UNIVERSITY OF NORDLAND

MASTER THESIS

Cadmium concentrations of macrofauna in the Salten region, northern Norway

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Abstract

Due to recent findings in the Salten region of northern Norway that claw meat of *Cancer pagurus* contained elevated concentrations of cadmium (Cd) above EU regulations for safe consumption, the sale of edible crab from the region was prohibited. The source of cadmium is unknown, but the main pathway of accumulation in *C. pagurus* is likely via consumption of benthic organisms. The aim of this study was i) to describe the structure and diversity of the macrofaunal communities at six locations in the affected area and ii) to assess the Cd concentration of macrofauna representing different taxonomical groups and trophic levels in the same locations. The six stations in the coastal region of Bodø represented a gradient in Cd concentration of *C. pagurus*.

Community structure showed similar macrofaunal diversity and abundance at all stations with little variation between stations, indicating an ecosystem devoid of substantial disturbance events or heavy pollution sources. The overall mean Cd concentration of macrofauna differed between stations, but did not reflect the Cd gradient found for *C. pagurus*. Cadmium concentrations of macrofauna also varied between taxa, with the highest concentrations (>10 mg/kg AFDW) found for some taxa of Porifera, Mollusca and Annelida, while concentrations were lowest (<1 mg/kg AFDW) for all Arthropoda. The dominant feeding mode of the taxa with highest Cd concentrations was suspension feeding; and, excluding Porifera, these taxa are potential prey of *C. pagurus*. This study indicates that the uptake and bioaccumulation of cadmium in *C. pagurus* may be through their macrofaunal diet. The results further suggest that a distinct, locally restricted source is inconclusive and that larger scale effects may contribute to the elevated Cd concentrations in the region.

1. Introduction

Fishing industry has played and is playing a major role in Norwegian socioeconomic structure and sustainable livelihood for generations. With seafood exports of more than 2.5 million tonnes annually amounting to approximately 90% of total yield, it has become increasingly important to monitor and manage the quality of seafood in Norwegian waters (Van Hoey et al., 2010; Julshamn et al., 2012; Anonymous, 2013).

Cancer pagurus, more commonly known as the edible crab or brown crab, has been a key harvested species in Norway since the early 1900s and is abundant along the Norwegian coast northward to Troms County (Woll et al., 2006). Unlike most of Scandinavia and the United Kingdom, landings of *C. pagurus* in Norway quadrupled during the early 2000s reaching annual catch rates in excess of 8000 tonnes (Ungfors et al., 2007; Sandberg, 2011). The edible crab became a targeted species for commercial fishing shortly after they were discovered in the Bodø and Salten regions of northern Norway during the early 1990's, probably due to northward larval migration via the Norwegian Coastal Current (S. Skreslet pers. comm.). Since its introduction to the fishing industry, edible crab has been both a sustainable and lucrative option for the area fishermen. At approximately 5000 tonnes per year it represents only a minor fraction of Norway's total catch, but in 2012 was valued at over 46 million Norwegian kroner (Sandberg, 2011). Nordland County exhibits the second largest fish landings in the country, and while most of the area has seen a noticeable decline in human population over the last decade, Bodø and Salten municipalities have experienced growth (Anonymous, 2009).

In Norway both white meat (claw) and brown meat (hepatopancreas) of *C. pagurus* are consumed, the latter being less common (Julshamn et al., 2012). Marine arthropods are

widely known to accumulate heavy metals in higher concentrations than fin fish, particularly in the hepatopancreas (Davies et al., 1981; Nunez-Nogueira et al., 2006; Barrento et al., 2009). Cadmium (Cd), a trace metal, is broadly recognized as a human carcinogen, with food being the main exposure source (EFSA, 2009; Anonymous, 2012). Currently the European Union regulations limit claw meat Cd levels for safe consumption to 0.5 mg/kg wet weigh, which has also been adopted by Norwegian legislation (EC, 2006). There is presently no upper limit established for brown meat, which commonly contains Cd concentrations above this threshold.

In February of 2010, the Norwegian Food Safety Authority (Mattilsynet) was notified that a random sampling by a Swedish agency had found elevated levels of Cd in *C. pagurus* from Bodø (Falk, 2012). Based on these findings and local socioeconomic concerns, the Norwegian FSA conducted sampling and analysis of *C. pagurus* in the area. The study, conducted in 2010 and 2011, using samples of crabs collected from 14 different locations in the Salten area, confirmed that both claw meat and brown meat were above the accepted limit, ranging from 0.09 mg/kg to 1.1 mg/kg from the area of Salfjorden to Steigen (Falk, 2012; Julshamn et al., 2012). The survey also indicated a decreased Cd level in claw meat south of Bodø region, indicating a regional pollution source.

Following the results of the aforementioned 2010 survey, the Norwegian FSA issued a dietary advisory for *C. pagurus* landed between Saltfjorden and Folda, and prohibition of sales (Hatlestad, 2011). Since then several seafood companies have experienced heavy losses, with a local shellfish company forced to declare bankruptcy and more than a dozen fishing vessels left to find new methods of livelihood (Julshamn et al., 2012; Helgerudveien, 2014). In response, the Norway-based research company Akvaplan-niva conducted a survey of

selected metals in sediment, sampling along the coast from Støtt to Andholmen. No consistent trends in elevated Cd were observed, giving no evident correlation between sediment Cd concentration and that of *C. pagurus* (Falk, 2012). Hypotheses regarding the source of elevated Cd levels in edible crabs of the Salten region range from industry to war-time shipwrecks, but there remains no scientific evidence to adequately support any such hypotheses. A more widely endorsed theory relates to the vertical transport of Cd via upwelling events possibly generating increased concentrations in the habitat of *C. pagurus* (Boyle et al., 1976; Lares et al., 2002).

In order to ascertain the source of Cd elevation in *C. pagurus*, it is essential to identify the possible uptake mechanisms. While the resulting destination of heavy metals in the body of any invertebrate essentially involves their particular physiological traits, the uptake sources can be simplified to either the surrounding aquatic environment or dietary composition (Rainbow, 2002). While the source of Cd in this case is unknown, the main pathway of cadmium accumulation in *C. pagurus* is probably via feeding on benthic organisms (Davies et al., 1981). The diversity of benthic species in the coastal regions is extremely high, representing a variety of different life modes and trophic levels (Oug et al., 2012). Thus, depending on the potential source of cadmium pollution, the uptake of cadmium by the benthic fauna may depend on the position in the food web and the feeding mode.

The general aim of this master project is to reveal insights into the cadmium accumulation in benthic organisms representing different taxonomical groups and trophic levels in the coastal ecosystem of the Salten region. The objectives are (i) to determine the cadmium concentrations of selected benthic key species, representing different trophic levels, along a gradient of cadmium pollution in the Bodø region and (ii) to describe the benthic

diversity and community structure at the different locations. Given the aforementioned objectives, I hypothesize distinct differences in Cd concentration between sample stations and differing taxa. By understanding the community structure and its differential cadmium load within the benthic ecosystem of the area, we will gain additional insight into the possible source of elevated Cd in *C. pagurus* of the Salten region.

2. Materials and Methods

2.1 Study Area

Sampling was conducted in the Salten area of northern Norway between 66-69° N, and the stations were chosen based on collective interpretation of studies conducted by the National Institute of Nutrition and Seafood Research (NIFES) and Akvaplan-niva regarding Cd concentrations in the meat of *C. pagurus* and in sediment samples of the area. Samples were collected from six stations, one of which served as a reference (Fig. 1). The stations were chosen primarily in relation to Cd concentrations in claw and brown meat of the edible crab (Julshamn et al., 2012). A secondary consideration was the Cd concentration in the sediments, which were in general relatively low across all stations sampled (Falk, 2012). After reviewing both reports, previously sampled locations were divided into three categories based primarily on the Cd concentrations of claw meat: low (<0.3 mg/kg), moderate (0.3-0.7 mg/kg), and high (>0.7 mg/kg). Considering Cd load while also restricting sediment composition types to those that were appropriate for the sampling equipment used, two sites were chosen from each of the three categories. Of the six stations, the southernmost station 19 was elected as a reference, based on the lowest levels of Cd concentration in the meat of *C. pagurus* and a relatively low level of Cd concentration in the sediment (Table 1).

2.2 Sampling Strategy

Initial sampling was done throughout 2013 during March, April and June and included both sampling of macrofauna and epifauna. A second set of samples was later deemed necessary to collect only additional epifauna and was carried out in November 2013. Sampling was done using the vessel “Tanteyen” under the supervision of chief engineer Morten Krogstad. The selected stations represented a variety of depths (~20-170m) and sediment types ranging from fine shell fragments to brown-green clay (Table 1).

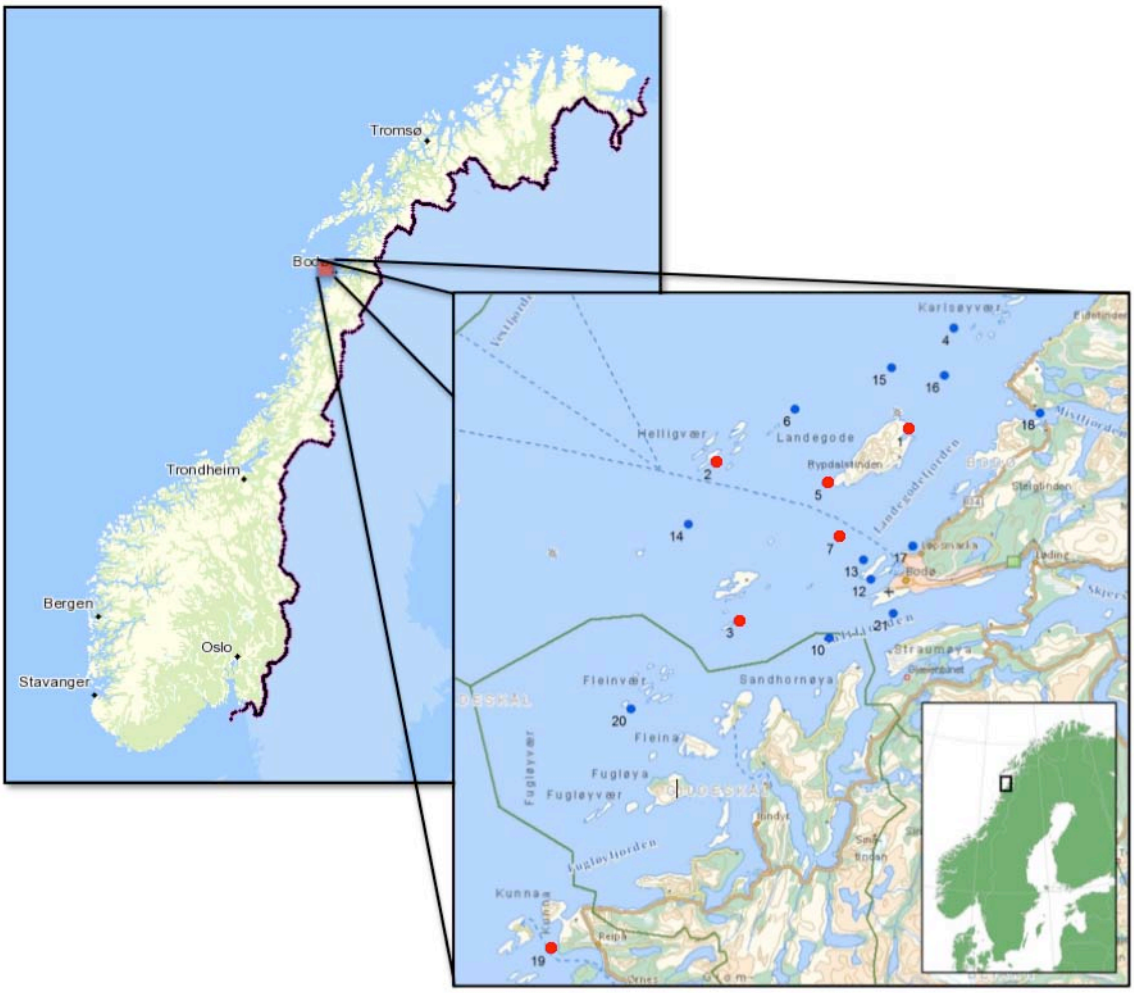

Figure 1. Location of sampling area. For this study, only stations 1, 2, 3, 5, 7, and 19 were used (shown in red). Figure of station locations courtesy of Akvaplan-niva (Falk, 2012).

2.3 Sampling method and processing

Aboard the University of Nordland vessel "Tanteyen," samples were collected using a Van Veen grab (0.1 m^2) from the aforementioned sites. At each station, two replicate samples were taken for the analysis of macrofaunal community structure. The samples were then sieved on board over 1mm mesh, fixed with 4% formaldehyde and buffered with Borax.

Samples of macrofauna and epifauna for the Cd measurements were taken with a Van Veen grab and a triangle dredge (40 × 40 × 40 cm), respectively. A total of 12 grab and 18 dredge samples were taken over the course of the sampling dates. The use of a triangle dredge was essential for the collection of samples in the analysis of Cd because of minimum biomass requirements of 0.5 g wet weight, which proved difficult to attain without the use of slightly larger epifaunal specimens. The analysis procedures for Cd measurement used in this study (see 2.3.2 Cadmium concentration) required that samples not be treated with any chemicals or fixatives. Therefore, samples for Cd analysis were immediately (within 6 hours after the sampling) processed and deep-frozen.

2.3.1 Community structure

Samples for the community structure analysis were processed in the laboratory first by adding Rose Bengal stain and sorting with use of a stereomicroscope. For any sample containing more than 0.75 l of sediment, a decantation procedure was used. The sample was rinsed and stained then transferred to a secondary, larger container. It was then swirled in an oversupply of water and suspended matter was filtered through a fine mesh. This was performed three times, after which the resulting filtered macrofauna was sorted using a stereomicroscope and transferred to ethanol (70%). All organisms were identified to family level when possible or the lowest possible taxonomic group thereafter. Any meiofauna (e.g. Nematoda) found were omitted from further analyses.

Table 1. Description of sampling sites. Mean Cd sediment concentration shown with station minimum and maximum in parentheses. Qualitative description of the sediment composition and Cd concentrations taken from Falk (2012), with claw meat Cd concentration values shown in wet weight (ww).

Station	Depth (m)	Location	Date of primary sampling	Date of secondary sampling	Sediment description	Mean Cd concentration in the sediment (mg/kg)	Cd concentration of crab claw meat (mg/kg ww)	Classification level
1	62-70	67°43'106 N, 14°40'809 E	29/4/13	28/11/13	Sand, shell fragments, clay below	<0.1	1.1	high
2	33-65	67°39'555 N, 13°91'380 E	18/3/13	29/11/13	Coarse sand, some shell fragments	0.20 (0.12 - 0.24)	0.69	medium
3	50-81	67°23,767 N, 13°97'760 E	29/4/13	29/11/13	Sand, shell fragments, clay below	0.20 (0.10 - 0.27)	0.35-0.69	medium
5	46-168	67°37'677 N, 14°19'903 E	29/4/13	28/11/13	Sand, few shell fragments, some clay	0.176 (0.14 - 0.22)	0.27	low
7	86-146	67°32'321 N, 14°23'174 E	13/6/13	28/11/13	Brown/green clay, some coarse sand	0.07 (<0.1 - 0.12)	0.81	high
19 (reference)	35-98	66°90'624 N, 13°51'656 E	10/6/13	29/11/13	Brown/green clay, some shell fragments	0.11 (<0,1 - 0,14)	0.11	low

2.3.2 Cadmium concentration

Samples for the analysis of cadmium concentration, collected during each sampling campaign (see Table 1), were immediately sorted by hand without the use of a stereomicroscope, identified to family or higher level, and deep-frozen for transport to the NIFES facility in Bergen where additional preparation and laboratory analysis was done to determine Cd concentration. In the laboratory the samples were weighed and recorded (wet weight), freeze-dried to remove any moisture, homogenized using a mortar or coffee grinder, and once again weighed (dry weight). The Cd analysis used required a minimum sample biomass, which in some cases was not obtainable without combining or "lumping" replicates. Percent solids, or the amount of solid material present in a liquid (or partial-liquid) sample, were calculated using the following formula:

$$\text{Solids (\%)} = \frac{\text{Dry weight}}{\text{Wet weight}} \times 100\%$$

Prior to analysis of trace metals using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), samples were first converted into liquid state by adding 30% hydrogen peroxide (H_2O_2) and concentrated nitric acid (HNO_3) to the weighted sample (0.2–0.25 g). To break the molecular bonds, the mixture was placed in Teflon (TFM) containers and heated using a microwave digestive system (MILESTONE MLS-1200 MEGA Microwave Digestion Rotor). After cooling the containers, sample solutions were diluted to 25ml and placed in 50ml centrifuge polypropylene containers. Using the prepared sample solutions in addition to several blanks and control solutions (1566b Oyster Tissue and TORT-2 Lobster Hepatopancreas), the ICP-MS machine (Agilent 7500 ICP-MS) was readied and calibration completed, using 5% nitric acid as a washing solution. For a more detailed description of ICP-MS procedures, refer to Tverdal (2012).

For the purpose of cadmium analysis using ICP-MS, it was necessary to combine or lump replicates and/or stations to achieve the minimum biomass for some taxa. Samples which, when combined together across replicates of the given station had adequate biomass for analysis, were labeled as Combined Replicates (CR). Conversely, samples that had less than three "Combined Replicates" with adequate biomass for analysis were lumped across all stations and labeled Combined Stations (CS) (see Appendix 1). This allowed the use of samples that would otherwise have been omitted due to inadequate biomass. In addition, and partly because of this, several stations were without or with limited representation of the phylum.

2.4. Data description and analysis

2.4.1. Community analyses

To quantitatively describe the macrofaunal community the mean total abundance and mean number of taxa was calculated for each station. The standard deviation (SD) was also calculated as a measure of variability in the data. In addition, the Shannon-Weiner index (H'), which represents a measure of diversity accounting for dominance and taxa number, was calculated as follows:

$$H' = -\sum_{i=1}^{N} p_i (\ln \cdot p_i)$$

where P_i is the proportion of total sample represented by taxon *i* and N is the total number of taxa. For all calculations natural logs were used ($\log_e$). The mean H' and the standard deviation was calculated for each station.

2.4.2. Cadmium concentration

For the analysis of Cd concentrations entire organisms were used, with different proportions of calcified tests of skeletal parts depending on the phylum. To account for these differences, Cd values were converted to ash-free dry weight (AFDW) by using conversion factors available for each phylum (Brey, 2001). The AFDW represents the biomass of the non-calcareous soft tissue only. The applied conversion allowed relating the Cd concentration to the soft tissue body mass only, assuming that Cd is mainly accumulating in the tissue and not significantly in the calcareous parts.

3. Results

3.1 Overall community composition

From the 12 grab samples taken, a total of 1,216 individuals were identified spanning 80 different families. These taxa represented seven phyla: Annelida (31), Mollusca (18), Arthropoda (16), Echinodermata (8), Cnidaria (3), Sipuncula (2), and Phoronida (1) (Table 2).

Table 2. List of taxa identified from the sampling area, number of stations at which each family was present, and total abundance combined across all stations (ind. 1.2 m^{-2}**)**.

Phylum	**Class**	**Order**	**Family**	**Stations present**	**Total abundance**
Annelida	Polychaeta	Amphinomida	Amphinomidae	1	1
		Eunicida	Eunicidae	1	3
			Lumbrineridae	1	1
			Onuphidae	6	44
		Phyllodocida	Aphroditidae	1	6
			Glyceridae	5	43
			Hesionidae	4	29
			Nephtyidae	5	15
			Nereidae	1	7
			Pholoidae	6	47
			Phyllodocidae	6	40
			Polynoidae	4	16
			Sigalionidae	1	1
			Sphaerodoridae	1	1
			Syllidae	3	9
		Sabellida	Oweniidae	1	32
			Sabellidae	6	77
			Serpulidae	2	3
		Spionida	Spionidae	6	147
		Terebellida	Ampharetidae	6	34
			Cirratulidae	6	90
			Flabelligeridae	2	8
			Pectinariidae	3	7

Table 2 cont.

Phylum	Class	Order	Family	Stations present	Total abundance
			Terebellidae	4	34
			Capitellidae	6	146
			Maldanidae	3	67
			Opheliidae	1	1
			Orbiniidae	4	24
			Paraonidae	2	2
			Polygordiidae	1	2
			Scalibregmatidae	1	1
Arthropoda	Malacostraca	Amphipoda	Ampeliscidae	3	7
			Gammaridae	1	2
			Haustoriidae	1	4
			Ischyroceridae	1	1
			Lysianassidae	4	12
			Melitidae	2	4
			Oedicerotidae	2	6
			Pardaliscidae	2	7
			Phoxocephalidae	3	9
		Cumacea	Leuconidae	1	1
		Decapoda	Galatheidae	1	8
			Hippolytidae	1	1
			Majidae	1	1
			Oregoniidae	1	1
			Paguridae	1	1
		Isopoda	Gnathiidae	1	1
Cnidaria	Anthozoa	Actiniaria	Edwardsiidae	4	22
		Ceriantharia	Cerianthidae	4	9
	Hydrozoa	Anthoathecata	Tubulariidae	1	1
Echinodermata	Echinoidea	Spatangoida	Spatangidae	2	10
		Clypeasteroida	Echinocyamidae	2	6
		Camarodonta	Strongylocentrotidae	2	6
	Holothuroidea	Apodida	Synaptidae	2	3
		Aspidochirotida	Holothuriidae	1	4
	Ophiuroidea	Ophiurida	Amphiuridae	4	12

Table 2 cont.

Phylum	**Class**	**Order**	**Family**	**Stations present**	**Total abundance**
			Ophiactidae	1	1
			Ophiuridae	3	14
Mollusca	Bivalvia	Veneroida	Arcticidae	2	3
			Cardiidae	4	5
			Mactridae	1	1
			Semelidae	2	9
		Pectinoida	Pectinidae	2	5
		Nuculida	Nuculidae	1	1
		Nuculanoida	Nuculanidae	1	1
		Mytiloida	Mytilidae	2	6
		Lucinoida	Lucinidae	1	1
			Thyasiridae	3	34
		Limoida	Limidae	1	4
		Carditoida	Astartidae	4	8
	Caudofoveata	Chaetodermatida	Chaetodermatidae	3	11
	Gastropoda	Cephalaspidea	Scaphandridae	1	1
		Littorinimorpha	Naticidae	2	3
			Lottidae	1	3
	Polyplacophora	Chitonida	Mopaliidae	3	36
	Scaphopoda	Dentaliida	Dentaliidae	2	2
Phoronida			Phoronidae	2	3
Sipuncula	Sipunculidea	Golfingiida	Phascolionidae	2	10
			Sipunculidae	2	5

3.2 Spatial variability of mean abundance and diversity

The differences in abundance and number of taxa between the sample sites are shown in Figures 2 and 3. The highest mean abundance (145 ± 4 ind. $0.1m^{-2}$) was found at station 1, located NE of the island Landegode (Fig.1), while the lowest mean abundance was found at station 3 with 84 ind. $0.1m^{-2}$. The total number of taxa was highest for the three northernmost stations 1, 2 and 5, ranging between 38 families $0.1m^{-2}$ (stations 1 and 2) and 37 (station 5), and slightly lower at the more southern stations 3, 7 and 19.

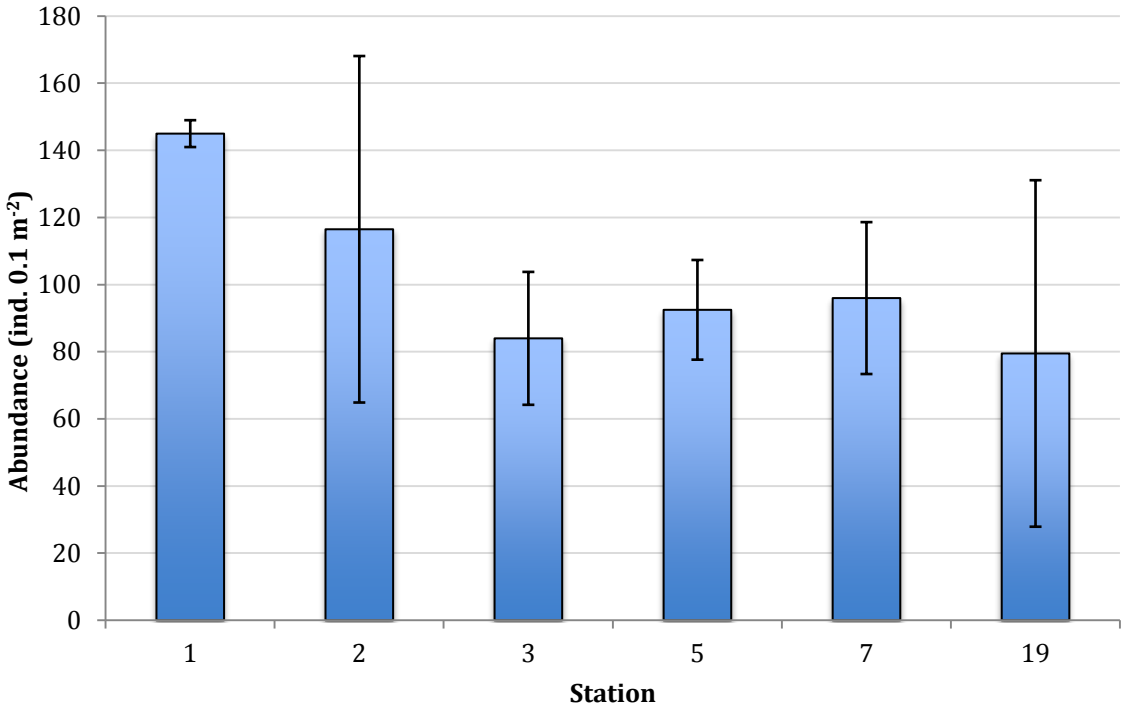

Figure 2. Mean total abundance (ind. $0.1\ m^{-2}$)(±SD).

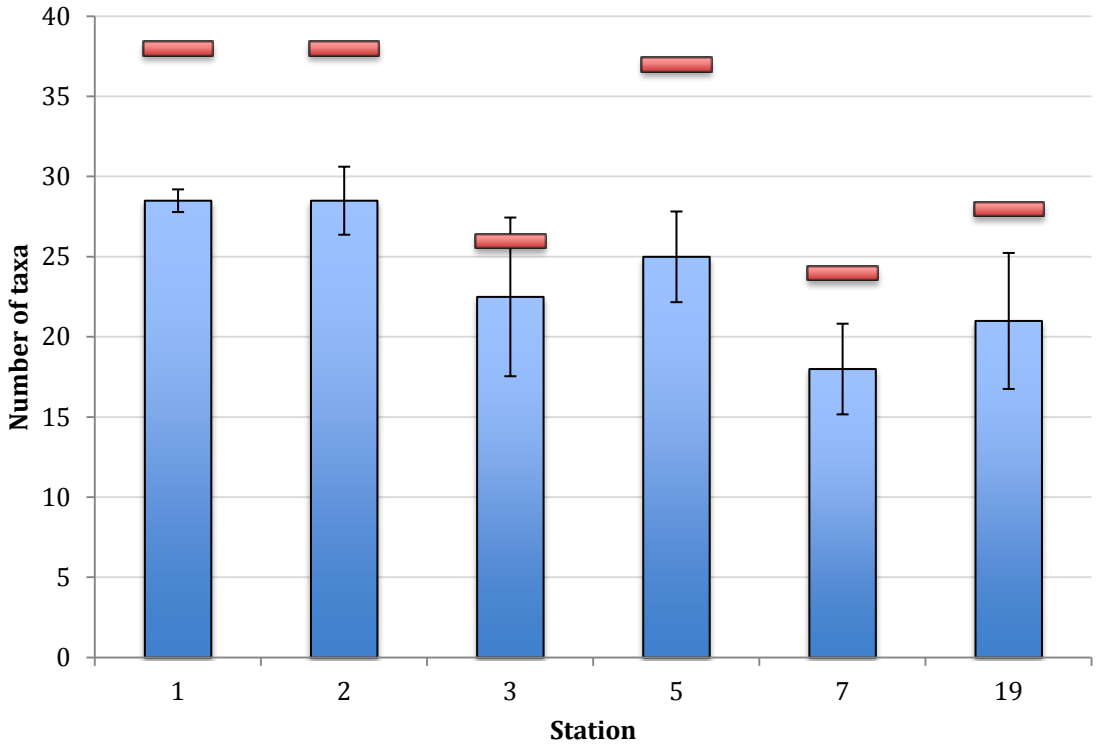

Figure 3. Mean number of taxa per station (0.1 m^{-2} ±SD) using family taxonomic level. Red bars indicate total number of taxa (0.2 m^{-2}) per station.

The Shannon Wiener Index, which reflects changes in diversity based on dominance and taxa number, showed mean values between 2.26 and 2.9, station 7 being the lowest and station 2 being the highest (Fig. 4).

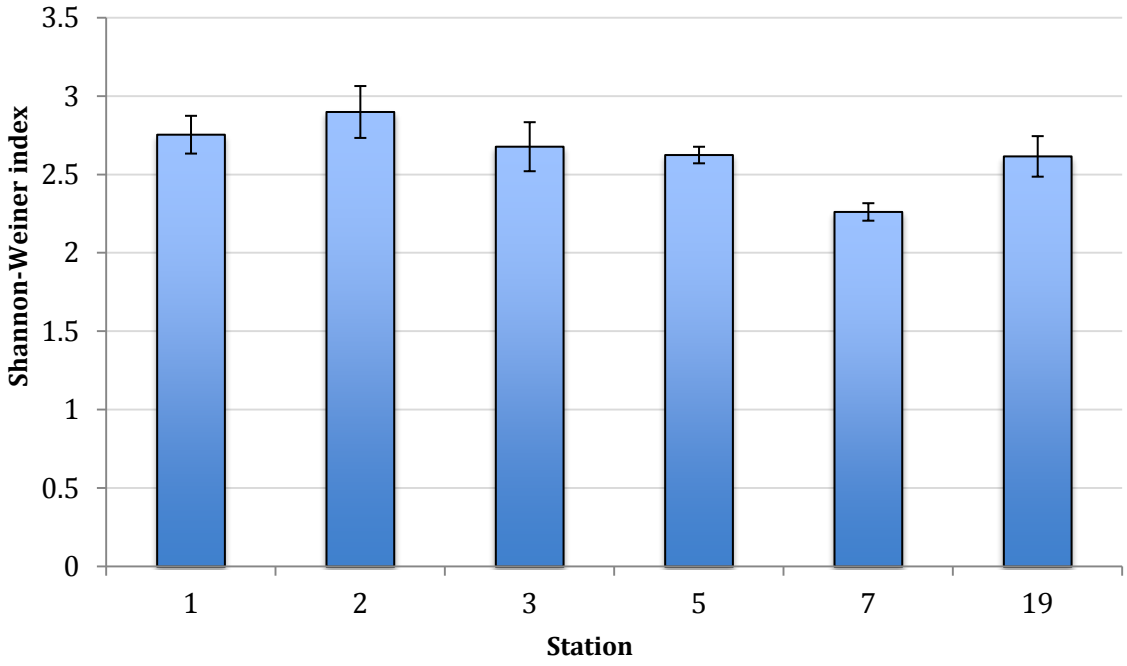

Figure 4. Mean Shannon-Weiner index (±SD) based on family level.

3.3. Spatial differences community composition

The differences in the composition of macrofaunal communities compared at the phylum level are shown in Fig. 5. All stations were clearly dominated by annelids, accounting for more than 60% of total abundance at all stations, followed by Mollusca at most stations (Fig. 5). While most phyla occurred at almost all stations, such as Annelida, Mollusca, Echinodermata and Arthropoda, the phyla Phoronida or Sipuncula only occurred at stations 1, 7, and 19. Furthermore, station 7 differed from the other stations, with the highest dominance of Annelida at 87.5% followed by Arthropoda and Sipuncula, whereas other phyla only accounted for 1% (Fig. 5).

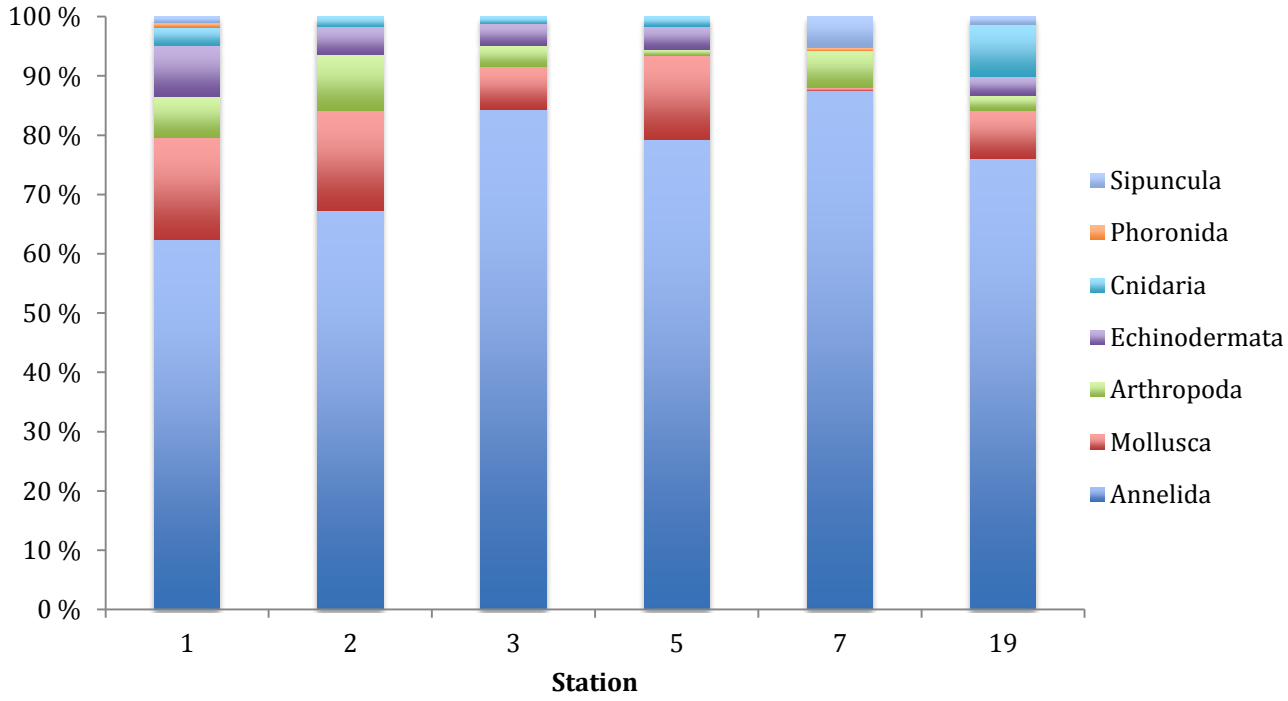

Figure 5. Relative abundance (%) of phyla.

The five most abundant families from each station combined to form 13 families comprised of three phyla: Annelida, Mollusca, and Echinodermata. The polychaete families Spionidae and Capitellidae occurred with high abundances across most stations (Table 3). A clear dominance of one or few taxa in terms of abundance was not found at any station, though annelids composed the majority of most abundant taxa. Other taxa, such as Ophiuridae, Thyasiridae and Mopaliidae, were among the most abundant species at stations 1, 2, and 5 only.

Table 3. Five most abundant taxa, using family, across stations.

Station no.	Five most abundant taxa	Total abundance
1	Spionidae	53
	Cirratulidae	52
	Thyasiridae	31
	Capitellidae	12
	Ophiuridae	10
2	Sabellidae	43
	Mopaliidae	23
	Terebellidae	16
	Capitellidae	14
	Pholoidae	13
3	Oweniidae	32
	Capitellidae	26
	Orbiniidae	13
	Phyllodocidae	11
	Spoinidae	11
5	Capitellidae	46
	Sabellidae	18
	Spionidae	18
	Mopaliidae	12
	Pholoidae	11
7	Maldanidae	65
	Capitellidae	29
	Spionidae	18
	Terebellidae	13
	Ampharetidae	11
19	Spionidae	41
	Cirratulidae	15
	Glyceridae	12
	Capitellidae	12
	Ampharetidae	11

3.4 Cadmium concentration of macrofauna

3.4.1 Differences in Cd concentrations between stations

The results of the overall Cd concentration by station showed mean Cd values varying between 1.79 and 6.5 mg/kg AFDW. Standard deviation was relatively high across all stations, indicating low sample size and high variation between taxa within each station (Fig. 6). These results can only be used as an approximate indication of differences and variability, as Cd values were averaged across taxa, not accounting for the taxonomic composition and number of organisms measured at each station. Nevertheless, station 5 showed the highest mean Cd concentration, followed by stations 7, 19, 1, 2, and 3.

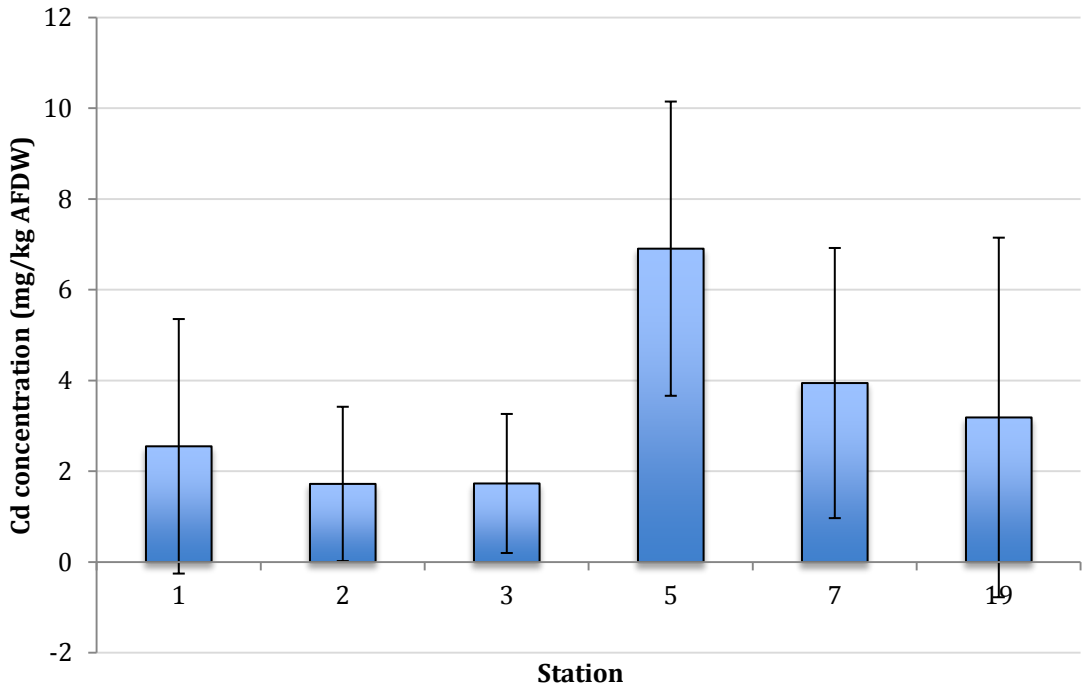

Figure 6. Mean Cd concentration per station (±SD).

Echinodermata and Mollusca were the only taxa with Cd data available across all six stations. For Echinodermata the highest Cd concentration was found at station 5 with 2.71 mg/kg AFDW and the lowest at the reference station 19 with 0.4 mg/kg AFDW (Fig. 7). This pattern was also found for the molluscs with maximum and minimum Cd values at stations 5 and 19, respectively. Arthropoda showed the lowest values of all sampled taxa with only little variation between the stations. The mean Cd concentration ranged from 0.46 mg/kg AFDW at station 3 to 0.59 mg/kg AFDW at station 1, with no data available for stations 5 and 19 (Fig.7).

In general, the highest mean Cd concentrations for Annelida, Echinodermata, Mollusca and Porifera were invariably found at station 5, while the reference station 19 showed the lowest values for Annelida, Mollusca, and Echinodermata, but not for Porifera (Fig. 7). Mollusca displayed the highest mean Cd concentration for any station at 9.59 mg/kg AFDW followed by Porifera (9.33 mg/kg AFDW), both at station 5. Annelida showed an upper mean slightly lower (6.0 mg/kg AFDW), also at station 5. Arthropoda showed the lowest values of all sampled taxa, ranging from 0.46 mg/kg AFDW (station 3) to 0.59 mg/kg AFDW (station 1). Station differences were variable within taxa, lacking data at some stations. Porifera, which showed values for three of the six stations, displayed the most consistently high mean values, whereas Mollusca and Annelida showed greater variability (Fig. 7).

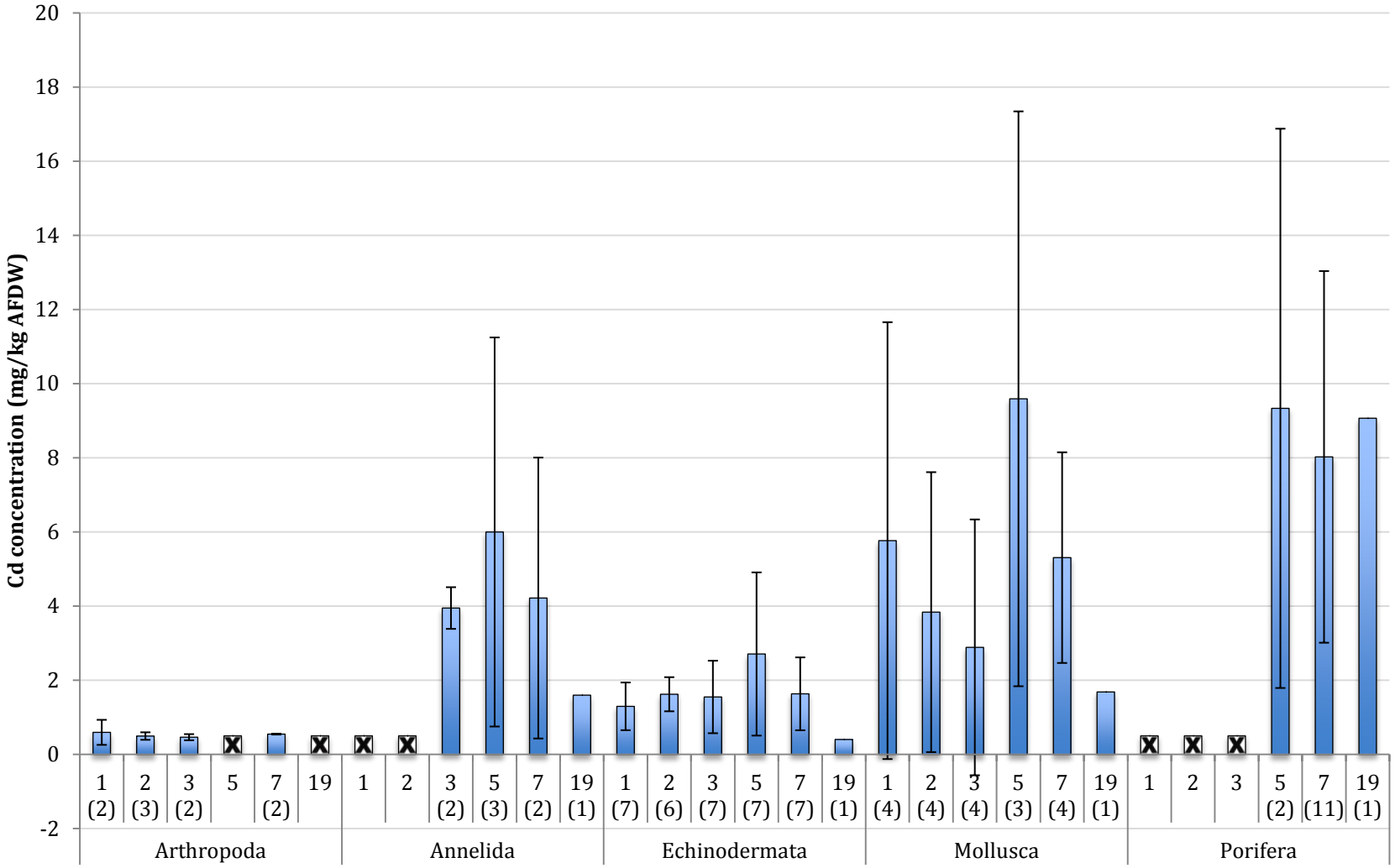

Figure 7. Cd concentration (mg/kg AFDW) by station and phylum (±SD). Stations marked as "x" indicate no data. Number of measurements included in value specified by parentheses.

3.4.2. Differences in Cd concentrations between taxa

Observed mean values of Cd concentration in regard to phyla across all stations showed that Porifera has a distinctly higher mean value than any other phylum, followed by Mollusca and Annelida (Fig. 8). The lowest mean Cd concentration was found for the Arthropoda and Echinodermata with 0.64 mg/kg AFDW and 1.72 mg/kg AFDW, respectively.

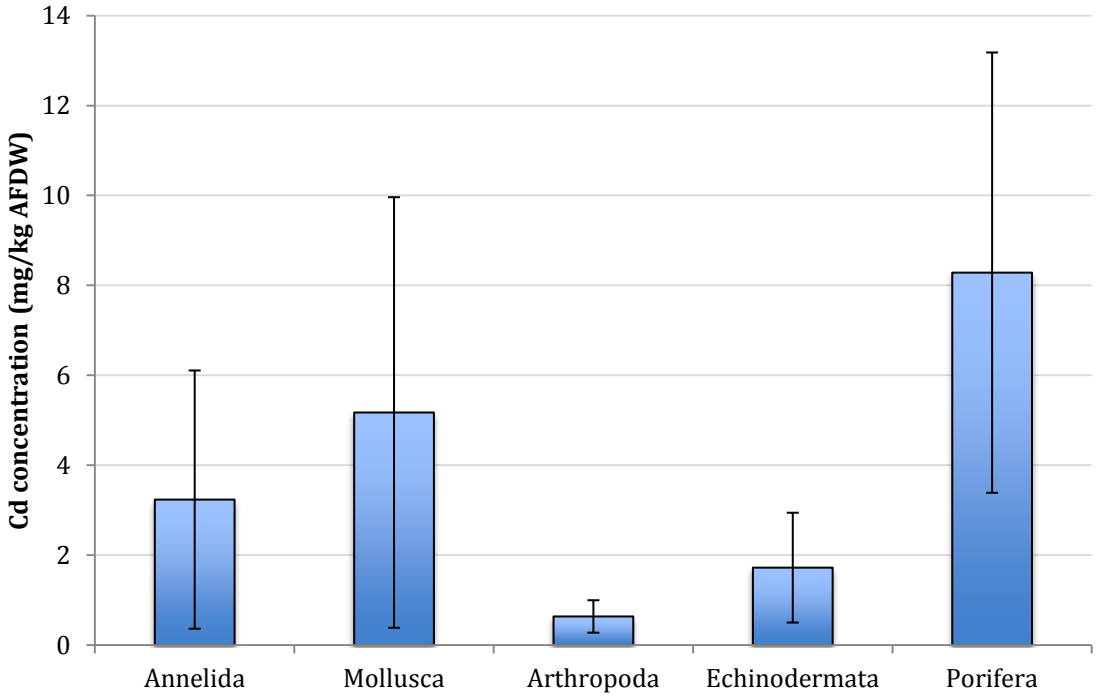

Figure 8. Mean Cd concentrations (mg/kg AFDW) per phyla across all stations (±SD).

Figure 9 shows mean Cd concentration by taxa at the family level, excluding Porifera which were categorized as phyla only. Concentrations were highly variable, but some noticeable trends occurred. The families with the highest Cd concentration (Pectinidae and Thyasiridae) were found in Mollusca. The third highest Cd concentration was shown within the phylum Porifera, which also consisted of the greatest number of individuals (14). Low Cd levels occurred in families belonging to all phyla, most consistently among the arthropods,

which in some cases had a larger number of measurements compared to other phyla. The lowest values belonged to the families Capitellidae (Annelida) with 0.31 mg/kg AFDW, Holothuriidae (Echinodermata) with 0.42 mg/kg AFDW, and Paguridae (Arthropoda) with 0.47 mg/kg AFDW.

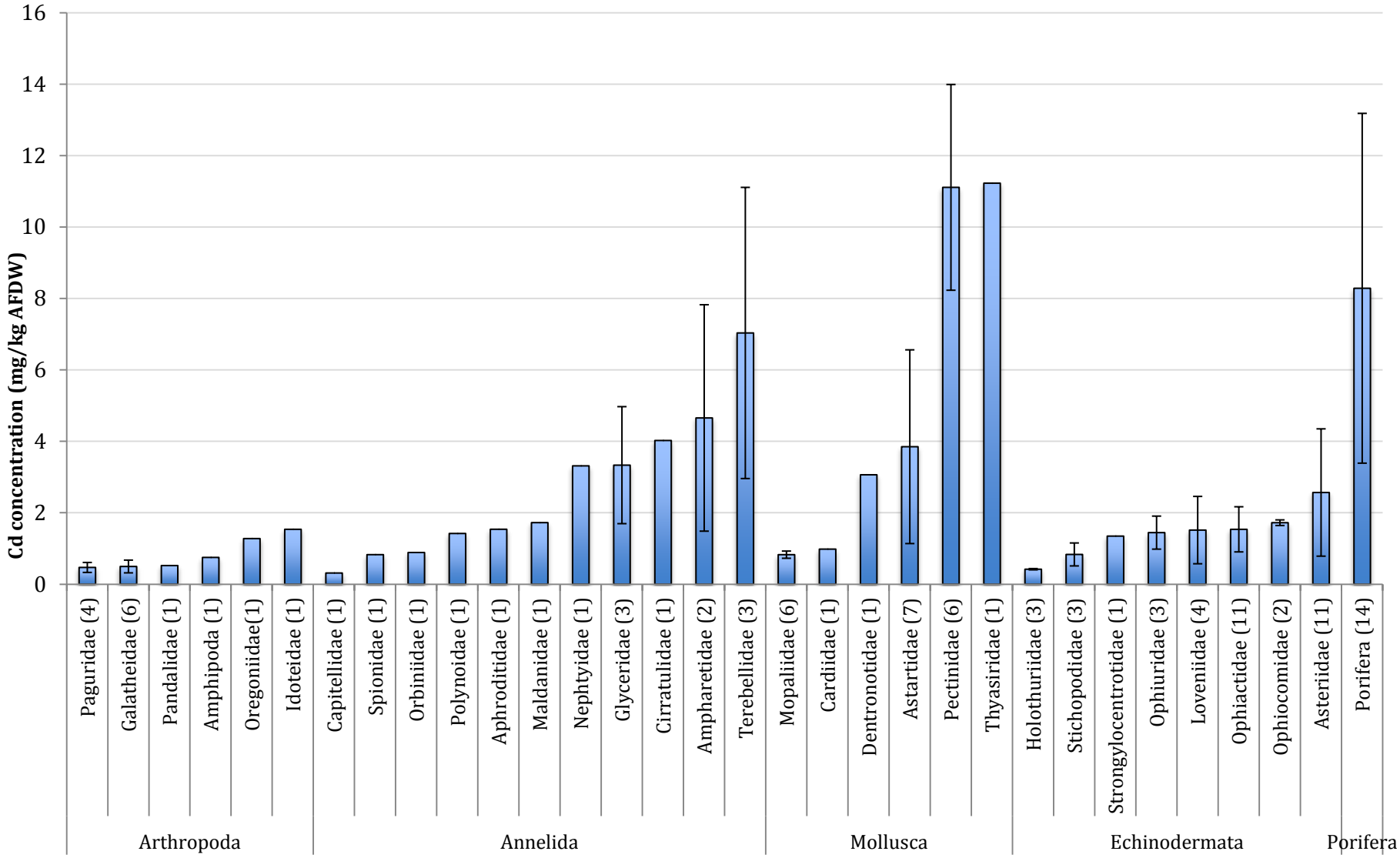

Figure 9. Mean Cd concentration (mg/kg AFDW) by family (±SD). Number of measurements included in value specified by parentheses.

Porifera, Mollusca, and Annelida, in the aforementioned order, were found to contain the highest concentrations of Cd among the identified taxa (Fig. 8). Figures 10-12 show Cd concentrations of each phylum by family, per station replicate. Of these three, Porifera exhibited the uppermost concentration of any individual or combined sample analyzed (Axinellidae), with a value of 18.67 mg/kg AFDW. Other samples in the phylum Porifera showed consistent, relatively high Cd concentrations, with 50 percent of samples having values higher than 8.0 mg/kg AFDW.

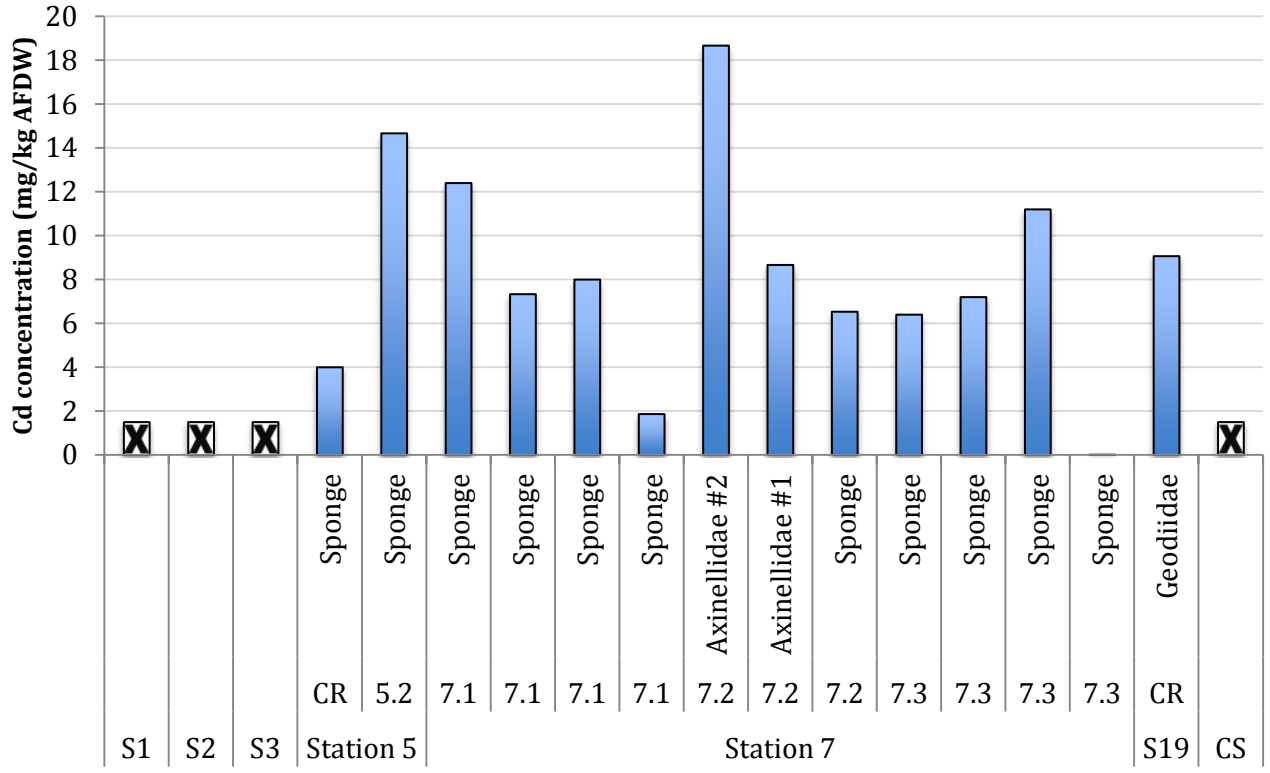

Figure 10. Cd concentrations of the phylum Porifera per replicate and station. Stations marked as "x" indicate stations without specified taxa found. Numbered measurements (#) indicate different individuals. CS and CR indicate Combined Stations and Combined Replicates, respectively.

Mollusca (Fig. 11), having the second highest mean Cd concentration among phyla, also had one of the largest sample sizes. Pectinidae showed consistently high concentrations at five of the six stations, accounting for a majority of the high average value shown by the phylum. Conversely, Mopallidae showed consistently low values. Cd concentration was variable within the family Astartidae, displaying noticeable differences within station 7 from 2.98 mg/kg AFDW to 8.77 mg/kg AFDW. Thyasiridae, one of the higher concentration families, had only one measurement for all stations combined.

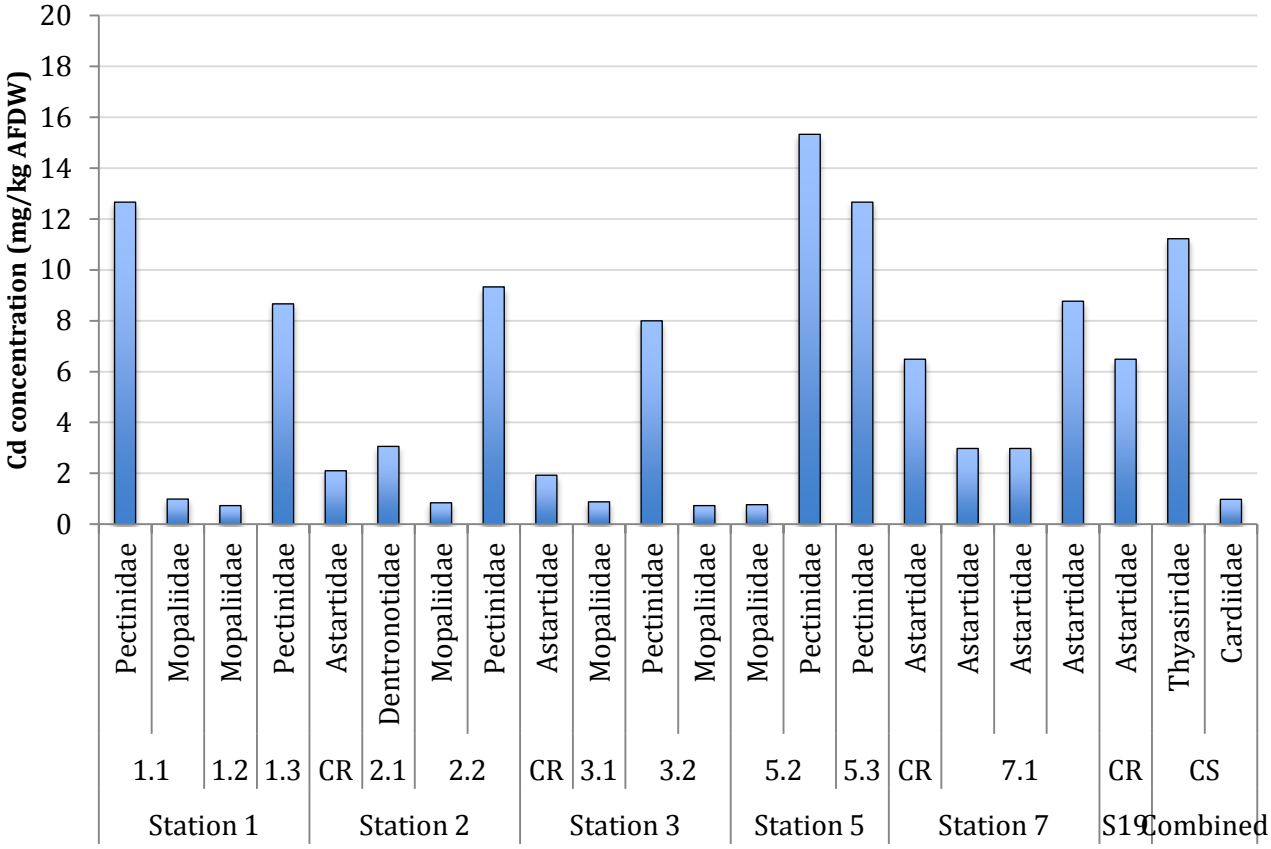

Figure 11. Cd concentrations (mg/kg AFDW) of the phylum Mollusca per replicate and station. CS and CR indicate Combined Stations and Combined Replicates, respectively.

Annelids exhibited substantial variability in concentrations of Cd across samples (Fig. 12). The lowest was Capitellidae with 0.31 mg/kg AFDW, followed by Spionidae and Orbiniidae, with values of 0.83 mg/kg AFDW and 0.89 mg/kg AFDW respectively. Terrebellidae showed the highest Cd concentration with 11.72 mg/kg AFDW and was the only annelid family with values higher than 8 mg/kg AFDW, followed by Ampharetidae with 6.9 mg/kg AFDW. More than 60 percent of sampled annelids displayed Cd concentrations less than 4 mg/kg AFDW.

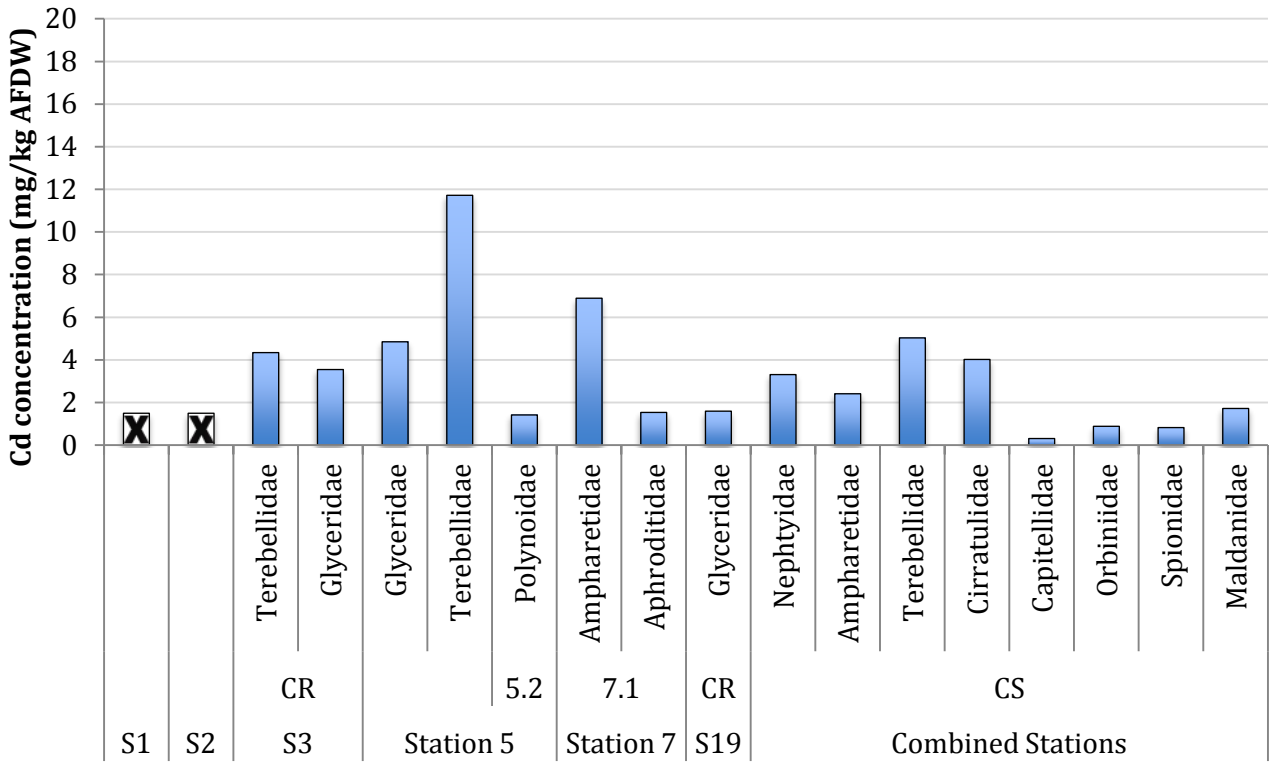

Figure 12. Cd concentrations (mg/kg AFDW) of the phylum Annelida per replicate and station. Stations marked as "x" indicate stations without specified taxa found. CS and CR indicate Combined Stations and Combined Replicates, respectively.

4. Discussion

It is widely known that accumulation of cadmium occurs in marine invertebrates and benthic organisms (Jennings & Rainbow, 1979; Bargagli et al., 1996). Benthic marine invertebrates are commonly used as bioindicators because it has been demonstrated that the macrobenthos respond rapidly to stress, both natural and anthropogenic (Pearson & Rosenberg, 1978). This study investigates the local benthic diversity and community structure as well as cadmium concentration of various macrofaunal taxa.

The presented results show differences in cadmium content between both taxa and sampling stations in the Salten region of northern Norway, although statistical tests could not be applied because of the low number of measurements. Variation occurred between stations and between taxa within stations. Mean station values showed highest Cd concentrations at stations 5, 7 and 9 respectively, and taxa with high concentrations included Porifera, Mollusca, and Annelida. In some cases, Cd concentrations differed notably for the same family per replicate (e.g., Astartidae, Pectinidae). Much of the variation detected can be related to differences in anatomy and life modes of specific taxa. No clear sign of disturbance or stress was detected with respect to diversity and community structure; diversity showed only minor variation.

4.1. Macrofaunal community structure

Benthic communities are shown to change along a gradient of increasing disturbance, differing in diversity, abundance, and species composition dependent on their tolerance to the specific disturbance (Van Hoey et al., 2010). The results of the community structure analysis in this study showed no noticeable differences in diversity that would suggest a local pollution source or disturbance event. The variation in diversity, mean abundance, and

relative abundance is small, and can most likely be accounted for by differences in station characteristics such as depth or sediment type. In this study, time series data on benthic community structure was not available so abundance and diversity data is based on inconsistent sampling intervals. Nevertheless, the given data can provide insight into possible disturbance events. Marine environments are heterogeneous in nature, and are variable in both space and time (Reice, 1994). Often, under stressful disturbance events such as heavy pollution, benthic communities become dominated numerically by one or a few highly tolerant species (e.g., annelids like *Capitella* spp.) (Warwick, 1986). Nevertheless, concentrations of heavy metals in marine environments are generally low, even if elevated concentrations from pollution occur (Gray & Elliott, 2009), and a clear response of the macrofaunal community might not be expected. Although Annelida dominated the communities at all stations and short-living, *r*–selected taxa such as Capitellidae and Spionidae were among the most abundant taxa at several stations, no clear dominance of these taxa were found and the community composition was similar across all stations. Thus, given the results of this study, a local disturbance event is not likely, although a local source of Cd pollution cannot be excluded based on these community composition results.

4.2 Spatial differences in Cd concentration of macrofauna

Cadmium concentration among sampled taxa was variable and indicated higher bioaccumulation at specific stations. The mean values indicated that among sampled taxa, those found at station 5 contained highest overall mean Cd concentrations with 6.5 mg/kg AFDW, although variation was relatively high among all stations. In contrast, station 3 showed a low mean value of 1.79 mg/kg AFDW. Station 7, located nearest to station 5, had the second highest mean value among stations. Although the results of stations 5 and 7 suggest a geographic correlation, all other station values indicate otherwise, showing no

spatial relationship. Individual taxa found at multiple locations showed relatively similar Cd concentrations, such as Mopaliidae and Glyceridae, indicating availability of Cd throughout the entire study area rather than a locally restricted source. Only the Pectinidae and Terebellidae displayed variability in cadmium concentrations consistent with mean station values. This could be due to an increased sensitivity to, or uptake of cadmium; metal accumulation in marine organisms is affected by both endogenous and exogenous factors (Barrento et al., 2009).

In comparison to previous data regarding station specific Cd concentrations of sediment and claw meat of *C. pagurus* (Table 1), the study results show little similarity. Station values from sediments, claw meat of *C. pagurus*, and macrofauna show no consistent pattern when compared, indicating little to no relationship therein. Claw meat concentrations were highest at stations 1 and 7, whereas sediment values were highest at stations 2 and 3. Station 19 (reference station) showed low mean concentrations for both claw meat and sediments, but were slightly elevated in relation to mean Cd concentrations among benthic organisms, primarily due to the occurrence of Porifera (see below).

Relative to spatial differences, it is possible that bottom topography and/or biophysical factors play a role in the resulting Cd prevalence in the area (Lares et al., 2002). Furthermore, the dissimilarities could be explained in part by time difference in sampling dates − changes to the marine environment of the study area between study periods (2010-2013) − or on a shorter time scale, seasonal variation. These time/season differences can affect current flow, temperature, and the prevalence of specific disturbances of a marine environment. This can influence the life cycles and seasonal recruitment of organisms within the benthic community (Beche et al., 2006). Thus, while the long living *C. pagurus* may

provide information of Cd concentrations integrated over relatively long time periods, some of the short living macrofaunal taxa, such as Annelida, only give indications of Cd accumulation over shorter periods and, therefore, might be more influenced by short-term (seasonal or inter-annual) variation of Cd availability.

Furthermore, differences in spatial patterns can be difficult to interpret because *C. pagurus* can have both seasonal and diurnal migratory habits, with some individuals (primarily females) traveling 2-3 km per day while migrating up to 200 nautical miles (Pawson & Britain, 1995; Woll & Alesund, 2006). These habits can influence their temporary environmental locality as well as their dietary composition (both abundance and taxa composition of prey). Thus, location of Cd uptake either via feeding or the surrounding water and location of sampling of *C. pagurus* might be uncoupled, making it difficult to determine the exact location of the Cd source based on *C. pagurus* individuals. In addition, age and sex have been shown to highly influence cadmium accumulation patterns of *C. pagurus*; both growth rate and feeding habits are dependent on these factors (Davies et al., 1981; Woll et al., 2006). During long migrations, berried females generally do not feed. This means that Cd uptake during this period must be acquired from the surrounding aquatic medium, and the gill is thought to act as the primary site of Cd uptake (Jennings & Rainbow, 1979; Davies et al., 1981). In such cases, Cd has been shown to accumulate predominantly in the carapace and is therefore less applicable to the practicalities of this study as sampling sites were based on claw meat Cd values.

4.3 Differences in Cd concentration between taxa

Ranking from high to low, Porifera, Mollusca, and Annelida displayed the greatest mean Cd concentrations among sampled phyla, followed by Echinodermata and Arthropoda. These results are consistent with the literature: sponges and bivalve species frequently show high concentrations of Cd and are therefore often used as bioindicators (Olesen & Weeks, 1994; Bargagli et al., 1996; Shiel et al., 2013). Although Porifera showed consistently high values, it was not a well-represented phylum at a majority of the stations. The dominant phylum, Annelida contained relatively high Cd concentrations, with a mean value of 3.24 mg/kg AFDW. The remaining two phyla, Echinodermata and Arthropoda, showed the lowest Cd content among sampled phyla. Accumulated cadmium levels in marine organisms can vary significantly and are dependent on many factors, sometimes leading to differences within closely related taxa (Rainbow, 2002).

There are two general sources of exposure to Cd (surrounding aquatic medium or food source), but depending on the individual taxa and their biological traits, Cd can be present internally in metabolically available and/or detoxified and stored forms in varying concentrations (Rainbow, 1993). Organisms differ in their placement of detoxified, stored metals, sometimes using specific organ tissues as primary deposit sites (e.g., hepatopancreas [brown meat] in *C. pagurus*). Moreover, the rates of Cd metabolism, detoxification, storage and excretion of an organism can differ greatly among taxa and are dependent on their accumulation strategy (Rainbow, 1993). These strategies range from high accumulation of all trace metals to a balanced level of excretion, approximately matching the given uptake rate. For example, P. Rainbow and White (1989) showed that among three crustacean taxa representing Decapoda, Amphipoda, and Maxillopoda, all were net accumulators of cadmium. This implies that through whichever specific metabolism and distributive storage

methods used, all were excreting the trace metal at a slower rate than the rate of overall accumulation. Furthermore, accumulation of heavy metals is both concentration and time-dependent, so the individual age of an organism can have an effect on total accumulated Cd (Engel & Fowler, 1979). For short-lived taxa like the polychaete family Capitellidae, there is relatively little time for accumulation to occur (see Fig. 12) (McHugh & Fong, 2002).

Life mode and feeding type of various taxa can play an important role in amount, concentration, and pathway of Cd uptake (Rainbow, 1995). Cadmium is a naturally occurring trace metal and is found in both sediment and in the water column. The results of this study showed the highest Cd concentration within taxa that are primarily suspension and surface deposit feeders (Table 4). In contrast, the taxa with the lowest Cd concentrations were not suspension feeders, but mainly predators or omnivores (Table 4).

Thyasiridae and Pectinidae, both bivalve molluscs, were the families with the highest Cd concentrations in this study. Although the blue mussel (*Mytilus edulis*) was not found to have elevated concentrations of Cd in the affected area, this study showed opposing results with regard to other bivalve molluscs (Tverdal, 2012). Bivalves are known metal accumulators and commonly used as bioindicators for heavy metals and other pollutants in the marine environment (Kimbrough et al., 2008; Pan & Wang, 2011). They are able to filter large volumes of water, indicating elevated levels of pollutants in the water column (Ciutat & Boudou, 2003).

Porifera, an obligate suspension feeder, displayed high Cd concentrations. Like the aforementioned bivalves, sponges are highly tolerant of trace metals and because of the high levels of water passing through their body structures, are capable of accumulating significant

concentrations (Olesen & Weeks, 1994). Sedentary suspension feeders like sponges and many bivalves probably cannot meet adequate heavy metal excretion rates to compensate for their significant uptake rates, thus yielding high body concentrations (Bargagli et al., 1996). Results suggest that feeding mode plays a key role in absorption and bioaccumulation of Cd.

Table 4. The five sampled families containing the highest and lowest cadmium concentrations (mean values across all stations) found in this study and their respective feeding modes.

High

Family	**Cd conentration (mg/kg AFDW)**	**Feeding mode**
Thyasiridae	11.228	Suspension [2,8]
Pectinidae	11.111	Suspension [2,8]
Porifera	8.286	Suspension [1,8]
Terebellidae	7.034	Surface deposit, interface, suspension [3,8]
Ampharetidae	4.655	Surface deposit, suspension [3,8]

Low

Family	**Cd content (mg/kg AFDW)**	**Feeding mode**
Capitellidae	0.314	Subsurface deposit [2,8]
Holothuriidae	0.42	Surface deposit [6,8]
Paguridae	0.47	Omnivore, predator, scavenger [4,8]
Galatheidae	0.496	Omnivore, predator, scavenger [5,8]
Pandalidae	0.522	Omnivore, predator, scavenger [7,8]

[1] Jørgensen (1952) **[2]** Stanley (1970) **[3]** Fauchald & Jumars (1979) **[4]** Kunze & Anderson (1979) **[5]** Janßen et al. (2000) **[6]** Hudson et al. (2004) **[7]** Yeh & Drazen (2009) **[8]** "WoRMS Editorial Board" (2014)

Both Terrebellidae and Ampharetidae are surface deposit and suspension feeders. They feed partly on detritus and other particles that reach the sediment surface (Fauchald & Jumars, 1979), but they can switch to suspension feeding depending on the prevailing hydrodynamic conditions. During conditions of strong current flow, they spend the majority of time suspension feeding with their tentacles outstretched into the water, while during conditions of stagnance, they can shift to surface deposit feeding (Fauchald & Jumars, 1979; Dauer et al., 2003). Among the taxa with lower Cd concentrations, while a variety of feeding modes were represented, the majority were omnivorous, predatory scavengers. This study

indicates that suspension feeding macrofaunal taxa in the Salten region consistently contain elevated concentrations of Cd.

4.4 Cadmium concentrations of *Cancer pagurus* in relation to macrofaunal diet

In relation to Cd content within the species *C. pagurus*, the results of this study can reveal a possible foraging link between elevated Cd concentrations of *C. pagurus* and their diet. *Cancer pagurus* is a predator and scavenger that has been shown to accumulate high concentrations of Cd in the hepatopancreas following consumption of food contaminated with Cd, suggesting diet as the main uptake pathway (Davies et al., 1981). Although diet and foraging behavior of *C. pagurus* is poorly understood, previous studies have shown that Mollusca and Polychaeta (Annelida) are predominately consumed, with molluscs (gastropods and bivalves) as the main food source (Table 5).

Table 5. Percentage of total individuals (*C. pagurus*) with specified taxa present in stomach contents (2nd column) and stomach contents (%) of *C. pagurus* by phylum based on biomass (3rd column). Data adopted from Shelton et al. (1979) and Woll (1995), respectively.

Taxa	% stomachs containing taxa	Stomach contents percentage
Porifera	0	0
Mollusca	-	80
• Gastropoda	29	-
• Bivalvia	44	-
Annelida	17	13
Echinodermata	24	1
Arthropoda	31	6

Mollusca was also the second most abundant phylum found in the study area, possibly lending to their prevalence in the edible crab diet. The family that showed the highest Cd concentrations within Mollusca, Pectinidae, is epibenthic and therefore relatively easily accessible to *C. pagurus.* In contrast, Thyasiridae or Cardiidae are endobenthic molluscs and

showed lower Cd concentrations (Schejter & Bremec, 2007). Porifera, the only phylum in this study containing higher levels of Cd than Mollusca, is not known to be consumed by *C. pagurus* (Shelton et al., 1979; Woll, 1995). According to Shelton et al. (1979), polychaetes were found to consist of 13 percent of the diet of *C. pagurus*. Depending on the taxon consumed, this once again lends to a high Cd intake via feeding (Table 5). However, because of the grinding action in the gastric mill, it is difficult to identify soft-bodied organisms like polychaetes in stomach contents of *C. pagurus* with accuracy and their importance as prey might be underestimated. Nevertheless, results indicate that *C. pagurus* feeds mainly on taxa containing high concentrations of Cd relative to other available taxa.

4.5. Implications for potential Cd sources in the Salten region

Relating Cd concentrations to taxa, their life modes, and the diet of *C. pagurus*, the results and literature suggest that *C. pagurus* preys predominantly on filter-feeding invertebrates that correspondingly contain relatively high Cd concentrations. Hence, elevated Cd concentrations in *C. pagurus* may be caused by the uptake and accumulation of Cd via macrofaunal prey organisms. Variability in Cd concentration between the different taxa is high and without more detailed knowledge regarding the dietary composition of *C. pagurus*, conclusions about Cd pathways are difficult to draw. Nevertheless, the question of the sources of Cd in the coastal ecosystem of Salten still remains unanswered.

The presence of differences in mean Cd concentration between stations suggests a possible point source; Cd concentrations at stations 5 and 7 were notably higher than other stations, both overall and among several taxa. However, when comparing these values with

patterns from sediment and claw meat concentrations, there remains a clear dissimilarity that suggests a potential larger scale source of Cd.

Possible factors contributing to elevated Cd concentrations in claw meat of *C. pagurus* and other macrofaunal taxa are biophysical processes, such as upwelling. Although the Norwegian Coastal Current (NCC) flows northward with southerly alongshore winds lending to predominant downwelling, numerous physical processes can cause periodic upwelling events, specifically northerly alongshore winds (Asplin et al., 1999). Cadmium is widely known to increase in coastal areas during upwelling events, and although these northerly wind events along the Norwegian coast are very short-lived (about one day), the volume flux can be substantial, bringing large amounts of Cd and nutrient rich water into the coastal zone (Asplin et al., 1999; Lares et al., 2002; Takesue & van Geen, 2002). This results in increased exposure of the benthos to Cd, both *C. pagurus* and its potential prey. Moreover, a previous study by Jennings and Rainbow (1979) showed that in a laboratory setting, the concentration of Cd in seawater has a strong effect on Cd accumulation in certain crab species. They demonstrated that Cd concentrations, primarily in the exoskeleton, increased proportionally to external exposure and were more affected than internal tissue. Their results also suggested that the gill serves as a main uptake pathway for acute absorption and loss of Cd. However, the study did not adequately test the effects of Cd uptake via dietary consumption, which may relate more to sustained increases.

Another potential source of Cd is the produced water and drilling mud released into the sea by the oil and gas industry (Wasmuth & Jensen, 2011). Oil industry activities release Cd and other pollutants which can be transported by currents along the coast, finally resting on the seabed (Akvaplan-NIVA, 2010; Wasmuth & Jensen, 2011). However, if petroleum

industry activity were the cause, elevated levels of other heavy metals (i.e., lead, mercury, etc.) should also be found in claw meat of *C. pagurus* but this was not the case (Falk, 2012).

4.6 Potential sources of error and limitations

Biases and/or errors can include both equipment and human error. Sampling, handling, processing, and interpreting errors can have minor effects on the results of the study.

As described previously, sampling for this study was done in the field on a small research vessel using manual sampling and processing techniques. During sampling, equipment failure, human error, and approximation failure can be factors that limit overall accuracy. In this study, where preliminary processing of samples was done on board, the sieving process and transfer of animals to fixation jars are the most likely steps to introduce errors (ECSA, 2007). In addition, sampling gear is not always 100 percent effective, and failed attempts are common, resulting in minor spatial errors. Sample sorting and identification was done manually and introduces further possibility for human error.

Due to time limitations and analysis restrictions pertaining to the collection and analysis of macrofaunal Cd concentrations, the variability of Cd within and among taxa and stations could not be addressed sufficiently to allow statistical testing of my hypothesis. In addition, to reach minimum biomass requirements it was necessary to combine individuals, resulting in fewer samples than the study had initially aimed for. Furthermore, the use of conversion factors in order to determine ash-free dry weight values can introduce a potential bias. However, it was by the use of these factors that the results had as little bias as achievable. *Cancer pagurus* are claimed to be able to feed on the soft parts of molluscs

without consuming the entire shell, but for this study, all calcareous material was included in the analyses (Shelton et al., 1979). By using conversion factors, it was possible to eliminate the weight of calcareous material from the results. Assuming that calcareous material of the macrofauna contained little or no Cd, this would influence the results negligibly or not at all. However, it has been demonstrated in some bivalve species that metals can be incorporated into their shell (Lares et al., 2005). To whatever degree this calcareous accumulation may have taken place in the macrofauna of this study, the converted AFDW values may be biased, exhibiting elevated values.

The use of Inductively Coupled Plasma Mass Spectrometry (ICP-MS) also presents inherent possibilities for error. However, as policy requires, all necessary precautions and calibration procedures were followed in accordance with laboratory protocols, leaving results within accepted standards of error. Finally, due to biomass restrictions related to heavy metal analyses, some taxa were not represented.

While the study was subject to various limitations and constraints, the results offer a valuable indication of the possible patterns/pathways upon which further, more detailed studies can be based.

5. Conclusion

This study was designed and implemented to investigate the benthic community structure and corresponding concentration of cadmium among identified taxa as it pertains to regionally elevated cadmium concentrations within the claw meat of *Cancer pagurus.* Results showed that Cd concentrations among the benthos were variable, with highest concentrations among filter feeding families belonging to Porifera, Mollusca, and Annelida. In addition, previously published data showed that part of these taxa play a prominent role in the dietary composition of *C. pagurus.* This supports the hypothesis that the food web and diet of *C. pagurus* is a contributor to the high levels of Cd detected. A spatial gradient of Cd concentration proved difficult to identify, as there were no consistent patterns across the different ecosystem and habitat components measured.

As the first study of its kind in the region, data is limited. Moreover, relatively little is known about the feeding habits of *C. pagurus.* Because of this, there is insufficient data to support any substantial claims regarding a correlation between select key benthic species, their Cd concentrations, predation by *C. pagurus*, and elevated Cd concentration of claw meat in *C. pagurus.* The data suggests a plausible interrelationship, but more research is needed. Other factors, such as sediment Cd concentration and upwelling, likely contribute to Cd levels. This thesis suggests that benthic prey and dietary habits of *C. pagurus* are a significant source of Cd and the bioaccumulation, beginning with lower level taxa, of the trace metal in the food web.

In relation to this study topic, there are many possibilities for future research. To better assess the source of elevated cadmium as it relates to the food web, it is necessary to have a better understanding of Cd content across a greater scope of the benthic community.

Including samples from more distant areas such as Trøndelag or Bergen and assessing variation in Cd concentration of key taxa between regions could serve as a useful comparison method. In addition, determining the significance of Cd absorption from diet versus seawater and its accumulation in *C. pagurus*, in relation to both internal and exoskeletal tissue, could prove as valuable information in better determining the Cd source. Lastly, regardless of the source, ecological stress is most effectively assessed using multiple methods of evaluation. Optimistically, the results presented in this thesis will aid in the further discussion and disclosure of the study topic.

6. References

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7. Appendix 1 – Results of ICP-MS analyses

Tables 1 and 2 show results from the ICP-MS analyses done at NIFES facility in Bergen. Any labeled taxa followed by CR indicate combined replicates: samples which when combined together with replicates of the same station had adequate biomass for analysis. Those followed by CS (combined stations) indicate samples that represented less than three "combined replicates" with adequate biomass, and were therefore combined and homogenized across all stations before analysis.

Table 1. Results from first Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis. Cadmium values are emboldened.

Label	# of ind.	Ag	As	Ba	Cd	Co	Cu	Fe	Hg	Mn	Mo	Pb	Se	Sn	Sr	V	Zn
Nephtys CS	18	0.055	32	0.39	**0.56**	0.95	3.2	150	0.026	1.5	0.8	1	4.4	0.061	44	5.7	77
Ampharete CS	63	0.16	4.2	1.4	**0.35**	0.18	8.4	130	0.026	5.9	0.1	0.52	1.1	0.037	24	0.47	20
Terrebellidae CS	53	0.15	6.3	3.8	**0.73**	0.35	2.6	190	0.02	5.5	0.3	1.2	1.6	0.088	38	1.5	28
Cirratulidae CS	69	0.092	25	1.6	**0.68**	1.3	4.1	310	0.044	4.2	2	1.6	3	0.26	35	1.8	28
Heteromastus/ Notomastus CS	44	0.048	4.2	2	**0.053**	0.2	1.1	280	0.01	3.6	0.3	0.69	1.5	0.15	74	0.73	9
Scoloplos CS	19	0.015	6.9	1.6	**0.15**	0.52	1.4	180	0.029	3	0.7	0.41	6.6	0.14	35	0.62	11
Spionida CS	84	0.042	3.7	2	**0.12**	0.39	1.9	200	0.014	5.1	0.2	0.93	1.2	0.13	46	0.91	20
Maldanidae CS	27	0.18	2.8	2.4	**0.25**	0.7	3.1	320	0.044	6.3	0.1	0.97	0.54	0.018	19	0.99	11
Asterias rubens CS	7	0.11	2.3	0.77	**0.31**	0.042	1.4	68	0.01	0.74	0.1	0.08	0.21	0.006	180	0.11	30
Ophiocomina nigra CS	44	0.17	2.7	2.6	**0.15**	0.065	0.98	140	0.006	1.9	0.1	0.16	0.27	0.027	360	0.17	20
Strongylocentrostus CS	44	0.029	1.3	1.8	**0.066**	0.072	0.42	150	0.004	1.6	< 0.1	0.087	0.11	0.008	400	0.18	6
Thyasira CS	25	0.075	1.5	4.1	**0.64**	0.16	1.2	210	0.008	0.64	0.4	0.29	0.21	0.045	390	0.17	7
Cardiidae CS	16	0.034	1.5	4.1	**0.056**	0.23	1.3	670	0.004	4.5	< 0,2	0.44	0.56	0.065	880	0.6	10
Amphipoda CS	128	0.1	2.5	6.2	**0.12**	0.073	6.7	98	0.006	2.6	0.1	0.21	0.2	0.17	240	0.32	16
Galathea CS	16	0.056	4.5	3.1	**0.071**	0.062	9.2	190	0.006	6.8	< 0,1	0.088	0.25	0.021	670	0.24	11
Pagurus pubescens CS	6	0.077	4.1	2.7	**0.052**	0.054	14	160	0.003	4	< 0,1	0.081	0.26	0.018	470	0.21	15
Hyas arenarius CS	9	0.14	6.9	2.8	**0.23**	0.16	5	290	0.007	7.7	0.2	0.24	0.59	0.045	590	0.76	18
Idotea CS	3	0.086	7	1.6	**0.38**	0.046	3.3	110	0.004	1.3	< 0,1	0.026	0.077	0.012	450	0.094	13
Sipuncula CS	21	0.22	2.5	1.3	**0.065**	0.13	2	200	0.078	5	0.4	0.74	2.2	0.21	21	0.71	9
Ascidia	1	0.016	1.5	4.6	**0.1**	0.26	1.1	720	0.009	34	0.6	0.7	0.5	0.1	160	89	16
Porifera/Sponges (Station 5)	1	0.028	0.7	1.1	**0.3**	0.088	0.66	130	0.006	7	0.1	0.22	0.41	0.044	39	0.69	4

Table 1 cont.

Label	# of ind.	Ag	As	Ba	Cd	Co	Cu	Fe	Hg	Mn	Mo	Pb	Se	Sn	Sr	V	Zn
Phakellia (Station 7)	1	0.27	4.8	2.4	**1.4**	0.11	0.93	250	0.023	7.6	0.1	0.27	1.7	0.11	23	0.77	5
Axinella (Station 7)	1	0.037	1.1	3.8	**0.65**	0.3	0.99	580	0.006	23	0.2	0.62	0.58	0.15	39	1.7	4
Sponge (unknown) (Station 7)	1	0.042	1.6	11	**0.49**	0.98	1.3	2200	0.007	98	0.2	1.7	0.42	0.089	100	3.7	7
Geodia (Station 19)	1	0.039	3.4	4.8	**0.68**	0.22	2.4	380	0.049	11	0.2	0.4	3.8	0.089	91	0.78	14
Glycera CR 3	6	0.056	15	4.1	**0.6**	0.13	1.8	53	0.009	1.1	1	0.71	1.3	0.18	25	0.27	49
Glycera CR 5	5	0.086	6.4	5.6	**0.82**	0.058	2	20	0.011	0.78	< 0.08	0.23	0.61	0.073	14	3.1	31
Glycera CR 19	9	0.11	7.6	1.1	**0.27**	0.12	2.7	54	0.012	0.78	0.2	0.31	0.97	0.033	11	0.58	43
Holothuroida CR 1	25	0.006	1.4	8.3	**0.049**	0.57	0.92	1700	0.005	31	< 0,2	0.69	0.86	0.32	160	3.5	16
Holothuroida CR 3	22	0.006	1.3	2.6	**0.047**	0.14	0.75	250	0.007	6.6	0.1	0.72	1	0.13	170	0.71	11
Holothuroida CR 19	27	0.011	1.5	5.8	**0.045**	0.33	0.81	840	0.003	19	0.1	0.84	0.62	0.073	200	1.7	9
Ophiopholis CR 2	62	0.018	1.5	13	**0.12**	0.12	0.66	440	0.016	6	< 0,2	0.27	0.27	0.016	770	0.17	21
Ophiopholis CR 3	22	0.19	3.2	9.7	**0.15**	0.19	1	790	0.018	13	< 0,2	0.48	0.52	0.031	950	0.81	26
Ophiopholis CR 7	7	0.016	1.5	5.8	**0.087**	0.11	0.68	420	0.012	5.9	< 0,2	0.078	0.26	0.033	670	0.17	15
Echinocardium CR 1	5	0.007	0.55	7.4	**0.037**	0.36	0.83	930	0.003	14	< 0.1	0.84	0.16	0.21	210	2	6
Echinocardium CR 2	4	0.011	0.4	5.1	**0.048**	0.15	0.68	390	0.003	5.6	0.07	1.4	0.13	0.32	280	1.3	3
Echinocardium CR 3	4	0.012	0.79	7.5	**0.072**	0.37	1.3	1200	0.006	21	< 0,2	1.4	0.54	0.3	800	3.1	7
Echinocardium CR 7	4	0.026	1.7	17	**0.14**	1.3	2.6	3800	0.042	89	0.2	3.9	0.33	1.6	480	8.5	12
Ophiura CR 2	10	0.02	2.3	2.9	**0.16**	0.22	0.71	730	0.006	1	< 0,2	0.44	0.36	0.012	1100	0.35	23
Ophiura CR 3	12	0.017	1.5	1.7	**0.14**	0.11	0.72	390	0.011	0.85	< 0,1	0.18	0.31	0.017	570	0.14	31
Ophiura CR 7	5	0.061	1.3	4.2	**0.22**	0.17	0.68	620	0.007	5.4	< 0,2	0.55	0.24	0.018	920	0.18	20
Astarte CR 2	14	0.017	1.1	33	**0.12**	0.37	1.5	1400	< 0,003	4.8	< 0,3	0.41	0.23	0.016	1400	0.63	3
Astarte CR 3	8	0.014	1.3	29	**0.11**	0.41	1.3	1500	< 0,003	16	< 0,3	1.2	0.24	0.022	1300	1.4	3
Astarte CR 7	1	0.038	3.4	16	**0.37**	0.54	1.2	1800	0.008	23	0.4	2.4	0.34	0.022	1300	2	4
Astarte CR 19	5	0.018	2.4	21	**0.096**	0.66	1.6	2200	0.004	44	0.3	1.6	0.3	0.048	1100	2.6	5

Table 2. Results from second Inductively Coupled Plasma Mass Spectrometry (ICP-MS) analysis. Cadmium values are emboldened.

Label	# of ind.	Ag	As	Ba	Cd	Co	Cu	Fe	Hg	Mn	Mo	Pb	Se	Sn	Sr	V	Zn
GALATHEA 1.1	1	0.095	7.7	1.1	**0.15**	0.049	9.2	100	0.007	3.7	0.1	0.83	0.33	0.62	200	0.24	18
PALLIOLUM 1.1	5	0.26	2.2	2.2	**1.9**	0.075	0.66	28	0.009	11	< .2	0.47	0.64	0.19	420	0.18	43
POLYPLACOPHORA 1.1	16	0.013	40	5.3	**0.27**	0.54	8.6	420	0.044	110	0.5	2.1	8.8	0.34	1400	1.7	18
POLYPLACOPHORA 1.2	17	0.015	26	4.9	**0.2**	0.33	7.4	360	0.023	64	0.2	1.9	4.3	0.28	1700	1.4	11
OPHIOPHOLIS 1.2	1	0.008	1.1	29	**0.11**	0.032	0.5	30	0.026	7.7	< .2	0.23	0.34	0.038	710	0.15	18
PAGURUS PUBESCENS 1.3	2	0.15	3.1	2.7	**0.13**	0.034	19	130	0.007	2.7	< .1	0.15	0.59	0.045	300	0.18	26
GALATHEA 1.3	3	0.057	3.1	2.4	**0.064**	0.035	8.8	210	0.007	4.9	< .2	0.19	0.25	0.082	460	0.28	17
PALLIOLUM 1.3	1	0.27	2.5	4.4	**1.3**	0.18	2.1	120	0.013	88	< .3	0.53	1.2	0.044	620	0.38	63
OPHIOPHOLIS 1.3	8	0.028	1.1	33	**0.098**	0.048	0.68	430	0.014	7.2	< .2	0.38	0.3	0.099	620	0.44	24
ASTERIAS RUBENS (#1) 1.3	1	0.09	2.3	1.6	**0.29**	0.043	1.7	34	0.016	1.2	0.1	0.12	0.6	0.02	370	3.2	38
ASTERIAS RUBENS (#3) 1.3	1	0.14	1.9	0.72	**0.23**	0.041	1.4	23	0.02	1.4	0.1	0.13	0.48	0.008	170	0.21	28
ASTERIAS RUBENS (#2) 1.3	1	0.095	1.8	0.92	**0.17**	0.062	1.2	110	0.014	2.7	0.1	0.13	0.5	0.014	150	0.34	26
ASTERIAS RUBENS 2.1	1	0.037	1.3	0.63	**0.19**	0.019	0.7	10	0.006	0.76	< .07	0.03	0.13	0.004	190	0.052	19
DENTRONOTIDAE 2.1	1	0.007	1.1	0.066	**0.53**	0.053	0.21	7	0.003	0.43	0.09	0.028	0.15	0.001	7	0.049	17
OPHIOPHOLIS 2.2	7	0.035	2.1	15	**0.21**	0.04	0.39	17	0.011	2.9	< .2	0.24	0.49	0.018	810	0.68	20
O. NIGRA 2.2	7	0.22	2.4	12	**0.16**	0.025	0.85	21	0.006	2.6	< .2	0.12	0.38	0.021	590	0.22	17
POLYPLACOPHORA 2.2	28	0.02	25	3.8	**0.23**	0.17	7.9	290	0.025	26	0.2	0.71	4.3	0.06	1400	0.71	12
GALATHEA 2.2	5	0.051	5.6	2.2	**0.078**	0.019	6.3	23	0.009	4.2	< .1	0.06	0.41	0.029	680	0.14	12
PALLIOLUM 2.2	3	0.2	2.2	3.2	**1.4**	0.065	0.68	29	0.007	8.3	0.2	0.2	0.49	0.015	480	0.19	33
PAGURUS BERNHARDUS 2.2	2	0.17	6.9	2	**0.11**	0.035	17	11	0.008	2.6	< .2	0.029	0.7	0.015	660	2	26
PAGURUS PUBESCENS 2.2	20	0.14	6.2	2.5	**0.079**	0.031	12	18	0.008	4.7	0.1	0.047	0.7	0.015	540	0.56	24
PANDALIDAE 3.2	1	0.22	12	0.75	**0.094**	0.029	7	11	0.008	0.94	< .1	0.033	0.46	0.019	190	0.19	16

Table 2 cont.

Label	# of ind.	Ag	As	Ba	Cd	Co	Cu	Fe	Hg	Mn	Mo	Pb	Se	Sn	Sr	V	Zn
TEREBELLIDAE CR 3.2/3.1	9	0.014	4.6	0.48	**0.63**	0.096	1.4	66	0.009	2.3	< .2	0.64	0.44	0.03	21	0.22	29
OPHIOPHOLIS 3.2	6	0.037	1	9.9	**0.086**	0.023	0.35	26	0.007	4.4	< .1	0.15	0.25	0.028	530	0.2	16
POLYPLACOPHORA 3.2	29	0.018	41	5.9	**0.2**	0.33	8.2	410	0.04	80	0.3	0.94	7.7	0.062	1200	2.2	14
PALLIOLUM 3.2	4	0.11	2.3	1.8	**1.2**	0.07	0.72	49	0.009	14	0.3	0.19	0.71	0.022	420	0.28	38
ASTERIAS RUBENS 3.2	1	0.055	1	1	**0.43**	0.017	0.5	6	0.004	1.2	< .08	0.068	0.2	0.008	320	0.038	16
GALATHEA 3.1	1	0.046	4.3	1.9	**0.073**	0.021	5.6	23	0.005	4.3	< .1	0.048	0.31	0.026	790	0.15	14
OPHIOPHOLIS 3.1	10	0.13	2	5.1	**0.08**	0.03	0.64	41	0.008	5.2	< .2	0.19	0.44	0.046	450	0.17	15
POLYPLACOPHORA 3.1	41	0.016	51	6.5	**0.24**	0.33	8.7	450	0.046	73	0.4	0.98	9.2	0.072	1200	1.9	19
ASTERIAS RUBENS 5.1	4	0.021	0.61	0.36	**0.1**	0.008	0.16	5	0.003	0.67	< .03	0.024	0.1	0.001	99	0.023	6
ASTERIAS RUBENS 5.2	1	0.018	0.31	0.21	**0.022**	0.004	0.32	2	0.001	0.27	< .03	0.009	0.049	0.002	70	0.011	4
ASTERIAS RUBENS (#1) 5.3	1	0.3	3.1	0.92	**0.71**	0.031	1.9	41	0.021	1.5	< .1	0.074	0.39	0.007	230	0.2	54
ASTERIAS RUBENS (#2) 5.3	1	0.11	3.6	1.1	**0.36**	0.031	3.2	32	0.028	1.6	< .1	0.083	0.49	0.006	310	0.13	35
ASTERIAS RUBENS (#3) 5.3	1	0.059	2.3	0.85	**0.69**	0.023	1.1	12	0.011	0.93	< .1	0.045	0.31	0.005	200	0.082	41
TEREBELLIDAE CR 5.2/5.3	7	0.01	4	0.56	**1.7**	0.12	1.1	69	0.012	3.1	< .2	0.47	0.55	0.036	22	0.23	41
PALLIOLUM 5.3	2	0.18	1.3	1.9	**1.9**	0.073	0.5	31	0.007	10	0.2	0.15	0.62	0.028	540	0.17	39
OPHIOPHOLIS 5.3	13	0.14	1.3	30	**0.13**	0.035	0.52	42	0.012	7.5	< .2	0.24	0.51	0.049	770	0.2	18
HARMOTHOE 5.2	9	0.018	5.4	2.4	**0.24**	0.16	2.2	45	0.009	14	0.5	0.31	0.6	0.055	12	1.9	37
OPHIOPHOLIS 5.2	25	0.044	1.6	30	**0.21**	0.029	0.66	22	0.013	6.2	< .2	0.16	0.38	0.042	660	0.15	19
POLYPLACOPHORA 5.2	37	0.006	25	5.2	**0.21**	0.34	5	180	0.025	55	0.2	0.43	6	0.083	1100	0.51	6
SPONGE (#5) 5.2	1	0.1	1.5	0.77	**1.1**	0.051	0.86	74	0.013	5	0.09	0.35	0.68	0.015	27	0.26	6
PALLIOLUM 5.2	5	0.26	2	2.3	**2.3**	0.12	0.59	65	0.008	15	0.2	0.2	0.69	0.034	490	0.24	36
OPHIOPHOLIS 7.1	7	0.068	1.6	4.1	**0.24**	0.043	0.54	34	0.009	4.6	< .2	0.77	0.45	0.006	640	0.25	26

Table 2 cont.

Label	# of ind.	Ag	As	Ba	Cd	Co	Cu	Fe	Hg	Mn	Mo	Pb	Se	Sn	Sr	V	Zn
LOTTIDAE 7.2	1	0.38	25	1.5	**8.4**	0.11	2.1	150	0.19	10	0.7	0.26	1.2	0.017	290	1.1	13
SPONGE (#1) 7.3	1	0.09	1.6	1.3	**0.48**	0.048	0.37	70	0.008	3.1	0.2	0.13	2.2	0.053	16	0.24	4
GALATHEA 7.1	2	0.077	2.2	3.9	**0.1**	0.15	3.7	470	0.006	14	0.1	0.58	0.32	0.035	460	1	10
SPONGE (#2) 7.3	1	0.046	0.83	1.3	**0.54**	0.095	0.44	83	0.004	6.6	0.3	0.18	1	0.032	23	0.25	4
SPONGE (#4) 7.3	1	0.000 0004	0.00 002	0.00 001	**0.000 02**	0.0000 02	0.000 03	0.0 01	0.0000 01	0.000 06	0.0000 03	0.0000 05	0.000 02	0.0000 01	0.00 02	0.0000 04	0.00 07
SPONGE (#6) 7.3	1	0.039	1.2	2.2	**0.84**	0.17	0.7	160	0.007	13	0.3	0.29	0.83	0.059	27	0.56	7
SPONGE (#7) 7.1	1	0.024	2.4	1.1	**0.55**	0.044	0.52	69	0.006	2.5	0.08	0.092	0.68	0.006	10	0.17	3
SPONGE (#8) 7.1	1	0.01	1.9	3.3	**0.14**	0.32	0.97	420	0.02	10	0.1	0.71	0.6	0.005	33	1.3	10
SPONGE (#10) 7.1	1	2.4	2.3	3.2	**0.93**	0.1	0.46	260	0.019	5.5	0.1	0.27	1.9	0.02	25	0.6	5
SPONGE (#11) 7.1	1	0.021	2.1	1.6	**0.6**	0.064	0.67	99	0.006	3.2	0.1	0.12	0.65	0.009	11	0.24	3
STICHOPODIDAE (#1) 7.3	1	0.024	3.7	0.13	**0.048**	0.016	0.33	5	0.006	1.1	2	0.015	1.1	0.011	16	0.048	5
STICHOPODIDAE (#2) 7.3	1	0.008	1.3	0.16	**0.028**	0.008	0.1	7	0.002	0.86	0.3	0.014	0.32	0.017	13	0.039	3
STICHOPODIDAE 7.1	1	0.016	1.2	0.7	**0.024**	0.043	0.16	100	0.003	2.4	0.3	0.11	0.48	0.016	33	0.2	2
ASTARTE (#1) 7.1	1	0.061	2.3	12	**0.17**	0.096	0.67	270	0.005	9.8	< .3	0.92	0.39	0.01	1100	0.76	3
ASTARTE (#2) 7.1	1	0.016	1.8	18	**0.17**	0.18	0.69	160	0.004	17	< .3	0.98	0.44	0.01	850	0.54	3
ASTARTE (#3) 7.1	1	0.15	4	14	**0.5**	0.3	1.2	650	0.01	27	0.4	2.4	0.68	0.021	1500	1.9	8
PAGURUS PUBESCENS 7.1	1	0.11	4.7	14	**0.097**	0.04	8.7	35	0.01	18	< .1	0.057	0.51	0.012	480	0.14	17
AMPHARETIDAE 7.1	18	0.11	2.1	3.5	**1**	0.17	0.74	300	0.013	11	0.2	0.44	1	0.015	42	0.83	7
APHRODITINAE 7.1	2	0.038	3.5	7	**0.26**	0.59	1.5	120 0	0.009	29	0.2	1.3	0.49	0.013	90	4	23