Small Craft Harbours in the Pacific Region: Habitat Impact, Benign Alteration or Habitat Creation?

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SMALL CRAFT HARBOURS IN THE PACIFIC REGION: HABITAT IMPACT, BENIGN ALTERATION OR HABITAT CREATION?

by

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ABSTRACT

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Canada has 1155 small craft harbour (SCH) facilities that provide safe and secure moorage for both the fishing and recreational industries. The presence of a SCH, with structures such as docks, breakwaters, wharfs and dredged basins, generally represents an alteration in aquatic habitat relative to pre-harbour conditions. Docks, floating breakwaters and wharfs alter light attenuation to benthos, and create hard substrate habitat in the upper portion of the water column. Breakwaters alter water circulation patterns and benthic substrate composition. Dredging changes depth profiles and disturbs benthic communities. By concentrating vessel traffic, SCH's are also potential hotspots for petroleum and metal contaminants and are a potential high priority environmental risk among a plethora of federally administered sites. However, the construction of harbour structures can create new benthic substrate, that frequently supports vibrant biological communities within the harbour authority.

In an effort to better understand the effects of development on coastal habitats, a DFO collaborative research program was developed in conjunction with Science, Small Craft Harbours (SCH) and the Oceans, Habitat and Enhancement Branch (OHEB – now Fisheries Protection Program, FPP). Three harbours each constructed with both rubble mound and floating breakwaters were chosen for preliminary sampling of hard substrate benthic communities using quadrats and settling plates placed on both the protected and exposed sides of the structures. Soft bottom communities were sampled with a Ponar grab inside, and at adjacent references locations outside of each harbour. A portion of the sample was taken for analysis of sediment characteristics and contaminants including metals, hydrocarbons, and Polynuclear Aromatic Hydrocarbons (PAHs). The scraping of material from within quadrats provided greater taxonomic discrimination among harbours and their features (i.e. rubble vs floating breakwaters, exposure vs protected) than samples from settling plates. Both methods found rock rubble structures to be characterized by a community of barnacles, mussels, and annelids as compared to dense mussel communities on floating structures which created opportunities for caprellids, isopods, and amphipods. Communities also differed among harbours; Cowichan and Port Hardy had more amphipods, isopods and barnacles, while Lund had more mussels, caprellids and annelids. Detailed taxonomic resolution, particularly to describe functional groups (e.g. ecosystem engineers, feeding guilds) maybe important for understanding ecological processes but even low levels of resolution were adequate for discrimination among benthic communities at different locations. Cowichan Harbour had the lowest level of contamination with levels of many individual markers similar to reference conditions regardless of the location sampled within the harbour. Three chemical groups differentiated the inner harbours; Lund was characterized by high PAH levels while Port Hardy tended to have high Molybdenum and hydrocarbon levels (F4). We speculate on the sources. Cu was found among all of the harbours perhaps ubiquitous in the presence of antifouling requirements of commercial and recreational vessels. Sediment toxicity in each harbour, based on three independent tests, was universally low. Confirmation of these results and improvements in our ability to predict and regulate the impacts of coastal development await similar examinations in additional harbours. A deeper

examination of the influence of harbour structures on water circulation patterns and benthic substrate characteristics will improve our understanding of ecosystem processes and possible development liabilities associated with coastal development.

RÉSUMÉ

Macdonald, J.S., H.E. Herunter, et E. Chiang. 2018. Ports pour petits bateaux dans la région du Pacifique : impact de l'habitat, altération bénigne ou création d'habitat? Can. Tech. Rep. Fish. Aquat. Sci. 3255: v + 58 p.

Le Canada compte 1155 installations de ports pour petits bateaux (PPB) qui fournissent un amarrage sécuritaire et sécurisé pour les industries de la pêche et des loisirs. La présence d'un PPB, avec des structures telles que des quais, des brise-lames et des bassins dragués représente en général une altération de l'habitat aquatique par rapport aux conditions précédant le port. Les quais et les brise-lames flottants altèrent l'atténuation lumineuse des benthos et créent un habitat de substrat dur dans la partie supérieure de la colonne d'eau. Les brise-lames altèrent les tendances de circulation de l'eau et la composition du substrat benthique. Le dragage change les profils de profondeur et perturbent les communautés benthiques. En concentrant le trafic maritime, les PPB sont également des points névralgiques potentiels pour les contaminants de pétrole et de métal et un risque environnemental potentiel à priorité élevée parmi une multitude de sites d'administration fédérale. Toutefois, la construction de structures de port peut créer de nouveaux substrats benthiques, qui soutiennent souvent des communautés biologiques vibrantes au sein de l'administration portuaire.

Afin de mieux comprendre les effets du développement des habitats côtiers, un programme de recherche collaborative du MPO a été élaboré en conjonction avec Sciences, Ports pour petits bateaux (PPB) et la Direction des océans, de l'habitat et de la mise en valeur (DOHMV – maintenant le programme de protection des pêches). Trois ports, chacun construit avec un brise-lames en enrochement et des brise-lames flottants, ont été choisis pour l'échantillonnage préliminaire des communautés benthiques de substrat dur à l'aide de quadrats et de plaques de fixation placés sur les côtés protégé et exposé des structures. Des communautés des fonds meubles ont été échantillonnées avec une benne de Ponar à l'intérieur et à des emplacements de référence adjacents à l'extérieur de chaque port. Une partie de l'échantillon a été analysée pour détecter les caractéristiques sédimentaires et les contaminants dont les métaux, les hydrocarbures et les hydrocarbures aromatiques polynucléaires. La mise au rebut du matériel des quadrats a fourni une plus grande discrimination taxonomique parmi les ports et leurs caractéristiques (p. ex., brise-lames en enrochement vs brise-lames flottants, exposition vs protection) que les échantillons des plaques de fixation. Les deux méthodes ont révélé que les structures en enrochement sont caractérisées par une communauté de cirripèdes, moules et annélides en comparaison aux denses communautés de moules sur les structures flottantes qui ont créé des occasions aux caprelles, isopodes et amphipodes. Les communautés diffèrent également parmi les ports; Cowichan et Port Hardy avaient plus d'amphipodes, d'isopodes et de cirripèdes, tandis que Lund avait plus de moules, de caprelles et d'annélides. La résolution taxonomique détaillée, en particulier pour décrire les groupes fonctionnels (p. ex., les ingénieurs d'écosystèmes, le régime alimentaire) peut être importante pour comprendre les processus écologiques mais même les faibles niveaux de résolution étaient adéquats pour la discrimination parmi les communautés

benthiques à différents emplacements. Le port de Cowichan avait le plus faible niveau de contamination avec des niveaux de nombreux marqueurs individuels similaires aux conditions de référence peu importe l'emplacement échantillonné dans le port. Trois groupes chimiques différenciaient les ports intérieurs; Lund était caractérisé par des niveaux élevés d'hydrocarbures aromatiques polycycliques tandis que Port Hardy avait tendance à avoir des niveaux élevés de molybdène et d'hydrocarbures (F4). Nous spéculons sur les sources. Du cuivre a été trouvé dans tous les ports, peut-être omniprésent en présence d'exigences antisalissures des bateaux commerciaux et de plaisance. La toxicité par sédiment dans chaque port était universellement faible selon trois tests indépendants.   La confirmation de ces résultats et l'amélioration de notre capacité à prédire et à réguler les impacts du développement côtier attendent des examens similaires dans d'autres ports. Un examen plus approfondi de l'influence des structures de port sur les tendances de circulation de l'eau et les caractéristiques de substrat benthique rehaussera notre compréhension des processus écosystémiques et des responsabilités développementales associées au développement côtier.

1.0. INTRODUCTION

During the last few decades unprecedented development pressures on coastal habitat have resulted from a growing population demanding recreational, industrial, and residential properties. Natural beaches and shorelines have been replaced with modifications to intertidal and shallow sub-tidal habitat that includes rock rubble walls, floating breakwaters, dredged harbours, docks and marine service outlets. As a population seeks access to the water and marine services (Thom et al. 2005) or acts to avoid losing uplands to climate-induced increases in sea level (Sobocinski et al. 2010) the demand for these structures will become increasingly common.

In British Columbia, examples of these types of development pressures are manifested in marinas and harbours owned and operated by private entities, municipalities, or other levels of government. In Canada there are over 1000 Small Craft Harbours (SCHs) of which 106 are in BC that are owned or administered by Fisheries and Oceans Canada (DFO-SCH 2016). These harbours have provided vital infrastructure to coastal communities supporting transportation needs and economic activities. As such, SCHs often have a long history of commercial and industrial activities with environmental impact legacies to match (e.g. Pottinger Gaherty 2002, URS Canada 2004). More recently, these harbours have evolved to meet the needs of a growing recreational fishing and boating community. While SCHs represent a small portion of coastal development, they contain structures and activities commonly found throughout coastal BC and thus provide an experimental microcosm to examine the wider influence of coastal development on local ecosystems.

Harbour development pressure has been studied globally including in Australia (Glasby and Connell 1999), New Zealand (Turner et al. 1997), Italy (Burelli and Chapman 2010, Di Franco et al. 2011), the American Gulf Coast (Peterson et al. 2000), California (Davis et al. 2002, Pister 2009), and Puget Sound Washington State (Morley et al. 2012, Toft et al. 2007) with distinct and at times disparate conclusions about invertebrate colonization and habitat creation or loss. Harbour developments are designed to provide a sheltered area for activities related to vessel storage and operation which is often achieved by choosing naturally protected locations and/or the strategic placement of breakwaters. These breakwaters can be either rubble mound (often referred to as riprap) or floating structures and can introduce various effects on local biota including shading, reduced wave energy, reduced water exchange and quality, altered substrate regimes, and outright smothering of the benthos in the case of riprap placement (Nightingale and Simestad 2001). However, they do provide a substrate which can be colonized by invertebrates and algae (Glasby and Connell 1999) and subsequently utilized by fish for food and protection (Toft et al. 2007). Colonization of created habitats may produce biotic assemblages comparable to local natural communities (Pister 2009) or the communities produced may follow a different successional trajectory (Di Franco et al. 2011, Glasby and Connell 1999, Bulleri and Chapman 2010).

Following a philosophy of "no net loss" to habitat productivity, the construction and operation of SCHs has attempted to avoid having a negative influence on local biota (DFO 1986). Amendments to the *Fisheries Act* (R.S.C., 1985, c. F-14) in 2012 allow permanent habitat destruction only with prior authorization in cases involving important fisheries. Attempts to fill a ledger of habitat gains and losses creates a contrast between that altered or lost to harbour construction and utilization, and the positive contribution of surfaces created by the construction of the harbour structures themselves. The issue becomes particularly acute when the nature and location of the habitat created differs from that which is lost. This remains a common and unresolved issue among habitat regulators that dates back to at least the 1980's. We still seek quantitative metrics to measure the contribution of habitat compensation (off setting) schemes relative to habitat lost to development (Waldichuk, 1993). Habitat restoration equivalency analyses have considered estimates of many metrics including areas, ecosystem services, specific life history bottlenecks and biological production at various trophic levels, as well as temporal recovery and longevity considerations (Peterson et al. 2003 and papers within, Wong and Dowd 2016).

Maintenance and operation of marinas and harbours commonly affects water quality and may result in an accumulation of contaminants in the local biota and benthic sediments (Boyd et al. 1998, Chapman et al. 1987, McGee et al. 1999). Potential contaminants include metals, antifoulants (e.g. copper), petroleum hydrocarbons, and polynuclear aromatic hydrocarbons (PAHs). The negative effects of these contaminants in the aquatic environment has been documented throughout the industrial world including Puget Sound (Long & Chapman 1985), Chesapeake Bay (McGee et al. 1999), San Francisco Harbour (Chapman et al. 1987) and Vancouver Harbour (Boyd et al. 1998, Goyette and Boyd 1989). Potential contamination in SCHs is being addressed through the Federal Contaminated Sites Action Plan (FCSAP 2016), with a mandate to assess environmental risk at federally owned sites.

Contaminants identified with sediment chemistry analyses imply only the potential for ecological impact (Apitz et al. 2005). Long and Chapman (1985) demonstrated that chemical concentrations in sediments alone did not indicate ecological impact, but were good indicators of the scope and severity of an impact once it was identified with biologically-based analyses. They proposed that assessment of sediment quality must involve at least three metric categories: 1) contaminant concentrations, 2) sediment toxicity, and 3) sediment infauna characteristics. Together these metrics form a "Sediment Quality Triad" (SQT) that infers ecological impact as the result of environmental contamination using a strength of evidence decision framework. This general approach has been widely adopted as a standard methodology for assessing aquatic contaminated sites, albeit with ongoing challenges and modifications (e.g. Green et al. 1993).

This report provides the results of physical, chemical, toxicological, and biological sampling from three SCHs and adjacent reference locations on Canada's Pacific coast. Epifaunal communities were examined from both floating and rubble mound breakwaters in each harbour. Sediment infauna, chemistry, physical parameters, and toxicity were evaluated within harbours and adjacent reference areas. The genesis for this research originated with concerns raised by several sectors within Fisheries and Oceans Canada including Science Branch, property managers in Real Property, Safety and Security Branch (RPSS) and the Oceans, Habitat and Enhancement Branch (OHEB – now Fisheries Protection Program, FPP). Collectively, they expressed an interest in developing economical and environmentally sensitive indicators, survey methods and analysis techniques that can capture environmental complexity from a wide range of coastal environments, both natural and altered (e.g. Hyland et al. 2005). This study provides an approach for examining the impact of coastal development in the Pacific Region. Within three harbours physical attributes, biological communities, and chemical, and toxicological characteristics were selected as potential indicators of response and compared among various types of structures with adjacent reference locations. Response variables were contrasted among the reference sites in quest of a single reference condition independent of geographic location, and among treatments to detect response consistency among harbours. Physical and chemical correlates with community characteristics were examined as possible evidence of ecological processes or pathways of effects. Traditional methods to analyze contaminant, toxicity and biological metrics (SQT) are used in conjunction with multivariate routines (Primer - Clarke and Warwick, 2001) to guide future more extensive monitoring programs that purport to weigh gains and losses associated with coastal development.

2.0. METHODS

2.1. STUDY AREAS

Three Small Craft Harbours, Cowichan Bay, Port Hardy and Lund, were chosen for study as they have many features in common, including both floating and rubble-mound breakwaters as well as docks, wharfs and a history of marine service outlets (e.g. fuel docks, marine ways, and shipyards, Figure 1a-f). All support mixed commercial and recreational boating activities.

Cowichan Bay is located on the east side of Vancouver Island, about 56 km north of Victoria, adjacent to the town of Duncan (population 5000). The harbour was established in 1879 and has approximately 285 m of floats. Lund (population 250) is located on the mainland about 23 km north of Powell River and began harbour operations in 1914; it has approximately 210 m of floats. Port Hardy (population 4000) is located on the north eastern side of Vancouver Island with 725 m of floats. It has been operated since 1965. Both Cowichan and Lund are located within the relatively calm waters of the Strait of Georgia, while Port Hardy is further north, on Queen Charlotte Strait which has stronger oceanic influences. Both Cowichan and Port Hardy have rivers/creeks flowing into their basins year-round; whereas freshwater influence at Lund is ephemeral.

Through the first two weeks of June of 2010, trips were made to each harbour to install temperature loggers and deploy settling plates. Invertebrate samples were collected inside the harbours and from the exposed sides of both rubble-mound and floating breakwaters. Benthic sites with comparable depths and sediment composition were sampled both inside and outside of the influence of the harbour at reference locations. Attempts made to locate adequate benthic references at sites adjacent to the harbours (within 0.5 of a nautical mile) were not always possible (Figure; details provided in Results). Subsequent trips were made through the summer, fall and in December to maintain the sampling equipment and to collect temperature loggers and settling plates.

2.2. WATER COLUMN PROPERTIES

Onset Hobo data loggers were placed on both riprap and floating breakwaters, on both exposed and inner harbour sides to provide hourly water temperature data records. Riprap samplers were exposed to tidal influence at a depth of 1.0 m above zero tide. On floating breakwaters samplers were located at a constant depth of 1.0 m below the surface and were not exposed to desiccation at low tide. Time series plots of average daily and delta (harbour minus exposed) temperature were produced from June to December. Additional oceanographic information was collected in June and December using a Yellow Springs Instruments model 85 meter to graphically characterize and compare oxygen, salinity, and temperature depth profiles at several stations within the harbours and outside in exposed locations. Summer profiles were not collected at Cowichan.

2.3. HARBOUR STRUCTURE BIOTA

Ten tile settling plates (15.25 x 15.25 cm) were randomly located five on the exposed and protected sides of each breakwater in each harbour. They were placed 50 cm beneath the surface on the floating breakwater (bolted to a 5 x15 cm plank) and at 1.0 m above tidal datum on rubble-mound structures (bolted to a cinder block anchor). After six months of deployment, the settling plates were collected and biota removed and fixed in a 10% formalin solution followed with preservation in 70% ethanol within two months.

In each harbour established invertebrate communities on the inside and outside of the breakwaters, were sampled by scraping five randomly selected locations. The smooth sides of the floating breakwater allowed the use of a 500 µm net attached to a 10 cm wide garden hoe to collect a strip of biota from a depth of 30 cm to the surface. On rubble-mound breakwaters sample locations were constrained to a depth of 1.0 m above zero tide height and were collected at low tide. Scrapers were used to remove all biota from solid surfaces within a 25 x 25 cm quadrat. When unconsolidated sediments were present within the quadrat, trowels were used to sample the sediments to a maximum depth of 10 cm. All breakwater samples were washed in a 500 µm sieve and preserved as described above. Invertebrate identification in samples from breakwaters did not extend beyond the order level. The biomass of each order was recorded as the dry weight after the samples were oven dried at 80 ^{o}C for 48 hours.

2.4. BENTHIC BIOTIC AND ABIOTIC PROPERTIES

Benthic sediments were collected at each of the harbours using a stainless steel Ponar grab (23 x 23 x 15 cm) deployed from a boat. Collections occurred from five randomly chosen sites inside of each harbour and at five reference locations in the vicinity of the harbour but outside of its influence. Volumes sampled (25 liters) were sufficient to assess biological community structure and sediment chemistry, and to perform sediment toxicity analyses using three biological standards. Sample distance from pilings or other visible sources of contaminants was recorded but always exceeded 2.0 m. Biota retained on a 500 µm sieve were preserved and sent to Biologica Environmental Services (634 Humboldt Street, Suite H-50, Victoria, BC V8W 1A4) for taxonomic identification to the genus or species level. Biomass of taxa were calculated by multiplying their abundance by an average individual weight from alcohol preserved individuals kept in a reference collection of specimens from the three harbours.

Benthic sediment grain size, total organic carbon (TOC), metals, extractable petroleum hydrocarbons, and polycyclic aromatic hydrocarbons were analyzed by the ALS Laboratory Group (8081 Lougheed Hwy, Suite 100, Burnaby, BC V5A 1W9). Additional analyses not common to all three harbours included: acid volatile sulphides, extractable metals, volatile organic compounds (Lund and Port Hardy only), and organotins (Port Hardy only). These were excluded from analyses as a balanced dataset was required for ordination analysis but raw values are included in Appendix 1. All values listed as being below a detection limit were assigned the detection limit value. We did not use TOC standardizations.

Three different sediment toxicity tests were performed by Environment Canada's Pacific Environmental Science Centre laboratory (2645 Dollarton Highway North Vancouver, BC, V7H 1B1). The tests included a marine amphipod (*Eohaustorius estuaries*) 10 day survival bioassay, an echinoderm (*Dendraster excentricus*) 72 hour fertilization assessment, and a Microtox® (*Vibrio fisheri*) 10 minute 50% inhibition concentration (IC50) solid phase test (Environment Canada 1998, 2002, 2011). All five inner harbour samples underwent chemical and toxicity analyses but budget constraints allowed for analysis of only three randomly chosen reference samples (i.e. samples A,C,E - Cowichan; samples A,B,D - Lund, samples A,B,D - Port Hardy). All test values were standardized with laboratory control values.

2.5. DATA ANALYSIS

The Diversity Index *"d"* (Green 1979) which compares biological diversity (number of taxa) with total individual abundance provides a convenient and analytically simplistic means to infer possible gains or losses of biological productive capacity among a variety of natural and created harbour substrates. Indices were calculated as averages of abundance in samples from each collection method and harbour feature within each harbour after adjusting for area sampled (densities, #/cm^2). Areas sampled by each method were dissimilar (233 to 625 cm^2) but a reduction in diversity with sampler size was only associated with the early stages of colonization. Averaged values were ln+1 transformed. Taxa were classified to the order level; the lowest resolution common to all sampling methods. A graphical presentation provided an initial over-arching biological evaluation of harbour health relative to the reference condition.

Investigations of anthropogenic influence of harbour features and sediment chemistry, and their impact on benthic community structure, will necessarily generate data sets with many potential response variables and a multi-factorial experimental design. Non-linear multidimensional scaling analysis (MDS) followed by an analysis of similarity (ANOSIM) explored overall data structure seeking similarities among biological community, toxicity data, and sediment chemistry samples in *a priori* grouping by harbours, their features and reference locations (Primer-E 2009). The ANOSIM test statistic, R, provides a gradient of similarity among groups where comparisons with values exceeding 0.30 were considered dissimilar if the probability (p) was <0.05. Subsequent application of the SIMPER routine (Primer-E 2009) elucidated the taxa responsible for data structure. The analysis of the sediment infaunal database was repeated with response variables identified to three levels of detail (phyla, order and species) to determine if overall conclusions regarding anthropogenic impact on community structure was robust to lower taxonomic resolution. The correlation among the three taxonomic levels was estimated with the BVSTEP (Primer-E 2009) routine.

All abundance and biomass data were square root transformed. Taxa with cumulative total abundance across all samples of less than 5 were excluded from analyses. Each routine began with the construction of a Bray-Curtis similarity matrix of the biological data. All chemistry data were normalized to convert data to a common scale using $(x-x_{avg})$/(standard deviation) resulting in values ranging from about -2 to +2 for each variable. A similarity matrix was then constructed using Euclidian distances prior to analysis. Correlation between the chemical and biological databases may be evidence of a causal link between the presence of certain contaminants, community structure and harbour development. Accordingly, the BVSTEP routine measured correlation between matrices, as the initial step towards the selection of a subset of functionally linked chemical and biological indicators.

Sediment grain size as a percentage in four categories (gravel, sand, silt, and clay) was compared among harbours and with their adjacent reference locations with a MDS/ANOSIM approach. TOC was analysed by location and harbour treatment with a two-way GLM ANOVA using arcsine transformed data followed with a Tukey pairwise comparison and plotted (Minitab 2007).

Traditionally, sediment quality triads have been used to summarize complicated multivariate datasets for the purposes of measuring pollution-induced degradation of coastal benthic habitats relative to unpolluted reference locations (Long and Chapman 1985, Chapman et al. 1987). Triads (SQT's) incorporate biological, chemical, and toxicological metrics that are reduced from their original multivariate expression into three indices and then plotted to create a triangular area (Chapman 1986). More recent work suggests that there are limits to the usefulness of Triad-based indices (Chapman 1996), but the general approach continues to be reported in the literature (Khim and Hong 2013). The use of three data sources as evidence for degraded ecosystems or contamination gradients was also adopted by Green et al. (1993) but with analysis approaches that recognized the multivariate nature of the data. Subsequently, a variety of presentation and interpretative approaches have been proposed for triad-based sediment toxicity data (Chapman and Hollert 2006) each trying to incorporate the simplicity of indices with the power inherent in multivariate data. The biological, chemical and toxicological data in this study used a range of analysis options contrasting interpretations based on indices with those made from multivariate analyses using ANOSIM.

The Triad analysis began with the compilation of six indices, each a ratio to a reference (RTR) and averaged to represent the biological conditions at each harbour. These were 1/total taxa (S), 1/total abundance (N), 1/species richness (d) (where d=(S-1)/LogN), 1/H' (where H'=Shannon Diversity), % Annelida, and 1/J' (where J'=Pielou's Eveness). Chemistry RTR values were an average of average metal, average hydrocarbon, and average PAH RTR values**.** Toxicology RTR results were standardized to laboratory control values, averaged and also plotted as their inverse. Once confident that the toxicological and chemical values among all reference sites represented a common, uncontaminated environment regardless of harbour location, we pooled them for comparison to the harbour treatment values. We were not confident that all biological reference locations represented a common reference condition, hence pooling was not considered and harbour treatments were compared to adjacent reference sites.

Five triads were created, one for each inner harbour sample, and their graphical areas were calculated, creating replicate measurements from each of the harbours. Large heterogeneity among samples at each site was addressed with log transformation of the data which also provided the homogeneity of variance assumed for parametric tests. Mean triad areas were compared using a one way ANOVA (Minitab 2007, Chapman 1996) to test the hypothesis that the environmental health of harbours relative to their reference conditions were indistinguishable. Conclusions based on the triad analysis were contrasted to similar comparisons based on ANOSIM R values calculated from multivariate pairwise comparisons among harbours and reference conditions. R values were calculated separately for the biological, chemical, and toxicity data sets and ranked from lowest to highest (the higher a pairwise R value, the more different a harbour was from reference conditions and the greater the impact) for comparison with a similar ranking of the three triad results.

3.0. RESULTS

3.1. PHYSICAL ENVIRONMENT

Surface water temperatures (Figure 2) ranged from 3.4 to 20^{o}C at the study locations over the duration of the experiment. Inner harbour measurements at Lund were the warmest particularly in early August while temperatures outside of Port Hardy were the coolest, later in the year. Any differences between inner and outer harbour riprap sites were generally less than 0.2 ^{o}C, well below the accuracy of the data loggers (Figure 2b, c). However, Port Hardy harbour was slightly warmer than the adjacent exposed station (sum delta T = 54.1^{o}C) and at least at Lund summer temperatures were warmer in association with the floating as opposed to the rubble mound breakwaters (Figure 2d). Further temperature comparisons were hampered by the failure to collect complete records due to equipment failure or loss.

Water temperatures warmed with depth in winter and cooled in the summer with thermoclines above four metres except were poorly defined at Lund (Figure 3). Port Hardy had salinities that were approximately 2‰ higher than other sites and a well defined halocline particularly in winter (Figure 3). Haloclines were not detected in the summer although data from Cowichan were unavailable. Dissolved oxygen declined with depth at all sites and was lowest between three metres and the bottom. It was consistently lower in the winter than the summer but was rarely below 5 mg/l. Temperature and salinity were not influenced by inner and outer harbour contrasts but dissolved oxygen was generally lower inside all of the harbours.

Sand and silt were the most common size fractions in the benthic environment accounting for an average of 85% of the material at all locations (Figure 4). Despite a tendency for most well protected harbour samples to have finer material relative to samples from adjacent less protected reference areas the differences were not detected with the ANOSIM (Global R=0.24, p=0.012). Location contrasts were hampered by considerable grain size variability within both reference and harbour samples particularly at Lund and Port Hardy. The prevalence of total organic carbon (TOC) in all harbours relative to reference locations was detectable (Figure 5, two way ANOVA p_{int}=0.165, p=0.002), and it was particularly high at Lund and Port Hardy relative to Cowichan (p=0.003).

3.2. BIOTA ON HARBOUR STRUCTURES

Nineteen epifaunal taxa categories, at the order level or above, were identified from quadrat and colonization plate samples (Table 1), but analyses were hampered by a loss of 6 of the 60 plates to damage or tampering related to harbour activities. Abundance and biomass were highly variable among samples and ranged from an average of 0.15 to 10.52 animals/cm^2 and from 0.0003 to 0.6203 g/cm^2 (Figure 6a, b). Established epifaunal communities on both rubble and floating breakwaters tended to be richer (18 taxa versus 12-13, Table 1) and of a greater mass (e.g. Cowichan 0.11-0.62 g/cm^2 vs < 0.21 g/cm^2, Figure 6b) than colonizing communities on the plates. Communities tended to be sparser on rubble relative to floating structures particularly in terms of colonization rates (Table 1). For example, colonization at Lund was between 2.3 and 10.5 animals/cm^2 on the floating breakwaters compared to fewer than 0.25 animals/cm^2 on rubble mounds.

In all three harbours, breakwater exposure had no influence on rubble-based communities but resulted in greater numerical abundance of select colonizing and established taxa on floating structures at Cowichan and established Port Hardy communities ($p<0.05$, R-values, Table 2, Figure 6). Exposure at Lund may have had the reverse effect. Mussels, barnacles and isopods were more common on the exposed sides of the floating breakwaters while caprellids and annelids were more common on the protected sides (Table 2, Figure 7). The nature of the communities were also specific to the harbour in which the floating breakwaters were found. Communities of mussels, annelids and caprellids in Lund contrasted with gammerids and isopods in Cowichan and barnacles and isopods at Port Hardy.

Pairwise comparisons of locations based on numerical abundance estimates were correlated with similar comparisons based on biomass data, and therefore both provide comparable measures of community response particularly among colonizing communities (as measured by plates, BVSTEP - Table 3). Consequently, spatial patterns in community structure that were based on taxa counts were largely confirmed with the biomass data. The abundance-biomass correlation was not as strong for established breakwater communities. A dominance of both barnacles and mussels was demonstrated by both types of measurements on the exposed sides of both breakwater types at Cowichan (numerical measurements presented in Table 2). Similarly, by both methods annelids and mussels were more abundant on the protected side of floating structures at Lund. Community discrimination among harbours was possible with biomass data but with lower confidence than when using taxa category counts. Furthermore, evaluations based on abundance data identified more complex, multiple taxa community differences among harbours than those based on biomass. Conclusions based on numerical abundance were occasionally refuted with biomass data. For example, mussels on floating structures composed the greater biomass in communities at Cowichan and Port Hardy but were numerically more abundant at Lund.

3.3. HARBOUR SEDIMENTS

3.3.1. Benthic Biota

Four hundred and twenty four taxa categories, many to the species level, were identified from the benthic grab samples (Appendix 2), but a subset of eight benthic invertebrate variables, the cnidarian (*Scolanthus sp*.), six annelids (*Eteone spp., Pholoe spp., Scoletoma luti, Capitella capitata, Opheliidae spp., Prionospio spp.*), and the bivalve *Rochefortia tumida* could reliably produce community distinctions among all harbour and reference locations (BVSTEP, correlation with the full database Rho = 0.952). In terms of both taxa counts and biomass, benthic habitats had lower biological density than established harbour structures and were lowest inside Port Hardy harbour (Figure 6a, 0.32 animals/cm^2 and Figure 6b, 0.0002 g/cm^2). Analyses of the benthic data at various taxonomic resolutions yielded similar community structure distinctions among the matrix of harbours and their adjacent reference locations (Table 4) albeit with less site differentiation and lower statistical significance as resolution declined (BVSTEP correlation, Rho = 0.72 to 0.81).

With the exception of Cowichan, benthic communities in harbours differed from those at adjacent reference locations but variation among all harbours and among all reference locations was even greater (Table 5, ANOSIM pairwise comparisons, Figure 8). This pattern remained consistent with both the abundance and biomass data, either could be used to discriminate among harbours and their reference locations (BVSTEP, correlation Rho = 0.92, Table 3). Sedentarian and errantarian polychaetes were more common in the harbours, bivalves were less common

(Table 5). Infaunal communities composed of clams (*Rochefortia tumida*) and oligochaetes (*Tectidrilus sp.)* distinguished Cowichan harbour from the others, while polychaetes (*Asabellides spp., Pholoe spp*.) were common at Lund. Port Hardy harbour benthos was relatively sparse (Figure 6) and characterized by the polychaete *Capitella capitata*, which is often cited as an indicator of perturbed environments (Kathman et al.1984, Bridges et al. 1994).

The benthic reference sites chosen as a contrast to harbour communities were different from one another (Figure 8). Bivalves (*Rochefortia tumida* and *Axinopsida serricata*) were more common near Lund; the annelid *Capitella capitata* was more common both inside and outside the Port Hardy harbour (Table 5). Finding reference locations proved to be more difficult than expected at Port Hardy and Lund, and the choices may have contributed to observed community variability among locations. At Lund, all attempts to collect samples outside of the influence of the harbour were thwarted by ubiquitous bedrock forcing sampling further a-field (Figure 1c). At Port Hardy the reference sites were found in close proximity to the harbour but two of them were found later to have been influenced by historic log storage activities, which resulted in large amounts of fine woody debris and coarse sediment. As a consequence the crustacean *Nebalia sp*. and the amphipods (*Anisogammarus sp*.) were more common and clams less common in samples B and D than at the other Port Hardy sites, or reference sites elsewhere (Figures 1e, 8, and 9). Several studies have demonstrated the progression of invertebrate functional groups from suspension to deposit feeders in the presence of even small amounts of bark accumulation (Conlan and Ellis, 1979; and Freese and O’Clair, 1987).

3.3.2. Sediment Chemistry and Toxicity

The benthic samples from within the harbours contained a substantial number of chemical contaminants; those from reference sites considerably less (Table 6, Figure 10, ANOSIM Global $R = 0.45$, $p<0.010$). The reference samples from all locations were chemically indistinguishable and were pooled as a common reference to compare harbours and estimate relative environmental disturbance (ANOSIM $p>0.10$). Harbour contamination was attributable to one or more chemical compound(s) that exceeded Interim Sediment Quality Guidelines (CCME 2001) when they were available; but each harbour had very different chemical signatures (ANOSIM pairwise $R > 0.31$, $p<0.032$). Cowichan harbour had elevated levels of metals such as Ni, and several PAH’s, albeit at concentrations lower than the other harbours (Figure 11). At Cowichan lower levels of contamination were reflected in a relatively small difference among samples collected inside and outside of the harbour (Figure 10). In comparison, Lund and Port Hardy harbours had elevated concentrations of a variety of PAH’s (particularly at Lund) or heavy extractable petroleum hydrocarbons (HEPH, particularly at Port Hardy) and at least seven types of metals (particularly Mo at Port Hardy). These contaminants exceeded ISGQ guidelines in nearly every sample (Table 6) which resulted in a general disparity between the harbour treatments and the reference samples (Figures 10 and 11). Elevated contamination was accompanied with large variability among samples at Port Hardy and Lund reflecting a distribution of chemicals to “hotspots” within each harbour (Figure 10). The source data set is provided (Appendix 1).

Despite the presence of chemical contaminants at all locations toxicity levels were generally low (Figure 12). The Microtox test (Environment Canada 2002), which is commonly used as a pre-screening tool, found four samples to be below the competency threshold of 1000 mg/l. Of these two fell below the 80% thresholds required for amphipod survival (Environment Canada 1998) or echinoderm development (Environment Canada 2011). The two samples that failed two toxicity tests were from inside Lund and Port Hardy harbours in samples with the highest concentrations of the hydrocarbons (F3 and F4, Lund5 and PtHd1, Table 6).

3.4. COMPARISONS OF HARBOURS AND THEIR HABITATS

3.4.1. Biotic Comparison among Harbour Habitats

Aquatic habitats within small craft harbours exemplify a wide range of habitat features, some natural and some created. Consequently a harbour may be expected to support a diverse range of biological communities (Tables 1, 2, and 5). Specifically a diverse range of substrate compositions had a great influence on the nature of the taxa in the community that was supported. Benthic communities associated with unconsolidated substrates logically differ from those associated with the consolidated surfaces of both types of breakwaters (Figure 13, ANOSIM pairwise $R > 0.77$ $p=0.001$). Similarly, the continually wetted surface on a floating structure supports a community that differs from tidally influenced riprap (pairwise $R > 0.41$, $p=0.001$ and Table 1).

Taxa richness (diversity) and overall taxa abundance are two metrics that measure ecological state regardless of harbour habitat type, and are perhaps more appropriate, simple, and direct than taxa composition for assessing the influence of the habitat created or lost during harbour development. These metrics were positively correlated (Figure 14) and could be used to distinguish among habitat types in the harbours and among the harbours themselves. Taxa richness and overall quantity was greatest among establish community samples with rubble perhaps having a slightly greater number of individuals and the floats having a greater taxa richness. Benthic habitats were nearly as rich taxonomically as breakwater substrates but with fewer individuals (Figure 14) that weighed less (Figure 6). Settling plates, having been exposed for only six months, had the lowest taxonomic diversity, and, based on the size of the ellipses had either the most variation among locations, on floating structures, or the least variation, on rip rap structures.

3.4.2. Overall Ranking of Harbour Health

Despite being conceptually appealing, a triad-based approach combining biological community, contaminant and toxicity characteristics in a single analysis did not corroborate statistically with the multivariate comparisons of harbour health. Multivariate comparisons based on ANOSIM analyses revealed harbours, their communities and the chemicals they contained (but not their toxicity) as distinguishable from references particularly at Lund and Port Hardy (Table 7). Areal comparisons of triads produced for each harbour were not significantly different (Table 7, SQT, $p=0.08$). However, as a tool to rank harbours based on their environmental impact the triad plots of average indices provided conclusions that were generally similar to the multivariate analyses (Table 7). Relative to references Port Hardy, with lower biological richness, and Lund, with high chemical concentrations, were more influenced by harbour construction and operation than Cowichan. Yet, biologically, the triad approach depended on measures of diversity and therefore at Lund it missed specific differences in the harbour community structure relative to the outside references (Figure 8). Also, metal and hydrocarbon contamination at Port Hardy, clearly identified with the MDS analysis (Figures 10, 11 and Table 6), was not identified as a sediment quality issue when examined with the triad approach (Table 7). Nevertheless, the contamination that did occur had little toxicological effect in any of the harbours (Table 7 and Figure 12).

4.0. DISCUSSION

With the many types of coastal alterations provided by harbour construction it is unlikely that ecological succession will follow a trajectory common among harbours or achieve taxonomic endpoints similar to natural systems. Hence estimating comparative losses or gains in productive habitat or predicting an ecological outcome in terms of community composition in relation to habitat alteration in small craft harbours is elusive (Glasby and Connell 1999). Harbour construction creates unnatural surfaces in unusual locations and disturbances to circulation and light that are specific to each harbour and generally doesn't attempt to create habitat to mimic that which is lost. Perhaps an accounting of habitat gains and losses will improve if based on metrics that represent overall ecosystem function such as biological production (Wong and Dowd 2016) or biodiversity. Furthermore, accounting for and comparison of harbour pressures occurs in the midst of a gradient of natural environmental influences, each geographically specific. Natural variability in water characteristics such as salinity and temperature were influenced by streams found adjacent to Cowichan and Port Hardy harbours, particularly during higher flows in the winter; or, in the case of salinity at Port Hardy, by proximity to the open ocean. Harbour structures which may contribute to habitat production can be detrimental in some circumstances if for instance decreased water flushing causes depressed dissolved oxygen values which were observed on occasion below the water quality guideline of 5 mg/l (BC Ambient Water Quality Guidelines 1997). Dissolved oxygen values are also positively influenced by summer photosynthesis and warmer winter temperature at depth in nearshore areas (Riche et al. 2014).

However, construction of breakwaters and shoreline installations will alter circulation patterns and water exchange and influence the settlement of contaminants (Guerra-Garcıa and Garcıa-Gomez 2005). Presumably, a floating breakwater or dock will have a different influence on circulation than a rubble mound wall and their placement in relation to prevailing conditions will create unique alteration to natural habitat features. Furthermore the upland activities adjacent to each harbour including parking lots, and storm water and sewage outfalls, and various industries, all potential sources of sediment and contaminants, will also have geographically unique origins and influences. Sediment with associated elevated levels of TOC provides binding sites for contaminants from both harbour and upland sources (Apitz et al. 2005). Port Hardy may receive TOC and contaminants via a nearby river but Lund, a much smaller community with modest freshwater input, may receive TOC through autochthonous algal production (Jassby et al. 1993) or from invertebrate faecal material, pseudo-faeces, exoskeletons, and shells settling from harbour structures to the benthos. Carbon enrichment of the sediments below mussel farms is well documented (Carlson et al. 2010) and may apply to the benthos below breakwaters, docks and boats. There is no ISQG for TOC in marine sediment; however Hyland et al. (2005) suggest that TOC below 1% represents natural conditions, while those above 3.5% are impacted. The 3.5% level reported at many Georgia Strait locations by Burd et al. (2008) is negatively correlated with biota abundance and diversity.

There is an expectation that the harbour's chemical signatures can be traced to historic events and accumulate from point sources unique to each harbour (e.g. Pottinger Gaherty 2002, URS Canada 2004). Large variation in chemistry among samples from locations within Lund and Port Hardy supports the notion that much coastal contamination is localized and can be sourced (e.g. Yunker et al. 2002). However, Port Hardy, arguably the most contaminated harbour of the three has the briefest history among the harbours, provided similar services and had no unique sources of impact. All three harbours cater to both the recreational and commercial boating industry (primarily focussed on fisheries) which likely explains copper from anti-fouling agents as ubiquitous in harbour benthic sediments. Each has or has had shipyards, petroleum outlets and they all support the upland residential and commercial activities common to small fishing and forestry communities. However, Port Hardy had the largest length of docks of the three harbours which is arguably a surrogate for total use and a metric that may prove useful to measure overall harbour health once examined across more harbours.

Generally, positive correlation exists between human population and PAH's (Foster and Cui, 2008) but Lund, the smallest community of the three harbours, had the greatest concentrations of PAH in excess of guidelines. Longer chain hydrocarbons (C20-C50) may originate from crankcase oil leaks or waste oil containment, or are a legacy of partial combustion associated with two-stroke motors (Dorsey et al. 1997). Molybdenum in harbour samples may also be sourced through petroleum combustion as it is a catalyst in the refining industry. It is also a lubricant and a component of stainless steel both used extensively in the marine environment (CCME 1999a). Molybdenum is mined at Island Copper situated 30 km from Port Hardy, the harbour with the highest molybdenum values, suggesting a source for elevated background levels.

However, linking contaminants to their source and geographical comparisons of their concentrations are complicated by chemical-specific rates of degradation and demonstrated associations such as exist between high levels of TOC and PAH (Foster and Cui 2008). Macdonald and Crecelius (1994) describe PAH's and chlorinated organics to have a strong affinity to sediments while some metals and soluble organics have less affinity and may distribute more uniformly and further from the source. Similarly, heavier hydrocarbon fractions have low evaporation and generally adhere to sediment particles, resisting breakdown and remaining in sediments for extensive periods (Dorsey et al. 1997). Furthermore, contaminant detection limits may be far below concentrations that have biological consequences. While concerns for PAH's are well established (CCME 1999b, Yunker et al. 2002), Goyette and Brooks (1998) found that PAH's measured at increasing distances from creosote pilings ceased to have a biological influence beyond 0.65 m. Without more harbour replicates a clear trend linking specific contaminates to depressed or altered community structure is only speculation. However, the elevated metals and heavy extractable hydrocarbons found in Port Hardy may have influenced some community metrics perhaps depressing infaunal communities but only at specific locations. There was no evidence of widespread toxicity.

The range of taxa recorded from the benthic locations examined in this study have been identified as representative of communities in shallow sub-tidal (<100 m) unconsolidated sediment on Canada's west coast (Burd et al. 2008). However, they also noted a "dramatic" variation in benthic infauna among stations in Georgia Strait, predicted largely by organic carbon flux and quality. Polychaetes (both Sedentaria and Errantia) and a variety of bivalves were universally common in this and other studies but the geographical heterogeneity in the specific invertebrate assemblages, even among reference sites, emphasizes the need for designs that pair treatments to adjacent non-impacted sites with similar qualities (Green et al. 1993). Geographic heterogeneity discourages the use of an aggregate of regionally-based samples to define the reference condition as suggested by Tillan et al. (2008). Even so, replicated reference sites that differ only in the absence of development disturbance were difficult to find adjacent to the harbours in this study and will likely be a limiting factor in subsequent research. Moreover, there is a limitation to the use of temporal reference comparisons where the opportunity to sample sites before harbour construction is hindered by the infrequency of new construction of small craft harbours in Canada.

The reference condition approach creates a baseline which is assumed to represent a natural pre-impact environment before harbour development (Tillin et al. 2008). Two of the harbours in this study had low biological diversity and high contaminant loads relative to reference conditions and a third harbour at Cowichan with the lowest contaminant loads had the highest measures of ecological quality. Environmental gradients created with just three harbours and the absence of a temporal perspective hamper conclusions that link harbour development to biological decline. Linking an event(s) to a physical and/or chemical condition(s) and ultimately to a biological response(s) can only be implied with a reference approach. However, a well-established ecological progression of suspension to deposit and herbivorous invertebrate feeding guilds to create communities with fewer bivalves, and more opportunistic annelids (e.g. *Capitella capitata* and *Armandia brevis*), in response to elevated levels of wood waste, TOC or general benthic degradation, is reflected in this and other studies (Reish 1955, Conlan and Ellis 1979, Freese and O'Clair 1987, Bridges et al. 1994). Annelids are not universal indicators of degraded sediment; several genera were found in the less polluted sediments of Cowichan harbour and several reference sites (see Appendix 2).

It may also be misleading to assume that a reference represents habitat of the highest possible natural quality, from which all possible deviations are degradations are attributable to one or more treatment events. Benthic community colonization and progression processes are naturally stochastic as reflected in the biological variability that exists among reference locations in this study. Asymmetrical experimental designs with replicated control locations are seen as an appropriate response regardless of the opportunity to examine replicated disturbances (Underwood 1993). Conceivably, among communities some individuals, functional groups or environmental patterns that may exhibit more rigorous response to treatment stress than reflected in the spatial and/or temporal variability of the community as a whole. Sediment triads and the index of biotic integrity exist in response but do not necessarily relate to ecological consequences (Underwood and Peterson 1988) or describe environmental pathways and processes essential to the understanding of ecological communities. Therefore community metrics, multivariate analytics and process-oriented studies that provide insight into basic ecosystem structure are fundamental for effective science-based management and regulation (Peterson 1993). Carefully chosen metrics such as diversity, biomass, certain functional relationships or particularly sensitive indicators may be prescient and central to future large scale management schemes but must be rigorous criteria of ecological stress. Future schemes may also incorporate social sciences, economics and humanities to better define achievable reference points and address real-world applications to preserve ecological functions in our quest for sustainable development (Peterson 1993, Tillin et al. 2008).

Assessment of ecological risk in nearshore locations often focuses on the influence of chemical contaminants (Burton and Johnston 2010). But nearshore areas have multiple stressors, both natural and anthropogenic, that have complex and confounding effects (Whomersley et al.

2010, Macdonald and MacConnachie 2011). Harbour development with rubble mound revetments, bulkheads, floating breakwaters and docks act cumulatively with the harbour's many possible chemical stressors to alter naturally dynamic ecosystems in a manner that has received little scientific attention (Sobocinski et al. 2010). This study has not been able to unravel the impacts of the many ecosystem alterations found in harbours, but it has considered the growing interest in the degree to which artificial structures can act as habitat surrogates and create habitat in their own right (Elliot et al. 2007, Bulleri and Chapman 2010).

The rubble mound rip rap structures do have natural counterparts in adjacent natural rock outcrops but unfortunately consolidated surface reference sites were not considered in our experimental design. The placement of riprap often obliterates the soft sediment habitat on which it was placed and by necessity creates steeper harbour habitat. Based on elevation and substrate then, both important drivers controlling biotic zonation in coastal habitats (Ricketts and Calvin 1948), the habitat they produce is unlike what is lost. It is not surprising that this and other studies have found that consolidated surfaces of breakwaters or shoreline armouring will not support the original taxa that are adapted to benthic sediments (Sobocinski et al. 2010, Toft et al. 2013). Rubble used to armour shorelines may eliminate supralittoral terrestrial vegetation and wrack deposition causing a reduction in a variety of marine and semi-terrestrial invertebrates thus disrupting detrital-based food chains (Romanuk and Levings 2003, Sobocinski et al 2010). However, the cavernous, coarse and consolidated surfaces of a rubble mound structure do provide opportunities for a suite of organisms unlike both pre-construction communities and those found on smooth consolidated artificial surfaces of a floating breakwater. Intertidal pools, crevices and gullies allow organisms to live at higher elevations than they would otherwise be found (Kozloff 1983) and are often engineered as "living shorelines" when habitats are recreated (Erdle et al 2006). Similarly, low intertidal benches and beaches used to enhance or replace vertical seawalls or rubble mounds can alter community structure, and increase invertebrate taxa diversity and density of larval and juvenile fishes (Toft et al. 2013). Protection from wave and solar exposure, and predation may also influence community structure (Thomas et al. 1983). Although, in this study the degree of breakwater exposure to wave energy did not have a clear influence on biological communities.

Some artificial structures create distinctively artificial habitat as with the wetted surfaces of docks and floats that are not exposed to falling tides and thus have no natural counterpart. Similarly, structures made of concrete, metal or treated lumber are unnatural substrate that may not support the same sessile communities found on rock (McGuinness 1989, Moschella et al. 2005). Kozloff (1983) suggests the biota on floats are those normally found at lower levels of the intertidal zone (Zone 3, 0.0 m to 1.2 m in Puget Sound). This was generally true on the floating breakwaters in this study where they supported mats of *Mytilus*. Our rip rap sampling took place at lower elevations in Zone 3 (1.0 m) to be somewhat comparable to the habitat created by the floating structures (Kozloff 1983), but a preponderance of barnacles, not mussels were observed. This elevation is generally thought to be within the normal distribution of mussels but may experience disturbances at a frequency that prevents mussel establishment (three – five years, Ricketts and Calvin 1968) or the rubble mounds were more accessible to predators such as scoters or the starfish *Pisaster ochraceus* a known mussel predator (Paine 1974). The susceptibility of barnacle species to desiccation or the resistance to desiccation of their natural predators, has been used to confirm natural zonation patterns at static locations

(Ricketts and Calvin 1968) but our taxonomic resolution was insufficient to apply this theory to the floating structures.

Where, due to location or protective strategies, mature mussels and barnacles are not readily consumed by fish (Paine 1974) or other predators they will create biogenic ecosystems providing three dimensional substrate to support community diversity with annelids, caprellids, gammerids, isopods and small demersal fish (Harley and O'Riley 2011). Mussel beds encountered in this study where commonly populated with amphipods, caprellids and isopods particularly on floating structures and perhaps should be fostered as a component of ecological engineering methodology. However, their taxa richness and quantity remained comparable to rubble mound sites with fewer mussels, both exceeded sub-tidal benthic communities. Mussel beds supported the only fish encountered in this study which were incidental captures of gunnels on floating structures. Toft et al. (2007) using enclosure nets found no difference in salmonid density among riprap, cobble, or sand beach habitat, but with snorkel surveys found higher densities associated with subtidal riprap and pier peripheries. They concluded that harbour structures were more likely to support a perch/crab/sculpin community than pelagic fish such as salmonids. Our observations support this conclusion although our sampling schemes were not designed to capture fish. Piers will also provide spawning substrate for herring if piles are covered to isolate wood preservative treatments (Squamish Stream Keepers 2005). Morley (2012) describes greater overall fish abundance on unarmoured ("natural") shorelines but found salmonids in similar numbers at both armoured and unarmoured locations.

The brief length of time colonization plates were deployed may have limited community development to early successional stages particularly on substrate that was influenced by periods of tidal drying (e.g. riprap). Regrettably, the effective length of plate deployment was limited by their susceptibility to loss and vandalism. Following a six month deployment colonized substrates were not representative of the established communities. Number of taxa, biomass and individual abundance all compared unfavourably, and the variability among samples was larger. As a sampling method, plate deployment measures community and individual development rates and is commonly used to compare population productivity among areas (Harriott and Fisk, 1987). However, the method may not represent natural community processes (Crossman and Cairns 1974, Tyrell and Byers 2007, Glasby and Connell 1999) and is therefore limited as a method to measure response to impacts (Green 1979). As an alternative on consolidated substrates, quadrat scraping was a simple method that appeared to capture representative samples and demonstrated community discrimination, particularly between floating and other types of structures. However scraping efficiency likely declined on the uneven and rougher surfaces possibly causing an underestimation of community metrics on rubble-mound structures.

Taxa diversity is frequently used as a simple means to define community structure complexity but many diversity indices may be unnecessarily complex and obscure (Rickleffs 1979, and Green 1979). Diversity expressed as simple counts of taxa is the only truly objective measure of diversity (Poole 1974) and, when plotted against numbers of individuals (Green 1979, Index-*"d"*) illustrated taxa-rich and abundant invertebrate communities on both floating and riprap breakwaters. Glasby and Connell (1999) found an increase invertebrate abundance on harbour pilings relative to natural references, but with alterations in community composition that could possibly threaten its natural order (Glasby et al. 2007, Burelli and Chapman 2010). Novel habitats may support an inordinate number of aquatic invasive species (Cohen et al. 1998) particularly in brackish estuarine environments (Lu et al. 2007) where harbours commonly occur. Tyrell and Byers (2007) found invasive species colonized artificial substrates more readily than indigenous substrates. In contrast, Pister (2009) suggests that rubble-mound structures, with time, may be expected to assume a natural biological function, and, according to Davis et al. (2002), support a wide array of communities across a broad spatial scale based on exposure to wave energy. However, Peterson et al. (2000) and Morley et al. (2012) suggest the contrary, and Moschella et al. (2005) cites increased sedimentation/scouring, human activities and lower habitat complexity to justify a conclusion that coastal armouring is a poor surrogate for natural rocky habitat. The absence of an unconsolidated reference location in this study prevented the formal examination of this theory.

When choosing response variables, the Sediment Quality Triad (SQT) assumes biological, contaminant and toxicological qualities are all necessary to describe the degree of impact to a site. Sediment toxicity, high in some British Columbian harbours (Chapman et al. 1988), was inconsequential in the three harbours examined in this study, and may have contributed unnecessary complexity and cost to our analyses. Furthermore, in the process of creating the three triad components the multivariate character of each data set was reduced to a series of indices with the inevitable loss of pertinent information (Green 1979). Perhaps the SQT concept would yield different results if applied to sites where toxicity was a greater concern. Since its inception triad analysis has evolved beyond the descriptive to include the ordination of response variable structure, the reduction of data dimensionality and the application of tests of significance (Chapman 1996). More recently it has considered additional data components beyond the original three (Chapman and Hollert 2006); a concept of limited use in this report as only the biological and chemistry components contributed to treatment discrimination. The multivariate alternative to SQT's described by Green et al. (1993) and Chapman (1996) are philosophical extensions of the belief that three sets of variables can provide the weight of evidence to demonstrate an impact. Alternatively, among a suite of multivariate approaches, MDS is singled out as a good method to address the non-linear relationships that commonly occur among biological response variables, environmental gradients and toxicity (Green et al. 1993). It retains information from the original three database components, and examines statistical relationships among them identifying those that are influential. In this study, an MDS approach based on the original response variables was a more efficient (and sensitive) test of the H_o, "equivalent degree of environmental impact among three harbours", than harbour comparisons based on a triad of indices. It was able to elucidate pathways and processes through the identification of both natural and development-driven physical, chemical and biological gradients that exist within and among harbours. A failing of the univariate triad approach is the inability to incorporate the large heterogeneity among harbour samples which are consequential to statistical assumptions and interesting in their own right. Whereas the MDS/ANOSIM approach was capable of incorporating sample heterogeneity. The retention of the original variables exposes their natural biological variability among reference sites, revealing spatial patterns that are not properly attributable to coastal development. Experimental designs should pair harbour treatments with samples from many reference sites located along natural gradients and sample extensively within harbours where much of the heterogeneity is an outcome of point source impacts. The "harbour treatment" is almost certainly composed of multiple anthropogenic stressors, all interacting in a manner unique to each harbour but creating an impediment to predictions of causality.

The chemical and biological variables examined in this study provided a sound basis for ranking harbours based on their environmental quality but with only three locations conclusions regarding the overall influence of harbour structures on nearshore ecosystem health are at best limited. Similarly, with limited replication our insights into the interaction among these variable sets and therefore harbour processes should simply be regarded as preliminary guidance for future sampling. The multiple samples taken within harbour locations are not true replicates for examining harbour effects (Hurlbert 1984) but are necessary to characterize the heterogeneous nature of taxa composition and chemical distribution within harbour environments. Ultimately, we are likely to find as others have, that development intensity does not necessarily predict degree of ecological loss or disturbance (Whomersley et al. 2010). Nor can any metric, index or original variable, on its own, document biological response to all manner of anthropogenic (Whilm and Doris 1968, Blanchet et al. 2008) and natural habitat variation (Ferraro and Cole 2007). Multivariate approaches based on multiple lines of evidence remain a compelling means to examine disturbance patterns and identify ecological pathways and processes. Accordingly, our ability to predict and regulate the ecological outcome of future coastal activities and ultimately inform developmental design will improve. While there remains many gaps in our understanding of the influence of development on coastal ecosystems, and its regulation is an inexact process we do know that coastal modifications and the addition of structures to the environment can create quantifiable ecological gains and losses. The societal consequences and values are more elusive.

5.0. ACKNOWLEDGEMENTS

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7.0. TABLES

Table 1. Mean abundance (taxa number/cm^2 or biomass g/cm^2) in natural benthic habitats or on two types of created breakwaters. Breakwater colonization was measured with settling plates and compared to scrapings of established communities from within quadrats. At each location samples from inside protected sites were combined with sites that were outside and exposed. Values are combined from all sampling trips.

			Average Abundance No./cm^2					Biomass g/cm^2				
Taxa			Benthos	Colonizing Floating	Colonizing Rubble	Established Floating	Established Rubble	Benthos	Colonizing Floating	Colonizing Rubble	Established Floating	Established Rubble
Annelida			0.719	0.490	0.036	0.225	0.465	0.0019181	0.0020970	0.0000311	0.0003172	0.0001864
Crustacea												
	Amphipoda											
		caprellids	0.003	1.641	0.003	0.214	0.000	0.0000004	0.0005425	0.0000030	0.0000239	0.0000003
		other	0.121	0.461	0.073	0.650	0.279	0.0013142	0.0004292	0.0000148	0.0002311	0.0000360
	Cirripedia		0.009	0.488	0.437	0.528	1.666	0.0000354	0.1247820	0.0129192	0.0096672	0.0893139
	Cumacea		0.006				0.025	0.0000015				0.0000029
	Isopoda		0.005	0.386	0.001	1.796	0.126	0.0000009	0.0011974	0.0000030	0.0049278	0.0000685
	Other		0.136	0.024	0.018	0.007	0.018	0.0008418	0.0000094	0.0000437	0.0000400	0.0002144
	Tanaidacea		0.035	0.003	0.005	0.024	0.056	0.0000148	0.0000026	0.0000044	0.0000067	0.0000131
Diptera					0.002	0.011	0.141			0.0000059	0.0000128	0.0000112
	Chironomids											
Echinodermata			0.033	0.004	0.0001	0.002	0.004	0.0005490	0.0001768	0.0000059	0.0029261	0.0000053
Mollusca												
	Bivalvia											
		clams	0.341			0.001	0.264	0.0012926			0.0000022	0.0002219
		mussels	0.002	0.491	0.063	2.096	0.681	0.0000004	0.0081657	0.0000622	0.3007433	0.0057824
	Gastropoda											
		limpets		0.005	0.007	0.022	0.049		0.0000052	0.0000481	0.0003672	0.0003304
		nudibranchs	0.001			0.002	0.004	0.0000031			0.0000111	0.0000133
		snails	0.018	0.011	0.004	0.002	0.076	0.0001881	0.0000077	0.0000222	0.0000050	0.0001221
	Polyplacophora					0.004	0.001				0.0010056	0.0000160
Nemertea			0.010			0.094		0.0005469			0.0002428	
Other			0.056	0.030	0.002	0.019	0.073	0.0068259	0.0000086	0.0011965	0.0000183	0.0000104
Platyhelminthes						0.052	0.006				0.0001150	0.0000040
	Total		1.495	4.034	0.650	5.749	3.934	0.014	0.137	0.014	0.321	0.096
	Frequency		15	12	13	18	18					
	total g/# by taxa		0.235	0.331	0.601	1.853	0.116					

Table 2. Numerical abundance comparisons of colonization and established invertebrate communities on the protected (I) and exposed (O) sides of two types of breakwaters (floating and rubble) in three harbours (Cowichan (Cow)-C, Lund-L, Port Hardy (PtHd)-P) using ANOSIM and SIMPER analyses (Primer-E 2009). Statistics are provided where pairwise community comparisons were significant (ANOSIM R>0.30, p<0.05) or indicated as not significant (n/s). A SIMPER analysis identified the taxa most responsible for the dissimilarities, and the locations where they were most abundant.

	Comparison	R Statistic	Highest ranked taxa responsible for differences
Colonizing Floating	**Global**	0.79	
	Harbour vs Exposed		
	Cow	0.733	Cirripedia (O)/ Bivalvia-mussels (O)
	Lund	0.744	Amphipoda-caprellids (I)/ Annelida (I)
	PtHd	ns	
	Harbour		
	Cow Harbour - Lund Harbour	0.91	Amphipoda-caprellids (L)/ Annelida (L)
	Cow Harbour - PtHd Harbour	0.73	Cirripedia (P)/ Isopoda (P)
	Lund Harbour - PtHd Harbour	0.98	Amphipoda-caprellids (L)/ Cirripedia (P)/ Annelida (L)
	Exposed		
	Cow Exposed - Lund Exposed	1.00	Amphipoda-caprellids (L)/ Cirripedia (C)
	Cow Exposed - PtHd Exposed	0.46	Isopoda (P)/ Cirripedia (P)
	Lund Exposed - PtHd Exposed	1.00	Isopoda (P)/ Cirripedia (P)
Colonizing Rubble	**Global**	0.50	
	Harbour vs Exposed		
	Cow	ns	
	Lund	ns	
	PtHd	ns	
	Harbour		
	Cow Harbour - Lund Harbour	0.71	Cirripedia (C)/ Bivalvia-mussels (C)
	Cow Harbour - PtHd Harbour	0.68	Cirripedia (C)/ Bivalvia-mussels (C)
	Lund Harbour - PtHd Harbour	0.74	Annelida (L)/ Cirripedia (P)
	Exposed		
	Cow Exposed - Lund Exposed	0.60	Cirripedia (C)/ Amphipoda (C)
	Cow Exposed - PtHd Exposed	0.34	Amphipoda (C)/ Cirripedia (C)
	Lund Exposed - PtHd Exposed	0.65	Cirripedia (P)/ Amphipoda (L)
Established Floating	**Global**	0.80	
	Harbour vs Exposed		
	Cow	0.79	Isopoda (O)/ Cirripedia (O)
	Lund	ns	
	PtHd	0.32	Isopoda (O)/ Cirripedia (I)/ Bivalvia-mussels (O)
	Harbour		
	Cow Harbour - Lund Harbour	1.00	Bivalvia-mussels (L)/ Amphipoda-caprellids (L)/ Cirripedia (L)
	Cow Harbour - PtHd Harbour	0.90	Isopoda (P)/ Cirripedia (P)/ Amphipoda (C)
	Lund Harbour - PtHd Harbour	1.00	Bivalvia-mussels (L)/ Isopoda (P)/ Amphipoda-caprellids (L)
	Exposed		
	Cow Exposed - Lund Exposed	1.00	Isopoda (C)/ Bivalvia-mussels (L)
	Cow Exposed - PtHd Exposed	0.88	Isopoda (C)/ Amphipoda (C)/ Cirripedia (C)
	Lund Exposed - PtHd Exposed	1.00	Isopoda (P)/ Bivalvia-mussels (L)
Established Rubble	**Global**	0.40	
	Harbour vs Exposed		
	Cow	ns	
	Lund	ns	
	PtHd	ns	
	Harbour		
	Cow Harbour - Lund Harbour	0.38	Bivalvia-mussels (L)/ Cirripedia (C)/ Amphipoda (C)
	Cow Harbour - PtHd Harbour	0.65	Cirripedia (C)/ Bivalvia-clams (P)/ Bivalvia-mussels (C)
	Lund Harbour - PtHd Harbour	0.44	Bivalvia-clams (P)/ Bivalvia-mussels (L)/ Cirripedia (L)
	Exposed		
	Cow Exposed - Lund Exposed	ns	
	Cow Exposed - PtHd Exposed	ns	
	Lund Exposed - PtHd Exposed	0.46	Cirripedia (L)/ Isopoda (P)/ Bivalvia-clams (P)

Table 3. Correlations (BVStep Rho, Primer-E 2009) between the description of community taxa using numerical abundance vs biomass. Colonizing and established communities found on both floating and riprap breakwaters were considered separately.

Community Sampled	**Correlation (Rho) (Biomass to Abundance)**
Colonizing Floating	0.76
Colonizing Riprap	0.82
Established Floating	0.61
Established Riprap	0.63
Benthos	0.92

Table 4. Correlations (BVStep Rho, Primer-E 2009) among three taxonomic resolutions used to identify benthic communities. Samples were from replicated PONAR grabs in three harbours locations and their adjacent reference sites.

Grab Abundance	**Taxon1**	**Taxon2**	**Taxon3**
Taxonomic Resolution	Phyla	Order	Species
Number of Taxa	10	27	200
Correlation to Taxon3	0.72	0.81	

Table 5. Numerical abundance comparisons of benthic invertebrate communities sampled with replicate PONAR grabs in three harbours (I) and at adjacent reference sites (O) using ANOSIM and SIMPER analyses (Primer-E 2009). Statistics are provided where pairwise community comparisons were significant (ANOSIM R>0.30; p<0.05) or indicated as not significant (n/s). Taxonomic resolution was to the species level. Taxa most responsible for the dissimilarities and the locations where they were most abundant are identified (Cowichan (Cow)-C, Lund-L, Port Hardy (PtHd)-P).

Comparison	R Statistic	Highest ranked taxa responsible for differences
Global	**0.68**	
Harbour vs Reference		
Cow	ns	
Lund	**0.41**	Polychaeta Sedentaria (Asabellides spp., Armandia brevis) (I)/ Bivalvia (O)/ Polychaeta Errantia (Pholoe spp.) (I)
PtHd	**0.59**	Polychaeta Sedentaria (Capitella capitata) (I)/ Leptostraca (Nebalia sp.)/ Bivalvia (Rochefortia tumida) (O)
Harbour		
Cow Harbour - Lund Harbour	**0.97**	Polychaeta Sedentaria (Asabellides spp.) (L)/ Oligochaeta (Tectidrilus sp.) (C)/ Polychaeta Errantia (Pholoe spp.) (L)
Cow Harbour - PtHd Harbour	**0.96**	Polychaeta Sedentaria (Capitella capitata) (P)/ Bivalvia (Rochefortia tumida) (C)/ Oligochaeta (Tectidrilus sp.) (C)
Lund Harbour - PtHd Harbour	**0.95**	Polychaeta Sedentaria (Capitella capitata, Asabellides spp.) (P)/ Polychaeta Errantia (Pholoe spp.) (L)
Reference		
Cow Reference - Lund Reference	**0.35**	Bivalvia (Axinopsida serricata, Rochefortia tumida) (C)/ Polychaeta Sedentaria (Prionospio spp.) (C)
Cow Reference - PtHd Reference	**0.82**	Leptostraca (Nebalia sp.) (P)/ Polychaeta Sedentaria (Capitella capitata) (P)/ Bivalvia (Axinopsida serricata) (C)
Lund Reference - PtHd Reference	**0.79**	Leptostraca (Nebalia sp.) (P)/ Polychaeta Sedentaria (Capitella capitata) (P)/ Amphipoda (Anisogammarus pugettensis (P)

Table 6. Sediment chemical concentrations (mg/Kg) relative to the Interim Sediment Quality Guidelines (ISQG) for each sample in three harbours and their adjacent reference locations (shaded). Values for metals and PAH's are the amount they exceeded ISQG's; no guidelines exist for hydrocarbons or some metals (NG). Values less than ISQG's or those below detection limits were left blank. Harbour location codes are identified in Figure 1. Four chemicals were responsible for much of the variability among locations (*). See also Figure 11.

		Station																							
Parameter	ISQG (mg/Kg)	Cow1	Cow2	Cow3	Cow4	Cow5	CowA	CowC	CowE	Lund1	Lund2	Lund3	Lund4	Lund5	LundA	LundB	LundD	PtHd1	PtHd2	PtHd3	PtHd4	PtHd5	PtHdA	PtHdB	PtHdD
METALS																									
Arsenic (As)	7.24									11.16								1.36		0.06	3.96	3.36			0.46
Cadmium (Cd)	0.70	0.10								1.03				0.08		0.26		1.64	0.30	0.93	2.04	1.85			
Chromium (Cr)	52.30																								
Copper (Cu)	18.70	45.70	16.90	15.30	24.80	5.80				217.30	36.50	61.80		18.20				110.30	5.90	42.60	77.90	86.30			6.50
Lead (Pb)	30.20									90.80	14.80	7.80													
Mercury (Hg)	0.13									3.22	0.10							0.17		0.01	0.05	0.04	0.03		
Molybdenum (Mo)*	NG									5.5				5.8				11.9		5.3	11.3	11.1			
Nickel (Ni)*	NG	21.20	18.70	16.60	20.90	17.00	14.20	14.20	14.20	10.7	7.3	10.2	6.5	5.4				20.6	11.7	16.1	27.4	24.4	5.60	5.60	18.60
Vanadium (V)	NG	65.30	55.30	51.40	65.10	53.80	45.40	46.40	45.60	41.2	40.6	26		33.3	11.90	13.90	10.20	96.4	56	70.1	115.0	103.0			92.00
Zinc (Zn)	124.00									98.00								69.00			12.00	11.00			
PAHs																									
Acenaphthene	0.007			0.048						0.206	0.242		0.046							0.054					
Acenaphthylene	0.006		0.063	0.157	0.073					0.329	0.267		0.293	0.046											
Anthracene	0.047	0.094	0.070	0.343	0.096					1.433	0.731	0.128	0.910	0.187				0.040		0.045	0.037	0.105			
Benz(a)anthracene*	0.075	0.228	0.203	0.915	0.276					3.725	1.985	0.551	2.995	1.705				0.150		0.094	0.042	0.200			
Benzo(a)pyrene	0.089	0.171	0.133	0.674	0.248					2.601	1.401	0.215	1.761	0.786				0.075		0.064	0.037	0.130			
Chrysene	0.108	0.465	0.479	1.652	1.052					4.882	2.662	0.547	2.892	0.885				0.152		0.181	0.111	0.283			
Dibenz(a,h)anthracene	0.006			0.084						0.367	0.206		0.226	0.088											
Fluoranthene	0.113	0.877	1.117	3.307	1.077	0.036			0.057	6.257	5.117	0.626	3.477	4.017				0.529		0.690	0.200	0.422			
Fluorene	0.021			0.090						0.455	0.410	0.043	0.223	0.040						0.041					
2-Methylnaphthalene	0.020									0.102	0.223														
Naphthalene	0.035			0.046						0.203	0.284		0.022					0.019		0.032					
Phenanthrene	0.087	0.228	0.159	1.053	0.283				0.051	3.563	3.543	0.278	1.633	0.243				0.076		0.457	0.004	0.147			
Pyrene	0.153	0.957	0.664	3.227	1.027					5.777	4.117	0.569	3.397	4.507				0.658		0.818	0.764	0.947			
HYDROCARBONS																									
EPH19-32	NG									330								720		250	450	350			
HEPH*	NG									310								720		250	450	340			
F2 (C10-C16)	NG									38								57			57	40			
F3 (C16-C34)	NG	91		75	85					541	215	297	346	612		69		924	146	388	588	580	230	137	144
F4 (C34-C50)	NG									312	107	79	159	317				444	80	170	261	254	120	74	70
Total Organic Carbon (%)	NG	1.18	0.57	1.25	1.99	0.67	0.32	0.42	0.34	5.85	2.23	1.33	3.91	7.37	0.71	0.67	0.22	6.02	1.32	2.76	5.68	4.92	4.07	1.73	1.62
No. of failed toxicity tests														2				2					1	1	

Table 7. Harbour rankings from the least to the greatest impact based on biological, chemical and toxicity measurements using two analysis techniques, a Sediment Quality Triad (SQT) based on indices, and multivariate methods (MDS – ANOSIM). Values from both methods are derived relative to reference sites (RTR). SQT indices were averaged RTR values from each sample to create triangular areas for comparisons with an ANOVA. The ANOSIM provided R-values from pairwise comparisons between each harbour and its adjacent reference site. Biological values were based on comparison to references specific to each location while chemistry and toxicity references were pooled from all locations. Chemistry variables are listed in Table 6. ANOSIM values of R>0.30 indicated significant ($p<0.05$) site differences for the global and each pairwise comparison.

Method	Harbour	Biology	Chemistry	Toxicity	Triangular Area
SQT (ratio to reference)	Cowichan	1.2	3.1	1.0	2.6
	Lund	1.0	9.6	1.1	7.3
	Port Hardy	5.3	3.0	1.1	10.1
	ANOVA (df=2, F=3.2)				p=0.08
ANOSIM (R Values)	Cowichan	0.05	0.38	ns	
	Lund	0.41	0.65	ns	
	Port Hardy	0.59	0.58	ns	
	Global R	0.68	0.45	ns	

8.0. FIGURES

Figure 1. Features in three small craft harbours, located on the south coast of BC (a), were examined. Within the harbours, replicate samples of benthic communities and colonizing and established communities on rubble mound (riprap) and floating breakwaters were collected. They were contrasted to reference communities outside of the harbour's influence collected from the exposed side of the breakwaters or from the benthos (b-f). Harbour sampling stations are depicted with shaded shapes and exposed or reference stations with open shapes. For visual clarity, individual sampling sites on the breakwaters are not depicted. . Unconsolidated substrates were sampled with a PONAR grab, consolidated substrates were from scrapings within a quadrat (established communities) or by deploying settling plates on breakwaters (colonizing communities).

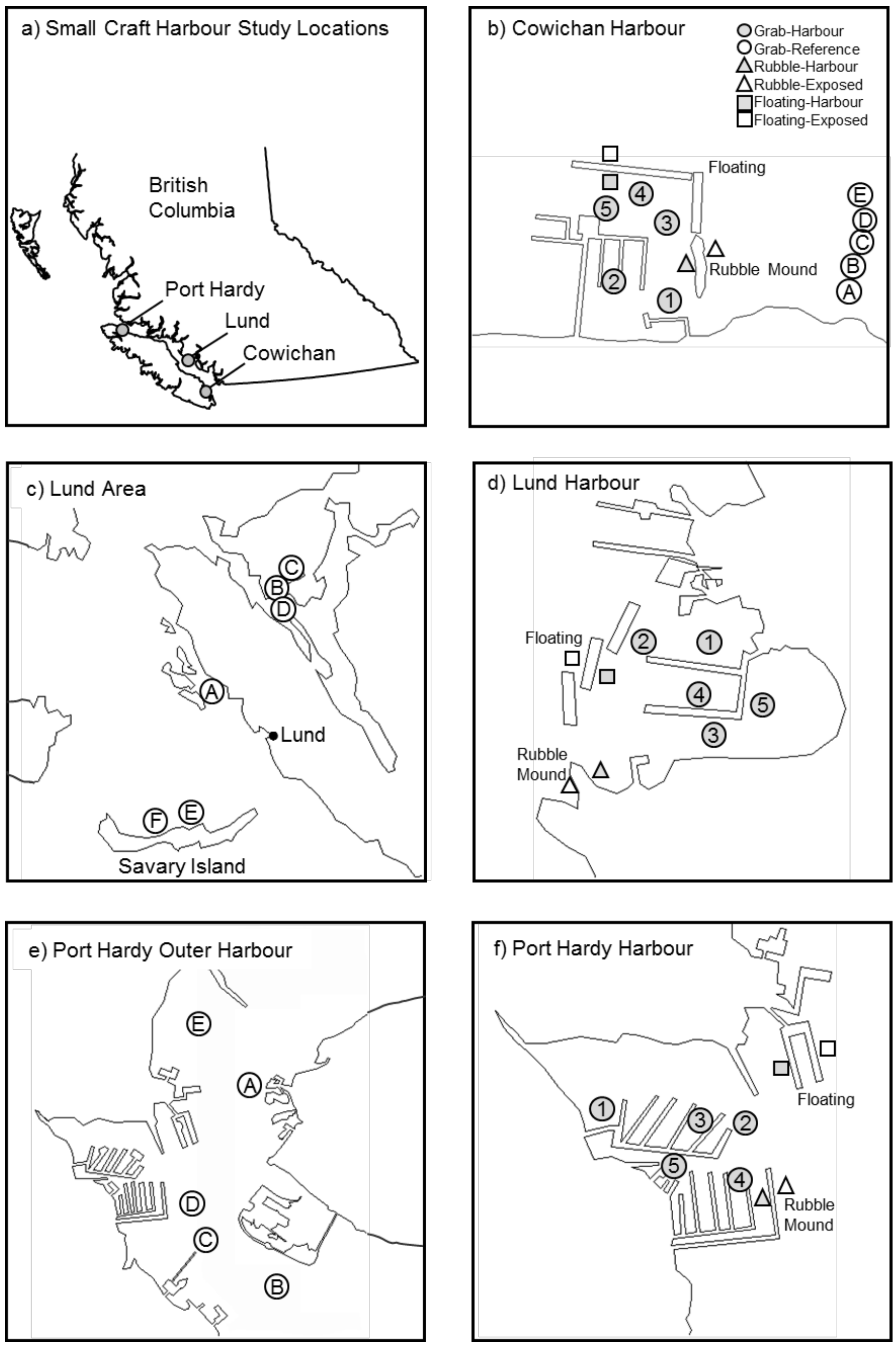


Figure 2. Daily average water temperatures (C^o) collected hourly from 1.0m below the water surface with data loggers (Hobo Tidbits®) attached to floating structures in three harbours (a). Delta comparisons of average daily temperature contrasting the exposed side of the rubble mound breakwater from the inside of the harbours at Lund (b) and Port Hardy (c) were calculated. Temperatures adjacent to two breakwater types in Lund harbour, floating and rubble mound were also compared (d).

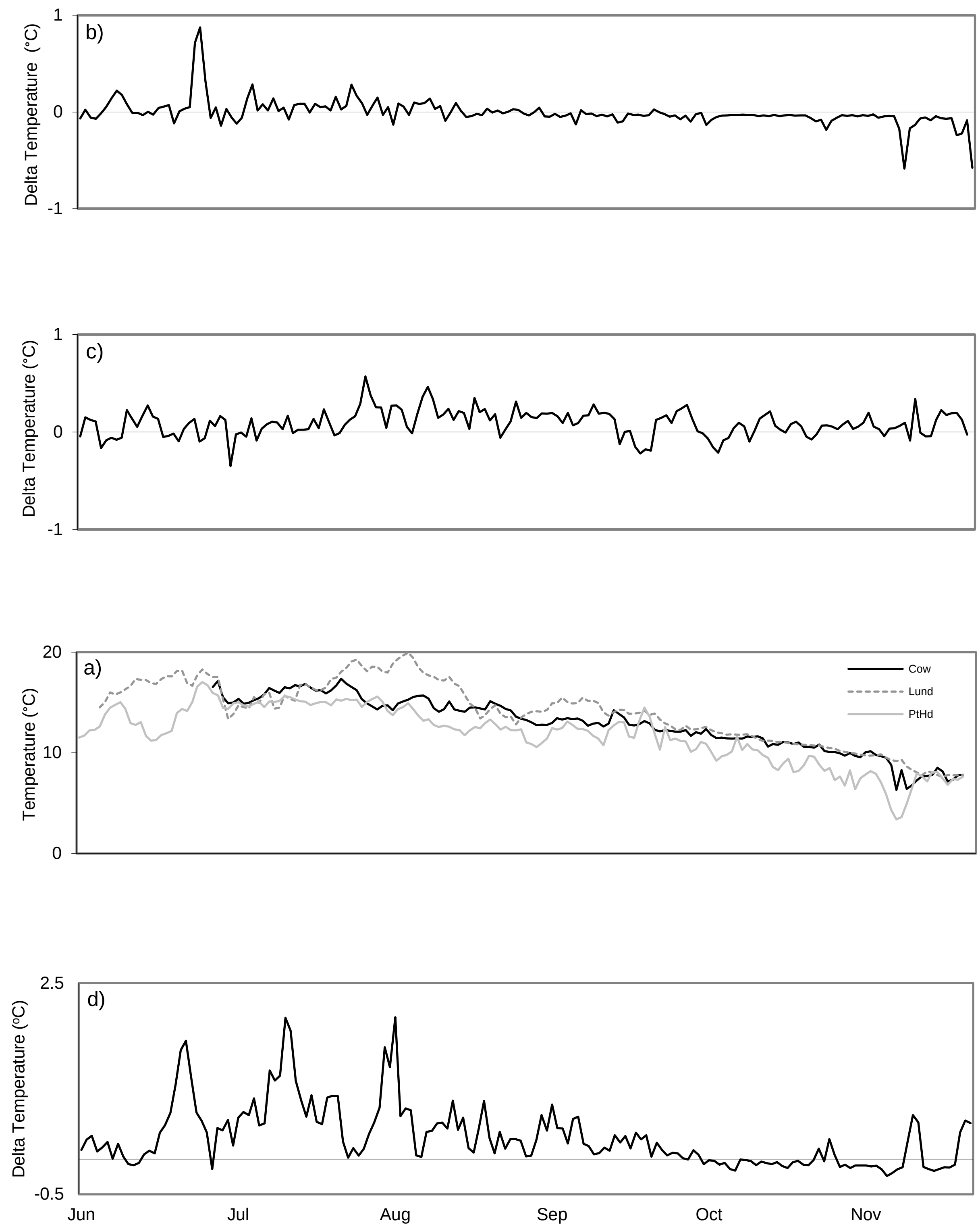


Figure 3. Temperature (C°), salinity (‰) and oxygen (mg/l) depth profiles (m) taken inside (In) and at reference sites outside (Out) of the three study harbours using a Yellow Springs Instruments model 85 meter. Samples were taken in December (Win) at all sites and in June (Sum) at Lund and Port Hardy.

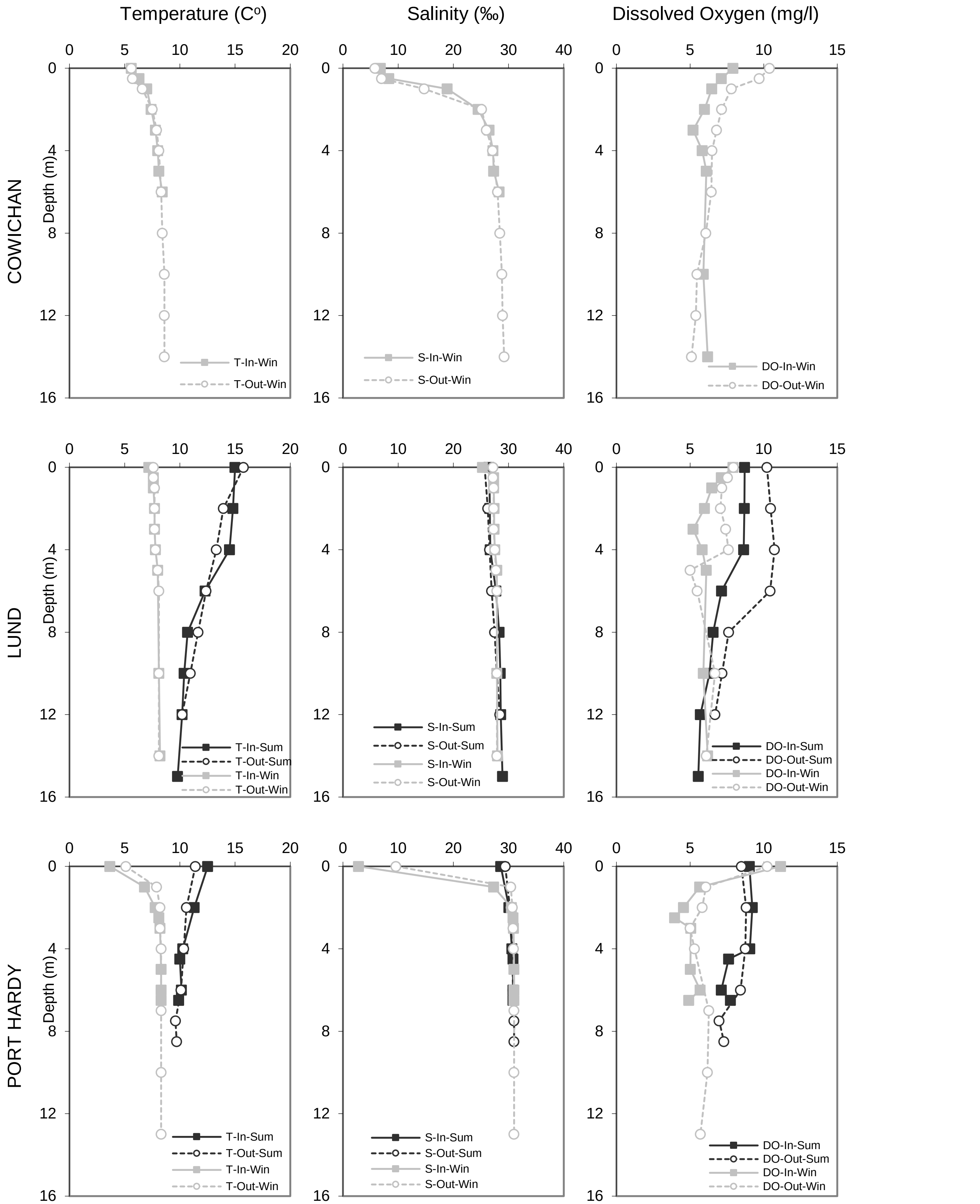


Figure 4. Average substrate size class distribution in sediment samples collected with benthic grabs and used to measure sediment chemistry at Cowichan (Cow), Lund, and Port Hardy (PtHd) harbours (n=5/harbour; shaded bars) and their associated reference stations (n=3/location; open bars). Substrate categories are gravel (a), sand (b), silt (c), and clay (d). Error bars indicate 95% confidence limits.

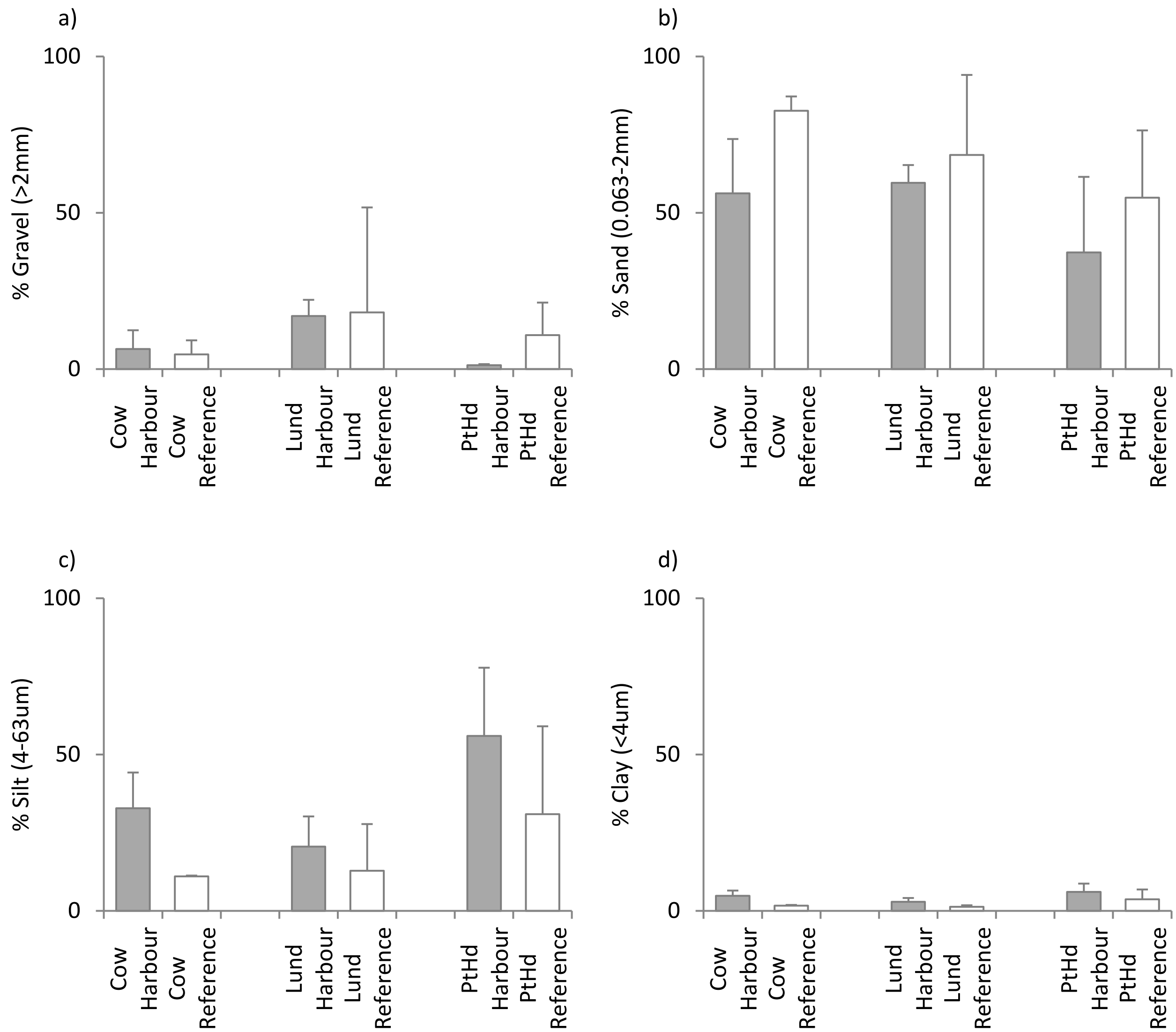


Figure 5. Mean percent total organic carbon (% TOC) in sediment samples collected from benthic grabs at Cowichan (Cow), Lund, and Port Hardy (PtHd) harbours (n=5/harbour shaded bars) and from adjacent reference locations (n=3/location, open bars). Data are presented with an arcsine transformation that was performed as a prerequisite to a two-way ANOVA (GLM location vs harbour treatment). Error bars indicate 95% confidence limits. TOC was higher in harbours than reference sites and Cowichan had the lowest values among locations.

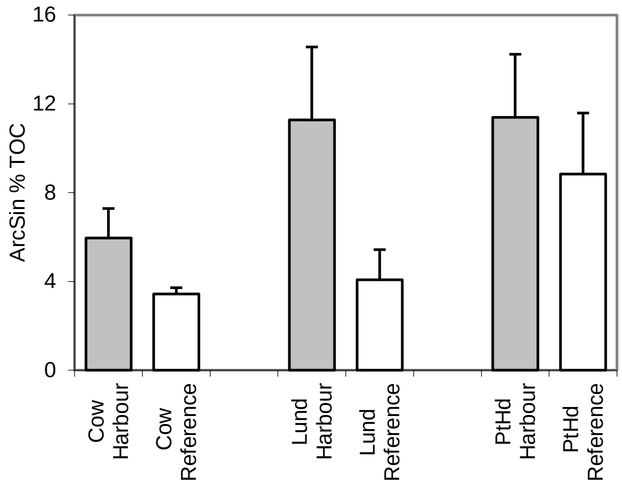


Figure 6. Mean numerical abundance (a) and biomass (b) of macro-invertebrates (>500μm) in samples from 3 harbours with error bars indicating 95% confidence limits. The small craft harbours, their breakwater locations, and the benthic and reference sampling sites are provided in Figure 1. Site abbreviations are used for Cowichan (Cow) and Port Hardy (PtHd). Colonizing and established communities were sampled on two types of breakwater with settling plates and quadrats. Benthic infauna were sampled with a PONAR grab. Benthic reference and exposed breakwater sites are represented with clear bars.

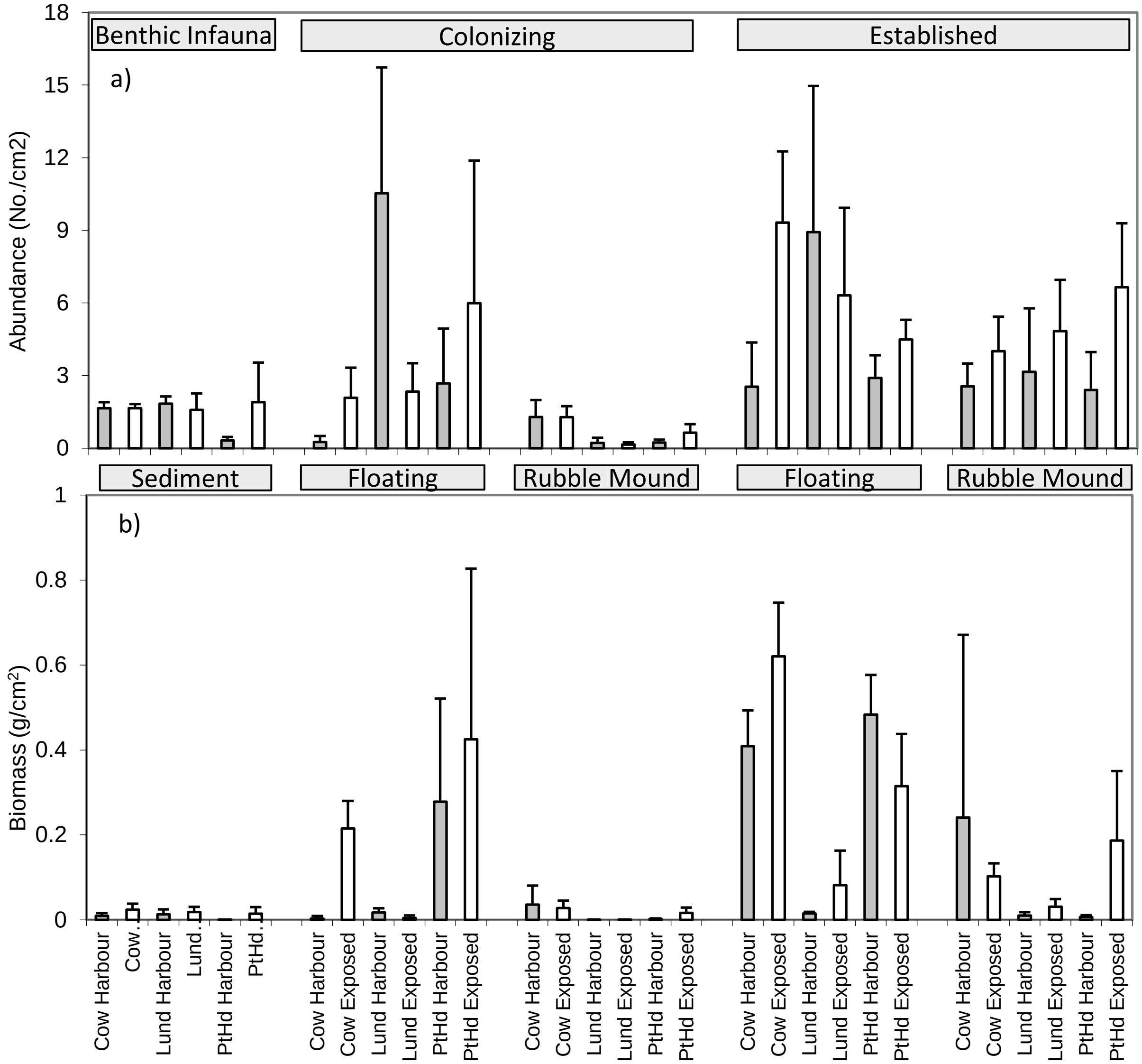


Figure 7. Two dimensional MDS plots of macro-fauna numerical abundance in the three small craft harbours, Cowichan (Δ), Lund (□) and Port Hardy (○), described on Figure 1. Results from the harbour side (solid symbols) and the exposed side (open symbols) of both floating (1) and rubble mound (2) breakwaters at each harbour are provided from separate analyses for colonizing (a - settling plates) and established (b - quadrats) communities. MDS and ANOSIM analyses were performed on square root transformed data in a Bray Curtis similarity matrix. Multiple comparisons with specific ANOSIM R values are provided in Table 2. Vectors describe taxa (order level resolution) most responsible for discrimination among harbours and breakwater exposure as determined using SIMPER analysis.

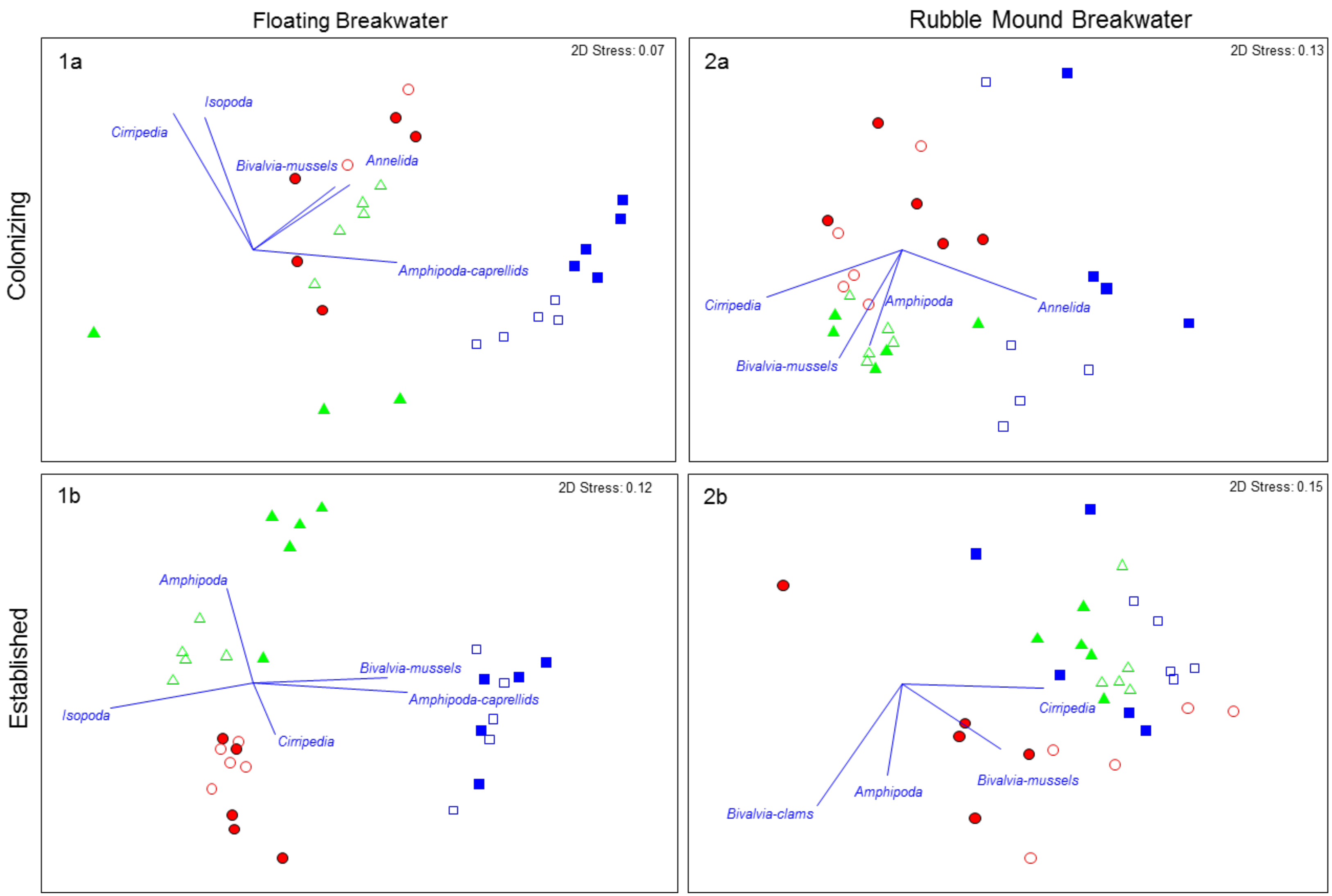


Figure 8. Two dimensional MDS plots of benthic macro-infauna (>500µm) abundance from the locations near Cowichan (∆), Lund (□) and Port Hardy (○) described in Figure 1. Taxonomic resolution was to the species level where possible. Results from collections inside each harbour (solid symbols) and outside from the reference sites (open symbols) show reference sites B and D (Port Hardy) as anomalous communities likely resulting from concentrations of wood waste (see text and Figure 9 for details). MDS and ANOSIM analyses were performed on standardized and square root transformed data in a Bray Curtis similarity matrix. Multiple comparisons with specific ANOSIM R values are provided in Table 5.

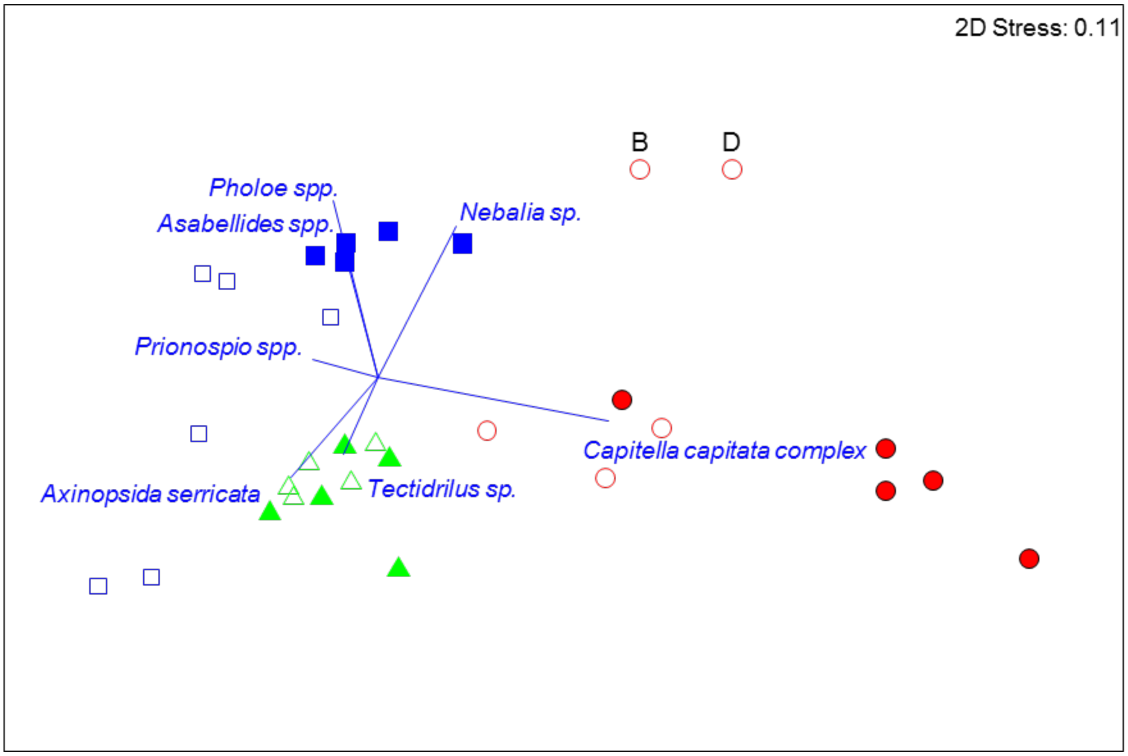


Figure 9. A focus on the unique benthic macro-infauna (>500µm) at stations B and D in Port Hardy where large quantities of unanticipated wood waste were encountered. At Port Hardy (PtHd) two deposit feeders, *Anisogammarus pugettensis* and *Nebalia* sp. were more common than the filter feeding Bivalvia, relative to reference stations in other harbours (Cowichan - Cow). Clear bars indicate a count of zero, error bars indicate 95% confidence limits.

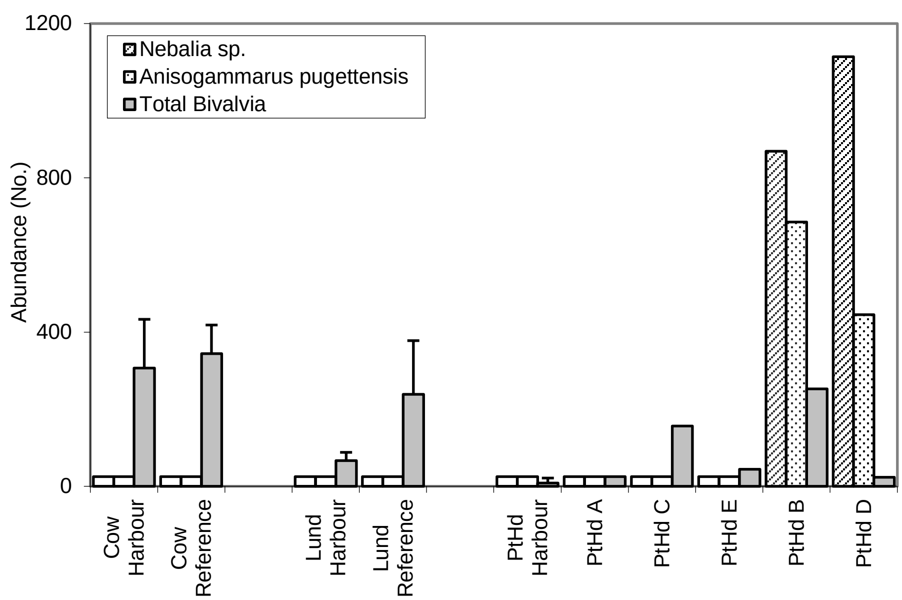


Figure 10. A two dimensional MDS plot comparing sediment chemistry at harbour stations in Cowichan (∆), Lund (□) and Port Hardy (○), relative to references pooled from all locations (◊) (Figure 1). MDS and ANOSIM analyses were performed on normalized data in a Euclidian similarity matrix. Vectors describe metal and hydrocarbon categories most responsible for discrimination among harbours and the reference locations (ANOSIM R=0.972) and are also plotted individually (Figure 11). Appendix 1 provides a complete list of the chemicals and their concentrations from all samples. Stations at Lund (5) and Port Hardy (1) were the only samples to fail more than one of the three toxicity tests (Figure 12).

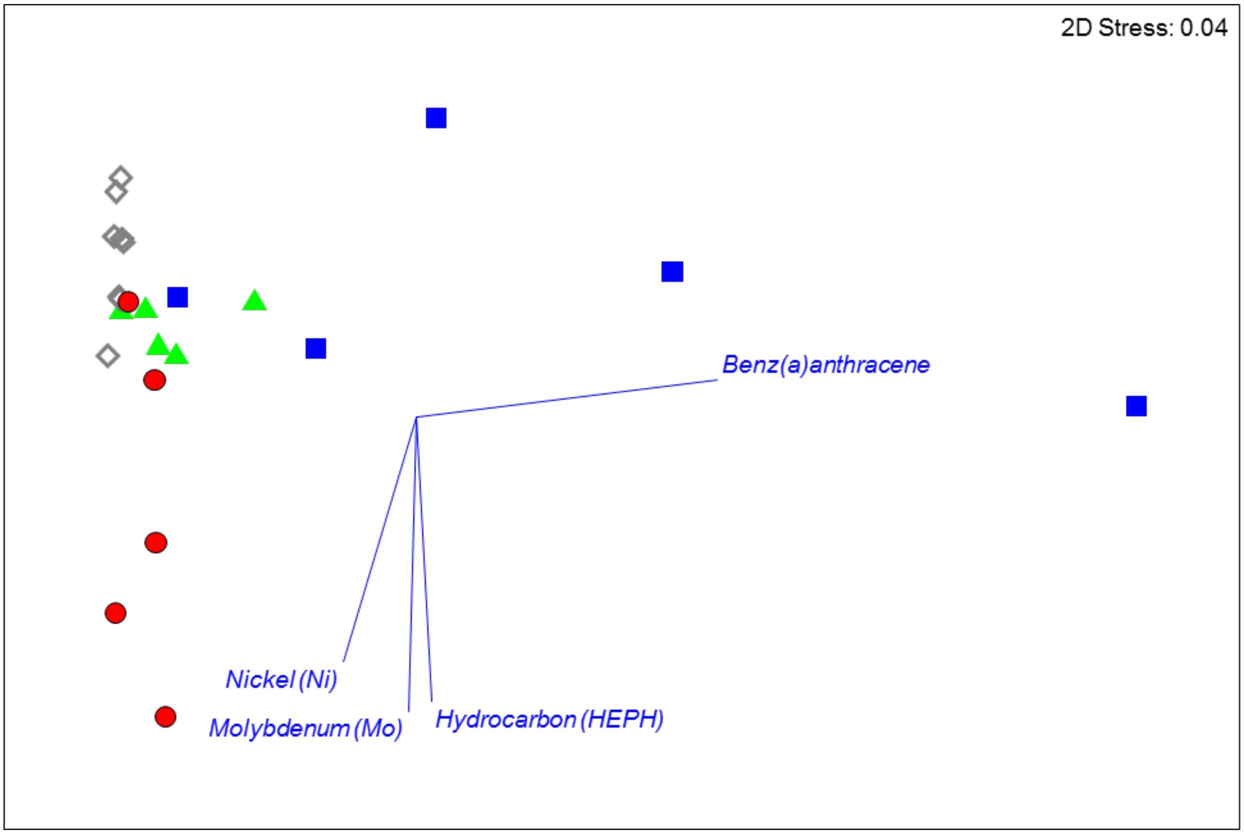


Figure 11. Mean sediment chemistry (mg/kg) in benthic samples from the three harbours (n=5/harbour, Figure 1) and from reference sites pooled from all locations (n=9). Interim Sediment Quality Guidelines (ISQG) are provided when available. Error bars describe 95% confidence limits. Copper and zinc (a, b), used in antifouling applications, are generally associated with vessel maintenance and harbour contamination. The chemicals most responsible for harbour discrimination, identified in Figure 10, are nickel (c), molybdenum (d), a PAH (Benz(a) Anthracene - e) and heavy extractable hydrocarbons (HEPH- f).

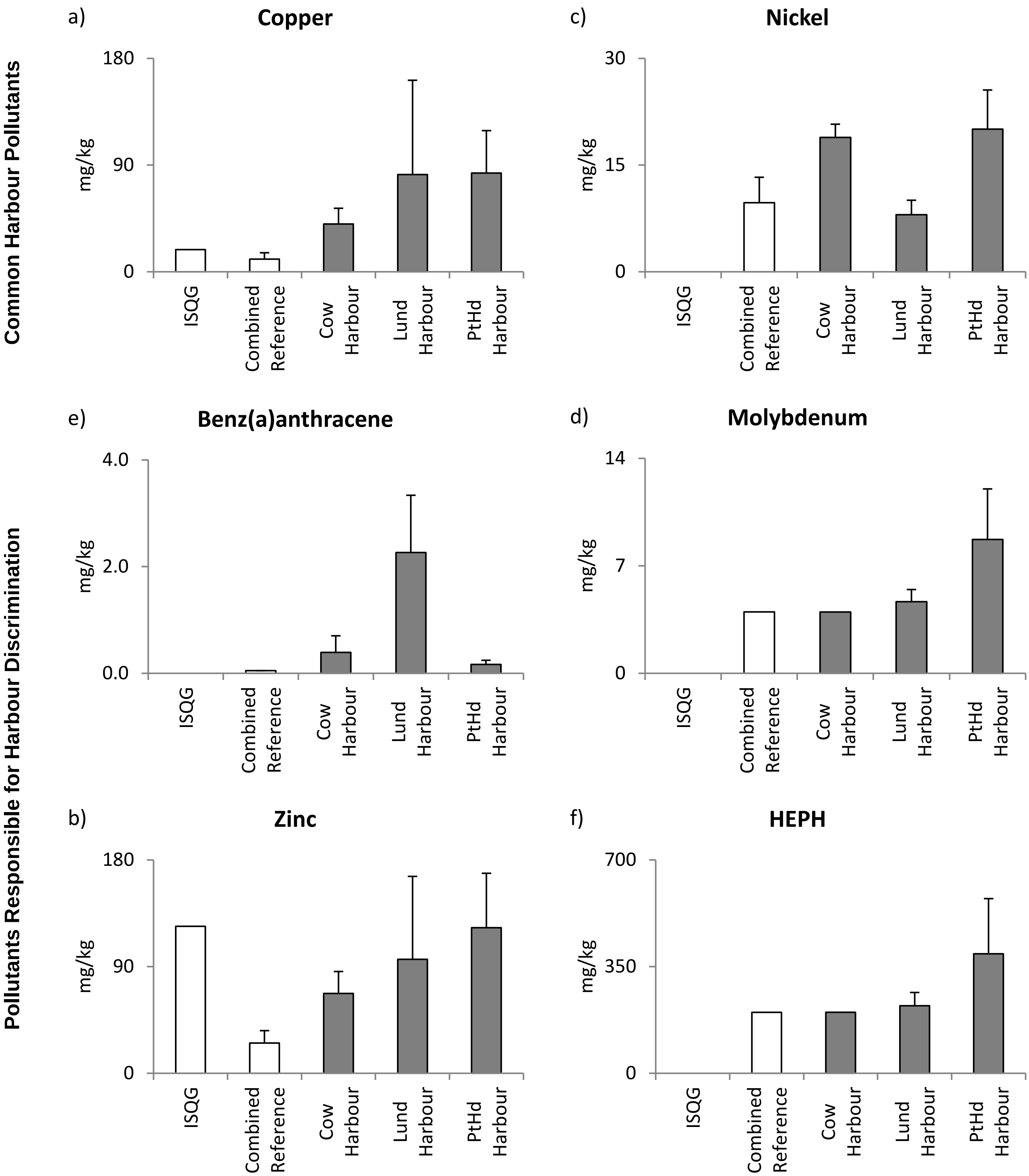


Figure 12. Three toxicity tests applied to individual benthic sediment samples from harbour treatment (numbers) and reference (letters) stations in Cowichan (Cow), Lund and Port Hardy (PtHd). The Microtox test (a) can be used to pre-screen samples before performing amphipod survival (b) and echinoderm development (c) tests. Horizontal lines indicate established toxicity thresholds below which the sample has failed.

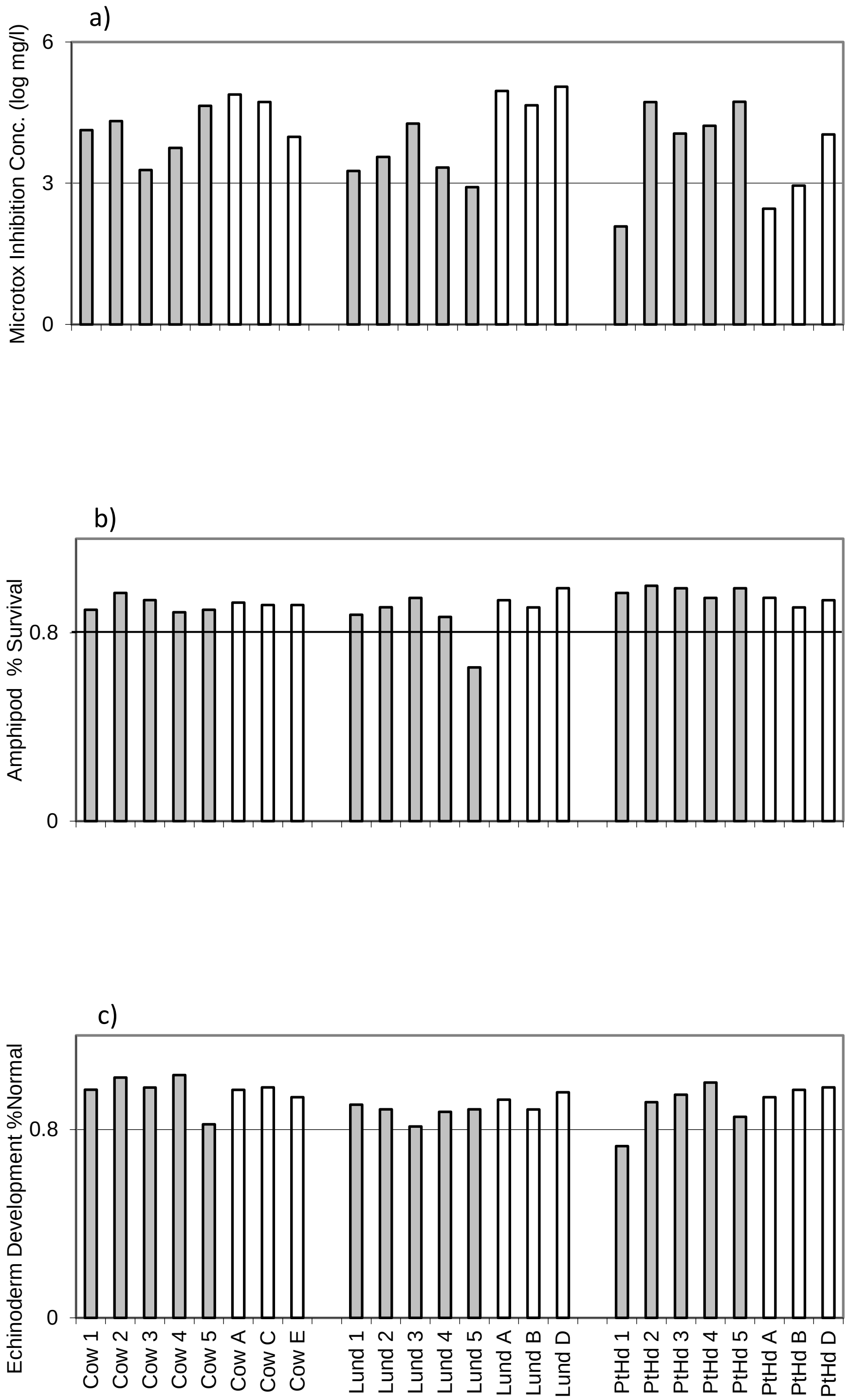


Figure 13. A MDS comparison of established biological communities from three different habitats commonly found in small craft harbours in B.C. Unconsolidated benthic habitats (∆), floating breakwater (□), and rubble mound (○) structures of the harbour had communities that were statistically distinct in all possible pairwise comparisons (ANOSIM R>0.41). Colonizing communities collected with settlement plates were omitted from this analysis. Taxa were resolved to the order level (Table 1) and data from all three harbours including both harbour (solid symbols) and reference or exposed stations (open symbols) were combined (Figure 1).

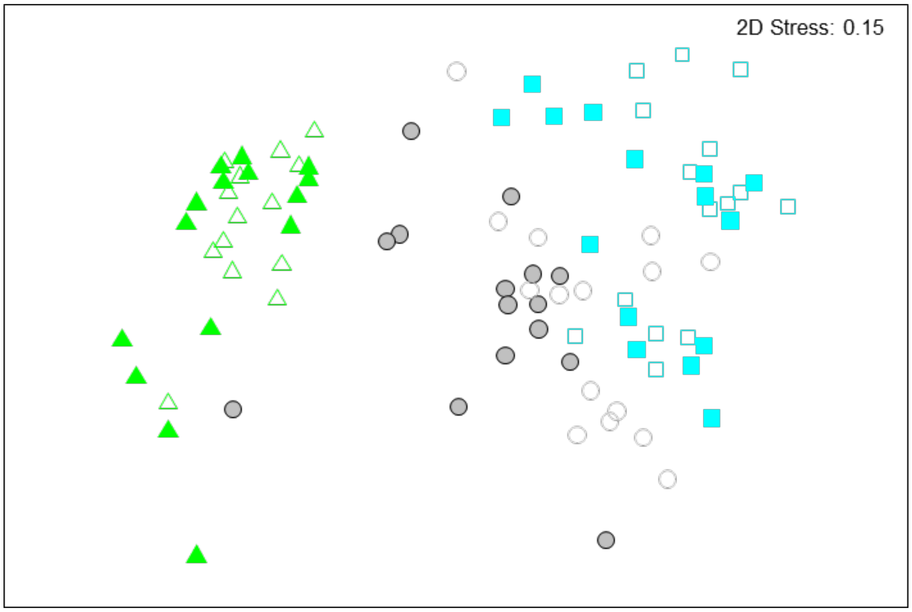


Figure 14. Numerical abundance (ln no./cm^2+1) vs taxa richness as a graphical representation of biological diversity in three harbours (Cowichan (∆), Lund (□) and Port Hardy (○) (Figure 1)), with three types of harbour habitat (benthic - blue symbols, floating structures – red and tan symbols, and rubble mound breakwaters – green and gray symbols), from harbour (solid symbols) and exposed sides of the breakwaters or benthic reference sites (open symbols). Collections of colonizers (settlement plates - red and green symbols) are plotted separately from established communities (quadrat or grab – blue, tan, and grey symbols) and enclosed in ellipses drawn by eye. Each symbol represents a mean of five samples with taxa resolution to the order level.

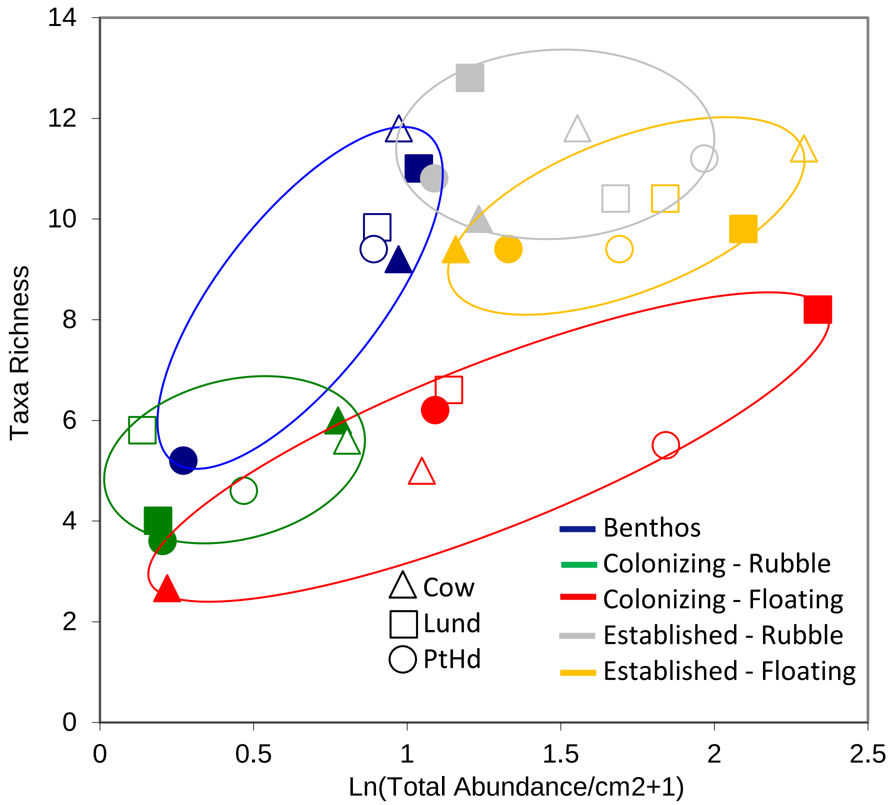
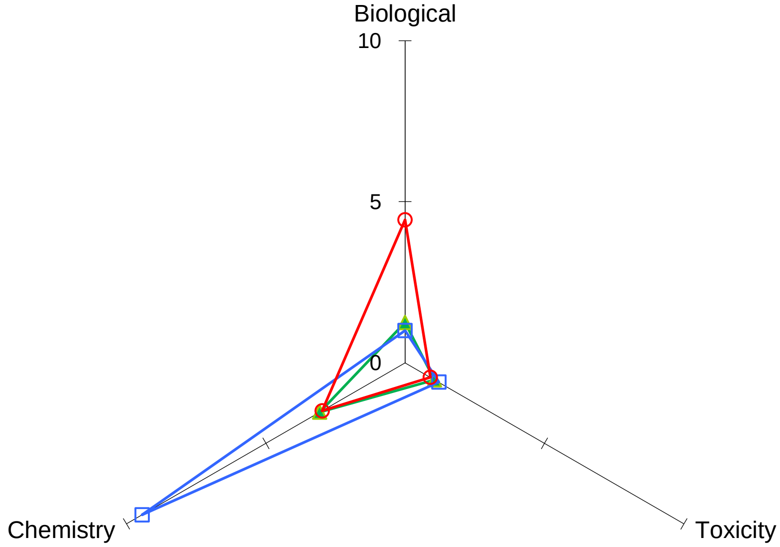


Figure 15. Biological, chemical and toxicological indices of environmental impact in Cowichan (Δ), Lund (□) and Port Hardy (○) harbours (Figure 1) relative to reference conditions, arranged in a triad for comparative purposes. . Chemistry variables are listed in Table 6. Chemical references are pooled among locations. The triangular areas provided a metric for statistical comparison of impact among harbours (Table 7).



9.0. APPENDICES

Appendix 1. Benthic sediment grain size and chemicals (by type) in samples from Cowichan (Cow), Lund and Port Hardy (PtHd) harbours (identified by number) or harbour reference locations (identified by letter). Chemical variables are in units of mg/Kg.

Type	Parameter	Cow1	Cow2	Cow3	Cow4	Cow5	CowA	CowC	CowE	Lund1	Lund2	Lund3	Lund4	Lund5	LundA	LundB	LundD	PtHd1	PtHd2	PtHd3	PtHd4	PtHd5	PtHdA	PtHdB	PtHdD
Physical Tests	Moisture	36.8	24.1	37.1	42.6	26.2	22.7	21.6	21.4	56.0	30.7	25.9	50.2	69.5	11.2	30.0	23.7	69.3	36.7	46.9	65.0	60.2	57.0	40.1	35.7
Physical Tests	pH	8.10	8.11	8.23	8.08	8.12	8.15	8.21	8.24	7.64	7.93	8.02	7.77	7.42	7.33	7.55	7.63	7.40	7.85	7.60	7.28	7.33	7.44	7.81	7.95
Particle Size	% Gravel (>2mm)	2.7	<1.0	10.9	16.3	<1.0	<1.0	4.2	8.9	11.4	23.1	23.7	13.4	13.1	52.4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.0	<1.0	19.2	12.4
Particle Size	% Sand (2.0mm - 0.063mm)	44.7	79.5	49.2	33.3	74.3	86.7	82.6	78.6	52.3	65.8	66.7	58.5	54.7	44.9	70.6	90.0	19.8	78.1	49.5	7.6	31.8	33.5	61.0	70.0
Particle Size	% Silt (0.063mm - 4um)	47.5	17.6	34.1	43.2	21.8	10.9	11.3	10.9	32.5	9.5	8.2	24.8	27.7	2.2	27.6	8.7	70.9	19.1	46.7	84.1	59.2	59.6	17.5	15.7
Particle Size	% Clay (<4um)	5.1	2.2	5.8	7.2	3.8	1.5	1.9	1.6	3.8	1.6	1.4	3.3	4.5	<1.0	1.8	1.1	9.3	2.3	3.5	8.3	6.9	6.9	2.3	1.9
Organic / Inorganic Carbon	Total Organic Carbon	1.18	0.57	1.25	1.99	0.67	0.32	0.42	0.34	5.85	2.23	1.33	3.91	7.37	0.71	0.67	0.22	6.02	1.32	2.76	5.68	4.92	4.07	1.73	1.62
Inorganic Parameters	Acid Volatile Sulphides									11.5	3.00	4.62	8.60	94.5	<0.20	0.62	<0.20	44.6	6.89	22.4	7.42	5.31	52.1	32.4	11.5
Metals	Antimony (Sb)	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Metals	Arsenic (As)	6.7	5.8	5.7	6.5	5.2	<5.0	<5.0	<5.0	18.4	5.2	5.6	<5.0	6.6	<5.0	<5.0	<5.0	8.6	5.5	7.3	11.2	10.6	<5.0	<5.0	7.7
Metals	Barium (Ba)	25.4	16.6	22.4	44.6	17.7	13.8	19.4	14.2	48.3	58.6	16.1	3.1	16.9	12.7	14.3	11.4	33.6	15.7	23.0	30.9	27.6	13.1	12.7	20.8
Metals	Beryllium (Be)	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
Metals	Cadmium (Cd)	0.80	<0.50	<0.50	0.54	<0.50	<0.50	<0.50	<0.50	1.73	0.52	0.60	<0.50	0.78	<0.50	0.96	<0.50	2.34	1.00	1.63	2.74	2.55	<0.50	<0.50	<0.50
Metals	Chromium (Cr)	29.4	23.0	23.5	29.6	24.8	19.1	19.9	19.3	26.7	14.7	30.2	<2.0	10.7	2.7	5.1	3.0	38.3	17.4	26.4	48.9	42.0	<2.0	<2.0	28.2
Metals	Cobalt (Co)	9.4	7.8	7.5	9.5	8.2	6.6	6.5	6.3	4.0	3.9	3.9	<2.0	4.0	2.4	2.3	<2.0	12.9	6.5	8.7	15.0	13.1	<2.0	<2.0	11.9
Metals	Copper (Cu)	64.4	35.6	34.0	43.5	24.5	13.8	17.2	15.5	236	55.2	80.5	<1.0	36.9	5.4	12.3	4.7	129	24.6	61.3	96.6	105	<1.0	<1.0	25.2
Metals	Lead (Pb)	<30	<30	<30	<30	<30	<30	<30	<30	121	45	38	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30	<30
Metals	Mercury (Hg)	0.0815	0.0358	0.0516	0.0616	0.0376	0.0168	0.0294	0.0245	3.35	0.227	0.0775	0.118	0.0544	0.0059	0.0180	0.0101	0.297	0.0489	0.144	0.184	0.170	0.161	0.0989	0.0291
Metals	Molybdenum (Mo)	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	<4.0	5.5	<4.0	<4.0	<4.0	5.8	<4.0	<4.0	<4.0	11.9	<4.0	5.3	11.3	11.1	<4.0	<4.0	<4.0
Metals	Nickel (Ni)	21.2	18.7	16.6	20.9	17.0	14.2	14.2	14.2	10.7	7.3	10.2	6.5	5.4	<5.0	<5.0	<5.0	20.6	11.7	16.1	27.4	24.4	5.6	5.6	18.6
Metals	Selenium (Se)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	1.25	<2.0	<2.0	14.0	<2.0	<2.0	<2.0	<2.0	1.11	<2.0	<2.0	<2.9	<2.1	17.2	15.0	<2.0
Metals	Silver (Ag)	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
Metals	Thallium (Tl)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Metals	Tin (Sn)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	42.7	13.0	9.2	<5.0	7.3	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Metals	Uranium (U)	0.967	0.463	1.04	1.11	0.734	0.315	0.349	0.362	4.31	1.55	1.12	2.98	2.39	0.799	0.639	0.338	3.15	1.03	1.72	2.91	3.07	1.75	1.26	1.05
Metals	Vanadium (V)	65.3	55.3	51.4	65.1	53.8	45.4	46.4	45.6	41.2	40.6	26.0	<2.0	33.3	11.9	13.9	10.2	96.4	56.0	70.1	115	103	<2.0	<2.0	92.0
Metals	Zinc (Zn)	96.2	51.9	58.1	82.9	48.2	34.1	37.4	36.9	222	72.5	96.1	1.0	89.0	22.6	25.1	16.0	193	51.0	99.3	136	135	3.5	3.4	50.7
Extractable Metals	Cadmium (Cd)-Extractable									0.011	<0.0050	<0.0050	<0.015	<0.010	<0.0050	0.0086	<0.0050	<0.040	0.0077	0.0122	0.017	0.0173	0.0056	<0.0050	<0.0050
Extractable Metals	Copper (Cu)-Extractable									0.260	0.324	0.285	0.797	0.030	0.015	0.046	0.015	0.309	0.080	0.078	0.233	0.419	0.180	0.097	0.084
Extractable Metals	Lead (Pb)-Extractable									0.434	0.147	0.058	0.358	0.119	<0.020	<0.020	<0.020	<0.16	<0.020	0.041	0.046	0.052	0.022	<0.020	<0.020
Extractable Metals	Mercury (Hg)-Extractable									<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Extractable Metals	Nickel (Ni)-Extractable									<0.10	<0.050	<0.050	<0.15	<0.10	<0.050	<0.050	<0.050	<0.40	<0.050	<0.050	<0.10	0.051	<0.050	<0.050	<0.050
Extractable Metals	Zinc (Zn)-Extractable									4.60	0.550	0.730	2.31	1.13	0.0608	0.163	0.0674	2.05	0.402	1.07	1.10	1.45	0.428	0.202	0.241
Volatile Organic Compounds	Benzene											<0.0050		<0.016				<0.018	<0.0070	<0.0070	<0.014	<0.010	<0.010	<0.0050	<0.0050
Volatile Organic Compounds	Ethylbenzene											<0.015		<0.016				<0.018	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015	<0.015
Volatile Organic Compounds	Methyl t-butyl ether (MTBE)											<0.20		<0.20				<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Volatile Organic Compounds	Styrene											<0.050		<0.050				<0.050	<0.050	0.055	<0.050	<0.050	<0.050	<0.050	<0.050
Volatile Organic Compounds	Toluene											<0.050		<0.050				<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Volatile Organic Compounds	ortho-Xylene											<0.050		<0.050				<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Volatile Organic Compounds	meta- & para-Xylene											<0.050		<0.050				<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Volatile Organic Compounds	Xylenes											<0.10		<0.10				<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Volatile Organic Compounds	Surrogate: 4-Bromofluorobenzene (SS)											90		83				84	90	86	86	88	84	89	91
Volatile Organic Compounds	Surrogate: 1,4-Difluorobenzene (SS)											92		86				88	93	90	87	88	86	91	92
Hydrocarbons	EPH10-19	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<320	<200	<200	<200	<290	<200	<200	<300	<230	<210	<200	<200
Hydrocarbons	EPH19-32	<200	<200	<200	<200	<200	<200	<200	<200	330	<200	<200	<200	<320	<200	<200	<200	720	<200	250	450	350	<210	<200	<200
Hydrocarbons	LEPH	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<200	<320	<200	<200	<200	<290	<200	<200	<300	<230	<210	<200	<200
Hydrocarbons	HEPH	<200	<200	<200	<200	<200	<200	<200	<200	310	<200	<200	<200	<320	<200	<200	<200	720	<200	250	450	340	<210	<200	<200
Hydrocarbons	F1 (C6-C10)											<10		<10				<10	<10	<10	<10	<10	<10	<10	<10
Hydrocarbons	F1-BTEX											<10		<10				<10	<10	<10	<10	<10	<10	<10	<10
Hydrocarbons	F2 (C10-C16)	<30	<30	<30	<30	<30	<30	<30	<30	38	<30	<30	<30	<47	<30	<30	<30	57	<30	<30	57	40	<33	<30	<30
Hydrocarbons	F3 (C16-C34)	91	<50	75	85	<50	<50	<50	<50	541	215	297	346	612	<50	69	<50	924	146	388	588	580	230	137	144
Hydrocarbons	F4 (C34-C50)	<50	<50	<50	<50	<50	<50	<50	<50	312	107	79	159	317	<50	<50	<50	444	80	170	261	254	120	74	70
Hydrocarbons	F4G-SG									<550	<500	<500	<500	1670				1020	<500	<500	<650	<600	<600	<500	<500
Hydrocarbons	Surrogate: 3,4-Dichlorotoluene (SS)											78		77				82	89	78	84	82	80	81	84

Polycyclic Aromatic Hydrocarbons	Acenaphthene	<0.050	<0.050	0.055	<0.050	<0.050	<0.050	<0.050	<0.050	0.213	0.249	<0.050	0.053	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.061	<0.050	<0.050	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Acenaphthylene	<0.050	0.069	0.163	0.079	<0.050	<0.050	<0.050	<0.050	0.335	0.273	<0.050	0.299	0.052	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Anthracene	0.141	0.117	0.390	0.143	<0.050	<0.050	<0.050	<0.050	1.48	0.778	0.175	0.957	0.234	<0.050	<0.050	<0.050	0.087	<0.050	0.092	0.084	0.152	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Benz(a)anthracene	0.303	0.278	0.990	0.351	<0.050	<0.050	<0.050	<0.050	3.80	2.06	0.626	3.07	1.78	<0.050	<0.050	<0.050	0.225	0.051	0.169	0.117	0.275	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Benzo(a)pyrene	0.260	0.222	0.763	0.337	<0.050	<0.050	<0.050	<0.050	2.69	1.49	0.304	1.85	0.875	<0.050	<0.050	<0.050	0.164	<0.050	0.153	0.126	0.219	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Benzo(b)fluoranthene	0.534	0.446	1.55	0.668	0.087	<0.050	0.053	<0.050	4.30	2.61	0.464	2.72	1.43	<0.050	<0.050	<0.050	0.373	0.063	0.367	0.341	0.495	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Benzo(g,h,i)perylene	0.131	0.087	0.293	0.136	<0.050	<0.050	<0.050	<0.050	1.34	0.782	0.108	0.680	0.264	<0.050	<0.050	<0.050	0.106	<0.050	0.090	0.075	0.096	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Benzo(k)fluoranthene	0.247	0.188	0.656	0.289	<0.050	<0.050	<0.050	<0.050	1.58	1.04	0.219	1.12	0.624	<0.050	<0.050	<0.050	0.148	<0.050	0.142	0.158	0.230	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Chrysene	0.573	0.587	1.76	1.16	0.078	<0.050	0.071	<0.050	4.99	2.77	0.655	3.00	0.993	<0.050	<0.050	<0.050	0.260	0.065	0.289	0.219	0.391	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Dibenz(a,h)anthracene	<0.050	<0.050	0.090	<0.050	<0.050	<0.050	<0.050	<0.050	0.373	0.212	<0.050	0.232	0.094	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Fluoranthene	0.990	1.23	3.42	1.19	0.149	0.079	0.107	0.170	6.37	5.23	0.739	3.59	4.13	<0.050	<0.050	<0.050	0.642	0.105	0.803	0.313	0.535	0.062	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Fluorene	<0.050	<0.050	0.111	<0.050	<0.050	<0.050	<0.050	<0.050	0.476	0.431	0.064	0.244	0.061	<0.050	<0.050	<0.050	<0.050	<0.050	0.062	<0.050	<0.050	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Indeno(1,2,3-c,d)pyrene	0.152	0.114	0.377	0.164	<0.050	<0.050	<0.050	<0.050	1.67	0.900	0.146	0.884	0.348	<0.050	<0.050	<0.050	0.141	<0.050	0.107	0.089	0.125	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	2-Methylnaphthalene	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.122	0.243	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Naphthalene	<0.050	<0.050	0.081	<0.050	<0.050	<0.050	<0.050	<0.050	0.238	0.319	<0.050	0.057	<0.050	<0.050	<0.050	<0.050	0.054	<0.050	0.067	<0.050	<0.050	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Phenanthrene	0.315	0.246	1.14	0.370	<0.050	0.075	0.059	0.138	3.65	3.63	0.365	1.72	0.330	<0.050	<0.050	<0.050	0.163	<0.050	0.544	0.091	0.234	<0.050	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Pyrene	1.11	0.817	3.38	1.18	0.130	0.069	0.071	0.123	5.93	4.27	0.722	3.55	4.66	<0.050	<0.050	<0.050	0.811	0.126	0.971	0.917	1.10	0.053	<0.050	<0.050
Polycyclic Aromatic Hydrocarbons	Surrogate: d10-Acenaphthene (SS)	129	110	130	115	104	130	121	114	91	82	88	84	87	84	79	88	91	80	93	79	91	88	86	88
Polycyclic Aromatic Hydrocarbons	Surrogate: d12-Chrysene (SS)	116	99	113	103	92	116	106	101	91	80	87	82	84	76	67	76	92	77	92	77	88	84	80	83
Polycyclic Aromatic Hydrocarbons	Surrogate: d8-Naphthalene (SS)	118	100	120	109	100	123	116	109	88	79	85	82	85	82	77	89	86	77	90	77	88	86	84	86
Polycyclic Aromatic Hydrocarbons	Surrogate: d10-Phenanthrene (SS)	120	102	118	108	105	117	110	106	91	82	88	83	86	81	75	85	93	80	92	80	91	87	86	86

Appendix 2. Biological collections from benthic sediments in three harbours in B.C. to the lowest taxonomic resolution possible. Locations are Cowichan (Cow), Lund and Port Hardy (PtHd).

TAXON1	TAXON2	TAXON3	Cow 1	Cow 2	Cow 3	Cow 4	Cow 5	Cow A	Cow B	Cow C	Cow D	Cow E	Lund 1	Lund 2	Lund 3	Lund 4	Lund 5	Lund A	Lund B	Lund C	Lund D	Lund E	Lund F	PtHd 1	PtHd 2	PtHd 3	PtHd 4	PtHd 5	PtHd A	PtHd B	PtHd C	PtHd D	PtHd E
ANNELIDA	Oligochaeta	Paranais litoralis																						1	3	1							1
ANNELIDA	Oligochaeta	Tectidrilus sp.	207	187	56		1	3	6	8	124	34		1	3		1														3		24
ANNELIDA	Oligochaeta	Tubificoid Naididae indet.		89	6		5	4	1	4	111	8	8		5	9	7	6							6				7		14	2	
ANNELIDA	Oligochaeta	Tubificoides sp.	30	158				1		35	64		6	1		3															2		
ANNELIDA	Polychaeta Errantia	Brania spp.																5															
ANNELIDA	Polychaeta Errantia	Cenogenus simpla																		43													
ANNELIDA	Polychaeta Errantia	Dorvillea annulata											6		2		11	1													1	1	
ANNELIDA	Polychaeta Errantia	Dorvillea longicornis																							5	1			1	6	2	32	1
ANNELIDA	Polychaeta Errantia	Dorvillea spp.														1																	
ANNELIDA	Polychaeta Errantia	Dorvilleidae indet.					3	2	2	9				53				1															
ANNELIDA	Polychaeta Errantia	Eranno bicirrata							1																								
ANNELIDA	Polychaeta Errantia	Eteone californica																							3								
ANNELIDA	Polychaeta Errantia	Eteone longa complex																															6
ANNELIDA	Polychaeta Errantia	Eteone nr. tuberculata	1											1												2		1				4	
ANNELIDA	Polychaeta Errantia	Eteone pacifica							1																								
ANNELIDA	Polychaeta Errantia	Eteone spilotus			4					1		2								1					1								
ANNELIDA	Polychaeta Errantia	Eteone spp.			1	4	1	4	4	1	1		5	9		6									41	4	7	8				2	
ANNELIDA	Polychaeta Errantia	Eulalia spp.															1																
ANNELIDA	Polychaeta Errantia	Eumida spp.														1						1											
ANNELIDA	Polychaeta Errantia	Eumida tubiformis												5							2												
ANNELIDA	Polychaeta Errantia	Exogone dwisula											3	2		3		7				17	4	1									
ANNELIDA	Polychaeta Errantia	Exogone lourei												1																1			
ANNELIDA	Polychaeta Errantia	Exogone molesta																	23	1	1		1										
ANNELIDA	Polychaeta Errantia	Gattyana cirrosa												1							1	1											
ANNELIDA	Polychaeta Errantia	Gattyana spp.																		1	2												
ANNELIDA	Polychaeta Errantia	Gattyana treadwelli				1		5																									
ANNELIDA	Polychaeta Errantia	Glycera americana	2	1	2		1				2	3																					
ANNELIDA	Polychaeta Errantia	Glycera nana		1					3							2	1	1	9	4	2												
ANNELIDA	Polychaeta Errantia	Glycera spp.	1										3	1		3	1	7															
ANNELIDA	Polychaeta Errantia	Glycinde armigera																1												1			
ANNELIDA	Polychaeta Errantia	Glycinde picta	1	4	1	6	4		2	1	6	2																					
ANNELIDA	Polychaeta Errantia	Glycinde polygnatha						2													6								1		2		
ANNELIDA	Polychaeta Errantia	Glycinde spp.	15	6	15	2	5	10	7	13	26	21	4	2	5			4	3	4		1	1										1
ANNELIDA	Polychaeta Errantia	Goniadidae indet.															1																
ANNELIDA	Polychaeta Errantia	Gyptis spp.														1																	
ANNELIDA	Polychaeta Errantia	Harmothoe imbricata											5	2																1			
ANNELIDA	Polychaeta Errantia	Harmothoe spp.				1					1		7	16	2	14		25	7	2		4	1						1	2			
ANNELIDA	Polychaeta Errantia	Harmothoinae indet.				4	3		2				18			5			1												1	4	
ANNELIDA	Polychaeta Errantia	Hesionidae indet.				2		1			1		12		28	34	27	6															
ANNELIDA	Polychaeta Errantia	Lumbrineridae indet.	4	1		37	48	60	24	32		10	2			7			8	8	4								1		3		
ANNELIDA	Polychaeta Errantia	Lumbrineris californiensis	1							7	3	5		42	2	2				7	11												
ANNELIDA	Polychaeta Errantia	Lumbrineris cruzensis				3	8	2	21				8										1										
ANNELIDA	Polychaeta Errantia	Lumbrineris inflata												1																			
ANNELIDA	Polychaeta Errantia	Lumbrineris spp.	1		3	4		1		5				11	5	4	3					2											
ANNELIDA	Polychaeta Errantia	Malmgreniella liei				1																											
ANNELIDA	Polychaeta Errantia	Malmgreniella macginitiei			1								1	2																			
ANNELIDA	Polychaeta Errantia	Malmgreniella nigralba														2																	
ANNELIDA	Polychaeta Errantia	Malmgreniella nr. liei								3																							
ANNELIDA	Polychaeta Errantia	Malmgreniella spp.											2	1								2											
ANNELIDA	Polychaeta Errantia	Microphthalmus sp.																							1				2				
ANNELIDA	Polychaeta Errantia	Microphthalmus spp.												5		1																	
ANNELIDA	Polychaeta Errantia	Micropodarke dubia				1	1	2	4		1		1	1	4	5	5	1			2									4	1	5	

ANNELIDA	Polychaeta Errantia	Nephtys caecoides																1				8	12										
ANNELIDA	Polychaeta Errantia	Nephtys cornuta		4		13	4	6	14	8									29	33	35												
ANNELIDA	Polychaeta Errantia	Nephtys ferruginea				3		1	1	4		1								1	2												
ANNELIDA	Polychaeta Errantia	Nephtys spp.						3			2				1			2				6											
ANNELIDA	Polychaeta Errantia	Nereidae indet.										2			1		9	33	1			2	7										
ANNELIDA	Polychaeta Errantia	Nereis procera	2		2		1			1							1	1							2						2		
ANNELIDA	Polychaeta Errantia	Nereis spp.									1																						
ANNELIDA	Polychaeta Errantia	Onuphidae indet.	2		3	2	7	19	7	7	18	7										20			2								2
ANNELIDA	Polychaeta Errantia	Onuphis elegans	1																														
ANNELIDA	Polychaeta Errantia	Onuphis spp.						1				1											5										
ANNELIDA	Polychaeta Errantia	Ophiodromus pugettensis						1					14	7	5	15	26													9	1	7	1
ANNELIDA	Polychaeta Errantia	Ophryotrocha sp.																								1		1	2				
ANNELIDA	Polychaeta Errantia	Paleanotus bellis					2	2	2	1								1											1				
ANNELIDA	Polychaeta Errantia	Paleanotus spp.														1																	
ANNELIDA	Polychaeta Errantia	Paranaitis polynoides								1																							
ANNELIDA	Polychaeta Errantia	Pholoe glabra			4							1																					
ANNELIDA	Polychaeta Errantia	Pholoe minuta																			1												
ANNELIDA	Polychaeta Errantia	Pholoe spp.	1		2	1	2	1		1	1	1	94	36	89	58	93	31				6	7		1						1	1	
ANNELIDA	Polychaeta Errantia	Pholoides asperus				6	1	6	2				1	5																			
ANNELIDA	Polychaeta Errantia	Phyllodoce groenlandica					1			2		1		1				1				4											
ANNELIDA	Polychaeta Errantia	Phyllodoce multiseriata																	2														
ANNELIDA	Polychaeta Errantia	Phyllodoce spp.			1			4			1		1			1		1			1		1						2				
ANNELIDA	Polychaeta Errantia	Phyllodoce williamsi												1	4			1											1	2			
ANNELIDA	Polychaeta Errantia	Pilargis berkeleyae			1			1																									
ANNELIDA	Polychaeta Errantia	Platynereis bicanaliculata						1			1		34	4	13	7	18	17		1	1	2							1	2		3	1
ANNELIDA	Polychaeta Errantia	Podarkeopsis glabrus		1		2	3	1		4						1			1														
ANNELIDA	Polychaeta Errantia	Podarkeopsis perkinsi																			1												
ANNELIDA	Polychaeta Errantia	Proceraea cornuta																			3												
ANNELIDA	Polychaeta Errantia	Scoletoma luti	7	2	1	57	25	29	12	46		1							14		17												
ANNELIDA	Polychaeta Errantia	Sphaerodoropsis sphaerulifer				3	5	4	3		1								1														
ANNELIDA	Polychaeta Errantia	Sphaerosyllis bilineata				1	3	3				4																					
ANNELIDA	Polychaeta Errantia	Sphaerosyllis ranunculus	1			12	6	17	3	3				1		2			1														
ANNELIDA	Polychaeta Errantia	Syllidae indet.															2															
ANNELIDA	Polychaeta Errantia	Tenonia priops																				1	1										
ANNELIDA	Polychaeta Errantia	Typosyllis caeca				12	17	14	10	7				26																			
ANNELIDA	Polychaeta Errantia	Typosyllis cornuta												1																			
ANNELIDA	Polychaeta Sedentaria	Ampharete labrops	1		1	1									1															2	11	1	1
ANNELIDA	Polychaeta Sedentaria	Ampharete nr. acutifrons																													1		
ANNELIDA	Polychaeta Sedentaria	Ampharete spp.			1	1																			2				9				
ANNELIDA	Polychaeta Sedentaria	Ampharetidae indet.	1		1			2	1	2	3	3	16	2	1				2			1	3								1		
ANNELIDA	Polychaeta Sedentaria	Anobothrus gracilis					3		1																							
ANNELIDA	Polychaeta Sedentaria	Aphelochaeta sp.N1								1									17	5	4												
ANNELIDA	Polychaeta Sedentaria	Aphelochaeta spp.		1	1	1	1																									
ANNELIDA	Polychaeta Sedentaria	Arenicolidae indet.							1																							
ANNELIDA	Polychaeta Sedentaria	Aricidea catherinae												1																			
ANNELIDA	Polychaeta Sedentaria	Aricidea nr. wassi																	2														
ANNELIDA	Polychaeta Sedentaria	Aricidea ramosa																	8	1													
ANNELIDA	Polychaeta Sedentaria	Armandia brevis	11	5	18		5	1			3		275	5	54	143	108	43				10	15		7	1	2	1		5	9	6	11
ANNELIDA	Polychaeta	Asabellides spp.											51		151	218	120	55			1												

	Sedentaria																																
ANNELIDA	Polychaeta Sedentaria	Axiothella rubrocincta																			50	55										
ANNELIDA	Polychaeta Sedentaria	Barantolla nr. americana								1			4			1																
ANNELIDA	Polychaeta Sedentaria	Boccardia pugettensis																														3
ANNELIDA	Polychaeta Sedentaria	Boccardiella hamata																		3												
ANNELIDA	Polychaeta Sedentaria	Capitella capitata complex	3	4	7	2	21	11	6	2	10	11	2				70				1			282	12	153	26	133	14	29	29	74	173
ANNELIDA	Polychaeta Sedentaria	Caulleriella pacifica											4		3	5	1	2															
ANNELIDA	Polychaeta Sedentaria	Caulleriella spp.												1																			
ANNELIDA	Polychaeta Sedentaria	Chaetopteridae indet.							1																								
ANNELIDA	Polychaeta Sedentaria	Chaetozone nr. columbiana																													1		
ANNELIDA	Polychaeta Sedentaria	Chaetozone spp.					1																								1		
ANNELIDA	Polychaeta Sedentaria	Chone bimaculata											10			8																	
ANNELIDA	Polychaeta Sedentaria	Chone spp.						1					1								1												
ANNELIDA	Polychaeta Sedentaria	Circeis armoricana											2					1															
ANNELIDA	Polychaeta Sedentaria	Cirratulidae indet.					1																		1								
ANNELIDA	Polychaeta Sedentaria	Cirratulus spectabilis						2																						8			
ANNELIDA	Polychaeta Sedentaria	Clymenura spp.																		6													
ANNELIDA	Polychaeta Sedentaria	Cossura pygodactylata				16		2																									
ANNELIDA	Polychaeta Sedentaria	Decamastus nr. gracilis							1					14																			
ANNELIDA	Polychaeta Sedentaria	Dipolydora cardalia	1		4	2	1	1		1									5	5	4												
ANNELIDA	Polychaeta Sedentaria	Dipolydora spp.						3					3	1	2				2		2				1				13	2		6	3
ANNELIDA	Polychaeta Sedentaria	Euchone incolor								1																							
ANNELIDA	Polychaeta Sedentaria	Euclymene nr. zonalis	2							1				12					1	2													
ANNELIDA	Polychaeta Sedentaria	Euclymeninae indet.																	2	2													
ANNELIDA	Polychaeta Sedentaria	Euclymeninae sp.1																	5	7													
ANNELIDA	Polychaeta Sedentaria	Galathowenia oculata				6	1	4	4		1								1														
ANNELIDA	Polychaeta Sedentaria	Heteromastus filobranchus				1			1																								
ANNELIDA	Polychaeta Sedentaria	Lanassa venusta venusta																													3		
ANNELIDA	Polychaeta Sedentaria	Leitoscoloplos pugettensis	4	2	3	1	4	12	6	8	9	4		1	1			10	2		1		2		1						83		2
ANNELIDA	Polychaeta Sedentaria	Levinsenia gracilis				1																											
ANNELIDA	Polychaeta Sedentaria	Magelona longicornis							3	5		1							8	9	10	1											
ANNELIDA	Polychaeta Sedentaria	Magelona spp.					2	2			1																						
ANNELIDA	Polychaeta Sedentaria	Maldanella harai																7															
ANNELIDA	Polychaeta Sedentaria	Maldanidae indet.				9	36	19	9	18	11	20							5			1											
ANNELIDA	Polychaeta Sedentaria	Mediomastus ambiseta							1										36	20	20												
ANNELIDA	Polychaeta Sedentaria	Mediomastus californiensis	7	12	25		4	7	10	13	5		9	8	8	14	1	8	9	3	4		1		5						1		
ANNELIDA	Polychaeta Sedentaria	Mediomastus spp.												1								1											
ANNELIDA	Polychaeta Sedentaria	Mesochaetopterus sp.	2				1		1	1												1											

ANNELIDA	Polychaeta Sedentaria	Mesochaetopterus taylori																					2										
ANNELIDA	Polychaeta Sedentaria	Nicomache personata						9																									
ANNELIDA	Polychaeta Sedentaria	Notomastus hemipodus			2					2				4																			
ANNELIDA	Polychaeta Sedentaria	Notomastus tenuis															2																
ANNELIDA	Polychaeta Sedentaria	Opheliidae indet.				2								6									2		21				5		14	38	11
ANNELIDA	Polychaeta Sedentaria	Ophelina acuminata		1		4	16	6	4	3	2																						
ANNELIDA	Polychaeta Sedentaria	Owenia nr. johnsoni		2		1								1			1						3								5		
ANNELIDA	Polychaeta Sedentaria	Owenia spp.	3		1	3	1				10	1	31		155	50	22				24	30	26								1		
ANNELIDA	Polychaeta Sedentaria	Oweniidae indet.											18					11															
ANNELIDA	Polychaeta Sedentaria	Paraprionospio pinnata		1		13	5	4	7	1									4	4	3								1				
ANNELIDA	Polychaeta Sedentaria	Pectinaria californiensis							1						3				2	1													
ANNELIDA	Polychaeta Sedentaria	Pectinaria granulata				2			1								1	1				2	6										
ANNELIDA	Polychaeta Sedentaria	Pectinaria spp.	10	3	3	19	19	22	33	7	11	28	6		49	5	13	32			6	89	59										
ANNELIDA	Polychaeta Sedentaria	Petaloproctus borealis						10	2																								
ANNELIDA	Polychaeta Sedentaria	Pherusa neopapillata											2			1																	
ANNELIDA	Polychaeta Sedentaria	Pherusa spp.					1				1																						
ANNELIDA	Polychaeta Sedentaria	Pileolaria spp.											2	1																			
ANNELIDA	Polychaeta Sedentaria	Pista spp.																			1												
ANNELIDA	Polychaeta Sedentaria	Pista wui																		20													
ANNELIDA	Polychaeta Sedentaria	Polycirrus sp. A				12		2		1		1		2		2																	
ANNELIDA	Polychaeta Sedentaria	Polycirrus sp. I				1		2																									
ANNELIDA	Polychaeta Sedentaria	Polycirrus spp.				1	1			1	2		3	4		1	1			1													
ANNELIDA	Polychaeta Sedentaria	Polydora nr. websteri																					1										
ANNELIDA	Polychaeta Sedentaria	Praxillella gracilis																		1													
ANNELIDA	Polychaeta Sedentaria	Praxillella pacifica																	2														
ANNELIDA	Polychaeta Sedentaria	Prionospio (Minuspio) lighti	1	5	17	15	8	8	9	13	3					23	1	1	33	14	2												
ANNELIDA	Polychaeta Sedentaria	Prionospio (Minuspio) multibranchiata	1		1			1		1				3		6	4	1	2														
ANNELIDA	Polychaeta Sedentaria	Prionospio (Minuspio) spp.		6	1		3	1		3			105	37									2			11							
ANNELIDA	Polychaeta Sedentaria	Prionospio (Prionospio) spp.	165	26	144	32	56	38	22	58	63	26	21	31	82			424	8			3	1	1							16		
ANNELIDA	Polychaeta Sedentaria	Prionospio (Prionospio) steenstrupi			7	3	3	1	13	3	2	4		4			10	9	3		1										11		1
ANNELIDA	Polychaeta Sedentaria	Prionospio spp.	100		87	28	41	40	11	27	8	24	7	27	84	70	24	283	24	4	42	6	2								11	3	
ANNELIDA	Polychaeta Sedentaria	Pseudopotamilla occelata						2																									
ANNELIDA	Polychaeta Sedentaria	Rhynchospio glutaea									1																1				1		
ANNELIDA	Polychaeta Sedentaria	Sabellaria cementarium																			1												
ANNELIDA	Polychaeta Sedentaria	Sabellinae indet.																											1				
ANNELIDA	Polychaeta Sedentaria	Scalibregma californicum			1	1	24	23	3	7	1	1																					
ANNELIDA	Polychaeta Sedentaria	Scoloplos acmeceps	5	3	4	1	6			3	10	10						4			6				1								1
ANNELIDA	Polychaeta	Scoloplos sp.						1	3													31	7										

	Sedentaria																																
ANNELIDA	Polychaeta Sedentaria	Spio cirrifera																	1		1												
ANNELIDA	Polychaeta Sedentaria	Spio filicornis											4			5	8									2						1	4	15
ANNELIDA	Polychaeta Sedentaria	Spio spp.					1	2							2												2						
ANNELIDA	Polychaeta Sedentaria	Spiochaetopterus pottsi												157							1	6	4										
ANNELIDA	Polychaeta Sedentaria	Spiochaetopterus spp.	1		1	1	2	3				1	3										2										
ANNELIDA	Polychaeta Sedentaria	Spionidae indet.											1				1	1							1				1	1	1		
ANNELIDA	Polychaeta Sedentaria	Spiophanes berkeleyorum		2		3														3										2			
ANNELIDA	Polychaeta Sedentaria	Spiophanes spp.			1																								1				
ANNELIDA	Polychaeta Sedentaria	Spirorbidae indet.											1																				
ANNELIDA	Polychaeta Sedentaria	Terebellidae indet.											6	1		2		3	1		1												
ANNELIDA	Polychaeta Sedentaria	Terebellides californica																	3	3	9												
ANNELIDA	Polychaeta Sedentaria	Terebellides spp.																	1														
ANNELIDA	Polychaeta Sedentaria	Trochochaeta multisetosa				4	3	5	3	2																							
ARTHROPODA - CHELICERATA	Arachnida	Copidognathus sp.															1																
ARTHROPODA - CHELICERATA	Arachnida	Halacaridae indet.									1				1	1	1	2							2	2				1		4	
ARTHROPODA - CHELICERATA	Arachnida	Hydracarina indet.											1																				
ARTHROPODA - CHELICERATA	Pycnogonida	Phoxichilidium femoratum											1																				
ARTHROPODA - CRUSTACEA	Amphipoda	Americhelidium shoemakeri		1										2				2		2	32	6	2		1								37
ARTHROPODA - CRUSTACEA	Amphipoda	Americhelidium sp.																														1	
ARTHROPODA - CRUSTACEA	Amphipoda	Americorophium brevis				4																											
ARTHROPODA - CRUSTACEA	Amphipoda	Ampelisca unsocalae																	2	2													
ARTHROPODA - CRUSTACEA	Amphipoda	Anisogammarus pugettensis																												685		445	1
ARTHROPODA - CRUSTACEA	Amphipoda	Aoroides columbiae											25		11	21							10		1		1			4	1	61	
ARTHROPODA - CRUSTACEA	Amphipoda	Aoroides exilis									2						88																
ARTHROPODA - CRUSTACEA	Amphipoda	Aristas veleronis																														3	
ARTHROPODA - CRUSTACEA	Amphipoda	Byblis veleronis																			2												
ARTHROPODA - CRUSTACEA	Amphipoda	Caprella sp.											3																				
ARTHROPODA - CRUSTACEA	Amphipoda	Chromopleustes oculatus													1																		
ARTHROPODA - CRUSTACEA	Amphipoda	Crassicorophium crassicorne																				1											
ARTHROPODA - CRUSTACEA	Amphipoda	Deflexilodes enigmaticus																	5														
ARTHROPODA - CRUSTACEA	Amphipoda	Deflexilodes sp.																			1												
ARTHROPODA - CRUSTACEA	Amphipoda	Desdimelita californica																														28	
ARTHROPODA - CRUSTACEA	Amphipoda	Desdimelita desdichada																													2		
ARTHROPODA - CRUSTACEA	Amphipoda	Eobrolgus chumashi												6				35			3												
ARTHROPODA - CRUSTACEA	Amphipoda	Eogammarus confervicolus				7																			1								
ARTHROPODA - CRUSTACEA	Amphipoda	Eyakia robusta																												2			
ARTHROPODA - CRUSTACEA	Amphipoda	Gammaridea indet.							1		1					1	7						8							2		112	

ARTHROPODA - CRUSTACEA	Amphipoda	Gammaropsis chionoecetophila													2																		
ARTHROPODA - CRUSTACEA	Amphipoda	Guernea reduncans											1																				
ARTHROPODA - CRUSTACEA	Amphipoda	Hadzioidea indet.																														10	
ARTHROPODA - CRUSTACEA	Amphipoda	Heterophoxus conlanae												1					1		1												
ARTHROPODA - CRUSTACEA	Amphipoda	Heterophoxus sp.																		1													
ARTHROPODA - CRUSTACEA	Amphipoda	Hippomedon sp.														1						10	2										
ARTHROPODA - CRUSTACEA	Amphipoda	Lysianassoidea indet.												2																			
ARTHROPODA - CRUSTACEA	Amphipoda	Mayerella banksia																			2	19	18										
ARTHROPODA - CRUSTACEA	Amphipoda	Megamoera subtener																												3		12	
ARTHROPODA - CRUSTACEA	Amphipoda	Monocorophium insidiosum														9																	
ARTHROPODA - CRUSTACEA	Amphipoda	Monocorophium sp.										2	4	3	1		9								1								
ARTHROPODA - CRUSTACEA	Amphipoda	Pachynus cf. barnardi																			2												
ARTHROPODA - CRUSTACEA	Amphipoda	Peramphithoe plea																												5			
ARTHROPODA - CRUSTACEA	Amphipoda	Photis brevipes											9					1				27	27										
ARTHROPODA - CRUSTACEA	Amphipoda	Phoxocephalidae indet.																	1														
ARTHROPODA - CRUSTACEA	Amphipoda	Pleustidae indet.													1																		
ARTHROPODA - CRUSTACEA	Amphipoda	Protomedeia prudens																				90	31										
ARTHROPODA - CRUSTACEA	Amphipoda	Protomedeia sp.																			4												
ARTHROPODA - CRUSTACEA	Amphipoda	Westwoodilla tone				1			1												5												
ARTHROPODA - CRUSTACEA	Cirripedia	Balanidae indet.	2																														
ARTHROPODA - CRUSTACEA	Cirripedia	Balanomorpha indet.																												127	2		6
ARTHROPODA - CRUSTACEA	Cirripedia	Balanus crenatus						1																									
ARTHROPODA - CRUSTACEA	Cirripedia	Balanus glandula					3																										
ARTHROPODA - CRUSTACEA	Cirripedia	Balanus sp.							1	2	4			1																			
ARTHROPODA - CRUSTACEA	Copepoda	Botryllophilidae indet.						1																									
ARTHROPODA - CRUSTACEA	Copepoda	Zaus sp.									2																						
ARTHROPODA - CRUSTACEA	Cumacea	Cumella californica											1																				
ARTHROPODA - CRUSTACEA	Cumacea	Cumella morion																			1												
ARTHROPODA - CRUSTACEA	Cumacea	Cumella vulgaris	28	8	1			1			7	2			2								2		11	1			3			4	4
ARTHROPODA - CRUSTACEA	Cumacea	Diastylis abbotti																			2												
ARTHROPODA - CRUSTACEA	Cumacea	Diastylis pellucida								1																							
ARTHROPODA - CRUSTACEA	Cumacea	Diastylis sp.				2																											
ARTHROPODA - CRUSTACEA	Cumacea	Eudorella pacifica		1		1															5												
ARTHROPODA - CRUSTACEA	Cumacea	Leucon sp.	1																														
ARTHROPODA - CRUSTACEA	Cumacea	Mesolamprops sp.																				1											2
ARTHROPODA - CRUSTACEA	Decapoda	Cancer gracilis									2																						
ARTHROPODA - CRUSTACEA	Decapoda	Crangon alaskensis	2						1												1												
ARTHROPODA -	Decapoda	Hemigrapsus oregonensis															3																

CRUSTACEA																																	
ARTHROPODA - CRUSTACEA	Decapoda	Hemigrapsus sp.											1																				
ARTHROPODA - CRUSTACEA	Decapoda	Heptacarpus taylori														4																	
ARTHROPODA - CRUSTACEA	Decapoda	Heptacarpus tenuissimus																												3		4	
ARTHROPODA - CRUSTACEA	Decapoda	Lophopanopeus bellus														2																	
ARTHROPODA - CRUSTACEA	Decapoda	Oregonia gracilis												1																			
ARTHROPODA - CRUSTACEA	Decapoda	Pagurus armatus																1															
ARTHROPODA - CRUSTACEA	Decapoda	Pinnixa eburna																														2	
ARTHROPODA - CRUSTACEA	Decapoda	Pinnixa schmitti		1																1													
ARTHROPODA - CRUSTACEA	Decapoda	Pinnixa sp.					1						1																				
ARTHROPODA - CRUSTACEA	Decapoda	Pinnotheridae indet.	1																														
ARTHROPODA - CRUSTACEA	Decapoda	Pugettia richii																												2			
ARTHROPODA - CRUSTACEA	Decapoda	Pugettia sp.																														1	
ARTHROPODA - CRUSTACEA	Decapoda	Scleroplex granulata	1																														
ARTHROPODA - CRUSTACEA	Isopoda	Asellota indet.												1																			
ARTHROPODA - CRUSTACEA	Isopoda	Cleantis heathii																														2	
ARTHROPODA - CRUSTACEA	Isopoda	Epicaridea indet.	2																														
ARTHROPODA - CRUSTACEA	Isopoda	Gnorimosphaeroma oregonense				1																					1						
ARTHROPODA - CRUSTACEA	Isopoda	Haliophasma geminatum												2																			
ARTHROPODA - CRUSTACEA	Isopoda	Limnoria tripunctata																														6	
ARTHROPODA - CRUSTACEA	Isopoda	Munna chromatocephala											13	1	3	4	6	12							1				1			3	1
ARTHROPODA - CRUSTACEA	Isopoda	Munna sp.			1																												
ARTHROPODA - CRUSTACEA	Isopoda	Munnogonium tillerae	2		1	2						3										4	1										
ARTHROPODA - CRUSTACEA	Isopoda	Pleurogonium californiense				1	1	1		3	4																						
ARTHROPODA - CRUSTACEA	Isopoda	Uromunna ubiquita																														6	
ARTHROPODA - CRUSTACEA	Leptostraca	Nebalia sp.																							1				1	869	3	1114	1
ARTHROPODA - CRUSTACEA	Mysidacea	Neomysis mercedis																												14			
ARTHROPODA - CRUSTACEA	Mysidacea	Pacifacanthomysis nephrophthalma				1																											
ARTHROPODA - CRUSTACEA	Mysidacea	Pacifacanthomysis sp.			3																												
ARTHROPODA - CRUSTACEA	Ostracoda	Bathyleberis sp.																	1	1	7												
ARTHROPODA - CRUSTACEA	Ostracoda	Cyprideis sp.														1																	
ARTHROPODA - CRUSTACEA	Ostracoda	Euphilomedes carcharodonta					1															71	11								3		
ARTHROPODA - CRUSTACEA	Ostracoda	Euphilomedes producta					1	2			1								24	2													
ARTHROPODA - CRUSTACEA	Ostracoda	Euphilomedes sp.																				5											
ARTHROPODA - CRUSTACEA	Ostracoda	Hemicytherura sp.														1																	
ARTHROPODA - CRUSTACEA	Ostracoda	Loxoconcha sp.		1				10	2	2	1	2	1																				
ARTHROPODA - CRUSTACEA	Ostracoda	Ostracoda indet.																							1								
ARTHROPODA - CRUSTACEA	Ostracoda	Rutiderma lomae								5																							

ARTHROPODA - CRUSTACEA	Ostracoda	Rutiderma sp.					1																									
ARTHROPODA - CRUSTACEA	Tanaidacea	Leptochelia savignyi						8	6	3	3	1	171	14	11	38	141	17			4	47	36		2				1	5		2
ARTHROPODA - CRUSTACEA	Tanaidacea	Pseudotanais oculatus											10			16		4														
ARTHROPODA - CRUSTACEA	Tanaidacea	Tanaidaceae indet.											3			16		1														
ARTHROPODA - CRUSTACEA	Tanaidacea	Zeuxo normani																3					1									
ARTHROPODA - INSECTA	Coleoptera	Coleoptera indet.												1																		
ARTHROPODA - INSECTA	Diptera	Chironomidae indet.											3	1															2			
ARTHROPODA - INSECTA	Diptera	Saunderia marinus		1						1			1																			
BRYOZOA	BRYOZOA	Bowerbankia gracilis		1		3		1																				1				
BRYOZOA	BRYOZOA	Caulibugula californica											1			5																
BRYOZOA	BRYOZOA	Celleporella hyalina											1	1																		
BRYOZOA	BRYOZOA	Reginella spp.											1																			
BRYOZOA	BRYOZOA	Schizoporella unicornis														1							1									
BRYOZOA	BRYOZOA	Tegella sp.														1																
BRYOZOA	BRYOZOA	Tricellaria circumternata											1																			
BRYOZOA	BRYOZOA	Triticella elongata											1																			
BRYOZOA	BRYOZOA	Tubulipora tuba											2																			
CNIDARIA	Anthozoa	Halcampa decemtentaculata																			1											
CNIDARIA	Anthozoa	Pachycerianthus fimbriatus												2																		
CNIDARIA	Anthozoa	Pennatulacea indet.				1	3																									
CNIDARIA	Anthozoa	Scolanthus sp.	15	3	4	24	18	56	33	66	18	23	3		2				5	1	6											
CNIDARIA	CNIDARIA	Cnidaria indet.																			4		1									
CNIDARIA	Hydrozoa	Campanularia groenlandica									1				1	1	1					1										
CNIDARIA	Hydrozoa	Campanularia sp.	2			7	11	14	6	5		16								1	2	58	49								8	
CNIDARIA	Hydrozoa	Clava spp.														1																
CNIDARIA	Hydrozoa	Clytia edwardsii																1				2										
CNIDARIA	Hydrozoa	Clytia johnstoni											1										5									
CNIDARIA	Hydrozoa	Clytia minuta											1																			
CNIDARIA	Hydrozoa	Hydroida indet.																				1										
CNIDARIA	Hydrozoa	Monobranchium parasiticum																				1										
CNIDARIA	Hydrozoa	Obelia borealis											1																			
CNIDARIA	Hydrozoa	Obelia dichotoma											1																			
CNIDARIA	Hydrozoa	Obelia sp.																										1				
CNIDARIA	Hydrozoa	Obelia spp.																					2									
CNIDARIA	Hydrozoa	Perigonimus repens									1								1											1		
CNIDARIA	Hydrozoa	Syncoryne mirabilis																				1										
CNIDARIA	Hydrozoa	Syncoryne spp.											1																			
ECHINODERMATA	Asteroidea	Asteroidea indet.												1	5	5	1	2			1	2										
ECHINODERMATA	Echinoidea	Strongylocentrotus droebachiensis											1			1																
ECHINODERMATA	Echinoidea	Strongylocentrotus sp.											7	1		1		6				3										
ECHINODERMATA	Holothuroidea	Chiridota albatrossii											1				1															
ECHINODERMATA	Holothuroidea	Cucumariidae indet.											1																			
ECHINODERMATA	Holothuroidea	Holothuroidea indet.						1								12																
ECHINODERMATA	Holothuroidea	Leptosynapta clarki											2																			
ECHINODERMATA	Holothuroidea	Leptosynapta spp.													1	2		1														
ECHINODERMATA	Ophiuroidea	Amphiodia sp.				13	1	3	5	3									12													
ECHINODERMATA	Ophiuroidea	Amphiodia urtica				19	4	2	17	13						2				6												
ECHINODERMATA	Ophiuroidea	Amphipholis sp.														1																
ECHINODERMATA	Ophiuroidea	Amphipholis squamata											1		2	13	20															
ECHINODERMATA	Ophiuroidea	Amphiuridae indet.				4	7	5	6	12	1																					
ECHINODERMATA	Ophiuroidea	Ophiura luetkenii												5																		
ECHINODERMATA	Ophiuroidea	Ophiura sp.						1			1																					

ECHINODERMATA	Ophiuroidea	Ophiuroidea indet.	5	16	4	48	59	41	32	14	26	12				2	6		31	4		1										1	
ECHIURA	ECHIURA	Echiurus sp.				2		1		1																							
ENTEROPNEUSTA	ENTEROPNEUSTA	Enteropneusta indet.									1																						
ENTOPROCTA	ENTOPROCTA	Barentsia hildegardae						1																									
MOLLUSCA	Bivalvia	Acila castrensis					1												1	2	2												
MOLLUSCA	Bivalvia	Axinopsida serricata	86	16	9	48	154	90	40	113	22	72		5					1			1	1								12		
MOLLUSCA	Bivalvia	Bivalvia indet.	10	3	5	77	14	37	97	36	14	40	6		7	35	6	51	131	152	8	35	55				1		6	18	31	1	1
MOLLUSCA	Bivalvia	Chlamys sp.												1																			
MOLLUSCA	Bivalvia	Clinocardium nuttalli																											1				
MOLLUSCA	Bivalvia	Clinocardium sp.									1			1	4	4		1			3	35	20										
MOLLUSCA	Bivalvia	Compsomyax subdiaphana			1			1																									
MOLLUSCA	Bivalvia	Ennucula tenuis					1	1																									
MOLLUSCA	Bivalvia	Lucinoma annulatum																					1										
MOLLUSCA	Bivalvia	Lyonsia californica				3	1	4												1			1										
MOLLUSCA	Bivalvia	Macoma carlottensis							1																								
MOLLUSCA	Bivalvia	Macoma golikovi	1		2																												
MOLLUSCA	Bivalvia	Macoma nasuta				1																								1			
MOLLUSCA	Bivalvia	Macoma sp.			17	6	12	8	6	4	4	6					2	1							3				1	1	6		1
MOLLUSCA	Bivalvia	Macoma yoldiformis	1																														
MOLLUSCA	Bivalvia	Mactromeris polynyma																													1		2
MOLLUSCA	Bivalvia	Mytilidae indet.	1							1	2	1	3	4		6									1			1	1	2	1	2	1
MOLLUSCA	Bivalvia	Nutricola sp.	7			15	11	19	11	8	6	35				2					2	200	169							1	16		
MOLLUSCA	Bivalvia	Nutricola tantilla																				2											
MOLLUSCA	Bivalvia	Pandora bilirata					11	5	1																								
MOLLUSCA	Bivalvia	Parvilucina tenuisculpta	2		3	44	24	14	27	24	2	9	7	5	4	7	2	1	2		7	6	9										
MOLLUSCA	Bivalvia	Protothaca staminea	3		3			1	3	1		2																			3		
MOLLUSCA	Bivalvia	Rochefortia sp.																2		2		3											
MOLLUSCA	Bivalvia	Rochefortia tumida	124	73	265	253	199	123	190	223	151	233	56	58	30	47	31	182	1	8	45	120	125		31	3		1	16	228	80	20	39
MOLLUSCA	Bivalvia	Tellina sp.	5	6	5	1	4	3		1		4						9		1	2	9	20										
MOLLUSCA	Bivalvia	Tellinidae indet.									8							1															
MOLLUSCA	Bivalvia	Veneridae indet.			3			4	4	5	2	1						1												2	6		
MOLLUSCA	Gastropoda	Acteocina culcitella																	1	1													
MOLLUSCA	Gastropoda	Aegires albopunctatus											1																				
MOLLUSCA	Gastropoda	Aeolidacea indet.																					1										
MOLLUSCA	Gastropoda	Alvania compacta	2			1	7	4	5	2	1	6	9			1	1	8			6	3											
MOLLUSCA	Gastropoda	Alvania sp.																											1				
MOLLUSCA	Gastropoda	Astyris gausapata							3			3	1									1	1										
MOLLUSCA	Gastropoda	Caecum crebricinctum						1																									
MOLLUSCA	Gastropoda	Cephalaspidea indet.																									4						
MOLLUSCA	Gastropoda	Cylichna attonsa																		1													
MOLLUSCA	Gastropoda	Epitonium caamanoi												1																			
MOLLUSCA	Gastropoda	Gastropoda indet.	6		2	4	9	6	7	5	22	9	25	14		12		13	5		5	9	8							1		2	
MOLLUSCA	Gastropoda	Littorina scutulata															1				1												
MOLLUSCA	Gastropoda	Littorina sitkana																												1			
MOLLUSCA	Gastropoda	Margarites pupillus					1					1	1									6	9										
MOLLUSCA	Gastropoda	Muricidae indet.																												3			
MOLLUSCA	Gastropoda	Nassarius mendicus	1		2	1	1			2				1		1						1											
MOLLUSCA	Gastropoda	Nudibranchia indet.								1																							
MOLLUSCA	Gastropoda	Odostomia sp.																		1	2												
MOLLUSCA	Gastropoda	Oenopota sp.				1						1										1	1										
MOLLUSCA	Gastropoda	Olivella sp.										1																					
MOLLUSCA	Gastropoda	Opisthobranchia indet.											1																				
MOLLUSCA	Gastropoda	Parvaplustrum sp.																											2				
MOLLUSCA	Gastropoda	Turbonilla sp.					1											2	5	8		1	4										

MOLLUSCA	Gastropoda	Turridae indet.																			1											
MOLLUSCA	Polyplacophora	Mopalia lignosa																												1		
MOLLUSCA	Polyplacophora	Polyplacophora indet.											3			1																
NEMERTEA	NEMERTEA	Amphiporidae indet.											1																			
NEMERTEA	NEMERTEA	Amphiporus imparispinosus								1			1		3		2	1														
NEMERTEA	NEMERTEA	Anopla sp. (SCAMIT)	1								1																					7
NEMERTEA	NEMERTEA	Carinoma mutabilis							2					3				1				1										
NEMERTEA	NEMERTEA	Cerebratulus californiensis	2		1	15	3	8	3	8	4		3	6	12	10	2	7		1		7	4									
NEMERTEA	NEMERTEA	Lineidae indet.					1																									
NEMERTEA	NEMERTEA	Nemertea indet.	1	1		3		2	1					1																		1
NEMERTEA	NEMERTEA	Paranemertes californica														1														1		2
NEMERTEA	NEMERTEA	Paranemertes sp.																					1		1						2	6
NEMERTEA	NEMERTEA	Tetrastemma candidum									3	1											1									2
NEMERTEA	NEMERTEA	Tetrastemma nigrifrons									3																					1
NEMERTEA	NEMERTEA	Tetrastemma sp.						4		1	1											1	1									
NEMERTEA	NEMERTEA	Tubulanus polymorphus	3	1		1	1		1		2			2								1										
PHORONIDA	PHORONIDA	Phoronida indet.								1						1																
PHORONIDA	PHORONIDA	Phoronis psammophila												14	47		4	28				132	64									
PISCES	PISCES	Gobiidae indet.										1																				5
PISCES	PISCES	Pholis schultzi																												2		
PLATYHELMINTHES	PLATYHELMINTHES	Leptoplanidae indet.				1																										
PLATYHELMINTHES	PLATYHELMINTHES	Notoplana sp.									1							1														
PLATYHELMINTHES	PLATYHELMINTHES	Pseudoceros canadensis												1																		
PRIAPULIDA	PRIAPULIDA	Priapulida indet.								1																						
SIPUNCULA	SIPUNCULA	Nellobia eusoma	1																													
SIPUNCULA	SIPUNCULA	Sipunculida indet.	3				1	5		6	1																					
SIPUNCULA	SIPUNCULA	Thysanocardia nigra	4		1	2	5	15	5	7	2	1																				
UROCHORDATA	UROCHORDATA	Apilidium spp.												1																		
UROCHORDATA	UROCHORDATA	Corella spp.														1																
UROCHORDATA	UROCHORDATA	Urochordata indet.																						2			1					1