

Significance and Interspecific Variability of Accumulated Trace Metal Concentrations in Antarctic Benthic Polychaetes*

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Abstract

Trace metals were analysed in polychaetes collected on Polarstern cruise ANT XXI/2 (2003/04) to the Weddell Sea. Pb concentrations were largely less than 1.3 mg kg⁻¹ DW in all samples analysed. Statistical results indicate that the accumulated Cd, Cu and Zn concentrations are related to the feeding guild to which the animals are belonging. Relatively low Cd and Cu concentrations are found in macrophagous carnivores and relatively high concentrations in microphagous detritus feeders. The relationship between Zn concentrations and the feeding guilds of polychaetes is reverse. Cd concentrations range from (median values and interquartile ranges in brackets) 2.6 (1.5-3.2) mg kg⁻¹ DW in the carnivorous *Trypanosyllis gigantea* to 133 (37-176) mg kg⁻¹ in the microphagous detritus feeder *Lanicides bilobata*; Cu concentrations from 16 (11-19) mg kg⁻¹ in the carnivorous *Antarctinoe spicoides* to 40 (23-68) mg kg⁻¹ in the microphagous detritus feeder *Phyllocomus crocea* and Zn from 89 (69-97) mg kg⁻¹ in the microphagous detritus feeder *Isocirrus yungi* to 396 (372-404) mg kg⁻¹ in the carnivorous *Aglaophamus trissophyllus*. Ni is ranging from 3.7 (1.8-6.0) mg kg⁻¹ in *Polyeunoa laevis* to 34 (20-41) mg kg⁻¹ in *Antarctinoe spicoides*, but no significant differences are obvious regarding the feeding guilds. Since information on metals in Antarctic polychaetes is almost completely lacking, our results suggest further studies to clarify the role of feeding in the bioaccumulation of metals in this ecologically important taxonomic group.

Key words: Heavy metals, polychaetes, feeding guilds, Weddell Sea, Antarctica

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1. Introduction

Antarctica has very rich marine invertebrate benthic communities, showing great diversity and abundance, high levels of gigantism and longevity, slow growth rates, delayed maturation and absence of pelagic larval stages. The presence of ice, the unusual depth of the shelf (up to 500 m and more), the extensive area of deep water around the continent, and the lack of connection with temperate shelves made the Antarctic shelf an insular evolutionary site equivalent to Lake Baikal or the Galapagos (Bargagli, 2005, p. 116). Generally, Antarctica and the Southern Ocean are scarcely affected by environmental contamination, except in localised areas adjacent to abandoned or inhabited human settlements. Nevertheless, natural and anthropogenic contamination of the Antarctic marine ecosystems with trace metals and other xenobiotics receives continued attention in the scientific literature, as has been reviewed by Bargagli (2005).

Marine organisms accumulate certain trace metals from the bioavailable fraction of food and surrounding water. Furthermore, sediment can contribute to uptake from solution via the pore water, and/or contribute to uptake from the diet after ingestion by a deposit feeder. In order to differentiate human impact from natural variability, knowledge of background concentrations of metals and their fluctuations in biomonitor organisms is essential. Although the Antarctic environment was formerly considered to be unpolluted and accumulations of toxic elements were expected to be at a physiological level, concentrations in Antarctic marine organisms are not necessarily low (Bargagli, 2005; Bargagli et al., 1996; Jöst and Zauke, 2008). Previous studies on various organisms from the Southern Ocean have revealed particularly high concentrations of several trace metals, especially of Cd, referred to as the “Cd anomaly” (Bargagli et al., 1996; Jöst and Zauke, 2008; Petri and Zauke, 1993). The enhanced bioavailability of Cd in Antarctic coastal marine environments with relatively high values (e.g. Nolting and De Baar, 1994) compared to other ocean waters is probably due to the rapid regeneration of the metal in the water column (Orren and Monteiro, 1985) and/or to rapid mineralization in surface sediments during early diagenesis (Bargagli, 2005; Bargagli et al., 1996; De Baar et al., 1994).

Furthermore, accumulation patterns and subsequent accumulated concentrations in marine organisms often vary significantly. As a result, we can frequently find different species of marine invertebrates with greatly varying metal concentrations in the same body of ocean water (e.g. Keil et al., 2008). A great variability of trace metal concentrations in marine organisms can be also observed in relation to seasonal changes of both physiological and biological factors as has been shown, for example, for Arctic zooplankton (Ritterhoff and Zauke, 1997).

In a previous study trace metals (Cd, Cu, Ni, Pb and Zn) were analysed in crustaceans collected on Polarstern cruise ANT XXI/2 (2003/04) to the Weddell Sea (Keil et al., 2008). On this cruise also polychaetes occurred in the catches, which are one of the most abundant and most diverse invertebrate groups in the Southern Ocean (Schüller et al., 2009). Ecologically, polychaetes represent an important group in terms of both production and consumption in the Antarctic marine benthic food web while different polychaete families exhibit an array of feeding habits and occupy many ecological niches found in marine environments (Jarre-Teichmann et al., 1997; Kröger and Rowden, 2008).

The relationship between bioaccumulation of heavy metals in different feeding guilds of freshwater macro-invertebrates was reviewed by Goodyear and McNeill (1999). A conceptual framework on feeding guilds for polychaetes was originally presented by Fauchald (1977) and more recently reviewed by Miller (2004, p. 281 ff.). The potential relationship between feeding guilds and accumulation of metals (arsenic) in polychaetes was investigated also by Fattorini et al. (2005). Furthermore, the applicability of this concept was evaluated regarding polychaetes from the Georges Bank (Maurer and Leathem, 1981) and from the southern Brazilian coast (Pagliosa, 2005).

Since information on trace metals in Antarctic polychaetes is almost completely lacking, the main goal of the present study is to provide preliminary data on trace-metal concentrations in polychaetes from the Weddell Sea and to derive some initial, tentative ideas on possible relationships between accumulated trace metals and the feeding guilds to which the organisms are belonging as detailed above.

2. Material and methods

Polychaete samples were collected on “Polarstern” cruise ANTXXI/2 to the Weddell Sea in November and December 2003 at 21 stations north and west of Kapp Norvegia (Austasen; 70° 50.07' - 71° 19.19' S and 010°30.15' - 013° 57.45' W; water depth 119-883 m) (see Fig. 1), employing Agassiz and bottom trawls. On board ship, the animals were kept alive for 48 h in polyethylene buckets containing seawater of 33.5 - 34.5 ‰ salinity, at 0°C without light and food to allow for defecation (Keil et al., 2008). Upon sampling, the organisms were collected and sorted to the lowest possible taxonomic level under close visual observation, using a binocular microscope to ensure the absence of any foreign particles. Since a definite species determination was not possible on board ship, photos of the specimens collected were taken to facilitate later performance of this task. Selected organisms are shown in Plate I. Subsequently, the samples were thoroughly rinsed for a few seconds with double-distilled water to remove fine suspended materials, adhering seawater and labile metals from the surface of the animals. Afterwards the animals were dried on good-quality filter paper and stored at -20°C in Petri dishes or good-quality polyethylene bags, depending on their size and number.

Upon arrival in the laboratory in Germany, the frozen polychaete samples were defrosted for a short period of time to allow a non-destructive determination of the species. Because of this limitation an additional photographic documentation was performed. To avoid contamination only instruments made of Teflon or titanium were used. A summary of the full scientific names of the polychaete species analysed, information on feeding types and feeding guilds as well as on the total number of specimen collected for each species and the mean dry weight per individual for each species is given in Table 1.

Finally the samples were frozen again, subjected to freeze-drying for 72 h (Lyovag GT2, Leybold Heraeus) and were homogenised using a small boron carbide mortar and pestle or a ball mill made of agate. Aliquots of about 5 mg dried material were digested for 3 h at 95°C with 100 µl HNO₃ (65 %, suprapure, Merck) in tightly closed 1.5-ml Eppendorf safe-lock reaction tubes (Clason and Zauke, 2000; Jöst and Zauke, 2008). After cooling down, the sam-

ples were treated with 25 µl H₂O₂ (30%, p.a., Roth) for another hour at 56°C. The digests were allowed to cool down slowly again and were subsequently made up to 1 ml volume with double-distilled water. After appropriate dilution, final sample and standard solutions were adjusted to concentrations of 3.25% HNO₃. Metal determinations were performed using a Varian SpectrAA 300 instrument with deuterium background correction and a GTA 96 graphite tube atomiser, employing omega high performance graphite tubes. For Cd, Ni and Pb, palladium and magnesium nitrate modifiers were applied. Zn was assayed using an air-acetylene flame (Varian SpectrAA-30, deuterium background correction) and a manual micro-injection method (100 µl sample volume). All metal concentrations in biological tissues are reported in mg kg⁻¹ dry weight (DW).

The validity was evaluated using two certified reference materials which were randomly allocated within the determinations. The analysed values obtained for reference materials were in most cases in good agreement with the certified values (mean ± 95%-confidence intervals, in brackets); for Tort 2 (Lobster hepatopancreas): Cd 30.2 ± 4.3 (26.7 ± 0.6), Cu 117 ± 22 (106 ± 10), Ni 3.5 ± 1.1 (2.5 ± 0.19), Pb 0.5 ± 0.4 (0.35 ± 0.13), Zn 195 ± 25.9 (180 ± 6); and for CRM 278 (Mussel tissue): Cd 0.4 ± 0.6 (0.348 ± 0.007), Cu 9.9 ± 0.2 (9.45 ± 0.13), Ni 1.6 ± 1.1 (1.0), Pb 2.5 ± 0.8 (2.00 ± 0.04), Zn 81.2 ± 9.4 (83.1 ± 1.7) mg kg⁻¹ DW. Detection limits according to Büttner et al., 1980) were: Cd 1.7, Cu 0.7, Pb 1.3, Ni 3.6, Zn 31 (mg kg⁻¹ DW). These proved to be adequate for the range of Cd, Cu and Ni concentrations found in this study for Antarctic polychaetes, with the sole exception of Pb.

Since most of our data were not normally distributed, only non-parametric procedures were applicable. Thus we report median values and interquartile ranges instead of mean values and confidence intervals (Wilkinson et al., 2007). For multiple comparisons of feeding guilds we employed the non-parametric multiple comparison Z statistic to ensure an overall 95%-significance level ($\alpha = 0.05$), using the software BMDP (release 8.1 for Windows XP, Program 3S; <http://www.statistical-solutions-software.com/BMDP-documents/BMDP-3S.pdf>). Pairwise comparisons were also performed on polychaete species and families as units of investigation, respectively. Since most of the Pb concentrations were close to or below limit of detection, this element was not included in the data evaluation.

3. Results

Metal concentrations in polychaetes from the survey in the Weddell Sea are summarised in Tables 2 - 5. Median values as well as lower and upper quantiles are reported, since most of the data were not normally distributed. For all trace metals analysed we observe a substantial interspecific variability ranging from 2.6 (*Trypanosyllis gigantea*) to 133 mg Cd kg⁻¹ DW (*Lanicides bilobata*); from 16 (*Antarctinoe spicoides*) to 40 mg Cu kg⁻¹ (*Phyllocomus crocea*); from 3.7 (*Polyeunoa laevis*) to 34 mg Ni kg⁻¹ (*Antarctinoe spicoides*) and from 89 (*Isocirrus yungi*) to 396 mg Zn kg⁻¹ (*Aglaophamus trissophyllus*). Only for Pb do we find values close to or below the limit of detection (1.3 mg kg⁻¹) for all collectives analysed.

Regarding Cd, pairwise multiple comparisons of feeding guilds yield significant differences for CMJ vs. SST and for CMJ vs. BSX, but not for BSX vs. SST (see notes to Table 2). Com-

paring species, significant differences could only be detected for *T. gigantea* vs. *I. yungi*, *L. bilobata* and *P. mirabilis* with ZSTAT-values of 3.86, 4.26 and 4.13, respectively. With 12 groups, the critical value ZC is 3.37 for an overall 95%-significance level ($\alpha = 0.05$). Comparing families, significant differences could only be detected for Syllidae vs. Ampharitidae, Maldanidae and Terebellidae as well as for Polynoidae vs. Terebellidae with ZSTAT-values of 3.18, 3.86, 4.81 and 4.54, respectively (with 7 groups ZC is 3.04). Thus, two distinct homogeneous groups can be discerned, since significant differences between species and families do not occur within feeding guild groups. The first group is consisting of the feeding guild CMJ with median Cd concentrations ranging from 2.6 to 11 mg kg⁻¹ and the second is consisting of the feeding guilds BSX and SST, with median Cd concentrations ranging from 42 to 133 mg kg⁻¹.

Regarding Cu, pairwise multiple comparisons of feeding guilds yield significant differences for CMJ vs. SST and for BSX vs. SST, but not for CMJ vs. BSX (see notes to Table 3). Comparing species, significant differences could only be detected for *A. spicoides* vs. *P. mirabilis* with a ZSTAT-value of 3.53 (ZC=3.37) and comparing families only for Polynoidae vs. Terebellidae with a ZSTAT-value of 3.21 (ZC=3.04). Again, two distinct groups can be discerned, the first consisting of the feeding guilds CMJ and BSX with median Cu concentrations ranging from 16 to 32 mg kg⁻¹ and the second consisting of the feeding guild SST, with median Cu concentrations ranging from 26 to 40 mg kg⁻¹. However, the bar opposite of *L. bilobata* under group 2 indicates a certain overlap between both groups as detailed above.

Regarding Ni, pairwise multiple comparisons of feeding guilds yield significant differences only for BSX vs. SST (see notes to Table 4). Comparing species, significant differences could only be detected for *P. laevis* vs. *A. spicoides* and *I. yungi* with ZSTAT-values of 3.74 and 3.57, respectively (ZC=3.37), while for families no significant differences occurred at all. In this case, all feeding guilds considered can be allocated to one group, only with BSX appearing somewhat ambiguous as indicated by bars under group 1 and 2.

Regarding Zn, pairwise multiple comparisons of feeding guilds yield significant differences for CMJ vs. SST and for CMJ vs. BSX, but not for BSX vs. SST (see notes to Table 5). Comparing species, significant differences could only be detected for *I. yungi* vs. *A. trissophyllus*, *A. spicoides*, *Harmothoe crosetensis*, *Harmothoe cf. spinosa* and *T. gigantea* with ZSTAT-values of 4.16, 4.01, 3.39, 3.70 and 3.40, respectively (ZC=3.37). Comparing families, significant differences could only be detected for Maldanidae vs. Nephtyidae, Polynoidae and Syllidae as well as for Terebellidae vs. Nephtyidae and Polynoidae with ZSTAT-values of 4.16, 4.00, 3.40, 3.43 and 3.24, respectively (ZC=3.04). Again, two distinct groups can be discerned, since significant differences between species and families do not occur within feeding guild groups. The first group is consisting of the feeding guilds BSX and SST with median Zn concentrations ranging from 89 to 183 mg kg⁻¹ and the second is consisting of the feeding guild CMJ, with median Zn concentrations ranging from 187 to 396 mg kg⁻¹.

4. Discussion

4.1. Intraspecific heterogeneities of accumulated trace metals

Intraspecific heterogeneities of metals analysed can be depicted from the interquartile ranges reported in Tables 2-5. In any case, these are much lower than detected interspecific heterogeneities given by the ranges of median values. This fact and varying concentrations between species, ranging from low concentrations to rather high levels, may be regarded as an *a posteriori* quality assurance of sampling and sample preparation on board ship (Zauke et al., 1996; Zauke and Petri, 1993). Because of the methods used, possible contamination or other artefacts could only by chance have affected subsamples, but not specific polychaete species regarding all independent replicates.

4.2. Relationship between accumulated trace metals and feeding guilds

Results of the non-parametric multiple comparison *Z* statistics indicate that the accumulated Cd, Cu and Zn concentrations are related to the feeding guild to which the animals are belonging (see details in Table 1-5). Only for Ni such relationship is not apparent (Table 4). In particular, the feeding guild CMJ coincides with relatively low Cd and Cu concentrations, and the feeding guild SST with relatively high Cd and Cu concentrations (Table 2-3), despite the fact that the variability of Cd is much more pronounced compared to Cu. Most interestingly, the relationship between Zn concentrations and the feeding guilds of polychaetes (Table 5) is reverse. In any case, the groups differ significantly with an overall α of 0.05.

According to Fauchald and Jumars (1979) organisms belonging to the families Aphroditidae, Nephtyidae, Polynoidae and Syllidae do possess jaws, indicating that they consume large chunks either as a whole or by removing bites (see also more recent review in Miller, 2004, p.281 ff.). They can thus be regarded as macrophagous carnivores (CMJ). In contrast, species belonging to the families Ampharitidae, Maldanidae and Terebellidae do not possess jaws, indicating that they consume tiny particulate food and tend to eat them in bulk (Miller, 2004, p. 281ff.). These organisms can thus be regarded as microphagous detritus feeders (SST).

Hence, these differences in feeding might be a prime factor influencing the bioaccumulation of Cd, Cu and Zn in the polychaetes under study as has been already suggested for other Antarctic invertebrates by Bargagli et al. (1996 and the literature cited therein). More indications that feeding may be regarded as an important factor for bioaccumulation is provided e.g. by results for freshwater invertebrates (Goodyear and McNeill, 1999; also showing different relationships for different metals) and for Antarctic crustaceans (amphipods, isopods and decapods; Keil et al., 2008), where scavengers tend to show relatively low Cd but relatively high Zn concentrations. On the other hand, feeding types seem not to be a prime factor influencing the bioaccumulation of metals in Antarctic pantopods (Jöst and Zauke, 2008). Moreover, other species-specific peculiarities can sometimes have a great importance; in this respect, the variability of arsenic accumulation in polychaetes could not be related to feeding habits of the animals (Fattorini et al., 2005).

It should be noted, however, that the postulated influence of feeding is only one possible explanation of our data. It has been observed that several marine worms can concentrate high

levels of Zn (and Cu) in their jaws, probably related to specific structural functions (Lichtenegger et al., 2003). Since the different feeding types are characterised by different morphological features (see notes to Table 1), the latter may also have some influence on bioaccumulation of metals in the field. Thus, taxonomy and feeding habit, however, are often themselves co-correlates, probably confounding the interpretation of the data to some extent.

4.3. Interspecific heterogeneities of accumulated trace metals

Trace-metal concentrations in polychaetes from different regions of the world are compiled in Table 6 for comparison with the interspecific variabilities found in this study. Pb concentrations ($<1.3 \text{ mg kg}^{-1} \text{ DW}$) in most of our samples analysed are low, in good agreement with reported data for a polychaete from the Ross Sea (see Table 6). A possible explanation for low accumulation of Pb in marine organism is that Pb is particle-reactive and characterised by scavenging (Henderson and Maier-Reimer, 2002; Lin et al., 2000). It is interesting to note, however, that polychaetes are able to bioaccumulate Pb in laboratory experiments from the soluble phase (Bernds et al., 1998). Ranges of Pb concentrations reported for polychaetes from the German Wadden Sea indicate similarly low minimal values, while the maxima are slightly enhanced, probably indicating a certain degree of anthropogenic pressure. This is even more pronounced by data reported from UK estuaries with a documented pollution history (bold numbers in Table 6), but eventually also by reported data from the Mediterranean Sea or a mangrove wetland in India. Thus, low Pb concentrations $<1.3 \text{ mg kg}^{-1} \text{ DW}$ in polychaetes might serve as a regional or even global background value for comparison in bio-monitoring studies, in agreement with data reported for Antarctic amphipods and decapods (Keil et al., 2008) or pantopods (Jöst and Zauke, 2008).

The range of median Cd concentrations in Antarctic polychaetes (Table 2) is much higher compared to most of the data reported for other regions of the world (Table 6). Some exceptions refer to UK estuaries with a documented pollution history (bold numbers in Table 6), but eventually also to data from the Mediterranean Sea (Lebanon), probably indicating a certain degree of anthropogenic pressure. High Cd concentrations in agreement with our results were also reported for polychaetes from the Ross Sea, Antarctica, thus providing further evidence for the frequently postulated polar “Cd anomaly” (see Bargagli et al., 1996; Keil et al., 2008 and the literature cited therein). However, to support this hypothesis intraspecific comparisons of accumulated Cd concentrations in a widespread cosmopolitan species of polychaete would be very helpful.

The composition of phytoplankton assemblages and species-specific requirements of algae could play a very important role in the Cd transfer to primary consumers and into marine food webs, according to information compiled in Bargagli (2005, p.230). The enhanced bioavailability of Cd in Antarctic coastal marine environments with relatively high values ($60\text{--}94 \text{ ng l}^{-1}$; e.g. Nolting and De Baar, 1994) compared to other ocean waters is probably due to the rapid regeneration of the metal in the water column (Orren and Monteiro, 1985) and/or to rapid mineralization in surface sediments during early diagenesis (Bargagli, 2005; Bargagli et al., 1996; De Baar et al., 1994).

Antarctic near-shore waters and ice shelves are characterised by phytoplankton showing intense and brief blooms during austral summer. Additionally, during the austral summer the upwelling of waters favours the ad/absorption of Cd on phytoplankton cells. Due to the low biomass of zooplankton most algal cells sink and become food for very rich benthic communities, including polychaetes. This might explain why microphagous detritus feeders (SST) show the highest Cd concentrations in our study (see above).

Median Cu concentrations in polychaete samples from the Weddell Sea (Table 3) range from 16 to 40 mg Cu kg⁻¹ DW, in good agreement with data reported for other regions of the world (Table 6). As has been already mentioned for Pb and Cd, the sole exception refers to data reported from UK estuaries with a documented pollution history (bold numbers in Table 6).

The variability of Ni in Antarctic polychaetes (Table 4) is slightly higher compared to Cu, showing a similar range than worldwide reported data for polychaetes (Table 6), but also for Antarctic copepods (Kahle and Zauke, 2003) and Arctic zooplankton (Ritterhoff and Zauke, 1997). The maximum values in the Arctic study were obtained for the ostracod *Conchoecia borealis* (66 to 86 mg Ni kg⁻¹ DW). Even higher Ni concentrations were found in Antarctic pantopods (Jöst and Zauke, 2008) reaching 100 to 200 mg Ni kg⁻¹ DW. It was hypothesised in this paper that exceptional high Ni concentrations may act as a natural chemical defence against predation, as has been widely accepted for terrestrial plant-insect systems (Boyd, 2007; Boyd, 2009). The relationship between high metal accumulation and chemical defence in polychaetes is an interesting and emerging topic (see also Fattorini and Regoli, 2004; Notti et al., 2007). Furthermore, Kicklighter and Hay (2006) demonstrated that various polychaete tissues are unpalatable for consumers, also including some species close to those of the present study. This is also true regarding hyperaccumulation of vanadium in the Antarctic polychaete *Perkinsiana littoralis* (Fattorini et al., 2010). Organs of the polychaete which are exposed to predation, show exceptionally high V concentrations and the emerald rock cod *Trematomus bernacchi* refused polychaete tissues with high V concentrations after tasting.

The median range of Zn concentrations in polychaetes from this study (Table 5) also show a similar range than the worldwide reported data (Table 6). The pronounced interspecific heterogeneity of Zn may be related to different morphological features of the species involved, since polychaetes can concentrate high levels of Zn (and Cu) in their jaws, probably related to specific structural functions (Lichtenegger et al., 2003).

5. Conclusion

Our study provides first information of heavy metal concentrations in polychaetes from the Weddell Sea. Pb concentrations close to or below 1.3 mg kg⁻¹ DW might serve as a regional or even global background value. Statistical results indicate that the accumulated Cd, Cu and Zn concentrations are related to the feeding guild to which the animals are belonging. Relatively low Cd and Cu concentrations are found in macrophagous carnivores and relatively high concentrations in microphagous detritus feeders. The relationship between Zn concentrations and the feeding guilds of polychaetes is reverse. Since the different feeding types are characterised by different morphological features, the latter may also have some influence on

bioaccumulation of metals in the field. Because of the ecological importance of polychaetes, these aspects should be investigated in more detail in future studies.

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Table 1. Feeding types and feeding guilds of the Antarctic polychaete species investigated according to literature data.

Species	feeding type	feeding guild ⁸	ind	DW ind ⁻¹
<i>Aglaophamus trissophyllus</i> (Grube, 1877)	herbivore ¹ , selective omnivore or carnivore ^{2,5} , predator ^{3,5}	CMJ	5	1.17
<i>Antarctinoe spicoides</i> (Hartmann, 1986)	carnivore ⁵	CMJ	13	0.49
<i>Barrukia cristata</i> (Willey, 1902)	carnivore / predator ^{3,5}	CMJ	3	1.53
<i>Harmothoe cf. spinosa</i> Kinberg, 1856	carnivore, predator ⁵ / omnivore	CMJ	52	0.57
<i>Harmothoe crosetensis</i> (McIntosh, 1885)	carnivore ⁵	CMJ	6	0.43
<i>Isocirrus yungi</i> Gravier, 1911	deposit-feeder ⁵	BSX	10	0.67
<i>Laetmonice producta</i> Grube, 1877	predator / carnivore ^{5,6}	CMJ	4	9.31
<i>Lanicides bilobata</i> (Grube, 1877)	deposit-feeder ^{5,7}	SST	48	0.40
<i>Phyllocomus crocea</i> Grube, 1877	sessile deposit feeder ^{4,5}	SST	5	1.13
<i>Pista mirabilis</i> McIntosh, 1885	deposit-feeder ⁵	SST	44	0.26
<i>Polyeunoa laevis</i> McIntosh, 1885	carnivore ⁵	CMJ	73	0.09
<i>Trypanosyllis gigantea</i> (McIntosh, 1885)	herbivore / carnivore ⁵	CMJ	32	0.27

Notes. ¹ Desbruyeres (1977); ² Shepherd and Thomas (1982); ³ Pabis and Sicinski (2010); ⁴ Gerdes et al. (2003); ⁵ Fauchald and Jumars (1979); ⁶ Micaletto et al. (2003); ⁷ Kröger and Rowden (2008); ⁸ Feeding guilds for each polychaete family after Fauchald and Jumars (1979). In the three letter codes, the letter in first position indicates major mode, the second the motility pattern and the last letter the morphological structure used in feeding; in position 1: B, subsurface deposit feeder; C, carnivore; S, surface deposit feeder; in position 2: M, motile; S, sessile; in position 3: J, jawed; T, tentaculate; X, other structures; ind = total number of specimen collected for each species; DW ind⁻¹ = mean dry weight per individual for each species [g].

Table 2. Cadmium concentrations in Antarctic benthic polychaetes from the Weddell Sea. Values are medians, lower and upper quantiles [mg kg^{-1} DW].

Species	Family	feeding guild	N	median	Q1	Q3	groups		
							1	2	3
<i>Trypanosyllis gigantea</i>	Syllidae	CMJ	5	2.6	1.5	3.2			
<i>Barrukia cristata</i>	Polynoidae	CMJ	3	4.1	3.9	9.6			
<i>Harmothoe crosetensis</i>	Polynoidae	CMJ	5	5.3	3.7	9.7			
<i>Antarctinoe spicoides</i>	Polynoidae	CMJ	8	8.8	7.5	9.6			
<i>Polyeunoa laevis</i>	Polynoidae	CMJ	8	9.0	7.5	14			
<i>Harmothoe cf. spinosa</i>	Polynoidae	CMJ	11	9.1	6.2	11			
<i>Aglaophamus trissophyllus</i>	Nephtyidae	CMJ	4	9.9	9.4	11			
<i>Laetmonice producta</i>	Aphroditidae	CMJ	5	11	8.4	46			
<i>Isocirrus yungi</i>	Maldanidae	BSX	5	42	28	56			
<i>Pista mirabilis</i>	Terebellidae	SST	5	62	55	73			
<i>Phyllocomus crocea</i>	Ampharitidae	SST	4	75	24	226			
<i>Lanicides bilobata</i>	Terebellidae	SST	6	133	37	176			

Notes. DW = dry weight; N = number of replicates collected and processed independently in the laboratory; Q1 = lower quantile; Q3 = upper quantile; data are sorted according to increasing median values. Otherwise as in Table 1.

Statistical analysis: Multiple comparisons of feeding guilds

CMJ vs. SST: ZSTAT = 4.88*; CMJ vs. BSX: ZSTAT = 3.01*; BSX vs. SST: ZSTAT = 0.05.

* The null hypothesis is rejected if ZSTAT is larger than the critical value ZC = 2.39 (with 3 groups for an overall $\alpha = 0.05$). Bars (|) indicate homogeneous groups.

Table 3. Copper concentrations in Antarctic benthic polychaetes from the Weddell Sea. Values are medians, lower and upper quantiles [mg kg^{-1} DW].

Species	Family	feeding guild	N	median	Q1	Q3	groups		
							1	2	3
<i>Antarctinoe spicoides</i>	Polynoidae	CMJ	8	16	11	19			
<i>Polyeunoa laevis</i>	Polynoidae	CMJ	8	17	14	23			
<i>Isocirrus yungi</i>	Maldanidae	BSX	5	18	15	19			
<i>Harmothoe crosetensis</i>	Polynoidae	CMJ	5	20	13	25			
<i>Harmothoe cf. spinosa</i>	Polynoidae	CMJ	11	22	21	31			
<i>Barrukia cristata</i>	Polynoidae	CMJ	3	25	19	33			
<i>Lanicides bilobata</i>	Terebellidae	SST	6	26	23	29			
<i>Laetmonice producta</i>	Aphroditidae	CMJ	5	29	21	35			
<i>Trypanosyllis gigantea</i>	Syllidae	CMJ	5	31	27	47			
<i>Aglaophamus trissophyllus</i>	Nephtyidae	CMJ	4	32	27	35			
<i>Pista mirabilis</i>	Terebellidae	SST	5	37	34	41			
<i>Phyllocomus crocea</i>	Ampharitidae	SST	4	40	23	68			

Notes. See Tables 1 and 2.

Statistical analysis: Multiple comparisons of feeding guilds

CMJ vs. SST: ZSTAT = 2.78*; CMJ vs. BSX: ZSTAT = 1.54; BSX vs. SST: ZSTAT = 2.99*.

* The null hypothesis is rejected if ZSTAT is larger than the critical value $ZC = 2.39$ (with 3 groups for an overall $\alpha = 0.05$). Bars (|) indicate homogeneous groups.

Table 4. Nickel concentrations in Antarctic benthic polychaetes from the Weddell Sea. Values are medians, lower and upper quantiles [mg kg^{-1} DW].

Species	Family	feeding guild	N	median	Q1	Q3	groups		
							1	2	3
<i>Polyeunoa laevis</i>	Polynoidae	CMJ	8	3.7	1.8	6.0			
<i>Phyllocomus crocea</i>	Ampharitidae	SST	4	4.9	3.3	9.9			
<i>Lanicides bilobata</i>	Terebellidae	SST	6	5.7	3.7	7.3			
<i>Trypanosyllis gigantea</i>	Syllidae	CMJ	5	5.8	4.1	8.5			
<i>Aglaophamus trissophyllus</i>	Nephtyidae	CMJ	4	9.1	7.0	12			
<i>Barrukia cristata</i>	Polynoidae	CMJ	3	9.4	3.7	23			
<i>Pista mirabilis</i>	Terebellidae	SST	5	10	8.5	17			
<i>Laetmonice producta</i>	Aphroditidae	CMJ	5	15	9.7	29			
<i>Harmothoe cf. spinosa</i>	Polynoidae	CMJ	11	16	5.1	41			
<i>Harmothoe crosetensis</i>	Polynoidae	CMJ	5	19	4.8	85			
<i>Isocirrus yungi</i>	Maldanidae	BSX	5	31	24	36			
<i>Antarctinoe spicoides</i>	Polynoidae	CMJ	8	34	20	41			

Notes. See Tables 1 and 2.

Statistical analysis: Multiple comparisons of feeding guilds

CMJ vs. SST: ZSTAT = 1.52; CMJ vs. BSX: ZSTAT = 2.09; BSX vs. SST: ZSTAT = 2.77*.

* The null hypothesis is rejected if ZSTAT is larger than the critical value $ZC = 2.39$ (with 3 groups for an overall $\alpha = 0.05$). Bars (|) indicate homogeneous groups.

Table 5. Zinc concentrations in Antarctic benthic polychaetes from the Weddell Sea. Values are medians, lower and upper quantiles [mg kg^{-1} DW].

Species	Family	feeding guild	N	median	Q1	Q3	groups		
							1	2	3
<i>Isocirrus yungi</i>	Maldanidae	BSX	5	89	69	97			
<i>Lanicides bilobata</i>	Terebellidae	SST	6	147	135	190			
<i>Pista mirabilis</i>	Terebellidae	SST	5	161	145	185			
<i>Phyllocomus crocea</i>	Ampharitidae	SST	4	183	136	261			
<i>Polyeunoa laevis</i>	Polynoidae	CMJ	8	187	165	219			
<i>Laetmonice producta</i>	Aphroditidae	CMJ	5	192	182	290			
<i>Trypanosyllis gigantea</i>	Syllidae	CMJ	5	248	224	505			
<i>Harmothoe cf. spinosa</i>	Polynoidae	CMJ	11	250	230	344			
<i>Barrukia cristata</i>	Polynoidae	CMJ	3	267	237	457			
<i>Harmothoe crosetensis</i>	Polynoidae	CMJ	5	328	183	511			
<i>Antarctinoe spicoides</i>	Polynoidae	CMJ	8	333	232	569			
<i>Aglaophamus trissophyllus</i>	Nephtyidae	CMJ	4	396	372	404			

Notes. See Tables 1 and 2.

Statistical analysis: Multiple comparisons of feeding guilds

CMJ vs. SST: ZSTAT = 3.68*; CMJ vs. BSX: ZSTAT = 4.21*; BSX vs. SST: ZSTAT = 1.72.

* The null hypothesis is rejected if ZSTAT is larger than the critical value $ZC = 2.39$ (with 3 groups for an overall $\alpha = 0.05$). Bars (|) indicate homogeneous groups.

Table 6. Trace-metal concentrations in polychaetes from different regions of the world [mg kg⁻¹ DW].

Species	Region	Cd	Cu	Pb	Ni	Zn
<i>Nephtys hombergii / cirrosa</i>	German Wadden Sea ^{1,2,3}	0.1-2.2	11-33	0.7-3.4	-	160-370
<i>Nephtys hombergii</i>	Estuaries SW England ⁴	0.6-3.6	13-2200	4-45	-	260-520
<i>Nereis (Hediste) diversicolor</i>	German Wadden Sea ^{1,2,3}	0.1-1.8	13-64	0.4-1.7	1.5-2.6	90-370
<i>Nereis (Hediste) diversicolor</i>	Estuaries SW England ^{5,6,7}	0.1-5.0	19-1400	2-685	-	130-470
<i>Nereis (Hediste) diversicolor</i>	Estuaries SW England ⁸	0.2-0.6	44-3900	-	-	150-170
<i>Nereis (Hediste) diversicolor</i>	Atlantic coast, France ⁸	0.1-0.3	11-26	-	-	110-170
<i>Nereis virens</i>	German Wadden Sea ¹	-	11-39	0.6-2.5	0.4-1.1	140-190
<i>Arenicola marina</i>	German Wadden Sea ^{1,2,3}	0.2-0.9	10-30	0.5-2.5	6.8-13	81-91
<i>Hermodice carunculata</i>	Mediterranean, Lebanon ⁹	4.4-7.4	11-30	-	6.6-40	410-850
<i>Aphrodite aculeata</i>	Tyrrhenian Sea, Italy ¹⁰	0.2-1.8	-	-	-	-
<i>Sabella spallanzanii</i>	Tyrrhen./Adriatic Sea, Italy ¹¹	1.2-3.0	10-24	1.4-2.0	1.3-2.6	40-43
<i>Dendronerides arborifera</i>	Sundarban mangrove, India ¹²	0.4	33	1.0	7.8	140
<i>Mastobranchus indicus</i>	Sundarban mangrove, India ¹²	0.6-2.0	25-45	4-23	18-39	150-320
<i>Namalycastis fauveli</i>	Sundarban mangrove, India ¹²	0.2	31	2.2	7.5	85
<i>Perenereis cultrifera</i>	Sundarban mangrove, India ¹²	0.6-0.7	37-52	5-19	23-33	140-220
<i>Capitella capitata</i>	Sea of Japan, Vladivostok ¹³	1.8	8	-	-	180
<i>Dorvillea japonica</i>	Sea of Japan, Vladivostok ¹³	2.9	21	-	-	200
<i>Nereis vexillosa</i>	Sea of Japan, Vladivostok ¹³	2.0	8	-	-	270
<i>Harmothoe spinosa</i>	Ross Sea, Antarctica ¹⁴	3.9-5.3	-	-	-	-
<i>Perkinsiana littoralis</i>	Ross Sea, Antarctica ¹⁵	23-33	4-9	0.2-0.4	3-6	140-200

Notes. Bold figures refer to potentially contaminated sites; ¹ G.-P. Zauke, unpubl. data; ² Zauke and Meurs (1991); ³ Zauke et al. (1995); ⁴ Bryan and Gibbs (1987); ⁵ Bryan and Hummerstone (1971); ⁶ Bryan and Hummerstone (1973); ⁷ Bryan et al. (1980); ⁸ Berthet et al. (2003); ⁹ Shiber (1981); ¹⁰ Bargagli (1993); ¹¹ Bocchetti et al. (2004; data referring to thorax tissue); ¹² Alam et al. (2010); ¹³ Davydkova et al. (2005; data converted to DW assuming a factor of 6 after Berthet et al., 2003); ¹⁴ Bargagli et al. (1996); ¹⁵ Fattorini et al. (2010; data taken from a figure).

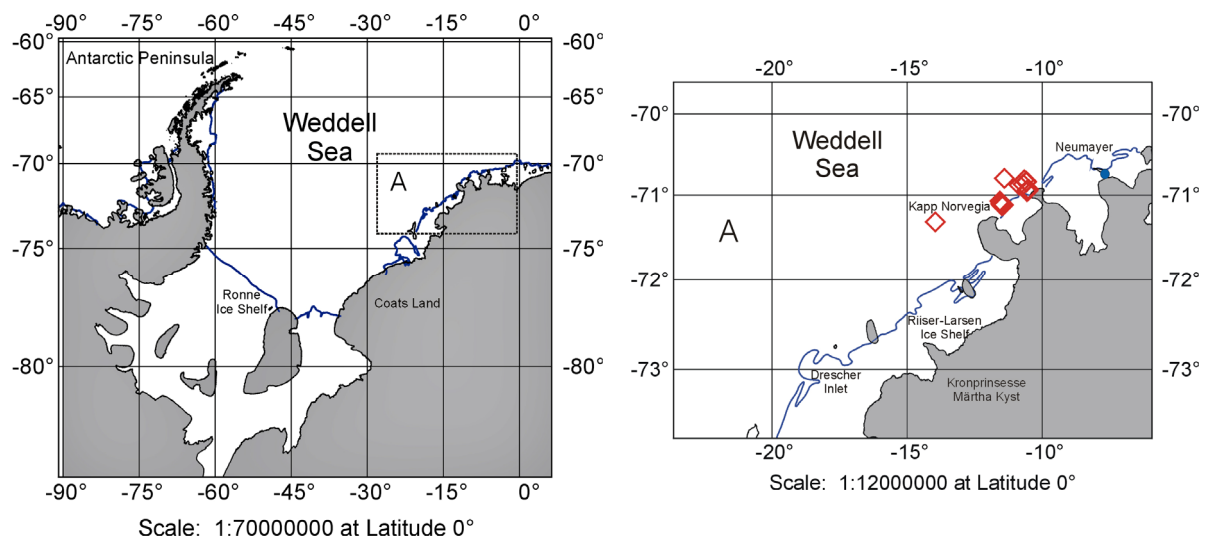


Fig. 1. Area of investigation within the Weddell Sea, Antarctica (left) and sampling locations in area A (right). Coastlines and ice-shelf lines prepared with PanMap 0.9.6. The German Neumayer Station is indicated for orientation. See text for more details.

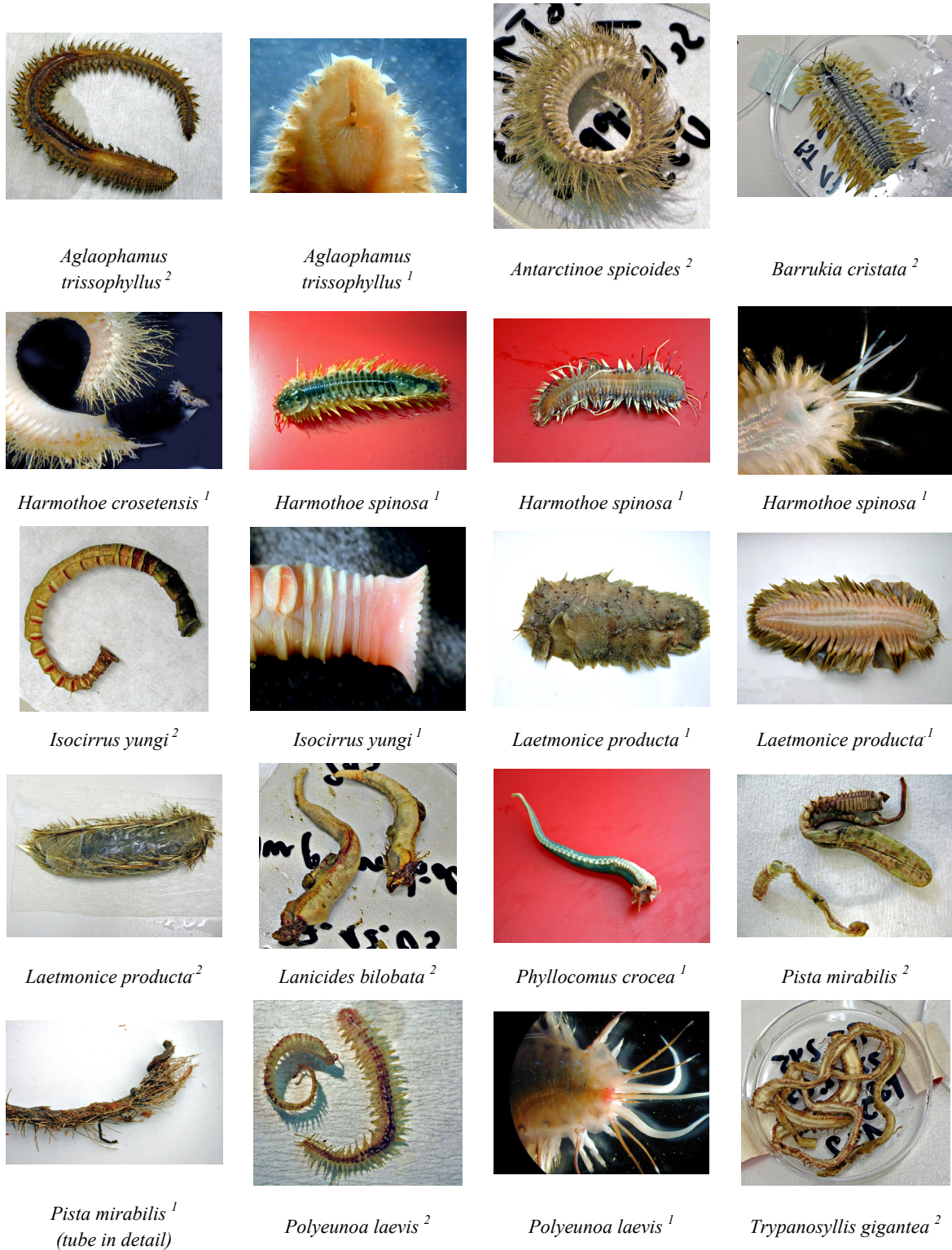


Plate I. Selection of organisms studied in the Weddell Sea. Photos by E. Vareschi[†] and G.-P. Zauke onboard ship (2003)¹ and by C. Jöst and J. Hans in the laboratory (2009)².