were plotted. These extents are per force approximate and should not be used as indicative of the state of eelgrass meadows at this time.
The meadows sampled inside the GINPRC were slightly smaller than outside in 2006 (median of 6,377 vs. 7,502 m^2; *Table 2*) but much larger in 2005 (6,024 vs. 1,519 m^2). The latter discrepancy can be attributed to the fact that there were only three (3) outside meadows measured in 2005.

TABLE 2. Sampling frequency and approximate subtidal extent (m^2) of eelgrass meadows measured in the Southern Gulf Islands National Park Reserve and immediate surroundings, in August of 2004, 2005 and 2006. NS: areal extent not determined.

Inside or Outside GINPRC	Location	Orientation	2004	2005	2006
IN	Beaumont	SE	NS	6,177	5,959
	Bennett Bay	SE	NS	NS	NS
	Cabbage Is	NW	NS	5,872	6,000 (1)
	Ella Bay	NW	NS	5,872	NS
	James Bay	NW	NS	2,503	6,377
	Narvaez	NW	NS	3,171	1,465
	Selby Cove	NW	NS	14,380	16,440
	Sidney Spit	NW	NS	69,050	70,000 (2)
	Tumbo	E	NS	51,530	60,000
	Winter Cove	SW	NS	NS	NS
OUT	Irene Cove	NW	NS	1,143	NS
	Irish Bay	SW	NS	NS	3,994
	James Is	N	NS	41,410	24,870 (3)
	Lyall Harbour	NW	NS	1,896	2,000 (4)
	Moresby E	NE	NS	NS	7,860
	Reynard Pt	NW	NS	NS	7,145

NOTES:
(1) Approximate area in immediate vicinity of sampling sites. Whole eelgrass meadow estimated at 81,870 m^2;
(2) Approximate area in immediate vicinity of sampling sites. Whole eelgrass meadow estimated at 183,000 m^2;
(3) part of a larger eelgrass meadow; only fringe along shoreline measured;
(4) part of a larger eelgrass meadow spreading across the bay; only fringe along shoreline measured

Example of fringed eelgrass band – James Bay

Example of eelgrass band in flat –Narvaez

3.0 OVERVIEW OF THE COASTAL HEALTH ASSESSMENT PROGRAM (CHAP)

The status of coastal ecosystem EI in national parks within Parks Canada's Pacific Bioregion is being evaluated using two indicators: "Intertidal" and "Subtidal" that can be rolled up into a single "Coastal" indicator. A key metric for the Coastal indicator is the Coastal Health Assessment Program (CHAP). The CHAP is being developed based on field sampling (initiated in 2004) in Gwaii Haanas, Pacific Rim and the Gulf Islands National Park Reserves. Eelgrass meadows are the ecosystem being used as the biological sentinel within the CHAP that consists of the following four measures:

1. Anthropogenic Disturbance Index
2. Environmental Assessment
3. Eelgrass Health Assessment
4. Fish Assemblage Assessment

There are two major principles behind the CHAP. First, the CHAP approach considers multiple lines of converging evidence when evaluating coastal health. These converging lines of evidence are focused on an ecosystem-level bio-indicator, eelgrass, because it is highly visible, easily sampled and monitored, and it responds relatively quickly to degradation (see Introduction). Second, the CHAP aims at assessing the health of several spatially separated eelgrass meadows (*Zostera marina*), including their surrounding environmental properties and fish communities, within a narrow temporal window (i.e., a low tide cycle in early August). Thus, the focus is on comparing several beds sampled within a region at the same time and comparing them among years. It is not the intent of the monitoring program to necessarily follow the changes in one eelgrass meadow, because resources do not allow for sufficient sampling to meet parametric statistical analysis assumptions. The analytical approach used in the CHAP relies upon non-parametric tests, such as the Kruskall-Wallis one-way ANOVA on ranks (corrected for ties). In the case of fish assemblage analyses, non-parametric multivariate tests are used (see below).

3.1 Anthropogenic Disturbance Index

The Anthropogenic Disturbance Index (ADI) is used to describe surrounding landscape or seascape disturbances affecting a single eelgrass meadow. The ADI consists of five measures (*Table 3*), and each eelgrass meadow is given a rank value for each measure based on local knowledge, field observations, nautical charts, topographic maps, and creel census data from Fisheries and Oceans Canada. Because these measures typically change little from year-to-year, the ADI for each eelgrass meadow needs only to be updated every five years.

The median ADI score calculated for 16 eelgrass meadows sampled in the southern Gulf Islands was 21 out of a maximum possible score of 25 (*Table 4*). To appreciate how disturbed Southern Gulf Islands (SGI) eelgrass meadows are, refer to *Figure 3*, which shows the median and 95% of ADI scores for three other regions of interest to Parks Canada Agency (PCA). Note that the southern Gulf Islands region (SGI) has significantly higher total ADI scores than the other three regions and Gwaii Haanas sites have significantly lower ADI scores (Tukey-Kramer HSD test, $P< 0.05$). Gulf Islands eelgrass meadows are subjected to a wide range of anthropogenic stresses due to their location near high human populations and intense coastal use.

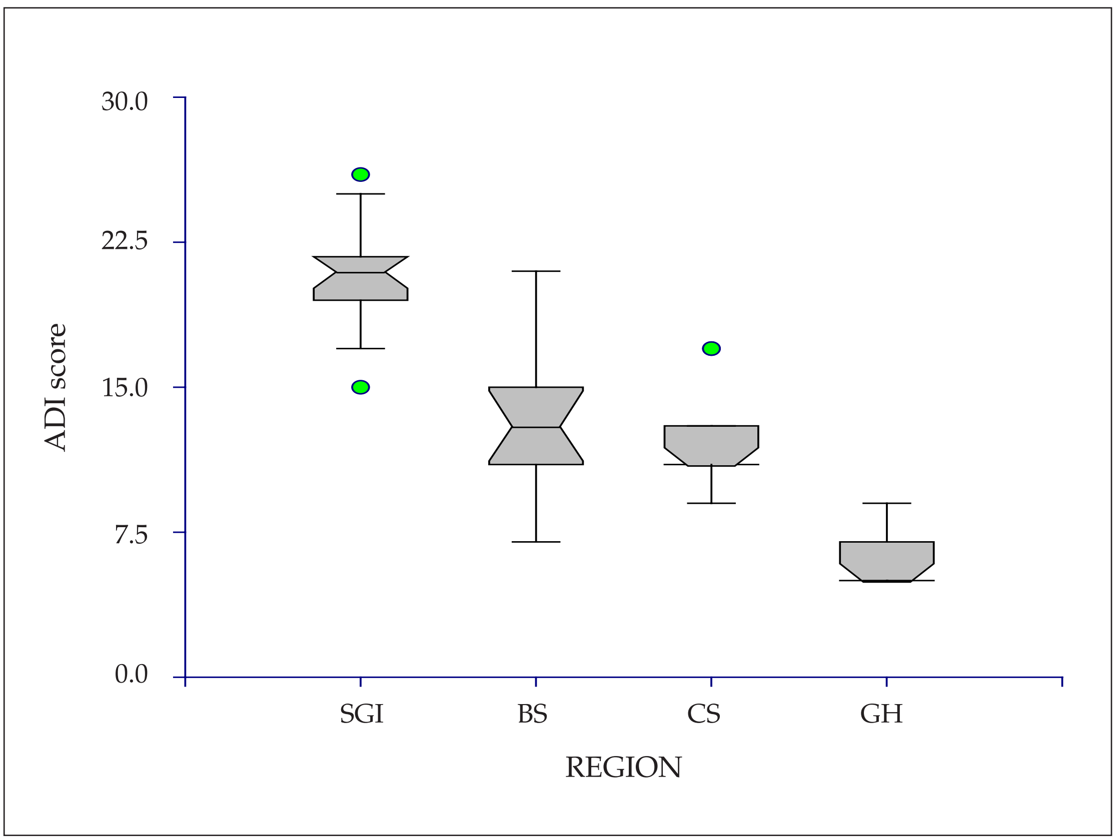
TABLE 3. Anthropogenic disturbance index (ADI) metrics, rank scores and descriptions used to calculate ADI scores for eelgrass meadows.

Metric	Rank	Description
LAND USE	1	Forested, pristine area with no development
	3	Single lodging or campsite on shore
	5	More than one house or building on shoreline
MARINE USE	1	No structures or use
	3	Light anchorage or a single dock or a small boat ramp
	5	Marina, large dock or heavy anchorage
BOAT TRAFFIC	1	Virtually no traffic, secluded
	3	Light boat use and traffic
	5	Heavy boat traffic, eelgrass meadow adjacent to a navigation aid
HUMAN ACCESSIBILITY	1	Isolated
	3	Easy access by boat
	5	Easy access by land/road
REGIONAL FISHERY PRESSURE	1	Low
	3	Moderate
	5	High

TABLE 4. Anthropogenic disturbance index scores for 16 eelgrass meadows sampled in the southern Gulf Islands during August 2004, 2005, and 2006. Refer to Table 3 for details.

Site	Land use	Marine use	Boat traffic	Human access	Fishery pressure	TOTAL EDI
Beaumont	3	5	5	3	5	**21**
Bennett Bay	3	5	5	3	5	**21**
Cabbage	5	5	5	5	5	**25**
Ella Bay	3	5	5	3	5	**22**
Irene	5	5	5	5	5	**26**
Irish Bay	3	3	5	5	5	**21**
James Bay	3	3	5	5	5	**21**
James Island	3	3	5	5	5	**21**
Lyall Harbour	3	3	5	5	5	**21**
Narvaez	3	3	5	5	5	**21**
Sidney Spit	3	3	5	3	5	**19**
Tumbo Island	5	5	5	5	5	**25**
Winter Cove	3	3	5	5	5	**21**
Reynard Pt.	1	3	5	5	5	**19**
Moresby East	1	1	5	3	5	**15**
Selby Cove	3	3	3	3	5	**17**

FIGURE 3. Anthropogenic Disturbance Index scores for eelgrass meadows sampled in four regions of interest to Parks Canada. Abbreviations: SGI: southern Gulf Islands, BS: Barkley Sound; CS: Clayoquot Sound; and GH: Gwaii Haanas. The SGI's value is significantly higher than other regions (Kruskall-Wallis one-way ANOVA on ranks, corrected for ties; $p < 0.0001$). Each box represents the interquartile range and extends from the 25th to 75th percentile. The horizontal line within each box is the median (50th percentile) value. If the median line is closer to the bottom of the box than the top, there is a tail toward larger values. The whiskers represent the range of data, while extreme values are dots above or below the whiskers (outliers). Notched boxes are used to make multiple comparisons among samples : if notches of two boxes do not overlap, the medians are significantly different.

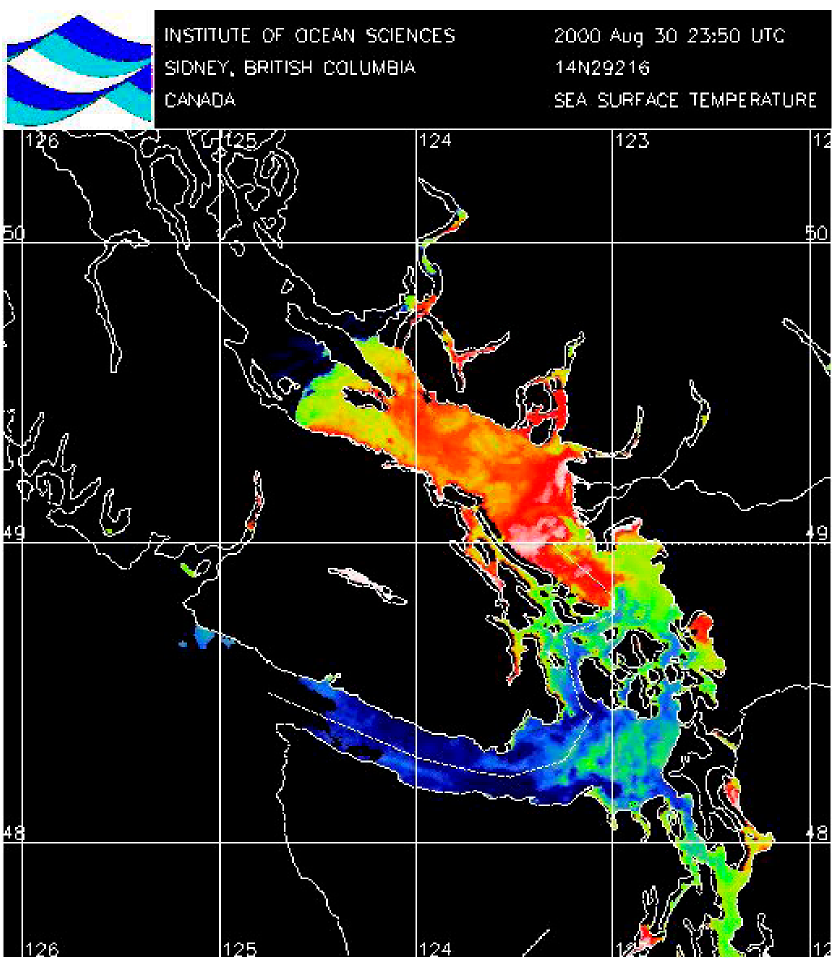


3.2 Environmental assessment

3.2.1 Regional environmental variability

It is important to understand the regional oceanographic climate of the Southern Strait of Georgia and Georgia Lowlands because these environmental conditions likely set the overall stage for the health of eelgrass meadows in the Gulf Islands. Nearshore ecosystems within the GINPRC are mainly influenced by three major processes: 1) Fraser River discharges, 2) winds and 3) tidal mixing (Thompson 1981; LeBlond 1983). The freshwater discharges from the Fraser River force a two-way exchange with ocean water coming from the Juan de Fuca Strait, and reach their annual peak in June because of snow-melt in the coastal and rocky mountains. The Fraser River plume extends across the southern Strait and enters the southern Gulf Islands. It is clearly visible as warmer (red) water in the satellite image below (F*igure 4*). The main features of the Fraser plume that influence the area are low salinities, higher water temperatures, and inputs of nitrates (the latter of which are limiting in marine systems). In the summer warmer freshwater coming from the north mixes with cooler oceanic water from the south. The GINPRC lies at the confluence of this mixing (*Figure 4*). Note that the deep blue regions on the satellite image represent cool surface waters, with likely higher salinity and nitrates, that are the result of strong tidal mixing of Juan de Fuca deep inflow (from the west coast shelf) in Haro Strait and Boundary Pass.

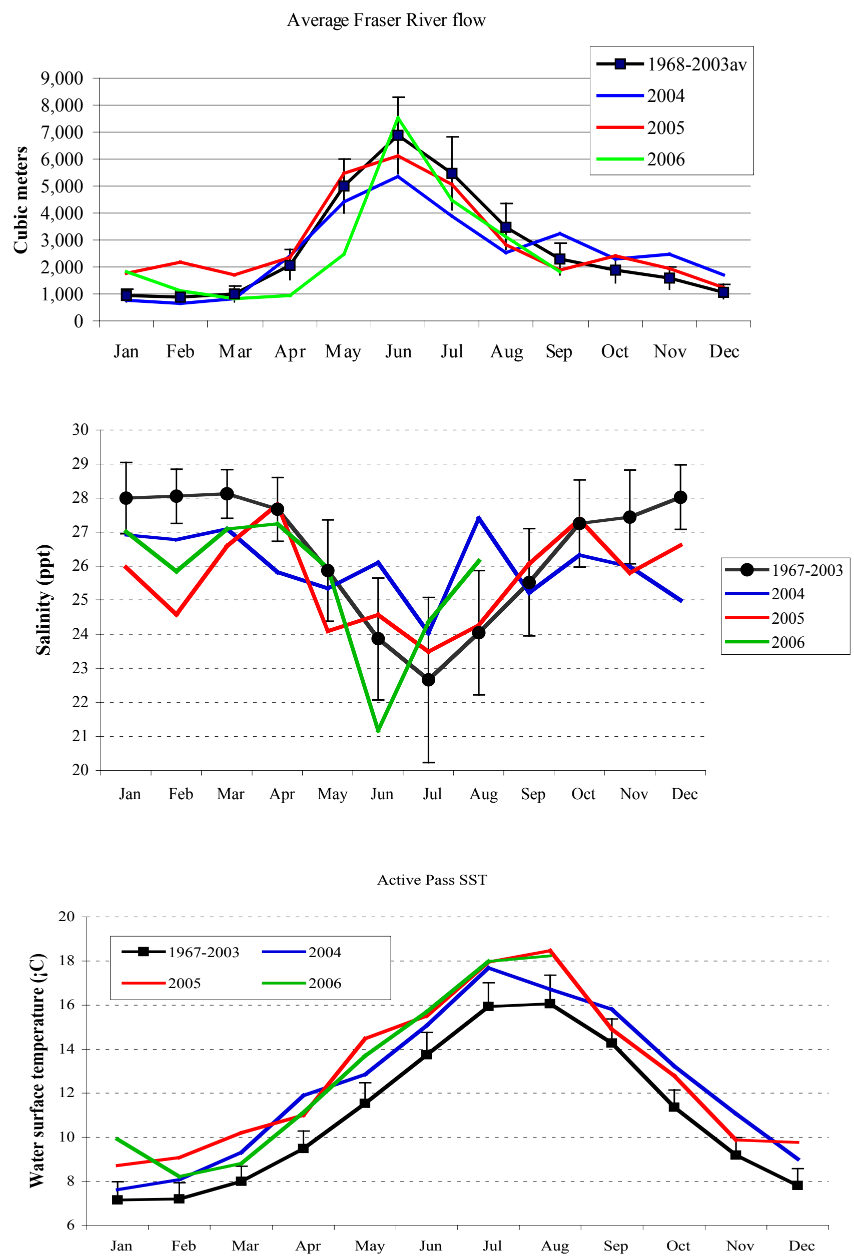
FIGURE 4. Sea surface temperatures in the Strait of Georgia and Juan de Fuca Strait, August 2000. Red indicates warm water, blue colder. Most of the GINPRC lies in the mixing area. The influence of the Fraser River is clearly visible (red).



Monthly data for Fraser River discharge were obtained from http://www.wsc.ec.gc.ca/staflo/index_e.cfm. Fraser River discharge during June-August 2004 was > 1 S.D. below the 30 year lower quartile, whereas 2005 and 2006 appeared to be more typical of the long term median flow (*Figure 5*, top). Surface salinity is usually inversely related to Fraser River discharge in the southern Strait of Georgia. For example, the higher salinities at Active Pass in June and August 2004 corresponded to the low discharge observed in the Fraser (F*igure 5*, middle).

Surface water temperatures in the southern Gulf Islands may be influenced more by solar radiation than by Fraser River discharge. For example, sea surface temperatures at Active Pass in August 2005 and 2006 were > 1 S.D. above the long term mean water temperature (*Figure 5*, bottom). Water temperatures were average in August 2004, but temperatures in all other months for that year were > 1 S.D. above the long term mean. Prolonged elevated water temperatures may prove stressful to eelgrass because respiration will exceed production. Thom et al. (2003) indicated

FIGURE 5. Top. Average Fraser River discharge. 2006 flows estimated from daily data. Middle: Sea surface salinities at Active Pass. Bottom: Water surface temperatures at Active Pass. Error bars are 1 SD.



for eelgrass in Oregon that water temperatures above 15ºC resulted in very low productivity to respiration ratios and in evidence that the plants were stressed. Studies in Puget Sound indicated that eelgrass was healthiest (using the productivity to respiration ratio) in a very narrow temperature range (5-8 ºC). The physiological response of eelgrass to elevated temperatures may be one reason why eelgrass in the southern Gulf Islands is primarily found in the subtidal region (water temperatures decrease with depth). In addition, the desiccation stress from exposure at low tide to very warm air temperatures would only worsen the scenario for eelgrass.

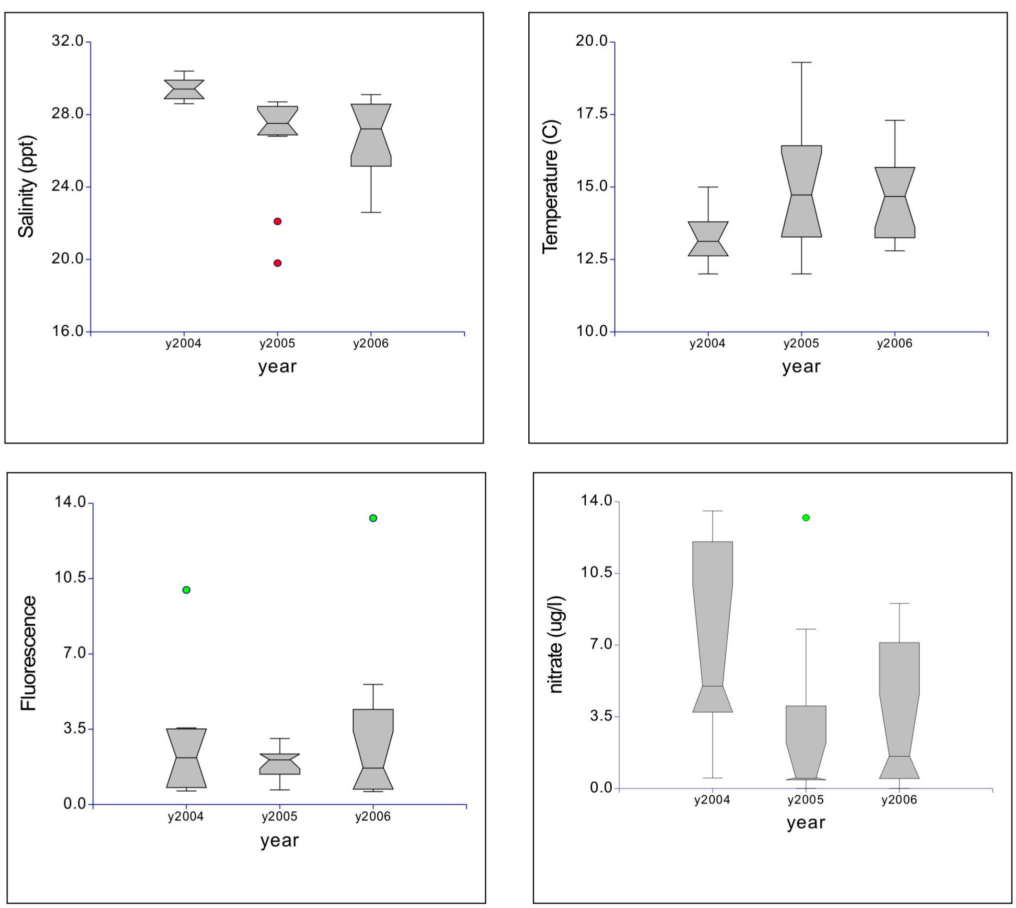
In summary, it appears that the regional environment in 2004 was unusual with low Fraser River discharges and higher salinities in the southern Gulf Islands. Another factor to consider, which was not measured, is the sediment load from the Fraser River. Wyllie-Echeverria et al. (2003) speculate that an unusually large sediment export may have occurred from the Fraser River in 2002, and that this may have resulted in the elimination of intertidal portions of eelgrass meadows in the San Juan Islands.

3.2.2 Local environmental variability

Environmental data collected in each eelgrass meadow were assessed to determine if local environments were responding in a similar manner to the larger, regional environment. Although point measurements are fraught with interpretation problems, sampling all eelgrass meadows within a short time period allows for snapshot comparisons of basic environmental properties among the meadows over the study region.

Measurements of water temperature and salinity were taken with a salinity/temperature meter (YSI 30™) at each eelgrass meadow after each beach seine (three measurements total; refer to Robinson et al (2006) for details) 50 cm below the surface, and recorded to the nearest decimal place. A surface water sample was also taken at each site. This sample was analyzed within 12 hours for fluorescence (equivalent to chlorophyll-a) and turbidity with a handheld fluorometer (Aquafluor ™ Handheld Fluorometer/ Turbidimeter). One litre was filtered and preserved for later chlorophyll-a and nitrates analyses.

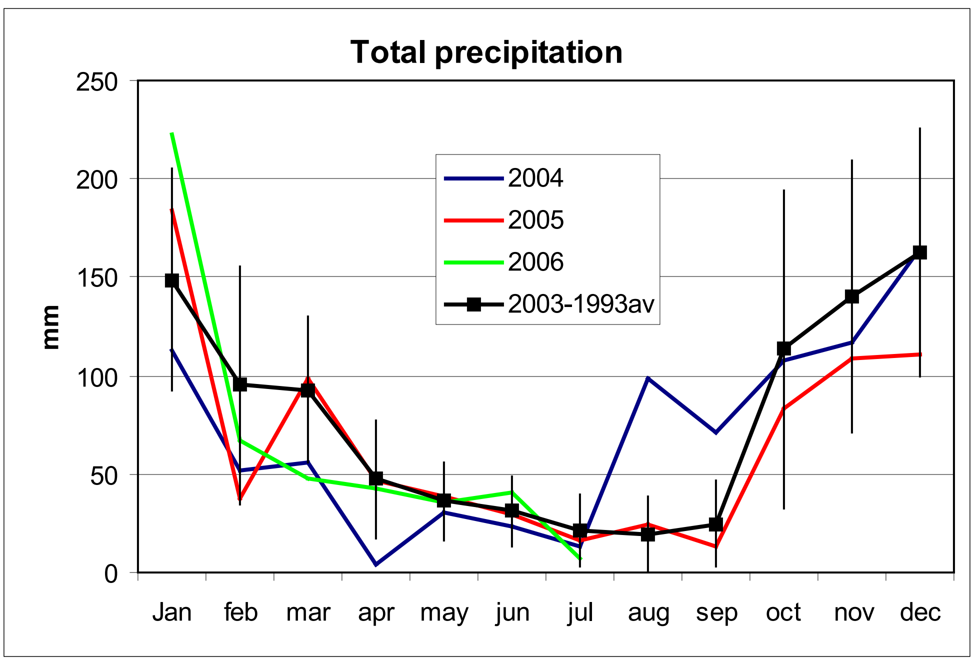
FIGURE 6.
Local water quality properties of eelgrass meadows sampled in August of 2004, 2005 and 2006. Refer to Figure 3 for legend.



Overall, local environmental conditions such as salinity, temperature and nitrates were more similar in 2005 and 2006 than in 2004 (*Figure 6*). The significantly higher nitrates observed in August 2004 may reflect an increase in marine nitrogen (recall that salinities were higher in 2004; salinity and nitrates are usually positively correlated) or the significant increase in local precipitations observed in August 2004 (*Figure 7*). It is important to note that the Puget Sound Water Quality Action Team considers inorganic nitrogen concentrations of 0.1 – 1.0 mg/l to be optimal to avoid blooms of macroalgae (such as ulvoids), and a concentration > 1.0 mg/l to promote algal blooms, including phytoplankton and benthic algae (epiphytes). The team also identified precipitations and solar radiations as the two most important weather factors influencing algal blooms.

To facilitate a better understanding of the links between temporal variability in regional oceanographic conditions and local eelgrass meadow conditions, we placed two temperature and light intensity underwater data loggers (HOBO® Pendant™ Data Loggers™) in 2006 at Cabbage Is and at James Is at approximately 0.5 m depths. The sites were chosen to encompass the extremes of conditions in the GINPRC: Cabbage Is is at the NE end of the GINPRC and is influenced by the Fraser River runoff whereas James Is is at the SW end of the GINPRC and faces more marine conditions. The data loggers are programmed to measure light intensity and water temperature every hour, and will yield information about daily and monthly variations in water temperature and light available to eelgrass.

FIGURE 7. Precipitation measured monthly at the Sidney airport. Note the anomalously high precipitation in August 2004 when sampling was conducted. Error bars are S.D.



3.2.3 Spatial variability in local environmental conditions

The Gulf Islands lie between the Straits of Georgia and Juan de Fuca and their water properties are likely influenced by the Fraser River discharge on the north end and by the oceanic waters from the Juan de Fuca Strait south (*Figure 4*). This section briefly examines the relative importance of these water masses on temperature, salinity and nitrates. Water properties data in eelgrass meadows sampled within and immediately outside the GINPRC were compared to those of sites outside the GINPRC. These were obtained from four sources:

- Fisheries and Ocean's water profile data inventory (http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/SearchProfiles_e.asp)
- Fisheries and Oceans' data from B.C. lighthouse (http://www-sci.pac.dfo-mpo.gc.ca/osap/data/SearchTools/Searchlighthouse_e.htm)
- Washington State Department of Ecology (http://www.ecy.wa.gov/programs/eap/mar_wat/mwm_intr.htm)
- Vancouver Port Authority's Deltaport Third Berth Project (http://www.portvancouver.com/container_expansion/deltaport/index.html)

Most sampling stations outside the GINPRC were either open water sites or near lighthouses. Their approximate locations are shown in *Figure 8*. Only data collected at the water surface and in the summer months (either June, July or August) were used. Nitrates concentrations were reported as the sum of nitrite and nitrates in the Fisheries and Oceans data. This does not affect comparisons between sites as nitrates are usually the dominant form of dissolved inorganic nitrogen in most water samples in the Strait of Georgia and Puget Sound and nitrite concentrations are often a minor portion of dissolved inorganic nitrogen (e.g., Bulthuis and Margerum 2005).

FIGURE 8. Approximate locations of water quality sampling sites outside the Southern Gulf Islands National Park.

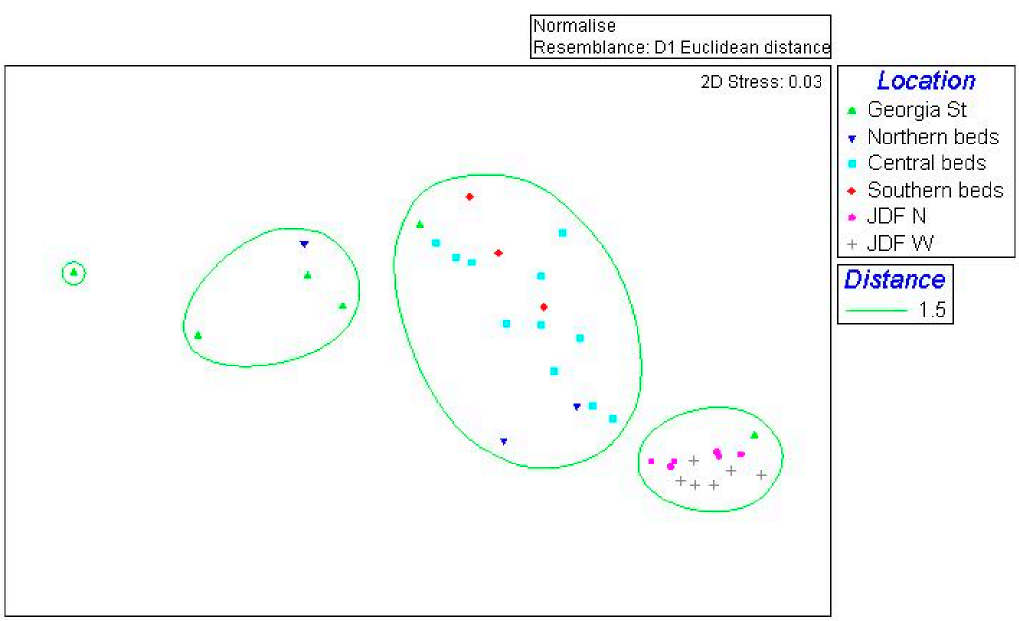
The stations were divided along a North – South axis (*Table 5*):

TABLE 5. Geographical groupings of water quality stations in areas within and adjacent to the Southern Gulf Islands.

Location	Water quality stations
Georgia Strait	DFO stations 2, 27 and 39, Roberts Banks (EVS sampling station)
Active Pass	Active Pass lighthouse station
SGI northern meadows	Eelgrass meadows sampled in Bennett Bay, Cabbage Is, Tumbo Is
Patos Island	Patos Is lighthouse station (University of Washington)
SGI central meadows	Eelgrass meadows sampled in Beaumont, Ella Bay, Irene Bay, Irish Bay, Winter Cove, James Bay, Lyall Harbour, Patos Is, Selby Cove, Narvaez
SGI southern meadows	Eelgrass meadows sampled in James Is, Moresby E, Reynard Pt, Sidney Spit
DFO 59	DFO station 59, immediately west of Sidney Spit
Juan de Fuca North	Race Rocks, DFO stations 62, 66, 65, and ADCP
Juan de Fuca West	DFO stations 69, 72, 75

The above groupings are essentially geographical. The statistical relevance of this scheme was tested through Multi Dimensional Scaling (MDS) on normalized data. Only sites for which data were available for salinity, temperature and nitrates were used in this analysis. This excluded sites like Patos Is (no nitrate data) and limited the analyses to years 2004 and 2005. Most sites clustered and conformed to the geographical groupings, in that there were more similarities among sites within a region than between regions (*Figure 9*), except for northern meadows (which can be attributable to the scarcity of data in this area). A two way crossed Analysis of Similarities (ANOSIM) on the data (sites x year) confirmed the validity of the groupings.

FIGURE 9. MDS on water properties (salinity, temperature and nitrates concentrations) of stations measured in areas adjacent to the Southern Gulf Islands, 2004-2005. Data were transformed with the Box-Cox transformation and then normalized prior to analysis. JDF = Juan de Fuca. Refer to Table 5 for sites names.

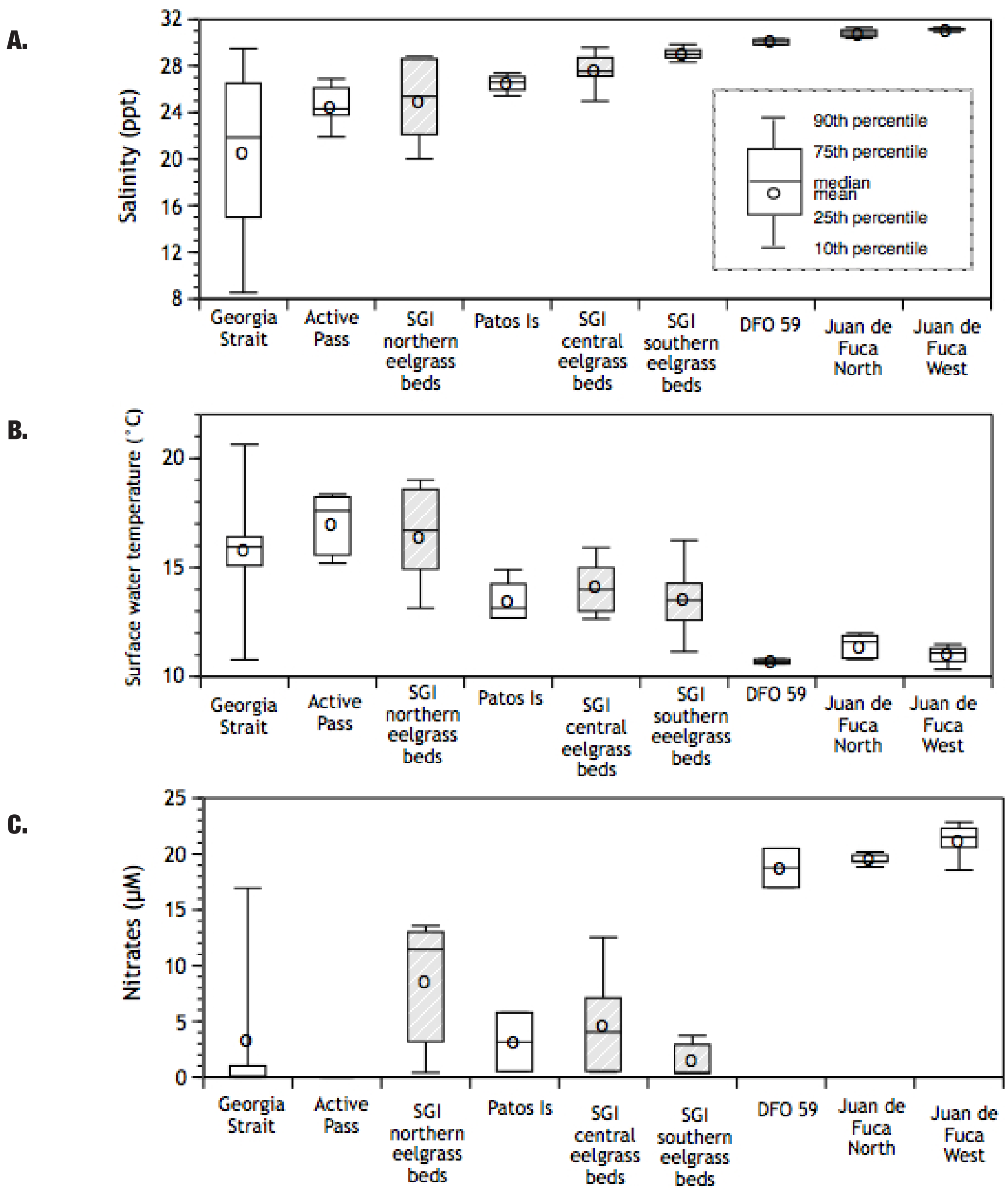


Surface salinities were usually lower and more variable in the Strait of Georgia than in the Juan de Fuca Strait due to the influence of the Fraser River (*Figure 10-A*). Salinities in the northern eelgrass meadows (Bennett Bay, Cabbage and Tumbo Is) were influenced by the Fraser whereas the southern meadows (Reynard Pt, Moresby, Sidney Spit and James Is) had higher, more oceanic salinities (F*igure 10-A*).

The mixing of water temperatures was evident as there were three statistically distinct groups (Tukey's HSD test on Box-Cox transformed data): warmer waters influenced by those of the Fraser River in the summer (Georgia Strait, Active Pass and northern eelgrass meadows), zone of mixing (Patos Is, central and southern eelgrass meadows) and cooler waters from the Juan de Fuca Strait (Juan de Fuca North and West; Figure *10-B*). The northern eelgrass meadows temperatures were thus closer to those of the Strait of Georgia than to those of the central or southern eelgrass meadows.

Nitrates come mainly from the Juan de Fuca Strait (they usually range from 25-30 µM at the surface water – Pawlowicz et al. 2003) and the

FIGURE 10. Range of salinity, temperatures and nitrates concentrations in surface waters measured in the Gulf Islands National Park Reserve of Canada eelgrass meadows (SGI) and in surrounding waters, 2004-2006. There were no nitrate data available for Active Pass.



input from the Fraser River is deemed low (< 5 μM, Pawlowicz et al. 2003). Eelgrass meadows in Padilla Bay have been shown to absorb dissolved inorganic nitrogen from the water as water flows over them in summer (Bulthuis and Margerum 2005). The same process might be at work in SGI meadows as nitrates concentrations dropped from the Juan de Fuca waters to the southern and central Gulf Islands eelgrass meadows (*Figure 10-C*). The nitrate data from the Georgia Strait were highly variable, due to the small number of stations, which reported this parameter.

In summary, it is apparent that the oceanography of the Gulf Islands is spatially intermediate between the Strait of Georgia and Juan de Fuca Strait. The Gulf Island eelgrass meadow environments can be divided into two major groups based on their closeness to the Strait of Georgia (northern group: Bennett Bay, Cabbage and Tumbo Is) and to a southerly mixed oceanographic group (Reynard Pt, Moresby, Sidney Spit and James Is, Beaumont, Ella Bay, Irene Bay, Irish Bay, Winter Cove, James Bay, Lyall Harbour, Patos Is, Selby Cove, Narvaez).

3.3 Eelgrass health assessment

The assessment of eelgrass health considers both intertidal and subtidal components.

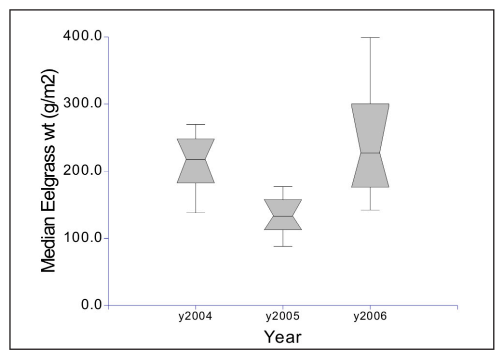
3.3.1 Intertidal eelgrass health assessment

The assessment of eelgrass health incorporates two measures reflecting the health of the intertidal portion of eelgrass meadows and two other measures reflecting the subtidal portion of the meadows. The health of the intertidal portion of the eelgrass meadows was assessed by field measurements of epiphyte load and eelgrass biomass. The two intertidal measures were derived from nine 0.1 m^2 quadrat samples collected in the field after fish sampling (see Robinson and Yakimishyn 2005 for methods). It is assumed that a higher epiphyte load and or a low eelgrass biomass are indicative of poor overall health. Ultimately, the species of epiphyte should also be considered because a high biomass of certain epiphytes (e.g., *Smithora*) will likely be ecologically more beneficial to fishes than a high load of benthic diatoms.

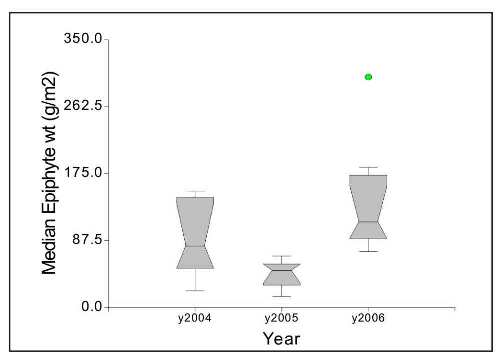
The number of sites sampled for eelgrass and epiphyte biomass in the Gulf Islands was limited because of a lack of intertidal components to the meadows. This property is itself a concern in terms of the health of SGI eelgrass beds. Where possible, samples were collected near the lowest low water mark, and typically in the shallow subtidal. Meadows sampled in 2005 had significantly lower eelgrass biomass than meadows sampled in 2004 and 2006 (*Figure 11A*). Epiphyte biomass was also significantly lower in 2005 (*Figure 11B*). The epiphyte load (epiphyte biomass divided by eelgrass biomass x 100) was relatively constant across years with median values of about 35-50% (*Figure 11C*). Note that epiphyte loads observed in the SGI are much higher than those observed in other coastal areas of interest to Parks Canada. Although direct comparisons are fraught with problems (different months sampled, different regional environments) they give a relative sense of the severity of epiphyte loading in the SGI.

FIGURE 11. Eelgrass biomass, epiphyte biomass, and epiphyte percent load (epiphyte biomass/eelgrass biomass X 100) for meadows sampled in the SGI. Refer to *Figure 3* for legend.

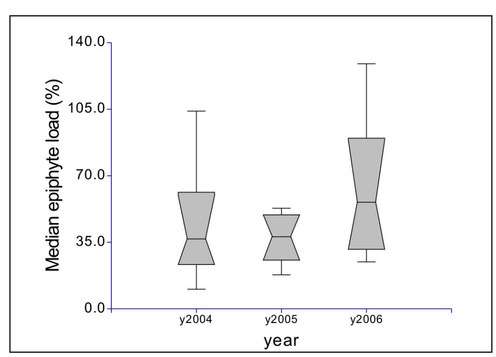
A.



B.



C.



3.3.2 Subtidal assessment of eelgrass meadows using underwater video

New to the program in 2005 was a qualitative assessment of the health of subtidal portions of the eelgrass meadows. The two subtidal measures were derived from qualitative analyses of underwater video (wasting disease and subtidal epiphyte load). See Robinson et al. (2006) for a discussion of the video method used. In general, wasting disease symptoms appear to be caused by the infection of a marine slime mould-like protist (*Labyrinthula zosterae*). *L. zosterae* can rapidly invade healthy blades, impairing photosynthesis. It is considered the primary pathogen causing the wasting disease infection (Moore and Short 2006). Infection in *Zostera* may be linked to already stressed eelgrass, and it is believed that healthy tissue can resist infection (see references in Moore and Short 2006). Disease symptoms and *Zostera* declines were apparently reported from Washington and British Columbia in the 1940s. The identification of wasting disease on eelgrass blades using underwater video is very striking. Examination of the video also allowed for estimates of epiphyte load in the subtidal portions of the meadows (not accessible at low tide). The following measures were used to assess the video:

Measure	Rank	Description
Subtidal epiphyte load	1	Less than 10% of blades with epiphytes
	3	Most blades have some epiphyte load, but no large mass
	5	Most blades have heavy epiphyte load: distinct mass of Kornmannia, diatoms or Smithora
Subtidal WastingDisease	1	None
	3	From 5-10% to < 25% of blades affected
	5	More than 25% of blades affected

Each eelgrass meadow was assessed in terms of meadow quality (thin, thick, patchy, visible epiphyte load, etc.), substrate type, adjacent habitat (meadowrock, kelp meadow, sand patch, etc.) and maximal depth through an underwater video camera. A Splash-Cam™ underwater video camera was towed in front or on the side of the boat and linked to a Canon digital video camera (Canon NTSC ZR40). Filming was usually carried on the same day of the beach seining, although some sites were lumped together on separate days to increase efficiency. In each case the camera was first lowered seaward of the eelgrass meadow and its position was recorded on a portable GPS. The boat subsequently moved slowly (approximately 1 to 0.7 km/hr) towards the shore while observers took notes about the substrate through an on-board monitor. Filming usually began a few m before the deepest limit of the eelgrass meadow. The camera was towed from 0.5 to 2.0 m above the eelgrass meadow. Three to five transects, accounting for 10-12 min on average were filmed on each site.

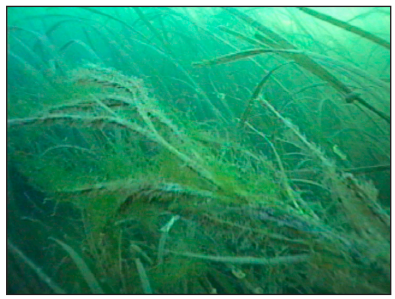
Videos were transferred to a hard drive and reviewed in the laboratory. Each site's footage was broken into sequentially numbered video clips. Notes were taken on substrate type and macrophytes within and adjacent to eelgrass meadows, eelgrass density, epiphyte load and presence of wasting disease, and incidence of fishes and invertebrates. All notes were referenced to the time within each clip (e.g., Lyall Harbour, clip 2, 2:44). Still pictures were extracted from the videos to emphasize some aspects of eelgrass meadow quality or unusual occurrences of fauna.

The maximal depth of each meadow was measured from a combination of video and depth sounder. Maximal depths were recorded by noting the depth and time when the subtidal limit of the meadow appeared in the underwater video. Depths were later transformed in Chart Datum (CD) depths through tidal algorithms.

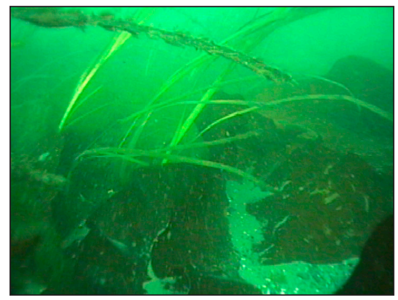
Subtidal descriptions of eelgrass meadows

All eelgrass meadows sampled in or near the GINPRC in 2005 and 2006 were subtidal. This is similar to the distribution of eelgrass meadows observed in the neighbouring San Juan Islands (e.g., Spear and Elliott 2005; Wyllie-Echeverria et al. 2003). There were no observed instances of wasting disease (recently confirmed in the Barkley Sound area) but this may be due to the generally high epiphyte load that would obscure most observations. Most eelgrass meadows were videotaped at high or flood tide. The following assessments (*Table 6*) are based on 2005 data from Robinson et al (2006) as the 2006 data were not yet analyzed at the time of this writing. Meadows were divided into three geographical areas: north GINPRC (northern portion of Mayne Is, Cabbage and Tumbo Is), central GINPRC, and southern GINPRC (Sidney Spit and James Is). The rationale for this grouping was elaborated in Section 3.2.3.

NORTHERN SITES.
Both sites showed high epiphyte load and were relatively thin. Cabbage Island might be more prone Fraser River influences because of its northwest exposure.

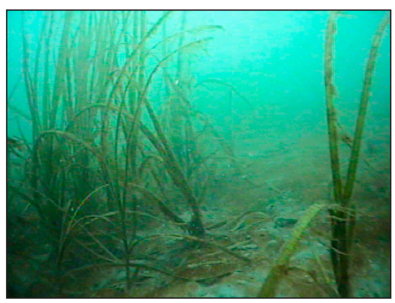


Cabbage Is eelgrass meadow underwater



Tumbo Is eelgrass meadow

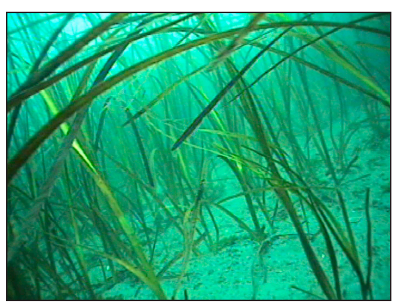
CENTRAL SITES.
The central sites' exposures and their adjacent habitats range from steep slopes to boulder and gravel shorelines to sandstone beaches. Six of the nine sites sampled and six of the seven sites videotaped faced the northwest (James Bay, Selby Cove, Ella Bay, Irene Cove, Lyall Harbour and Narvaez).



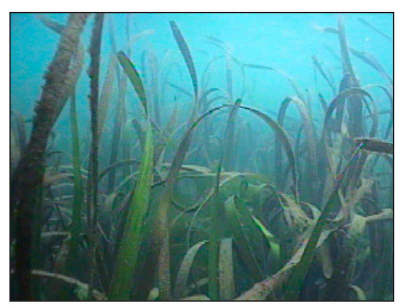
Beaumont eelgrass meadow

James Bay eelgrass meadow

SOUTHERN SITES.
The two southern sites are subjected to near oceanic conditions from the neighbouring Juan de Fuca Strait. Both are located in sheltered areas, abutted to low beaches, and had heavy epiphyte load in 2005.



James Is eelgrass meadow



Sidney Spit eelgrass meadow

In summary, the majority of eelgrass meadows examined in the southern Gulf Islands 1) were thin and patchy, 2) had a moderate to high epiphyte load, and 3) occurred over a wide depth range (1.3-5.6 m). The first two conditions are indicative of poor health (Deegan et al. 2002; Duffy 2006). It is important to note that the poor meadow conditions occurred across a wide range of potential anthropogenic activities, and hence may be related to the naturally high nitrate conditions resulting from tidal mixing in Haro Strait and Boundary pass (see below), or to the Fraser River (e.g., increased temperatures and siltation). Local conditions do not appear to be responsible for eelgrass health because there were no dramatic changes in eelgrass meadow conditions in different bays. The poor health conditions were widespread.

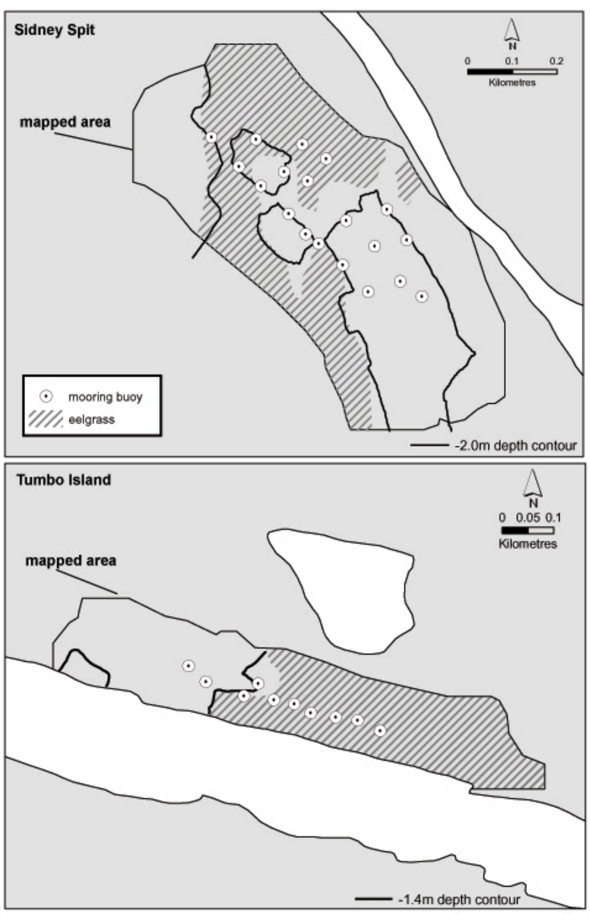
TABLE 6. Descriptions of eelgrass meadows sampled in 2005, in or adjacent to Gulf Islands National Park Reserve of Canada.

Location	Habitat	Human impact	Meadow	Maximal depth m (1)	Epiphyte load	Invertebrates (2)	Wasting disease
CABBAGE ISLAND	Rocky shores along S edge; gravel sand on others	High; popular mooring site	Thin on edges; thick in middle	2.3	Heavy (*Ulva*, diatoms, *Smithora*, *Kornmannia*)	Bubble shells (*Haminoea vesicula*)	No incidence
TUMBO ISLAND	abutted to a sandy beach and a salt march to the W; rocky sandstone shores on N and S edges	Low	Thin and patchy; understory of laminariales and *Ulva*	5.6	Heavy (diatoms, *Kornmannia*, *Smithora*)	moonsnails	No incidence
IRISH BAY	Open bay surrounded by sandstone; gravel, mud and sand	Medium	Thin; understory of *Ulva* and laminariales	N/A	Medium to heavy (diatoms, *Kornmannia*, *Smithora*)		No incidence
JAMES BAY	Narrow bay with steep slopes; meadowrock & boulders	Medium	Thin and patchy	1.5	Heavy (diatoms, *Smithora*)		No incidence
SELBY COVE	Narrow bay with steep slopes; meadowrock & gravel beaches	Medium	Dense on muddy bottom; diatom mats	1.3	Heavy (diatoms)	Nudibranchs, bubble shells, small gastropods, oysters; stauromedusae	No incidence
LYALL HARBOUR	End of a bay; shoreline of gravel & boulders	High, close to dock	Thin and patchy; extends across the bay	N/A	Heavy (diatoms, *Kornmannia*)	Horse clams	No incidence
ELLA BAY	Small and narrow bay surrounded by gravel beaches	Medium to high; houses at end of bay; recently built seawall; close to ferry dock	Patchy with dense patches; thick understory of Ulvoids and laminariales	4.1	Heavy (diatoms, *Smithora*, *Kornmannia*)		No incidence
IRENE COVE	Small and narrow bay surrounded by gravel beaches on S and sandstone on N edge	Medium; houses at end of bay	Patchy; dense understory of *Ulva*; Turkish towels and laminariales adjacent to meadow	4.4	Medium to heavy (diatoms, *Kornmannia*)	Small gastropods (*Lacuna* sp) common; kelp and Dungeness crabs	No incidence
NARVAEZ	N point of small cove; meadowrock and gravel	Low to medium; adjacent to mooring site	Thin; understory covered by Ulvoids and laminariales	2.7	Heavy (diatoms)	Graceful crabs, sunflower stars common	No incidence
BEAUMONT	Sheltered cove abutted to gravel beach; rocky reefs to S & SE	Low	Patchy; high abundance of woody debris; some laminariales	0.5	Heavy (diatoms)	High abundance of clams (possibly roughmyas); graceful crabs	Not recorded
JAMES ISLAND	Open beach, shallow slope	Low, but near a dock	Thick; understory of laminariales; *Ulva* meadow adjacent	6.8	Heavy (*Ulva linza*)	Juvenile green sea urchins; many juvenile Dungeness crabs; nudibranchs; meadow of sea pens deeper	No incidence
SIDNEY SPIT	Surrounded by flat and sandy shoreline E and SE; steep sandy slope SW	High; popular recreation area	Thick and extensive	1.7	Heavy (diatoms)	Bubble shells; graceful crabs	No incidence

NOTES:
(1) Chart Datum depth back calculated from measurements in the field;
(2) Invertebrates of note either because of their unusual abundance or their ecological function

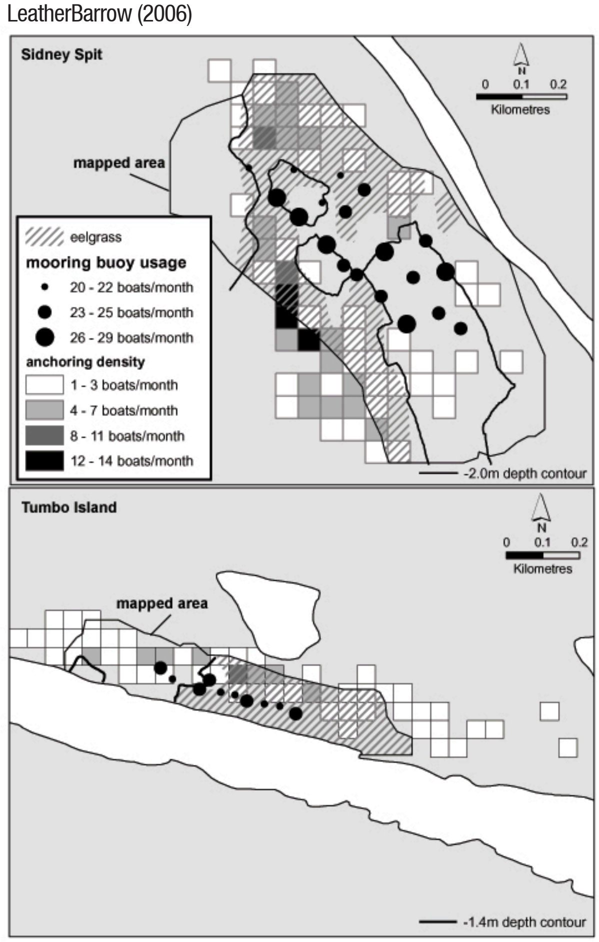
LeatherBarrow (2006) characterized the ecology and recreational boating activity at two popular anchoring sites located in the waters of the GINPRC (Sidney Spit and Tumbo Island) during the summer of 2004. The three components of the study were to: 1) characterize the distribution of eelgrass (*Zostera marina L.*), 2) build an inventory of anchoring/mooring activity, and 3) characterize the benthic infauna at each site. There are two important observations from this thesis work that are relevant to eelgrass health. First, there was high overlap between mooring buoy locations and eelgrass meadows at the two sites (*Figure 12*). Second, many boats were anchored directly over eelgrass (*Figure 13*). At Tumbo Island, boats were not expected to anchor east of the mooring buoy area due to the shallow water depth and distance from the onshore services. At Sidney Spit, boaters unable to find an available buoy or choosing not to use a mooring buoy may not have many eelgrass-free areas to anchor in. Boaters were however anchoring even when mooring buoys were available. Clearly there are opportunities for the Park to change boater behaviour to minimize anchoring impacts on eelgrass.

FIGURE 12. Polygons showing the 50% probability contour of eelgrass at Sidney Spit and Tumbo Island. From LeatherBarrow (2006)



The Park could mimic the program established by the Jefferson County Marine Resources Committee, the voluntary Anchor Protection Zone for the eelgrass beds in Port Townsend Bay in Puget Sound. Eelgrass beds were located during a 2001 shoreline inventory and marker buoys were installed around the perimeter of the eelgrass beds with signage encouraging boaters to anchor in slightly deeper water outside the shore-fringing eelgrass beds (Jefferson County Marine Resources Committee 2005). The Port Townsend community participates strongly in the project and has onshore education tools including brochures, dock signage, a demonstration eelgrass built at an old pier, and displays at community events detailing the importance of eelgrass beds in the region and the importance of anchoring outside the perimeter of the beds. Initial phases of the project have shown success, with anchoring inside eelgrass beds dropping from 20% in 2003 to only 1.4% in 2004. A more comprehensive monitoring program is in place that will hopefully show continued success in years to come.

FIGURE 13. Map of boat usage at Sidney Spit and Tumbo Island, showing mooring buoy usage and anchoring density. From LeatherBarrow (2006)



3.4 Assessment of fish assemblages

There are several reasons for assessing eelgrass fish assemblages. First, fish assemblage properties are known to change with changing health of the eelgrass meadows (Deegan et al. 1997). For example, as eelgrass meadows deteriorate there is generally a reduction in the number and types of species, abundances, and a reduction of benthic and sensitive species. Second, eelgrass, which is found along about 30% of the GINPRC coastline, attracts juvenile fishes (for protection and food), and is relatively easy to quantitatively sample compared to other habitat types (e.g., kelp forests or rocky shorelines). Third, changes in certain aspects of a fish assemblage found in eelgrass (e.g., number of juveniles of rockfishes, lingcod, and greenlings) may also indicate changes in the health of fish populations in habitats adjacent to eelgrass. This is because juvenile fishes are attracted to eelgrass, and they only temporarily reside in eelgrass in the summer months while growing.

Eelgrass meadows were sampled once each year in early August when juveniles and young-of-year fishes use the eelgrass beds for rearing and foraging (Yakimishyn 2003). Triplicate beach seine sets were completed at each site with a 9.2 m long beach seine with 4 mm stretch mesh, having a 3.1 m drop in the centre and tapering to 1.1 m at the wings. Seining was conducted during a two-hours window before and after the early morning lowest low water (tidal height < 0.6 m). The beach seine was set in a round haul manner from a small boat. After a beach seine was completed, fishes were removed from the seine and held in water filled rubber totes, and then the next seine was conducted about 5-10 m alongshore. After the third seine was completed, all fishes were identified to species, counted, and returned to the sea. The total area of each eelgrass meadow sampled after 3 beach seines was approximately 150 m^2. All fishes caught were kept in large totes, one per set. Fishes were enumerated and identified to species. Up to 30 individuals per species were measured (Total or Fork Length, depending on the species) per site, and up to 30 individuals per species were weighed, the latter only in the second site of the day. Fishes were released unharmed at the site of their capture. *Table 2* and *Figure 2* summarize eelgrass beds sampled in SGI during August of 2004, 2005 and 2006. Note that year is an independent factor in the analyses because eelgrass beds are recolonized by new young-of-year fish each year. See Yakimishyn et al. (2003) for more details on sampling methods.

3.4.1 Analysis of fish assemblage data

The general concept of power is a reasonable consideration for non-parametric and multivariate cases, but it is near impossible to carry over in any formal sense. Bob Clarke (founder of the PRIMER statistical package; personal communication 2006) indicates that one has to specify the alternative hypothesis to the null hypothesis, and because this includes a vast number of possible ways in which the community can change, this is unrealistic to specify in the multivariate case: "Looking at a single species, if the assumption of normality is justified (which it never is) you may want to detect a 10% increase or decrease in the abundance of the species if you had information on the variability in abundance for that species over replicates. In the multispecies case, you not only have to assume joint normality (impossible) and be able to specify the variances of each species (near impossible) but you also have to say whether you want to detect an increase or decrease in all individual species by a certain amount (but which species will go up and which ones down?). It would be impossible to specify the alternative hypothesis that you would like to have good power to detect". In PRIMER's non-parametric multivariate approaches such as non-metric multidimensional scaling or analysis of similarity, the experimental design should include "enough" replicates to generate sufficient permutations for comparing observed statistics (see below). In other words, although we can't formally test for power, it makes good intuitive sense that more replicates increase the chances that conclusions from non-parametric multivariate statistical approaches are meaningful.

To assess for the EI of fish assemblages, three major aspects of fish community structure were evaluated over time: species similarity, dominance, and relatedness. This approach is more consistent with ecosystem level assessments as opposed to evaluating how single species may change over time. Non-parametric multivariate approaches were used to assess changes in fish assemblage structure as discussed below

(PRIMER 6.0 software package, Clarke and Gorley 2006). Refer to the PRIMER web site (www.primer-e.com) for a large number of published studies describing their methods in detail.

3.4.2 Assemblage similarity

Multivariate methods base species assemblage comparisons on more than two variables from samples sharing particular species at comparable levels of abundance. We used non-metric multidimensional scaling (nMDS) because it makes few assumptions about the form of data or the interrelationships of the samples. The starting point for an nMDS is the generation of a similarity (or dissimilarity) matrix calculated between every pair of eelgrass sites. We used the Bray-Curtis similarity coefficient for this purpose. Abundances of each fish species (excluding juvenile seaperches) were square root transformed to remove the influence of overly abundant species. The advantage of nMDS is that it can generate plots of the configuration of samples in two or three dimensions. The key to interpreting an nMDS plot is to understand that sites with the most similar species assemblage and abundance are closest together on the plot, while least similar sites are furthest apart.

One would expect sites from the same year to cluster if fish assemblages were different among years (year 2004 sites together, year 2005 sites together, etc.). Furthermore, these clusters of samples would be widely separated on the plot. The adequacy of the sample representation in an MDS plot is evaluated by a stress value. A stress value < 0.05 gives an excellent representation of the relationships among samples, while a stress of < 0.1 gives a good ordination with no real prospect of a misleading interpretation, and a stress of < 0.2 gives a potentially useful 2-d picture. Stress values > 0.3 indicate that points (samples) are close to being arbitrarily placed (i.e., any relationship should be viewed with caution).

We also applied an analysis of similarity (ANOSIM) to the rank similarity matrix. ANOSIM is a non-parametric procedure that tests the null hypothesis that there are no fish assemblage differences between eelgrass sites grouped a priori by levels of a single factor or group (e.g., year). The ANOSIM generates significance levels and a Global R statistic. This R statistic varies between 0 (no differences between groups) and 1 (complete discrimination between groups). The significance level (p) of R is very dependent upon the number of replicates in each group, and as with univariate statistics, biologically trivial differences can still be statistically significant when sample size is large. The key is not to focus on the p values but on the Global R values; the higher the value of R the greater the separation of replicates from the groups. Global R values > 0.5 are worth noting. In this baseline assessment of fish assemblage similarities we were interested in evaluating the interannual differences in fish assemblage structure. Hence, eelgrass sites were grouped a priori by year (2004-2006) and these groupings were used in an MDS and ANOSIM of fish species richness and abundance.

Figure 14 shows a two-dimensional nMDS plot of eelgrass beds sampled in the SGI for each of three years. The relatively high stress value (0.19) and mixing of samples of any one year with other years indicates no obvious clustering of fish diversity and abundance among years. This conclusion is consistent with the results of the ANOSIM (Global R = 0.099 and p = 0.11). Overall, we can conclude that fish assemblages are very similar from year-to-year in the eelgrass beds sampled in the southern Gulf Islands.

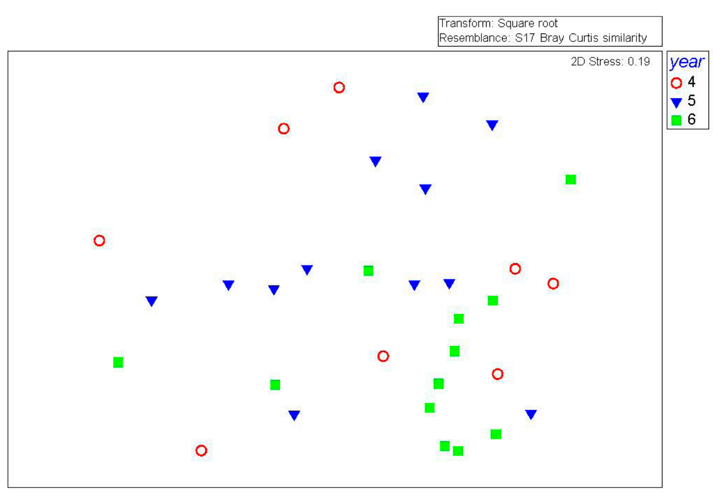


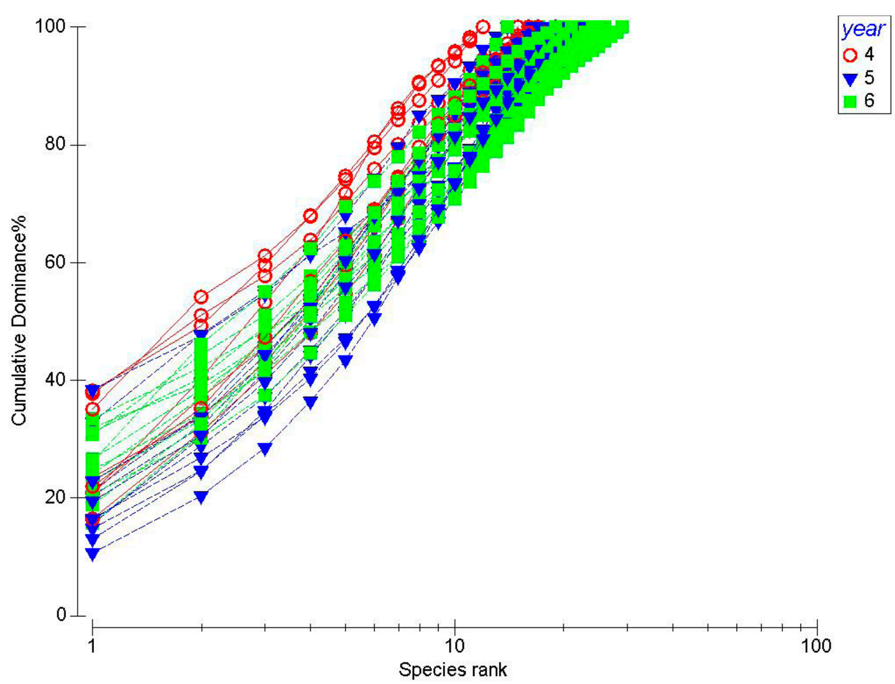
FIGURE 14. MDS on fish assemblages of eelgrass meadows sampled in the Southern Gulf Islands National Park Reserve, 2004-2006. Each data point represents one eelgrass meadow sampled in one year. There are no obvious clusters of years.

3.4.3 Assemblage Dominance

The relative abundance of individuals among different species in a sample is called evenness (or its opposite, dominance). Healthier sites should have an even distribution of species contributing to total site abundance or biomass. In theory as sites become disturbed they may become dominated by fewer (more tolerant) fish species. Hence, changes in dominance over time may reflect changes in fish assemblages. In this assessment, species dominance was based on the rankings of the abundance of species in decreasing order of their importance (Clarke and Gorley 2006). Cumulative ranked abundance curves plotted against species rank are called k-dominance curves. A steep k-dominance curve indicates that few species account for a large proportion of the total number of species in a site. To test for differences among k-dominance curves, curves need to be compared among replicates, both within and between years. The distances between every pair of cumulative curves are computed using the Manhattan distance. The triangular matrix of dissimilarity values is then entered into an ANOSIM to produce a significance test for the differences between years (Clarke and Gorley 2006). The more k-dominance curves vary (are further apart) among years than within years, the greater the Global R value will be.

K-dominance curves of fish abundance for eelgrass beds sampled in each year are shown in *Figure 15*. Each line represents the data from one eelgrass bed, and the colours correspond to beds sampled in the same year. An ANOSIM on the dissimilarity matrix indicates that there was a significant difference in dissimilarity among years ($p = 0.025$), but because the Global R value is close to 0 ($R = 0.13$), the differences in dominance are not considered ecologically meaningful. Recall that Global R values close to 0 mean that the sites (or years) are almost identical, and Global R values should be > 0.5 to be meaningful.

FIGURE 15. K-dominance curves for eelgrass meadows sampled in the southern Gulf Islands during July, 2004-2006. Each curve represents one eelgrass meadows sampled in a particular year. Flatter curves indicate that the fish assemblage is dominated by fewer species. Statistically, 2004 is different than 2005 or 2006 but because the Global R value is only 0.10, the differences are not considered ecologically important.



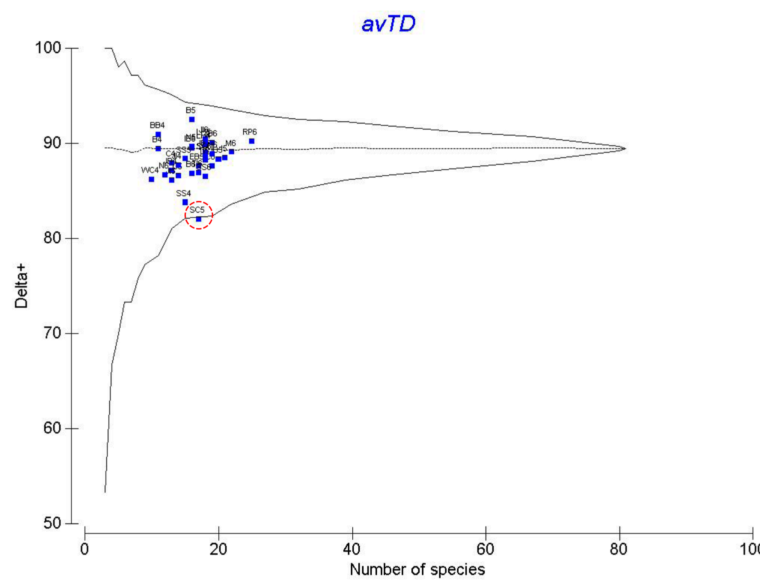
3.4.4 Assemblage relatedness

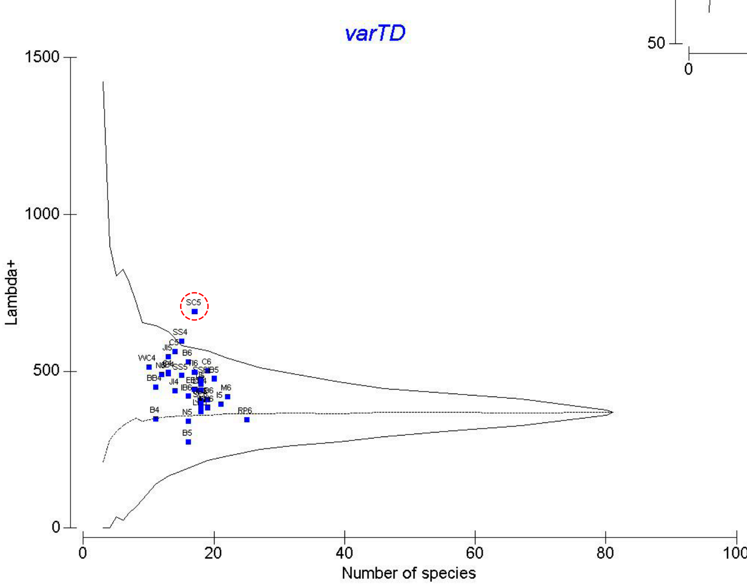
Most biodiversity studies focus only on species richness and evenness. Surprisingly few studies focus on the taxonomic relatedness of a group of species. For example, two sites may have the same number of species (10) but closer examination may reveal that the first site contains 10 species from the same family, while the second site contains two species from five different families. Obviously, the second site would be of higher conservation value for biodiversity representativeness. Furthermore, a loss or reduction in species relatedness at a site would be a cause for investigation. One statistic that has recently been developed and widely applied in marine biodiversity studies is the average taxonomic distinctness (avTD; Clarke and Gorley 2006). AvTD has been shown to be independent of the number of species in a sample, and is based on the taxonomic distance through the Linnean classification tree between every pair of species (Clarke and Gorley 2006). The avTD of a site is the average taxonomic distance between all pairs of species. Thus, the statistic gives a nice summary of the average taxonomic breadth of a site.

The assessment tool we used is based on the null hypothesis that a species list from one eelgrass site has the same taxonomic structure as the regional species list from which it is drawn. The observed site avTD is compared with "expected" regionally derived avTDs. Values below the lower probability limit (5%) suggest that the biodiversity at that site is different from the expectation for the region. Closer examination of the sites' species list reveal the cause of the different taxonomy.

All sites in all years, except for Selby Cove in 2005 (SC5), fell within the expected taxonomic relatedness for the region (*Figure 16*). In addition, the variance in taxonomic distinctness for SC5 was higher than expected by chance. Noticeably absent from SC5 were plated fishes (e.g., bay pipefish or sticklebacks), rockfishes, and greenlings.

FIGURE 16. The average and variability in taxonomic distinctness (avTD and varTD) for eelgrass meadows sampled in the southern Gulf Islands in August of 2004, 2005 and 2006. Dashed red circle is Selby Cove, which was significantly different from regional diversity expected in an eelgrass meadow.





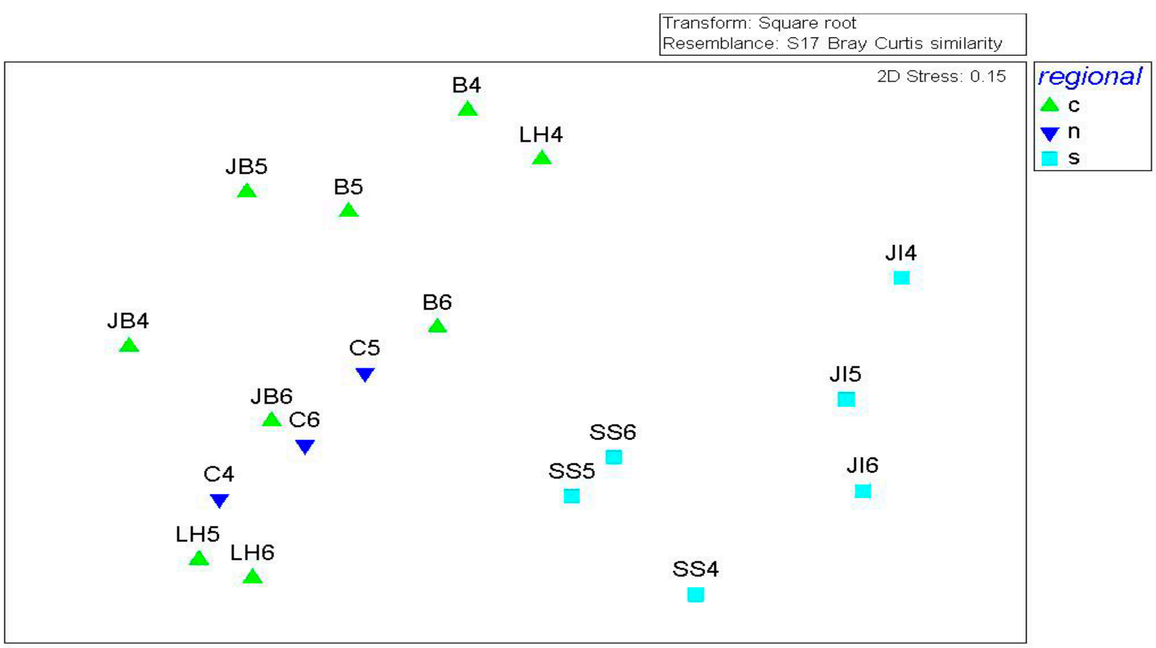
3.4.5 Spatial differences among fish assemblages

We noted earlier the spatial differences in environmental conditions in the Gulf Islands in relation to their proximity to the Strait of Georgia (Fraser River discharge) and Juan de Fuca Strait (marine). To further understand possible spatial differences in fish assemblages, we examined six eelgrass meadows sampled in each of the three years: one in the north (Cabbage Is), three central (James Bay, Lyall Harbour, Beaumont), and two southern sites (Sidney Spit and James Is).

Two important results emerge from this comparison. First, the spatial variability in species richness and abundance for these six sites shows that they were more similar to each other across years than to other meadows sampled in the same year (*Figure 17*). For example, the Sidney Spit fish assemblage (SS in *Figure 17*) was more similar to itself in 2004, 2005 and 2006 (i.e., it was clustered together) than to other meadows sampled in the same year. The same held for the other meadows, with the exception of Lyall Harbour (LH), which had the lowest average similarity among years. This was due to the fish assemblage for this site in 2004 being different from the other two years.

Second, the two southern eelgrass meadows (Sidney Spit (SS) and James Island (JI)) were more similar to each other, and significantly different from the four north-central sites. Recall that the southern meadows had higher salinities, cooler water temperatures and relatively lower nitrates than north-central meadows. The two southern meadows appeared to contain substantially fewer adult and juvenile shiner perch, more saddleback gunnels, more adult and juvenile sticklebacks, and more buffalo sculpins. These differences may reflect species-specific responses to local environmental conditions, or perhaps assemblage responses to local seascape properties (e.g., adjacent habitats). The importance of seascape factors on assemblage structure needs to be examined in more details.

FIGURE 17. MDS on eelgrass meadows resampled in 2004, 2005 and 2006 in or near the GINPRC. Each symbol represents one site in one year. B – Beaumont, C- Cabbage Is, JB - James Bay, JI– James Island, LH – Lyall Harbour, and SS – Sidney Spit. C: central sites, N: northern sites and S: southern sites.



In summary, it appears that fish assemblages in the southern Gulf Islands are primarily influenced by spatial variability in local eelgrass or seascape properties, and perhaps less so by regional interannual variability in oceanographic conditions (as measured by SST, SSS and nitrates). It is not yet known which local property of eelgrass meadows (e.g., shoot density) or seascape factor (e.g., adjacent habitat) drives this spatial coherence. It is worth noting that while only three years of data have been collected, the observed spatial coherence is consistent with results from other PCA study areas (Gwaii Haanas, Clayoquot Sound and Barkley Sound).

The implications of greater similarity in fish assemblages among the same meadows across years than with other meadows in the same area are:

1. Eelgrass meadow fish diversity cannot be treated as equivalent among meadows. This has huge implications for the protection of eelgrass meadows and their representativity. Randomly selecting eelgrass meadows for full protection does not guarantee that regional fish diversity will be represented or conserved.
2. A complete inventory of eelgrass meadow fish diversity needs to be completed for the park because there may be instances of rare or unique fish assemblages that use them.

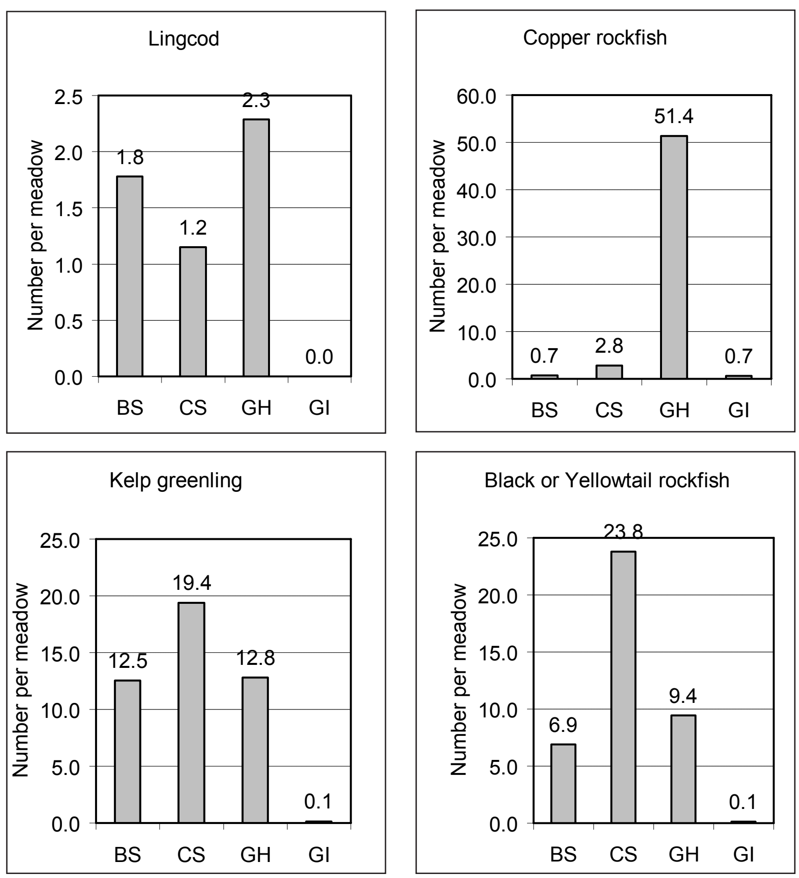
Local environmental conditions (such as habitat conditions and environmental properties) may be more important than regional environmental properties (e.g., Fraser discharge) in influencing eelgrass fish diversity. From a management perspective, each eelgrass meadow must be assessed on its own. Hence, a monitoring program may have to include a rotational sampling scheme to effectively monitor the different types of fish communities using different eelgrass meadows.

3.4.6 Frequency of occurrence of common fish groups among regions

When comparing the average number of fishes caught per meadow from the SGI to other regions on the west coast of British Columbia, some striking differences become apparent (*Figure18*). The major conclusion is that there are generally fewer juvenile rockfishes (copper and black), kelp greenlings and lingcod caught in SGI eelgrass meadows than elsewhere.

FIGURE 18. Average number of fish caught per eelgrass beds, 2004-2006.

BS: Barkley Sound
CS: Clayoquot Sound
GH: Gwaii Haanas
GI: Gulf Islands



Several factors may be responsible for these differences, among which:

1. Regional environmental conditions may exclude or reduce the abundance of some species. For example, the relatively low salinities observed in the SGI (as influenced by the Fraser River) may act as a physiological barrier to certain species, hence the absence of their juveniles in eelgrass. In the future, these relationships may be teased out using the Parks Canada southern Clayoquot Sound dataset on fish assemblages and gradients in environmental conditions.

2. The past intense fishing pressure in the southern Strait of Georgia may have reduced the numbers of adults of some species (e.g., rockfishes, lingcods), and hence there might be no 'supply' of young of the year (YOY) of these species to SGI eelgrass meadows. Non-destructive surveys could easily be conducted to establish presence and relative densities of adults of certain species. Perhaps local dive clubs could be encouraged to provide information on species and relative densities, and comparisons can be made across regions.

3. It is possible that the quality of the SGI eelgrass meadows is sufficiently poor that YOY of many fish species seek alternative rearing habitats (e.g., *Agarum*). This could be tested by using artificial seagrass to mimic healthy habitats and then determine use by YOY fishes or by surveying additional habitats such as adjacent kelp beds.

4. Some of the differences observed among regions may be attributed to differences in timing of beach seine surveys (mid June for southern Clayoquot, July for Barkley Sound, July for Gwaii Haanas, and mid August for SGI). This factor is likely lowest on the list because most species discussed above recruit to eelgrass in early summer (June) and typically remain until autumn (e.g., Yakimishyn 2003). In addition, tagging research in southeastern Alaska demonstrated that YOY copper rockfish actually remain within the same bed throughout the summer growing season.

4.0 RECOMMENDATIONS

- Healthy eelgrass communities are widely considered a useful sentinel of the condition of coastal ecosystems (Biber et al. 2005) and eelgrass consistently ranks highest among Pacific Northwest coastal ecosystems in terms of fish diversity and abundance (e.g., Murphy et al. 2000; Johnson et al 2003). Given their importance and the fact that only about 20% of the known eelgrass meadows have been sampled in GINPRC (cf. *Table 1*), it is recommended that the inventory of eelgrass meadows within and outside the GINPRC continue. The methods used by the WNSC can be implemented with minimal resources.

- The anthropogenic disturbance scores calculated for SGI eelgrass indicate that the meadows are located in regions of high human use and activity. Consequently, we might expect *a priori* that these meadows would be worse off relative to regions with less human use (e.g., Gwaii Haanas). We recommend that the ADI be re-calculated every 5 years to assess human use in the near shore.

- Regional and local environmental properties were shown to vary markedly among years. August of 2004 was perhaps unusual with low Fraser River runoffs, and higher salinities at Active Pass, and it also experienced significantly higher precipitations than the 30 year median. These environmental conditions translated into higher nitrate concentrations, cooler waters and higher salinities at eelgrass meadows in August 2004. Conditions observed in August of 2005 and 2006 were near longer-term observations. Regional environmental data should be analyzed annually to monitor the status of the nearshore Strait of Georgia ocean environment. This is very low cost and easy to do.

- The vast majority of eelgrass meadows in the GINPRC were found to lack intertidal components. It is not known if the eelgrass beds have always lacked an intertidal zone, but speculative evidence from the San Juan Islands indicates that the meadows may have lost their intertidal components in 2002 and 2003 due to unprecedented sediment loading from the Fraser River. This lack of intertidal component may also indicate that eelgrass meadows at one time experienced severe environmental conditions (e.g., heat stress) above the low tide mark. Available air photos shot at low tide or other sources of information pre-2000 should be examined for evidence of intertidal eelgrass in the SGI and San Juan Islands.

- Subtidal video surveys revealed that the SGI meadows are 1) thin and patchy, 2) have a moderate to high epiphyte load, and 3) occur over a wide depth range (1.3-5.6 m). The first two conditions are indicative of poor health (Deegan et al. (2002); Duffy 2006). No incidences of wasting disease were recorded (possibly because of the high epiphyte loading obscures the blades). It is recommended that subtidal assessments using underwater video be continued. The method provides an objective record of the state of eelgrass meadows and of their characteristics, offers a permanent record of the eelgrass meadows for future assessments of ecological integrity (EI), and allows for ground-truthing of aerial surveys. These surveys should continue.

- Subtidal video surveys reveal that some eelgrass beds also experience high macroalgal loadings. It might be worth considering removing algal biomass as an attempt to allow eelgrass to obtain enough light to grow. This kind of gardening has occurred, with some success, in Puget Sound.

- A recent graduate student thesis supported by the WNSC and SGINPRC conducted some mapping of eelgrass at Tumbo/Cabbage and Sidney Spit. A key result was that boaters frequently anchored within eelgrass beds in the summer of 2005. It is recommended that the park work towards shifting this anchoring activity away from the eelgrass. This is particularly important for Sidney Spit because of the size of this meadow and it being one of the few eelgrass meadows with an intertidal component left in the SGI. An educational approach similar to that of the Jefferson County Marine Resources Committee should be adopted for the 2007 summer boating season. In addition, the GINPRC should support, where possible, local community mapping initiatives to document distribution and change in eelgrass meadows in and around Park boundaries.

- There were clear interannual differences in environmental conditions in the SGI, but this was not reflected in components of the fish assemblage (similarity, dominance or relatedness). In addition, it appears that spatial differences are more important than temporal differences. At this time, it is not clear as to what seascape factors are responsible for these differences. We speculate that the mosaic of habitats adjacent to a seagrass meadow is fundamental to the structure of a given fish assemblage. Further research is required.
- The absence of young-of-the year rockfishes (coppers and black/yellowtail), kelp greenlings and lingcod is a concern. Recreational fishers target adults of these species. It is not however known what factors are responsible for the absence of juveniles (e.g., environmental, habitat quality, lack of adults). Experiments with artificial seagrass habitats may shed light onto some of the contending issues.
- The WNSC should continue to analyze eelgrass-environmental-fish data collected in 2004-2006, and evaluate the application of a multi metric fish index to understand eelgrass health in the Pacific bioregion.

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