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Biodiversity Stability of Shallow Marine Benthos in Strait of Georgia, British Columbia, Canada Through Climate Regimes, Overfishing and Ocean Acidification

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1. Introduction

The highest human population density in British Columbia, Canada is situated around the shores of the Strait of Georgia, where current government policy is focusing early efforts toward achieving ecosystem-based management of marine resources. Climate regime shifts are acknowledged to have affected commercial fishery production in southern British Columbia (McFarlane et al., 2000), and overfishing is well documented in the Strait of Georgia region for a variety of important species, to the extent that Rockfish Conservation Areas have been created (Marliave & Challenger, 2009). As CO_2 levels rise in the atmosphere, the oceans become progressively more acidic. While ocean acidification is predicted to be a great threat to marine ecosystems, little is known about its ecosystem impacts. Few taxpayer-funded studies have committed to long-term monitoring of full ecosystem biodiversity. This document presents results of over forty years of private taxonomic monitoring of shallow seafloors in the region centering on the Strait of Georgia. Also presented are records of ambient ocean acidity levels (pH), documented continuously by the Vancouver Aquarium through the same time period. Biodiversity data are summarized in ways that enable visualization of possible relationships to climate regimes and ocean acidification. This work does not attempt statistical analyses, in the hope that the data trends can be incorporated into future models.

Biodiversity survey data can reveal fundamental differences in community function, as with the disparate trophic complexity and rockfish nursery capacity of glass sponge gardens versus reefs (Marliave et al., 2009). Trophic cascades can be elucidated when coupling biodiversity surveys with transect abundance surveys (Frid & Marliave, 2010). It has been suggested that biodiversity provides more accurate definition of climate regime shifts than does physical oceanographic data (Hare & Mantua, 2000) and the abundance, survival and spawning distribution of commercial fish species have been linked to decadal-scale changes in ocean and climate conditions (McFarlane et al., 2000).

Ocean acidification can detrimentally impact anti-predator behaviors of fish (Dix et al., 2010). Ocean acidification is most intensive in the geographic area of the NE Pacific Ocean centering on the present area of study, surrounding the Strait of Georgia (Byrne et al., 2010). Ecosystem impacts of ocean acidification trends have not, however, been segregated from climate impacts such as El Niño winters or climate regime shifts. Indeed, it is difficult to segregate shorter term El Niño and La Niña years from climate regimes (Hare & Mantua, 2000), but there is consensus that the regime shift of 1976/1977 was major, followed by a prominent shift in 2000/2001 (Tsonis et al., 2007). McFarlane et al. (2000) provide evidence of another possible regime shift in 1989.

This data presentation summarizes results of 44 years of biodiversity monitoring in the Strait of Georgia region of southern British Columbia, in comparison with monitoring results for surrounding inland sea and outer coast regions at the same latitude and to the immediate north and south (Figure 1). The data treatment accommodates a continual increase in the knowledge base for identification of benthic nearshore marine life. A principal focus of this analysis is the possible climate shifts that have been proposed as regimes for the NE Pacific Ocean. The contention that biodiversity can serve to define climate regime shifts is implicitly tested in this study for the shallow seabeds of coastal NE Pacific regions. As well, perhaps the first long-term documentation of ocean acidification in this region is presented to permit comparison with any possible trends in biodiversity.

2. Methods

Biodiversity monitoring with SCUBA diving centered in the Strait of Georgia region has been conducted by Pacific Marine Life Surveys, Inc. (PMLS) from 1967 to the present, with over 4,500 dives entered into a database from which different data summaries can be extracted. Programming details are explained below for this PMLS database. A total of 1,185 taxa have been documented, but analyses of different climate regime periods are limited to the 328 more prominent species that were identified during the first regime period of 1967-1977.

The area covered by PMLS surveys is depicted in Figure 1. The Strait of Georgia is central to this region, with two other inland seas, Puget Sound and Johnstone Strait, to the south and north. Offshore of the Strait of Georgia is the west coast of Vancouver Island, with northern British Columbia and Alaska to the north, and the outer coast of Washington to the south.

This monitoring by PMLS was not derived from a traditional research program involving designated and pre-determined sampling sites visited at regular intervals. All species documented were observed underwater, during the actual dive profiles. The results are derived from a long-term monitoring effort involving sites selected for their accessibility and convenience for the three participating divers recording data. This effort was largely based on recreational SCUBA trips and relying on shore access or boat availability (charter or private).

An important confounding factor has been the increase over time of published taxonomic identifications, as well as the successive publication of increasingly useful taxonomic keys and identification guidebooks. Figure 2 shows the species accumulation at one dive site in the first five dives of each climate regime period. A wide field of specialist taxon experts gradually associated with PMLS as well, so that the PMLS team continuously increased the species list. Early focus was on fishes and larger crustacean, mollusc and echinoderm invertebrates. Sponges in particular required time to develop expertise with, and various species remain unidentified. It should also be noted that seaweeds were not a focus for identifications during the first 15 years of the survey. For these reasons, comparative

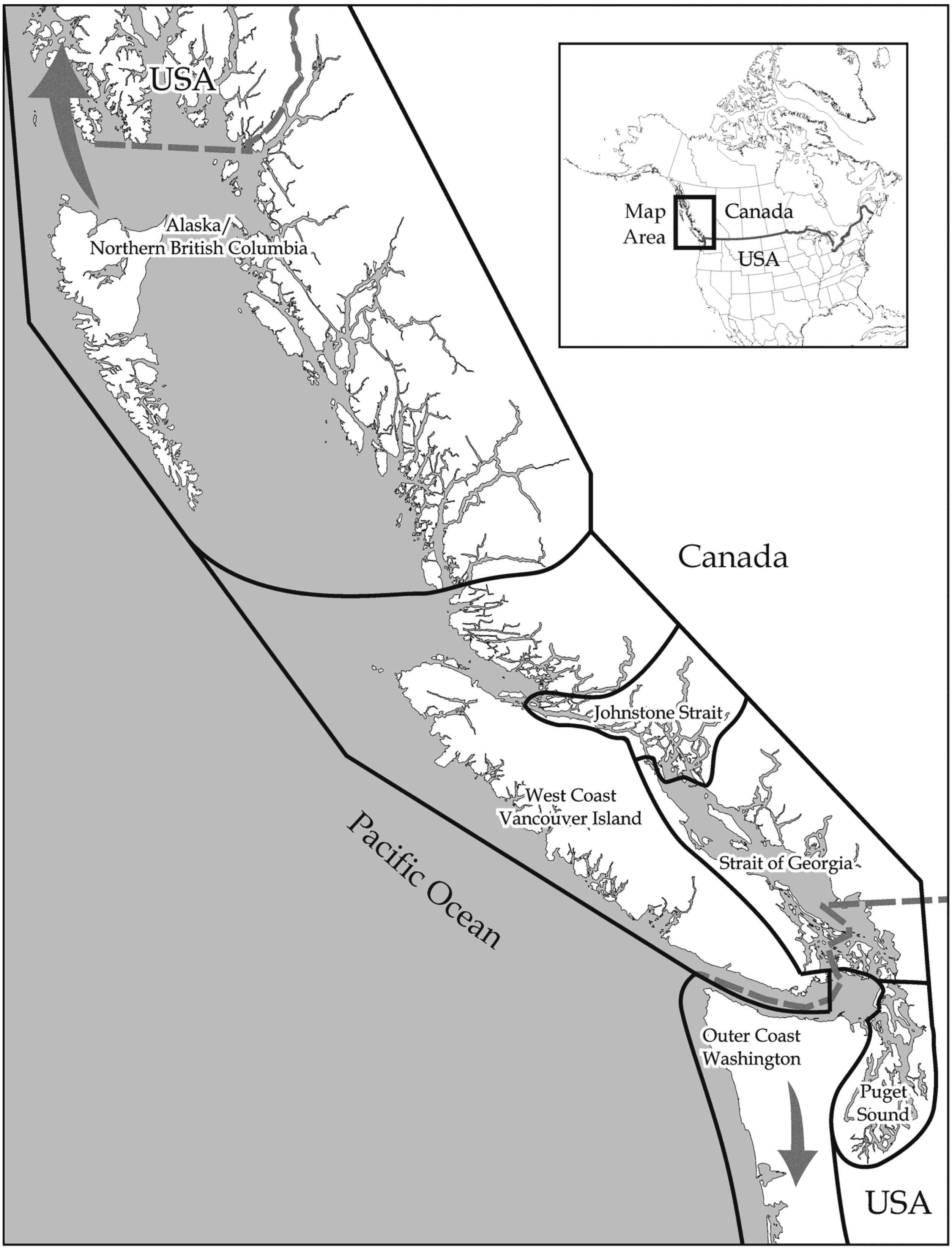


Fig. 1. Map of the coast of the eastern North Pacific Ocean, centering on the Strait of Georgia, British Columbia, with the six regions for which taxonomic data collations were organized for shallow marine benthos species.

analysis of different time periods (i.e. climate regimes) must be limited to the earliest species list of 328 species.

Another variable is the number of dives in a given region. It typically takes about 6-10 dives for the taxon list at a site to start to plateau, but that is assuming comparable depth profiles and time of day (Figure 2). The site with the greatest number of dives, Whytecliff Park, in West Vancouver, BC, involved the entire duration of the survey, considerable deep diving and many night dives as well, all factors that need to be assessed with the results, as the taxon list has not reached a plateau at that site. To demonstrate this asymptotic level of diversity for a site, dives were arranged in descending order of number of species identified on a dive, then the total cumulative species number for that site graphed next to the number of species for that dive (Figure 3). Some dives were oriented to other tasks so that only unusual species were recorded.

Lookout Point is adjacent to Whytecliff, but Lookout primarily involved shallow daytime dives, so reached a biodiversity plateau in a more typical number of dives than for Whytecliff, which received the highest number of dives and achieved the highest biodiversity list.

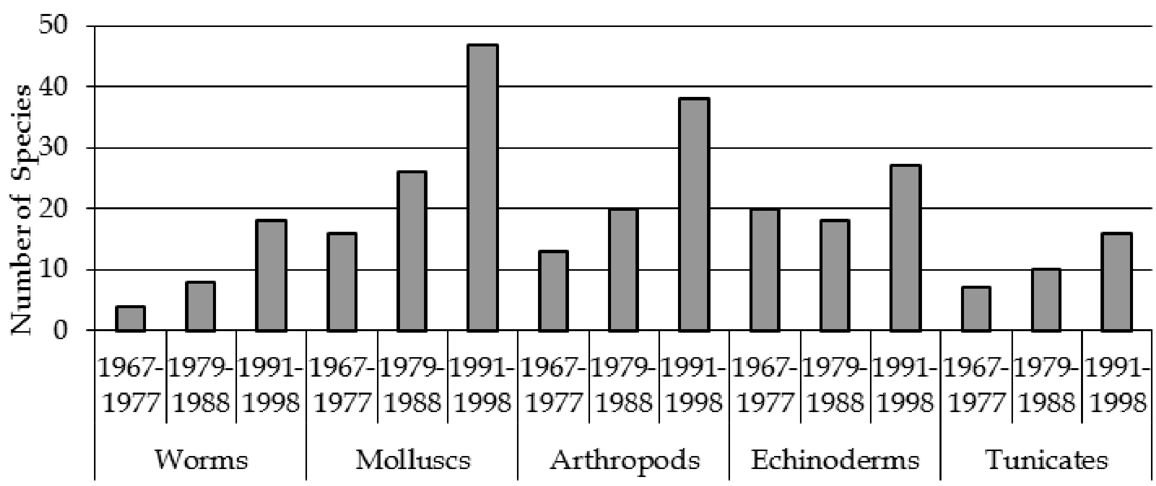


Fig. 2. Species were successively accumulated in these higher taxa at one dive site, Whytecliff (near Vancouver, in the Strait of Georgia), in the top five spp.-count dives of each climate regime period, illustrating artefacts from continually increasing taxonomic expertise. This graph is based on the ultimate total list of 1,185 species, versus the 382 for 1967-1977.

In recording relative abundance, a quotient is used. For each species recorded on each dive, the quotient is developed as follows: 0 = none sighted; 1 = few sighted (<10); 2 = some sighted (<25); 3 = many sighted (<50); 4 = very many sighted (<100); 5 = abundant sighted (<1,000); 6 = very abundant sighted (thousands). For each species, the values for all dives are averaged and then scaled so that the tabulated relative abundance rating is a number from 0 to 100 rather than 0 to 6. Species abundance ratings are calculated by averaging abundance scores for all dives, then dividing by 6 (highest score) and multiplying by 100.

All reports are driven directly from dive log data, which are stored as a set of CSV files, one per dive. Each log contains general information such as date, time, location, depth, diver name, and overall comments. In addition, an entry is made for each species observed on the dive; each entry consists of at least the species name, and may also include abundance estimates or comments (e.g. age or behaviour of specimens). Although this structure may

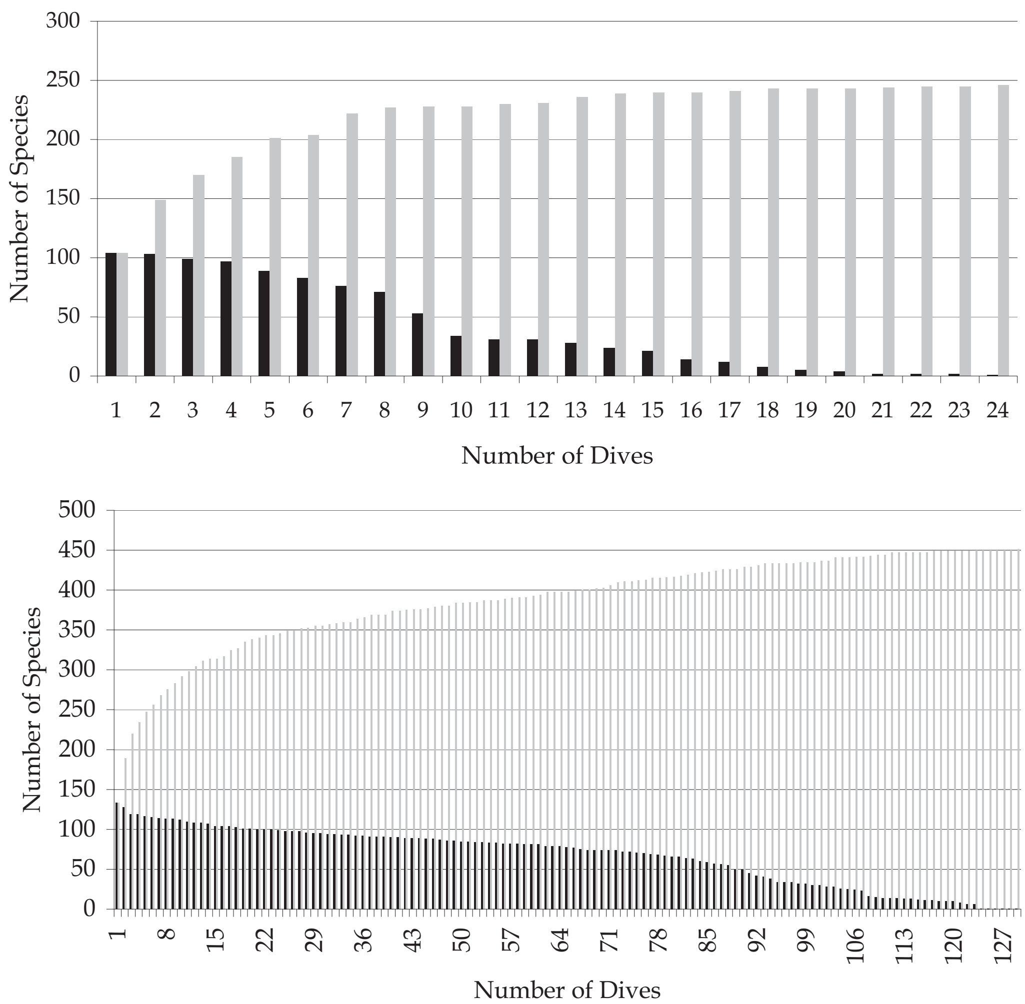


Fig. 3. Addition of cumulative species to site species lists through continued diving. Results are ordered according to number of species recorded, with cumulative total depicted in gray bars adjacent to bars for total species per dive. Note that only shallow (<20m) day dives were conducted at Lookout Point (above), within 0.5 km of Whytecliff (below), where day, night, shallow and deep (<40m) dives took place over the full time period of these surveys.

seem primitive in comparison with relational databases, it has the advantage of simplicity. Individual dive logs can be examined (and, if necessary, damaged portions repaired) with simple tools such as text editors and standard command-line utilities. Any updates to the dive logs will be reflected immediately in subsequent reports. The structure also makes it easy to write custom programs to analyze the data and generate results in any desired form. A species list table file provides detailed general information for each species (e.g. author and date). Another table file, keyed by location name, allows locations to be grouped into regions.

The search program is run once per region. All species' data are written to an intermediate file; each species is looked up in the species list, and its corresponding phylum is appended. The order of listing species is according to phylogenetic relationships within a phylum. The merge program counts all species by phylum to generate the final result. Note: all seaweed and flowering plant divisions (phyla) are grouped together for most compilations.

Seawater acidity was measured at the Vancouver Aquarium by colorimetric (titration) methods from 1954-1979, by adding a selective reagent to a sample of water so that a color was produced, the intensity of which was proportional to the concentration of Hydronium ions (H+) in the water, then matched to calibrated color standards. From 1954-1967, Winkler titration methods were employed on weekly grab samples taken by the veterinary department. Starting in 1967, the engineering department's seawater monitoring included pH determinations using colorimetric methods for the swimming pool industry. These methods employed a selective reagent and comparison to calibrated color standards. From 1980-1994, portable conventional pH electrodes were used, which allowed temperature compensation. From 1994-2009, portable field instruments with platinum free-diffusion junctions provided faster and more stable readings. A limitation to portable pH probes was that with time, the junction would become clogged with silver chloride or contaminants, causing large variation in the reference potential; clogged or fouled junctions could cause drift along with inaccurate, noisy, erratic and sluggish pH measurements. Some adjustments to data records during this period, for outlier data points related to fouled probes, was required in preparing data presentations. Therefore, annual minimum and maximum pH levels were tabulated for graphing only when at least five measures at that level were recorded on different dates in a year. Starting in 2010 professional lab bench instrumentation was introduced, with a free-flowing liquid-to-liquid junction that provides stable, drift-free measures from an easily cleaned junction that never clogs (a double junction design). Results are reported here for the period of the biodiversity survey for data from 1968-2010.

3. Results

From 1967 to 2010, when shallow dives <20m are undertaken in daylight, the biodiversity list for a site reached an asymptotic cumulative species number within 7-9 dives (Figure 2), whereas a higher overall biodiversity listing is obtained within 9-25 dives if a larger set of dives at both shallow and deep (<40m) depths was conducted during both daylight and night, as at Whytecliff Park. Different benthic habitat types at different locations had divergent biodiversities. It was necessary to restrict temporal analysis of trends for climate regimes to the species list that was generated during the earliest climate regime of 1967-1976, with a total of 328 species (versus 1,185 for the most recent period).

The species occurring at high relative abundance (rating of 6 or more in at least one region) for the overall study region are listed for different major regions in Table 1, based on the original 328 species identified during the earliest climate regime (1967-1976). Puget Sound had the greatest absence of species (26 species), and both Puget Sound and Johnstone Strait had the highest numbers of species (23 and 22, respectively) occurring at trace abundance. The only species absent from the Strait of Georgia was *Astraea gibberosa*, an exposed coast snail particularly associated with the kelp *Macrocystis integrifolia*.

In contrast to the Strait of Georgia, Puget Sound was lacking 23 species that occurred in all other regions. Puget Sound is a broad fjord with much less hard substrate compared to other regions in this study. In addition, it possesses few high current passages. These two factors combine to provide less habitat for organisms requiring rock and tidal current. Some of these missing species include the zoanthid *Epizoanthis scotinus* that occurs abundantly elsewhere and the hydroid *Garveia annulata* that also occurs abundantly everywhere else (least so in Strait of Georgia). Similarly, the chiton *Katharina tunicata* is absent from Puget Sound and only at trace abundance in Strait of Georgia, but this species is at high abundance in nearby Johnstone Strait, and also occurs at comparably high levels in outer coastal areas.

The red urchin *Strongylocentrotus franciscanus* is very abundant everywhere except Puget Sound, where it occurs at trace levels.

The Strait of Georgia and Alaska/north BC had the lowest numbers of species occurring at the highest levels of abundance. Although Puget Sound had the lowest biodiversity, it was the only region with high abundance of the anemone *Anthopleura artemesia*, a species that attaches to rock surrounded by sand or shell hash. The rockfish *Sebastes auriculatus* is very common in Puget Sound but usually rare in southern Strait of Georgia, where it is known for only a few areas. Similarly, the sculpin *Artedius fenestralis* is only abundant in Puget Sound. The sculpin *Chitonotus pugetensis* is primarily nocturnal, so its recorded abundance is affected by access to night diving, which took place mostly in Howe Sound (Strait of Georgia) and Puget Sound. The sole *Pleuronichthys coenosus* was also at high abundance in Puget Sound. Embiotocid perches were notably more abundant in Puget Sound (especially *Rhacochilus vacca* and *Embiotoca lateralis*) and only in trace numbers in Alaska/north BC. The northern range limits for NE Pacific embiotocid perches are in northern BC and southeastern Alaska. Strait of Georgia is closest to Puget Sound in overall embiotocid abundance. The sculpin *Enophrys bison* is much more abundant in Puget Sound and the outer coast of Washington than elsewhere and only occurs at trace abundance in Alaska and northern BC. Puget Sound differs considerably in biodiversity from the Strait of Georgia, as does Johnstone Strait at the northern end of the Strait of Georgia.

Some species like the anemone *Metridium farcimen*, the tubeworm *Serpula columbiana*, the shrimp *Pandalus danae*, the sea star *Pycnopodia helianthoides*, the sea cucumber *Parastichopus californianus*, the tunicate *Boltenia villosa* and the greenling *Hexagrammos decagrammus* are abundant in all the regions monitored in this project (Table 1). Most of the common species tend to be more abundant in one or more regions than in others. The only species uniformly occurring at limited abundance levels in all regions are several nudibranchs (*Doris montereyensis*, *Diaulula sandiegensis* and *Flabellina triophina*), the octopus *Enteroctopus dofleini*, the sea star *Pteraster tesselatus* and the tunicate *Aplidium solidum*.

A north to south trend can be detected from species absence where the outer coast of Washington and Puget Sound are both lacking species that occur everywhere else, including in the Strait of Georgia. These species more abundant in the north include the soft coral *Gersemia rubiformis* (prefers high current), the hydrocoral *Stylaster norvigicus*, the hydroid *Ectopleura marina*, the bryozoan *Phidolopora pacifica,* the sea anemone *Urticina lofotensis*, the snail *Astraea gibberosa*, the nudibranch *Tochuina tetraquerta*, the sea star *Stylasterias forreri*, the basket star *Gorgonocephalus eucnemis*, the feather star *Florometra serratissima* and the rockfish *Sebastes nebulosus*. As mentioned, the sculpin *Enphrys bison* is a southern species, as is the gunnel *Apodichthys flavidus*. The tunicate *Styela montereyensis* (a species ranging S to Mexico), is abundant on all outer coasts, but at trace levels in all inland seas.

Some abundant species peak at extremely high abundance in one area or another. The shrimp *Pandalus danae* is abundant everywhere, as mentioned, but considerably higher in abundance in Puget Sound than anywhere else. Other species are extremely abundant in only one region, absent in one other region, and moderately abundant elsewhere, as for the anemone *Cribrinopsis fernaldi*, very abundant in Johnstone Strait, absent in Puget Sound, and frequent in other regions. *Gersemia rubiformis* is extremely abundant in Johnstone Strait, at a trace in Strait of Georgia, absent from Puget Sound, and moderately abundant in outer coastal regions. Another cnidarian, *Garveia annulata,* is also abundant in Johnstone Strait and absent from Puget Sound

	ALNC	WCVI	OCW	JSTR	SoG	PS
Green algae (Chlorophyta)						
Ulva intestinalis	1	*	3	1	2	8
Ulva spp. / *Ulva lactuca*	8	7	19	8	13	25
Codium setchellii	5	6	3	20	2	-
Brown algae (Ochrophyta)						
Pterygophora californica	6	14	17	16	4	3
Red algae (Rhodophyta)						
Misc. branching red seaweeds	3	8	11	11	5	7
Sponges (Porifera)						
Rhabdocalyptus dawsoni	1	*	-	1	7	-
Aphrocallistes vastus	2	*	-	2	6	-
Cliona californiana	14	18	12	17	16	2
Myxilla lacunosa	2	9	4	18	2	*
Ophlitaspongia pennata	7	10	6	13	12	1
Misc. demo sponges	7	6	6	6	4	2
(Cnidaria)						
Metridium senile	9	23	20	27	9	28
Metridium farcimen	24	18	18	15	23	15
Cribrinopsis fernaldi	8	6	5	27	8	-
Urticina crassicornis	9	11	27	26	9	17
Urticina lofotensis	15	16	1	1	*	*
Urticina piscivora	11	14	6	*	*	-
Stomphia didemon	1	2	*	*	8	7
Anthopleura artemisia	1	1	*	*	*	7
Epiactis prolifera	*	6	7	19	1	4
Pachycerianthus fimbriatus	11	14	*	3	17	3
Epizoanthus scotinus	8	15	10	22	9	-
Gersemia rubiformis	14	13	2	29	*	-
Ptilosarcus gurneyi	8	11	2	1	10	11
Stylantheca spp.	8	6	9	21	6	*
Stylaster norvigicus	2	1	2	21	*	-
Aglaophenia spp.	4	7	8	11	3	1
Abietinaria spp.	12	14	19	21	11	3
Plumularia setacea	11	12	4	19	3	1
Obelia spp.	9	6	5	7	6	2
Garveia annulata	15	10	9	23	3	-
Ectopleura marina	4	6	2	20	4	*
Tubularia indivisa	2	*	*	9	*	-

	ALNC	WCVI	OCW	JSTR	SoG	PS
Segmented worms (Annelida)						
Protula pacifica	5	6	1	5	6	*
Serpula columbiana /vermicularis	31	29	21	30	18	26
Pileolaria spp. (spirorbids)	2	4	5	6	2	*
Dodecaceria fewkesi	6	21	12	30	11	2
Eudistylia vancouveri	4	11	6	8	2	19
Schizobranchia insignis	2	1	1	2	1	9
Bispira sp. (*Sabella crassicornis*)	7	5	7	4	3	9
Spiochaeopterus costarum	2	4	2	*	4	11
Bryozoans (Bryozoa)						
Membranipora serrilamella	14	9	18	11	8	5
Schizoporella unicornis	2	5	9	5	8	9
Bugula californica	5	7	6	*	2	3
Crisia spp.	5	11	11	14	7	1
Phidolopora pacifica	5	11	3	*	2	-
Heteropora pacifica	15	14	18	7	6	-
Diaperoecia californica	15	15	14	1	7	-
Hippodiplosia insculpta	7	7	4	*	1	*
Brachiopods (Brachiopoda)						
Terebratalia transversa	6	5	15	17	8	3
Molluscs (Mollusca)						
Tonicella lineata	16	21	20	31	15	3
Mopalia spp.	1	7	13	16	7	13
Katharina tunicata	1	3	9	8	*	-
Cryptochiton stelleri	12	13	20	24	7	2
Mytilus trossulus	8	3	3	3	8	15
Chlamys spp.	6	11	16	16	10	10
Crassadoma gigantea	12	22	13	21	10	3
Pododesmus macrochisma	8	6	10	7	13	17
Clinocardium nuttalli	2	1	2	*	1	6
Panopea abrupta	4	3	4	-	1	7
Entodesma navicula	2	5	6	13	3	*
Acmaea mitra	15	15	19	20	5	*
Diodora aspera	11	14	11	23	4	1
Haliotis kamtschatkana	6	11	6	9	1	-
Nucella lamellosa	3	4	12	6	9	10
Ceratostoma foliatum	11	17	15	12	11	2
Calliostoma ligatum	21	24	22	25	9	3
Calliostoma annulatum	8	6	5	*	1	-
Astraea gibberosa	9	13	*	*	-	-
Euspira lewisii	2	4	3	*	2	11
Fusitriton oregonensis	9	8	16	10	2	2
Peltodoris nobilis	4	12	5	3	6	4

	ALNC	WCVI	OCW	JSTR	SoG	PS
Molluscs, continued						
Doris montereyensis	2	6	5	3	4	8
Diaulula sandiegensis	2	6	5	8	3	6
Cadlina luteomarginata	5	8	6	5	12	1
Triopha catalinae	5	5	8	8	1	3
Tochuina tetraquetra	2	6	*	10	*	-
Dirona albolineata	4	7	11	*	6	11
Hermissenda crassicornis	18	14	6	9	5	6
Flabellina triophina	5	3	1	6	5	3
Enteroctopus dofleini	5	5	6	3	3	8
Arthropods (Arthropoda)						
Caprella spp.	6	2	1	2	1	1
Pandalus danae	10	10	19	14	16	28
Cancer oregonensis	3	7	16	14	5	6
Cancer productus	3	6	10	4	8	22
Cancer magister	1	1	2	*	4	14
Telmessus cheiragonus	*	*	6	*	*	1
Pugettia producta	*	2	5	*	2	19
Pugettia gracilis	4	6	9	13	2	6
Scyra acutifrons	4	17	16	15	8	19
Oregonia gracilis	8	6	12	5	6	8
Phyllolithodes papillosus	2	3	8	3	1	-
Lopholithodes mandtii	5	7	3	7	2	-
Pagurus beringanus	8	10	17	21	10	17
Elassochirus gilli	6	1	3	4	1	-
Pagurus armatus	2	1	3	*	3	17
Balanus glandula	6	6	8	2	17	29
Balanus nubilus	16	23	29	30	15	13
Echinoderms (Echinodermata)						
Pisaster ochraceus	8	9	4	1	14	10
Pisaster brevispinus	4	7	1	1	14	9
Evasterias troschelii	10	11	15	10	15	23
Orthasterias koehleri	17	20	10	9	14	*
Stylasterias forreri	7	8	*	1	3	-
Dermasterias imbricata	11	19	10	9	17	8
Asterina miniata	1	6	*	-	*	-
Mediaster aequalis	7	13	3	5	12	7
Pteraster tesselatus	4	6	3	3	9	3
Henricia leviuscula	10	5	4	4	4	*
Henricia aspera	1	13	15	18	11	12
Leptasterias spp. complex	1	3	8	*	*	-
Pycnopodia helianthoides	24	20	22	15	26	26

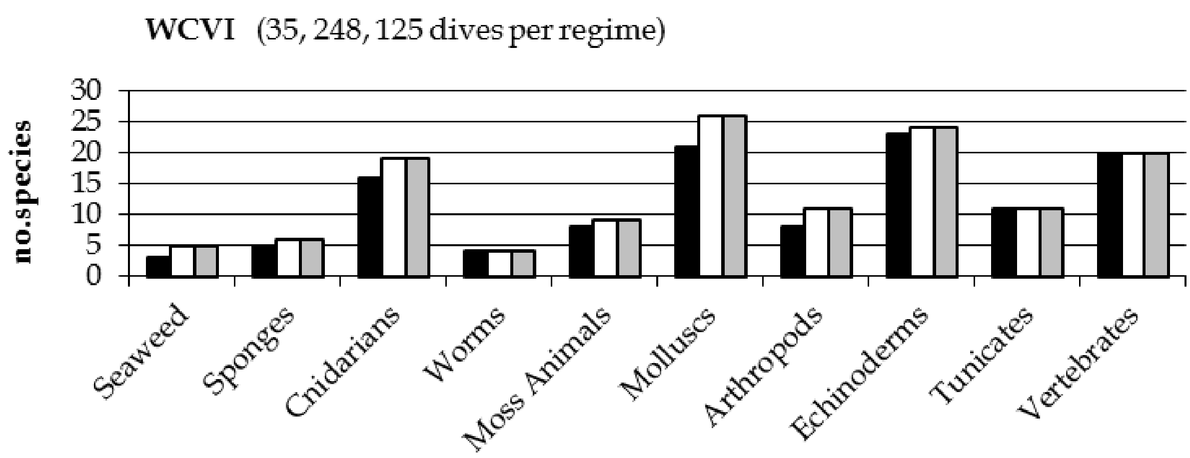
	ALNC	WCVI	OCW	JSTR	SoG	PS
Echinoderms, continued						
Crossaster papposus	7	6	*	2	7	5
Solaster dawsoni	8	9	7	10	11	9
Solaster stimpsoni	5	13	15	15	8	14
Ophiopholis aculeate	24	14	9	22	10	*
Ophiura lutkeni	6	1	-	-	11	*
Gorgonocephalus eucnemis	3	5	1	21	1	-
Florometra serratissima	*	1	*	1	11	-
Strongylocentrotus franciscanus	25	25	15	32	18	*
Strongylocentrotus droebachiensis	8	8	17	26	17	7
Parastichopus californicus	16	23	18	14	24	21
Cucumaria miniata	13	21	20	9	12	7
Eupentacta quinquesemita	8	16	15	16	9	11
Psolus chitonoides	12	18	18	26	14	3
Tunicates (Urochordata)						
Corella willmeriana	8	8	2	5	14	5
Ascidia paratropa	5	6	3	4	5	1
Cnemidocarpa finmarkiensis	9	15	10	6	14	*
Halocynthia aurantium	8	4	*	6	8	*
Halocynthia igaboja	9	13	4	20	9	*
Pyura haustor	8	12	14	8	8	13
Styela montereyensis	4	10	5	*	*	*
Boltenia villosa	11	12	11	8	13	13
Chelyosoma productum	8	8	8	*	5	3
Metandrocarpa taylori	17	13	21	12	8	*
Distaplia occidentalis	14	16	8	12	4	3
Aplidium solidum	4	7	4	9	2	2
Vertebrates (Chordata)						
Aulorhynchus flavidus	1	2	10	2	4	11
Ammodytes hexapterus	1	*	8	-	*	1
Rhinogobiops nicholsii	4	18	7	4	19	12
Ronquilus jordani	6	3	*	5	5	4
Chirolophis nugator	2	2	7	3	2	4
Apodichthys flavidus	-	*	4	*	*	6
Pholis laeta	2	*	5	1	*	12
Embiotoca lateralis	*	10	17	2	16	26
Rhacochilus vacca	*	6	6	1	9	20
Cymatogaster aggregata	*	4	5	1	10	17
Brachyistius frenatus	*	3	3	*	6	7
Sebastes caurinus	9	19	18	13	24	20
Sebastes maliger	12	18	9	17	19	13
Sebastes nebulosus	12	14	2	2	*	-
Sebastes auriculatus	*	*	-	-	1	13

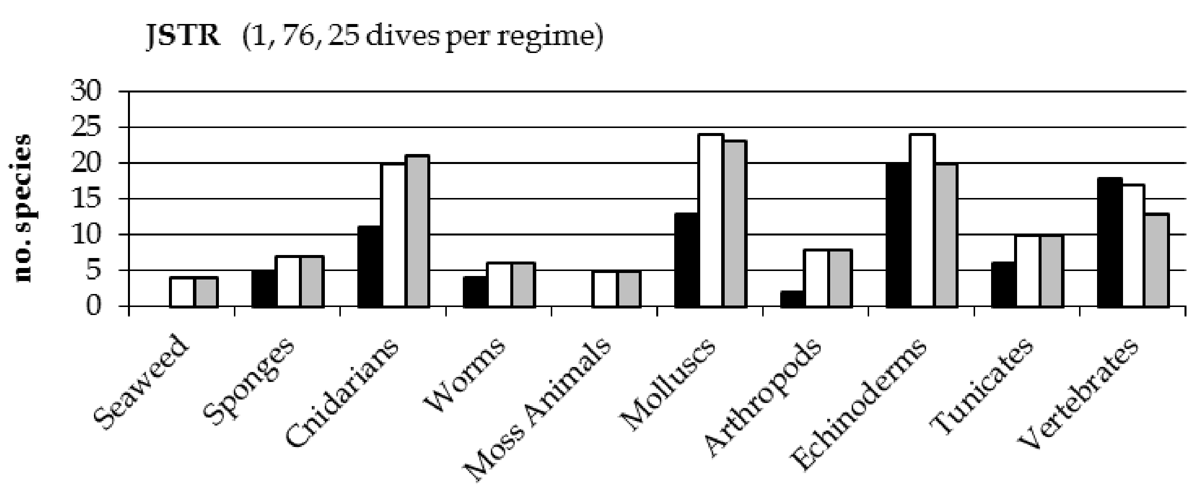
	ALNC	WCVI	OCW	JSTR	SoG	PS
Vertebrates, continued						
Sebastes melanops	19	25	14	13	2	4
Sebastes flavidus	13	22	5	20	1	*
Sebastes emphaeus	6	15	14	12	7	3
Hexagrammos decagrammus	19	26	26	28	19	10
Ophiodon elongatus	7	14	14	6	15	9
Oxylebius pictus	4	10	9	3	8	20
Artedius harringtoni	8	17	20	27	11	23
Artedius fenestralis	*	*	1	*	1	12
Jordania zonope	9	15	18	13	13	2
Scorpaenichthys marmoratus	1	3	3	4	3	15
Hemilepidotus hemilepidotus	6	7	5	15	3	13
Leptocottus armatus	*	*	*	*	1	7
Enophrys bison	*	1	11	3	2	17
Myoxocephalus polyacanthocephalus	2	*	2	1	*	7
Chitonotus pugetensis	1	*	-	*	2	8
Nautichthys oculofasciatus	1	1	1	2	2	6
Citharichthys stigmaeus	*	2	5	1	5	9
Pleuronichthys coenosus	*	*	1	-	2	10

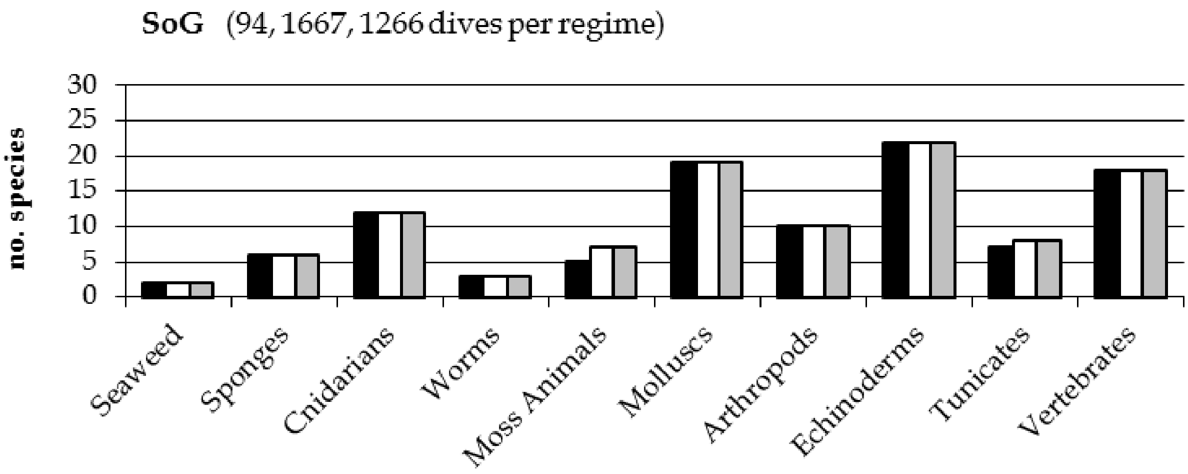
Table 1. Average abundance rating of most frequently observed species with a rating 6 or more in at least one region (asterisk = trace, dash = absent) for ALNC (Alaska and north coast British Columbia), WCVI (west coast Vancouver Island), OCW (outer coast Washington), JSTR (Johnstone Strait), SoG (Strait of Georgia) and PS (Puget Sound). See region locations on map in Figure 1. Within a higher taxon, species are listed according to phylogenetic relationships.

When biodiversity of these regions is considered for more abundant species (rating of 6 or more) in terms of two prominent climate regime shifts (1977, 2000) for the original 328 species from the first regime (Figure 4), it appears that biodiversity increased in Puget Sound and Johnstone Strait during the 1977-2000 regime, but that is likely an artefact of greater numbers of dives in that period. Biodiversity remained stable in Strait of Georgia and west coast Vancouver Island. There were too few dives in the other regions (Alaska/northern BC, outer coast Washington) to permit comparisons. It should be noted that Johnstone Strait had only a single dive in the first period. Another program run collated all species of abundance rating of 2 or more and showed the same very stable pattern of biodiversity as for the abundance rating of 6 or more depicted in Figure 4, indicating that, not considering the lowest trace abundances, species biodiversity is quite stable for animal phyla in the Strait of Georgia and nearby regions.

If climate regimes are considered to have shifted in 1977, 1989 and 2000, then it appears that biodiversity still remained relatively stable in Strait of Georgia and west coast Vancouver Island through at least the last three of four regimes (Figure 5), even when including species at all abundance levels. The biodiversity in the first regime for every area involved a lesser expertise on the part of observers as well as the lowest level of effort in every region except Puget Sound, where the fewest dives were conducted during the last regime. The single dive for the first regime period in Johnstone Strait necessarily limited the number of species recorded there. Nonetheless, the evident drop in biodiversity during the last, 2001-2010, regime, occurred in every region including Strait of Georgia, where the highest level of effort (and arguably the greatest level of expertise) was during that last regime. Thus, when all species including trace levels of occurrence are included for the list of the original 328 species (from the first regime), it appears that the regime shift of 2000 did lead to reduced biodiversity, but probably only for more rare species (considering the constant biodiversity stability for more abundant species depicted in Figure 3).







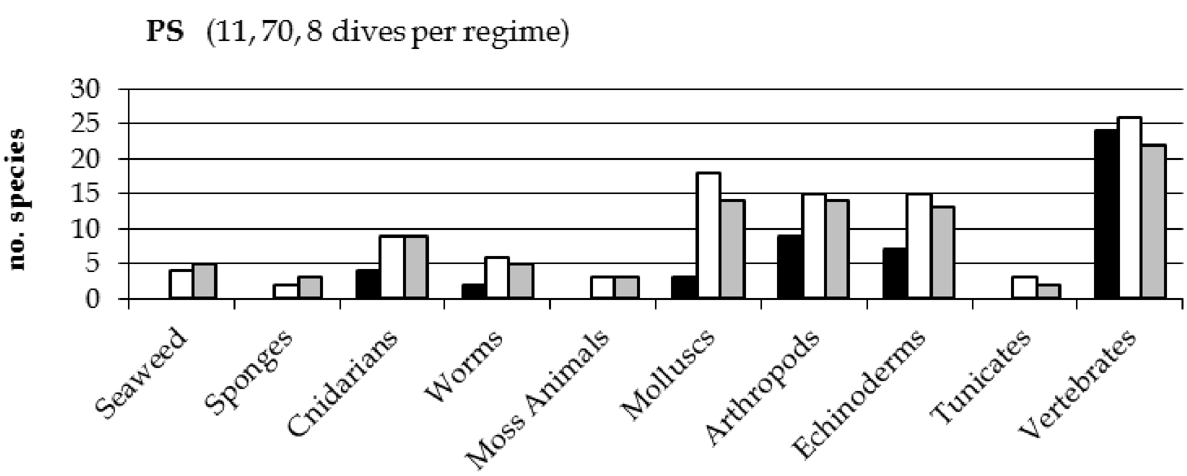
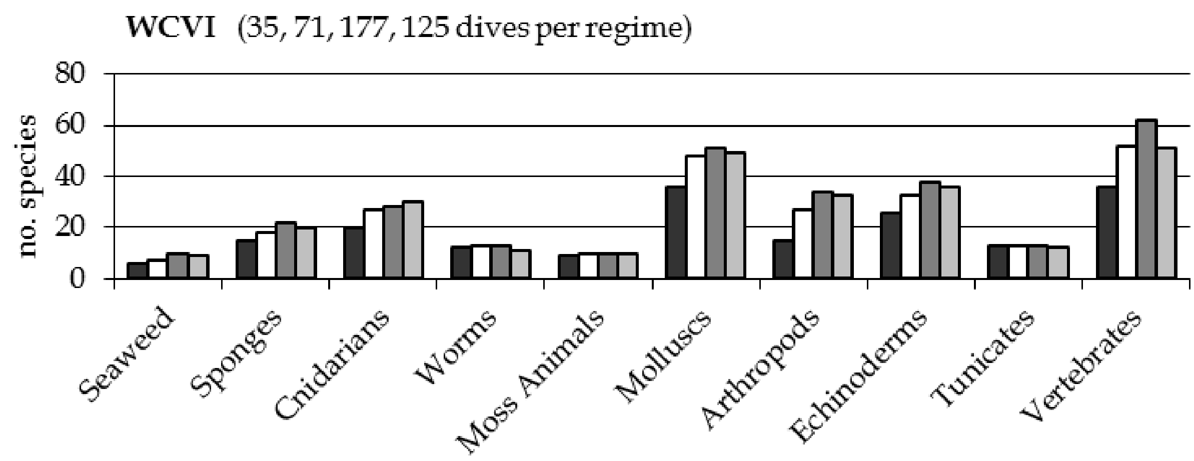
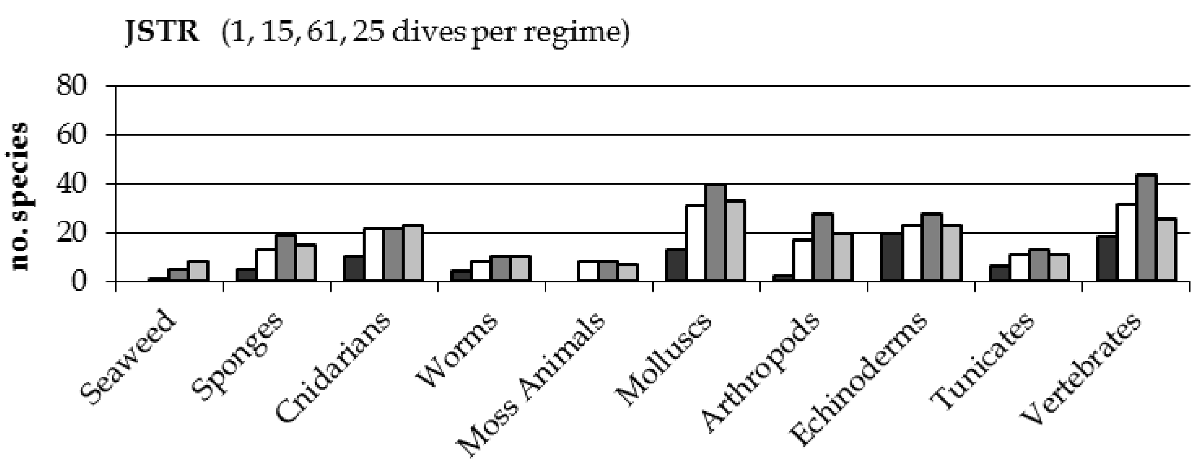
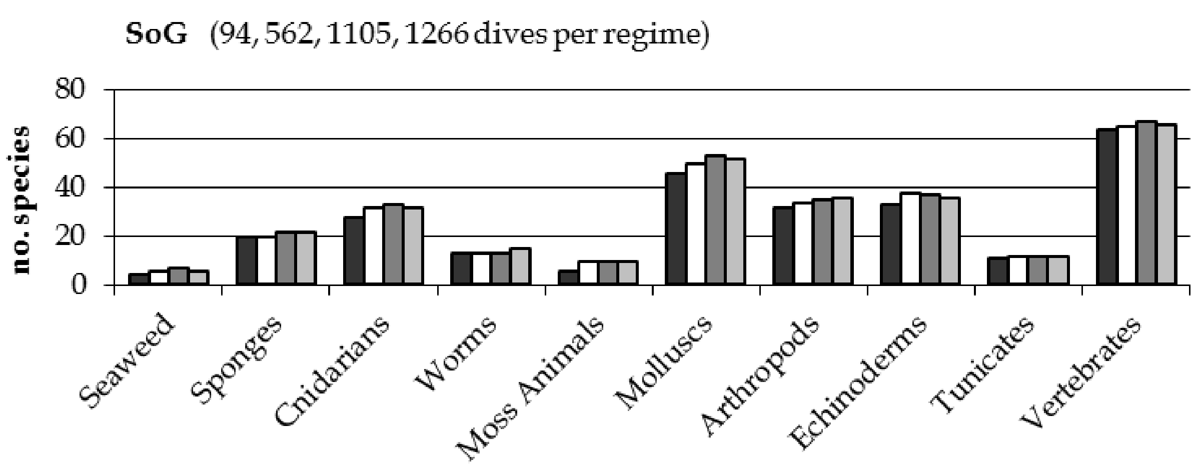


Fig. 4. Biodiversity in four Pacific coast regions according to higher taxon groupings, for three climate regimes: 1967-1976 (black bars), 1977-2000 (white bars), and 2001-2010 (gray bars). Number of species is on the vertical axis. Data are for species with relative abundance rating of 6 or more. Note that Johnstone Strait had only one dive for the first regime. WCVI = west coast Vancouver Island, JSTR = Johnstone Strait, SoG = Strait of Georgia and PS = Puget Sound.

Because seaweeds were not emphasized in the first climate regime, they ranked low diversity in that regime. Life forms with variable morphometry, like sponges and moss animals (bryozoans) were also poorly identified during the first regime, with gradual increases in diversity documented through the second, to the third regime (Figure 5, which includes all abundance ratings including trace occurrence). A less gradual increase in identification capability was evident for molluscs, for which a more marked drop in biodiversity occurred in the last, fourth regime. Similarly, although to a lesser extent, echinoderms and fishes peaked in diversity during the third regime.







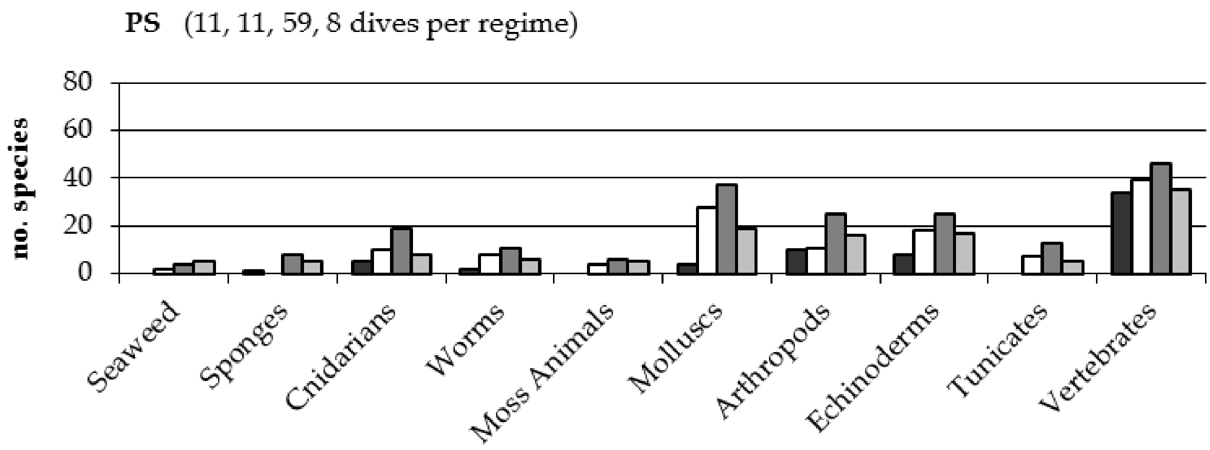


Fig. 5. Biodiversity in Pacific coast regions according to higher taxon groupings, for four climate regimes: 1967-1976, 1977-1988, 1989-2000, 2001-2010 (bars arranged left to right by time period). Numbers of dives for each period, in order, are in parentheses following each area name. Number of species is on the vertical axis. Data are for species at all relative abundance levels, including trace occurrence. WCVI = west coast Vancouver Island, JSTR = Johnstone Strait, SoG = Strait of Georgia and PS = Puget Sound.

Examining only one specific location, Whytecliff (in Strait of Georgia) for equal numbers of dives in each of four climate regimes (Figure 6) indicates that the third regime from 1989-2000 had a greater biodiversity than either the preceding or subsequent regimes. These data demonstrate that there does appear to have been a regime shift in 1989, and that biodiversity increased at this particular location during that third regime, then decreased somewhat during the fourth regime. The compilation of data for all sites in the Strait of Georgia (Figure 5) shows a slight tendency for the same trends, but not as distinctly as at a single site, probably owing to confounding effects of pooling biodiversity data from many locations

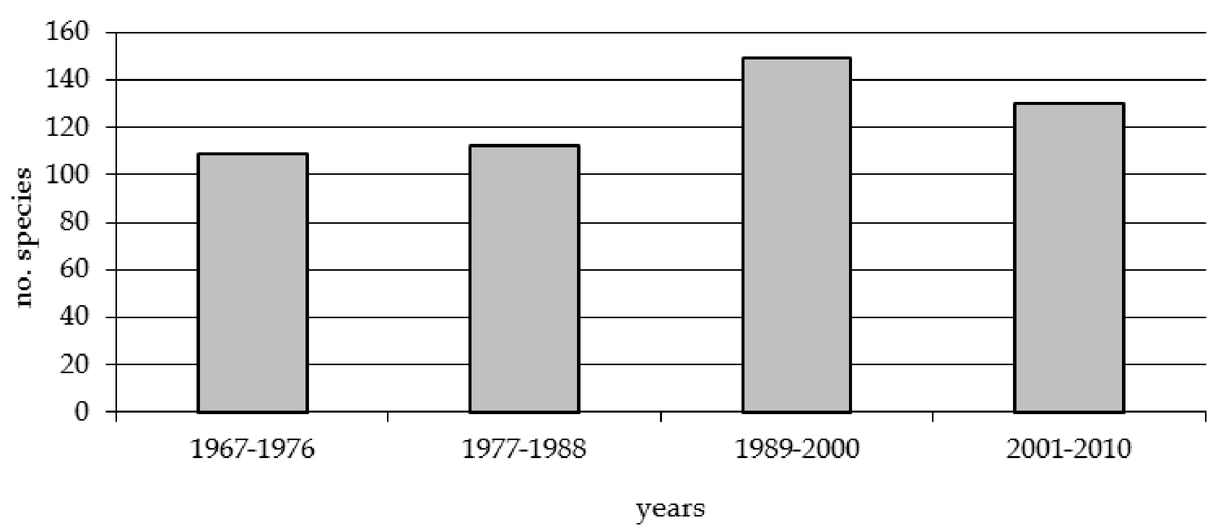


Fig. 6. Biodiversity based on the original 328 species during four regimes for just five dives (the total number for 1977-1988) at Whytecliff, in the Strait of Georgia.

	ALNC		WCVI		OCW		JSTR		SoG		PS	
	89-	01-	89-	01-	89-	01-	89-	01-	89-	01-	89-	01-
Flowering plants (Anthophyta)												
Zostera marina	-	2	4	5	8	9	*	5	8	2	22	3
Phyllospadix spp.	-	*	1	2	6	-	-	-	*	*	-	-
Green algae (Chlorophyta)												
Prasiola meridionalis	-	1	*	-	-	3	-	-	*	*	*	7
Cladophora spp.	-	2	-	1	*	-	-	-	*	*	2	1
Ulva intestinalis	-	1	1	*	4	6	-	4	3	2	9	7
Ulva spp./*U. lactuca*	4	8	8	10	21	43	6	14	16	15	29	28
Acrosiphonia coalita	-	2	-	*	-	-	-	-	*	*	-	-
Bryopsis spp./*B. corticulans*	-	*	-	-	*	4	-	-	*	*	*	-
Codium setchellii	-	5	7	8	4	-	17	36	3	2	-	-
Kornmania leptoderma	-	*	-	*	*	3	-	-	*	*	-	-
Brown algae (Ochrophyta)												
Ectocarpus complex	-	-	*	*	1	-	-	-	*	*	2	-
Fucus gardneri	-	10	5	7	3	18	-	6	12	12	3	7
Leathesia difformis	-	-	*	1	*	4	-	-	*	*	*	-
Hedophyllum sessile	-	-	*	3	1	-	1	4	*	-	-	-
Egregia menziesii	-	2	3	5	4	1	-	-	*	-	-	-
Alaria nana	-	3	*	2	*	-	-	1	*	*	-	-
Alaria marginata	-	13	1	9	6	12	-	21	1	5	*	3
Costaria costata	4	13	6	10	10	15	2	31	4	2	2	-
Cymathere triplicata	-	8	1	1	7	21	-	1	*	*	-	-
Laminaria saccharina	8	13	8	11	19	31	8	10	15	13	16	15
Laminaria setchellii	-	20	7	18	3	-	-	13	*	*	-	-
Pleurophycus gardneri	-	5	-	4	2	-	-	9	-	*	-	-
Lessoniopsis littoralis	-	5	*	4	4	-	-	-	2	-	*	-
Sargassum muticum	4	*	2	1	2	1	*	*	13	14	13	12
Desmarestia aculeata complex	-	17	3	9	6	16	1	24	1	1	2	-
Desmarestia ligulata/*D. munda*	4	19	9	18	17	9	5	29	2	2	7	13
Pterygophora californica	16	5	14	23	20	10	17	20	5	5	4	6
Eisenia arborea	-	*	3	9	-	-	-	1	*	-	-	-
Macrocystis integrifolia	8	4	3	9	4	1	-	1	-	-	-	-
Nereocystis luetkeana	12	24	18	20	29	13	22	55	10	8	11	4
Dictyota binghamiae	-	7	1	2	-	-	-	-	*	*	-	-
Agarum clathratum	-	-	-	1	-	-	-	5	-	*	-	-
Agarum fimbriatum	14	19	12	18	12	1	10	25	21	26	2	6
Red algae (Rhodophyta)												
Bangia spp.	-	-	*	-	*	-	-	-	*	*	2	-
Porphyra spp.	-	9	2	3	5	3	-	4	3	2	1	-
Endocladia muricata	-	2	*	1	-	-	-	*	*	*	-	-
Hildenbrandia spp.	4	11	17	21	4	10	7	34	10	23	*	3
Mastocarpus papillatus	-	-	-	1	-	1	-	*	*	*	*	7
Microcladia borealis	-	-	-	1	-	3	-	2	*	1	*	3
Halosaccion glandiforme	-	2	*	3	-	-	-	1	*	*	-	-
filamentous red algae	-	6	2	9	1	7	-	14	*	10	*	12
Prionitis lyallii	-	-	*	*	*	-	-	-	*	*	-	3
Clathromorphum etc.	16	49	33	55	23	13	26	54	21	23	8	15

	ALNC		WCVI		OCW		JSTR		SoG		PS	
	89-	01-	89-	01-	89-	01-	89-	01-	89-	01-	89-	01-
Melobesia / Mesophyllum	-	2	*	2	*	-	-	1	-	-	-	-
Bossiella / Calliarthron	8	29	23	43	12	6	23	35	4	1	*	-
Corallina vancouveriensis	-	4	2	3	*	-	-	6	*	*	-	-
Bossiella spp., *Calliarthron* spp.	-	15	7	15	1	3	-	20	*	*	-	-
Palmaria sp.	-	-	-	*	-	-	-	2	-	2	-	3
Ceramium pacificum	-	-	*	2	-	3	-	-	*	*	*	-
Callophyllis spp.	-	11	2	10	5	16	-	17	3	8	2	10
Chondracanthus exasperatus	-	1	2	7	5	19	1	*	4	6	11	24
Mazzaella splendens	4	*	2	4	7	7	3	1	3	2	1	10
Cryptopleura spp.	-	5	-	6	-	17	-	5	*	6	*	6
Hymenena spp.	-	2	-	*	-	-	-	*	*	1	-	3
Erythrophyllum delesseroides	-	2	*	1	-	-	-	1	*	*	-	-
Gracilaria/Gracilariopsis	-	-	*	*	-	3	-	1	*	1	-	-
Odonthalia floccosa	-	1	-	*	-	-	-	2	*	*	-	-
Odonthalia washingtoniensis	-	1	-	*	*	3	-	-	*	-	-	-
Laurencia spectabilis	-	1	-	1	*	7	-	-	*	*	*	3
Sarcodiotheca gaudichaudii	-	-	1	2	4	19	1	1	2	2	8	19
Rhodymenia californica	-	*	-	2	-	-	-	2	*	*	-	-
Schizymenia pacifica	-	-	-	1	-	-	-	4	-	1	-	-
Smithora naiadum	-	1	1	1	5	-	-	-	*	*	2	3
Polyneura latissima	-	1	-	*	-	4	-	-	*	*	*	-
Sparlingia pertusa	-	3	1	1	1	6	*	3	3	1	3	3
Constantinea subulifera	-	2	*	1	-	-	*	1	*	*	-	-
Constantinea simplex	-	1	*	2	*	-	*	1	2	1	-	-
Delesseria decipiens	-	2	1	1	-	-	-	9	*	1	1	-
Membranoptera platyphylla	-	1	*	1	-	4	-	2	*	1	1	-
Bonnemaisonia nootkana	-	2	*	1	*	-	-	1	*	*	-	-
Fauchea laciniata	-	15	10	13	12	1	5	18	1	1	2	-
Botryocladia pseudodichotoma	-	*	1	*	-	-	*	-	2	2	*	-
Opuntiella californica	-	5	5	7	4	-	4	6	2	2	-	6

Table 2. Average abundance rating of seaweed species with an abundance rating 2 or more in at least one region (asterisk = trace, dash = absent) for ALNC (Alaska and north coast British Columbia), WCVI (west coast Vancouver Island), OCW (outer coast Washington), JSTR (Johnstone Strait), SoG (Strait of Georgia) and PS (Puget Sound). See region locations on map in Figure 1. Abundance rating is listed for each of the last two climate regimes (89- = 1989-2000, 01- = 2001-2010) for each region. Within a higher taxon, species are listed according to phylogenetic relationships.

with different habitat attributes that tend toward different community species compositions at those various sites. Whytecliff actually had the most sampling of any site, but only five dives during the second regime period of 1977-1988. The five dives with the highest species counts were used for the other regimes.

For seaweeds, all species were being identified during the latest two climate regimes. In Alaska/northern BC, outer coast Washington and Puget Sound, however, too few dives were conducted in either the earlier or later regime, so that graphs summarizing biodiversity for those areas would not show valid trends. That is, for Alaska / northern BC, only 5 dives were conducted in 1989-2000, versus 103 dives in 2001-2010; on the outer coast of Washington, 75 dives took place in 1989-2000 versus only 5 in 2001-2010, and in Puget Sound, 59 dives were in 1989-2000, but only 8 dives in 2001-2010; thus these three regions are not presented graphically. The seaweed abundance ratings are listed for all marine plants occurring at abundance ratings of 2 or more in Table 2 and the relative biodiversity of different plant groups is depicted, including all abundance ratings, for Strait of Georgia, west coast Vancouver Island and Johnstone Strait in Figure 7. It can be seen from Table 2 that if the areas with disproportionate dive focus were graphed, there would be artefact appearance of biodiversity shifts, as with a decrease in all marine plant biodiversity in Puget Sound (resulting from only 8 dives there in 2001-2010).

Considerable confidence can be placed in identifications of the brown algae *Fucus gardneri, Hedophyllum sessile, Egregia menziesii, Alaria nana, Alaria marginata, Costaria costata, Cymathere triplicata, Laminaria saccharina, Laminaria setchellii, Pleurophycus gardneri, Lessionopsis littoralis, Sargassum muticum, Desmarestia lingulata/munda, Pterygophora californica, Eisenia arborea, Nereocystis luetkeana, Dictyota binghamae, Agarum clathratum* and *Agarum fimbriatum*. For red algae, some have been observed for many years as they were easily recognized, including *Porphyra* spp., *Hildenbrandia* spp., *Mastocarpus papillatus, Halosaccion glandiforme, Prionitis lyallii, Clathromorpha* etc. (encrusting corallines), *Callophyllis* spp., *Chondracanthus exasperatus, Mazzaella splendens, Sarcodiotheca gaudichaudii, Smithora naiadum, Sparlingia pertusa, Bonnemaisonia nootkana, Fauchea laciniata, Botryocladia pseudodichotoma* and *Opuntiella californica.* A considerable number of red algae, however, are not as readily identified by SCUBA divers in the field, particularly the branching and bladed forms. For that reason, diversity shifts in red algae, as depicted in Figure 7, are not as likely to represent genuine changes as are shifts depicted for the diversity of brown algae.

The data for the later two climate regimes in Figure 7 illustrate apparent increases in seaweed biodiversity for red algae in both the west coast of Vancouver Island and in Johnstone Strait, as well as an increase in brown algae diversity in Johnstone Strait during the latest regime. Considering that there were 61 dives during the 1989-2000 regime in Johnstone Strait, compared to just 25 dives there from 2001-2010, it seems that there may have been a genuine, significant increase in seaweed biodiversity in that region in particular. Note as well that the indication from limited diving in the more southerly regions is for decreasing, not increasing seaweed biodiversity over that time period, although those trends are not as likely to be valid.

The seaweed biodiversity in the Strait of Georgia remained very stable through the two most recent climate regimes (Figure 7), considering the increasing expertise in identification of red algae. Note from Table 2 that the red algae *Palmaria* sp., for example, was identified in the Strait of Georgia only during the last regime, but also in three other regions during the last regime, but nowhere during the previous regime. That species of intertidal dulse is very shallow and is difficult to identify, so probably does not represent a new appearance but rather a newly established identification capacity. For that reason, more confidence can be placed in apparent changes in brown algae biodiversity than in the reds, but considerable increase in seaweed biodiversity is apparent. This is in contrast to the overall appearance of loss of biodiversity in the last regime for the original list of 328 species, which included very few seaweeds.

Many dives (including the Whytecliff site) have been conducted near Vancouver, BC in Howe Sound, an area of fjord geography which experienced heavy sport fishing pressure

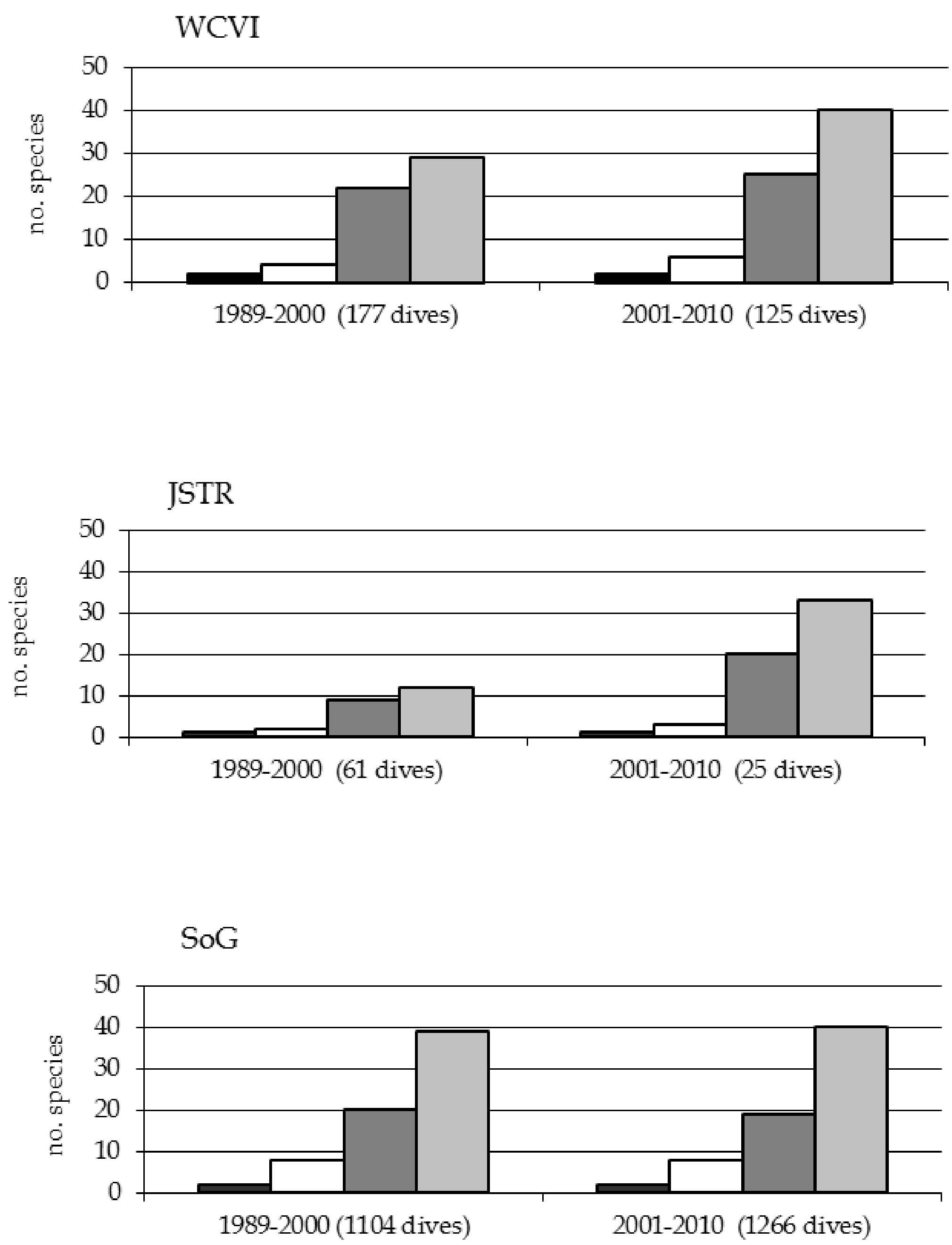


Fig. 7. Biodiversity of seaweeds is listed for the last two climate regimes (1989-2000 and 2001-2010). All abundance ratings are included. Considerable effort took place in these three regions. WCVI = west coast Vancouver Island, JSTR = Johnstone Strait and SoG = Strait of Georgia. Numbers of dives are listed in parentheses for regime periods. Black bars = flowering plants, white = green algae, dark gray = brown algae, light gray = red algae (see Table 2 for species with abundance rating of 2 or more).

before and during the early years of this survey. Howe Sound is now considered more overfished than the remainder of the Strait of Georgia (Marliave & Challenger, 2009). Howe Sound is contiguous with Vancouver Harbor, where the Vancouver Aquarium has maintained ocean acidity records through the period of this survey. The Vancouver Aquarium seawater records reveal that ocean acidification has steadily occurred through this period (Figure 8), with the range of pH in Vancouver Harbor shifting from typically pH 7.8-8.1 during the early period from 1954-1974, then increasingly varying to lower pH levels until the recent period when the range has often been from pH 7.3-7.9, sometimes varying to greater extremes. The most extreme high pH, in 1987, was during May-June, and the most extreme low pH, in 2001, was in July-August.

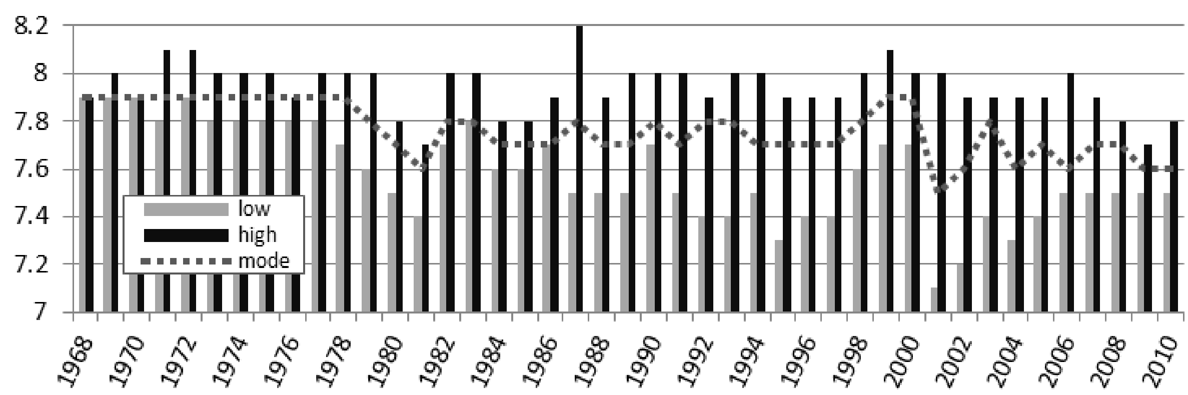


Fig. 8. Modal pH and extreme range (minimum 5 measures for low or high value) for Vancouver Harbor from 1968-2010.

This continual trend toward decrease in pH contrasts to the four reversing climate regime periods during the overall 1967-2010 time period for taxon records. The overall biodiversity remained stable in the Strait of Georgia in the presence of this declining pH level. The last three climate regimes, from 1978-2010, have included a steady decline in ocean pH in the middle latitudes of the Strait of Georgia, as seen in the data for Vancouver Harbor (Figure 8), yet the biodiversity has remained very stable, in fact more stable than for some of the adjacent areas, as for seaweeds in other regions.

4. Discussion

Overall, biodiversity was quite stable in the two most heavily investigated regions, west coast Vancouver Island and Strait of Georgia, for the study period of 1967-2010. The long duration of this biodiversity monitoring has involved an expanding network of experts and the discovery and description of new species so that the biodiversity list has continually expanded. For that reason, most of the results presented necessarily dealt with a curtailed species list of 328 species identified during the first climate regime period. This biodiversity stability has occurred through successive climate regimes and despite the continuous reduction in seawater pH, through global warming and through the continued state of stock depletion of fished groundfish and other fish species during that period. It is beyond the scope of this chapter to review the full literature on fisheries sustainability in the Strait of Georgia, but the reader may consult the review by Levy et al. (1996) to see a summary of historic declines in shellfish and finfish stocks in that region. There appear to have been no concomitant declines in overall biodiversity as one or another species has fluctuated in abundance. Consistent differences, however, persisted between adjacent regions, compared to the Strait of Georgia.

The region designations presented here are not based on any existing literature or governmental statistical areas for fisheries surveys. In fact, it may seem exceptional that smaller areas that seem to be inland seas are lumped together with outer coast areas such as the west coast of Vancouver Island (here including Queen Charlotte Strait inside the north end of Vancouver Island) and the extreme eastern end of the Strait of Juan de Fuca within the region of the outer coast of Washington. In the data compilation of Lamb et al. (2011) the occurrence of the exposed coast indicator species *Pyllospadix scouleri* and *Strongylocentrotus purpuratus* (Lamb & Hanby, 2005) on the southern coast of San Juan and Lopez Islands and the west coast of Whidbey Island was a rationale for designating these areas part of the fully wave-exposed outer coast rather than the protected inland seas of either Puget Sound or the Strait of Georgia, where all remaining portions of the San Juan Islands were included. The different, yet stable, biodiversities of the communities in these broad regions attest to the validity of the present region designations, and contrast rather markedly with some fisheries statistical areas. It might be well to conduct analyses of fisheries data in accordance with the present regional boundaries (Figure 1).

The literature is equivocal on whether a climate regime shift occurred in 1989, so results have been presented for both three and four climate regimes during the 1967-2010 period of this present study. Note that the first regime (here, 1967-1976) is actually considered to have persisted for a much longer time, from 1947-1976 (McFarlane et al., 2000). Whether the middle study period of 1977-2000 is considered to consist of just one climate regime or of two regimes (1977-1988, 1989-2000), the biodiversity appears (Figures 4, 5) to have been higher during that period than during either the first or last regimes. As well, differences between the second and third of the four regimes occurred (Figure 5), so that 1989 does appear to mark a climate regime shift, as proposed by McFarlane et al. (2000), from the standpoint of biodiversity, supporting the contention of Hare & Mantua (2000) that biodiversity accurately defines regime shifts. This is despite the evidence for increased observer expertise and improved capacity generally for taxonomic identifications based on field observation. Thus, there does appear to have been a slight overall reduction in biodiversity in recent years, in terms of the basic list of 328 species (mostly animals), in contrast to possible increases in seaweed biodiversity (based on the full species list).

The collation of species for one site at Whytecliff in four different climate regimes enabled a view of trends without concern over effects of habitat differences between sites within a region. The detailed data compilations for different areas within the Strait of Georgia region (Lamb et al., 2011) revealed that broad differences in biodiversity exist between different areas, apparently related to presence of high-energy tidal passes in areas like the southern Gulf Islands (Active Pass, Gabriola Pass, Porlier Pass) and Burrard Inlet (First Narrows, Second Narrows), where seaweed biodiversity is elevated in comparison to areas in middle latitudes of the Strait of Georgia. That study also showed considerable stability through time for those smaller areas in terms of their biodiversity differences from adjacent areas of different habitat characteristics. As well, that paper discusses the effects of sea urchins in creating "urchin barrens" where seaweeds are essentially absent in a confined area for some period of years. The effect of sea otters (*Enhydra lutris*) on reducing sea urchin densities and enhancing abundance and diversity of seaweeds is well demonstrated (Estes & Duggins, 1995) and is considered to relate to ecological stable states in terms of community persistence, resilience and stability. Such studies are typically conscribed to encompass specific study sites, whereas the present data compilation pools data from many sites for many years. It is likely that persistence of communities fluctuates with episodes of herbivore densities, as with urchin barrens, and that the present large-scale compilation masks shorter-term, more localized fluctuations between stable states.

The assessment of the 1977, 1989 and 2001 climate regime shifts may be confounded by the effects of overfishing and changing seawater acidity, but there is no basis for integrating those different effects. Nonetheless, this data presentation demonstrates that long-term records of pH do exist and that acidification trends can be related to trends in taxonomic diversity. Many fishing effects took place before this entire survey period, however (Levy et al. 1996). There has been no decline in biodiversity correlated to the trend of ocean acidification, with the possible exception of the disappearance of bull kelp (*Nereocystis luetkeana*) from mid-latitudes of the Strait of Georgia, especially the Sunshine Coast, where decline of bull kelp occurred during the time of dropping pH (Lamb et al., 2011). It should be noted, however, that the disappearance of bull kelp in middle latitudes of the Strait of Georgia has coincided with the establishment of the highest densities of human population in that part of the Strait of Georgia and where currents are generally least powerful (Lamb et al., 2011). Finally, the Strait of Georgia has warmed by one degree Centigrade over this same period from 1970 (Beamish et al., 2010). The greatest challenge in ecosystem-based management is to determine causal relationships where multiple correlations appear to be evident. Climate regime shifts were selected as the parameter on which to base comparisons since regimes have supposedly reversed two times (possibly three) during this overall period, but the biodiversity of this region has emerged as quite stable despite all of these possible influences.

There is only a very limited signal of climate regime shifts, particularly as reflected in changes in seaweed biodiversity after the regime shift of the year 2000. Seaweed identification was not well established by the present team during the first two regimes encompassed in the period from 1967-2010, so there is no long-term baseline for assessing seaweed biodiversity through time. Diversity of various seaweeds, however, showed signs of increasing at more northern latitudes and decreasing at the more southern latitudes in Washington state (outer coast Washington and Puget Sound), but the sampling effort may well have led to spurious appearance of lower seaweed occurrence in these southern areas. The most conservative data for the original list of 328 species shows stability. Note that few seaweeds occur in that list, so the apparent increase in seaweed diversity in recent years may relate to increased expertise in field identification. It can be discerned from Figures 4 and 5 that there was not only limited focus on seaweed identification in the early years, but that it took some time for groups of more plastic morphology like sponges and bryozoans to be registered in all areas. The greatest effort took place in the Strait of Georgia, which shows the greatest stability of biodiversity, probably to a considerable degree because of the level of effort. This was also a region where there was a tendency for continuing accumulation of additional species with repeated monitoring (Figure 3).

It is important to have continuity for single surveys such as the present in order to be able to evaluate relational databases that may in the future be derived from disparate studies that do not have equivalent metadata. The PMLS database has been used to assess bull kelp abundance (Lamb et al., 2011) and it has been found that biodiversity does not change when bull kelp disappears from a location. That publication by Lamb et al. (2011) also includes a complete species list with abundance data for the greater Strait of Georgia region, and serves as an adjunct to this present publication for reference purposes.

5. Conclusion

The biodiversity of the shallow seabeds of the Strait of Georgia and surrounding regions including Johnstone Strait, Puget Sound and the west coast of Vancouver Island show considerable stability through time. The most obvious biodiversity shifts appear to be in seaweeds in the most recent climate regime, but advances in taxonomic identification suggest that more monitoring effort is required. There are stable and reliable differences, however, in the biodiversity of shallow benthos in the different regions. The Strait of Georgia has a very high biodiversity in comparison to the adjacent inland seas of Johnstone Strait (to the north) and Puget Sound (to the south), but those other two inland seas have subsets of their biodiversity at uniquely high levels of abundance. The present data compilation, together with the more exhaustive records for Strait of Georgia in Lamb et al. (2011) will provide a baseline for comparison to future trends. In all, the news is encouraging that marine biodiversity can demonstrate such resilience in the face of documented fisheries exploitation, climate change and ocean acidification. The present study also serves to demonstrate that it is important to evaluate existing data archives for continuous records of such important aspects of marine biology as species identification and abundance estimates, as well as records of physical seawater quality, such as seawater pH. Models for ecosystem-based management need to minimize the assumptions made and incorporate as much quantified information as possible in order to ensure the greatest possible precision and accuracy of predictions. This work presents descriptive data without any attempt at statistical analyses, in the hope that the obvious data trends can be incorporated into future models. The current academic trend toward producing expertise in quantitative scientific methods needs to be balanced with training of taxonomists for the front line, in order that existing marine biodiversity can be fully monitored now and into the future. The work presented here would not have been produced with any continuity in any existing academic or government biological monitoring programs in this part of the world, and perhaps not anywhere.

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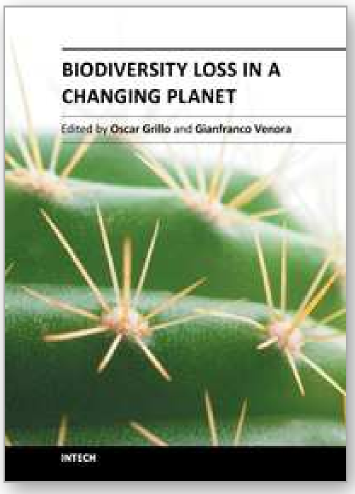

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Every ecosystem is a complex organization of carefully mixed life forms; a dynamic and particularly sensible system. Consequently, their progressive decline may accelerate climate change and vice versa, influencing flora and fauna composition and distribution, resulting in the loss of biodiversity. Climate changes effects are the principal topics of this volume. Written by internationally renowned contributors, Biodiversity loss in a changing planet offers attractive study cases focused on biodiversity evaluations and provisions in several different ecosystems, analysing the current life condition of many life forms, and covering very different biogeographic zones of the planet.

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