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Down-core changes in molluscan death assemblages as indicators of millennial-scale environmental shifts (Northern Adriatic Sea, Brijuni Islands)

verfasst von

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Inhalt

Introduction

Investigations on modern marine ecosystem responses to environmental changes are typically limited to annual or decadal time scales. This is because data from earlier periods are scarce. Importantly, however, it is the last few hundred years which have suffered major human impact and ecological shifts (Lotze et al., 2006). Methods used in the emerging research field *conservation paleobiology* (Dietl & Flessa, 2011) enable scientists to assess historical baseline communities and classify changes in the environment, thus providing the basis for management and restoration of sensitive, endangered marine areas (Jackson et al., 2001). Two approaches in *conservation paleobiology* are described by Dietl & Flessa (2011): the near-time approach, which uses data from the relatively recent past as a dynamic context for present environmental conditions, and the deep-time approach which uses the entire history of life as data sources and focuses on ecological and evolutionary dynamics over time.

The Northern Adriatic Sea is among the most degraded marine ecosystems worldwide and is therefore a case study for ecosystem modification under human pressure (Lotze et al., 2006). Studying the remains of hard-part-producing benthic macrofauna in a sediment core can contribute to a better understanding of alterations in species communities over time caused by environmental change and/or degradation. Understanding the pre-human state and historical changes is a necessity when evaluating anthropogenic impact on an ecosystem. Molluscan death assemblages can be seen as a window to the past, and the degree of variation between different community compositions over time serves as a proxy for ecological shifts (Grotzinger et al., 2008; Weber & Zuschin, 2013).

The Northern Adriatic is a shallow marine region with an average water depth of 50 m (McKinney, 2007). The seafloor consists of Pleistocene sands that are covered with Holocene deposits and a range of different sediment types (mud, muddy sand, sandy mud, sand). Furthermore, a west-east gradient from mud to sand, originating from the Po River and supporting a soft-bottom benthic community is documented for the area (Zuschin & Stachowitsch, 2009). Moreover, a macroevolutionary shift from epifauna- to infauna-dominated assemblages was observed in the Northern Adriatic. In some areas, however, epifaunal suspension feeding populations – which may be functionally equivalent to Paleozoic shelf communities – still dominate the shallow soft-bottom communities. The underlying causes for the shift are still being debated and, so far, no *in situ* study has measured the relevant environmental factors (McKinney, 2007; Zuschin & Stachowitsch, 2009). The status of the Northern Adriatic as a semi-enclosed, shallow basin with high river input, soft bottoms, stratification, long water residence duration, and high primary production (Ott, 1992;

Stachowitsch, 1991) led to the classification of the area as a "sensitive ecosystem" (Stachowitsch, 1984). Benthic mortalities caused by oxygen depletion as a result of eutrophication and the accumulation of dissolved organic matter (marine mucilage events) have occurred here periodically for centuries (Crema et al., 1991). Especially during the decades after 1969, environmental crises and mortalities of benthic communities became a frequent and widespread ecological problem. This was promoted by anthropogenic eutrophication through agriculture and waste water disposal, introduced above all as inflow from the Po and other rivers and transported by counter-clockwise currents along the coasts of Croatia, Slovenia, and Italy (Barmawidjaja et al., 1995; N'siala et al., 2008; Nerlović et al., 2011). Eutrophication leads to hypoxic and anoxic conditions, which have been shown to affect the behavior, survival, recruitment and growth of marine benthic species, depending on their ecological and physiological traits (Haselmair et al., 2010; Nerlović et al., 2011; Riedel et al., 2012; Stachowitsch, 1984). Therefore, benthic animals such as many mollusks are important indicators for the degree and severity of marine pollution. Studying mollusks as indicators of ecological conditions over time is advantageous for numerous reasons: While some benthic taxa such as echinoderms or crustaceans are often missing in highly impacted areas, many mollusk species are still abundant (Nerlović et al., 2011). Many marine molluscan taxa produce hard parts that remain largely unchanged and can be identified to species level even after hundreds or thousands of years. Furthermore, the taxonomic composition of the Adriatic molluscan fauna is well known (Cossignani et al., 1992; Riedl 1963; Vatova, 1949), which facilitates accurate identification and easy access to reference collections. Compared with other benthic taxa, mollusks are a diverse group concerning habitat requirements, and a broad spectrum from very sensitive to resilient species can be found within. Hence, their absence, presence, or abundance offer a variety of insights into possible effects of disturbances on species composition because the many different molluscan taxa vary greatly in habitat requirements and tolerance. Environmental changes result in alterations of community composition and abundance when sensitive species are reduced by disruptive factors, e.g. pollution and/or hypoxia, while tolerant species are present or even numerous (Dauer 1993; Miller et al., 2002; Pearson & Rosenberg, 1978; Stierhoff et al., 2006). Also, indicator species can be used to study alterations in the ecosystem. The basket shell *Corbula gibba*, for instance, is tolerant to a wide range of environmental disturbances such as pollution, hypoxia and increased turbidity and is therefore considered a bioindicator of environmental instability in soft bottom benthic habitats (Hrs-Brenko, 2006).

Large loadings of metals, organic chemicals and pathogens into the ocean lead to accumulations of pollutants in marine sediments. Due to the extremely slow desorption of contaminants that are bound or absorbed into particles, high concentrations of harmful or toxic substances in the sediment

can cause or contribute to significant long-term degradation of marine ecosystems (Burton, 2002). A range of heavy metals is frequently found in high concentrations in marine sediments and benthic species. Many of them originate from sources such as consumer waste, fuels, alloys, clearing sludge and fertilizers and make their way via the atmosphere or water system into the ocean and marine sediments, where they enter the food chain and negatively affect marine life and human health (Duysak & Ersoy, 2014; Pempkowiak et al., 1999; Wang et al., 2007).

Persistent organic pollutants (POPs) are hydrophobic and lipophilic organic compounds which remain in the environment and are resistant to break-down reactions. They therefore enter multiple circles of deposition and volatilization far from their point of origin, resulting in a wide distribution across the planet and accumulation in food chains (Jones & de Voogt, 1999; Rios et al., 2007). The two POP classes polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) have been monitored in water, sediments, and aquatic animals (Rios et al., 2007; Vane et al., 2007). PCBs are composed of a biphenyl ring and up to 209 different chlorinated compounds (congeners), which include 113 congeners that are known to occur in the environment (Pascall et al., 2005). They were produced for fluids needed in electric apparatus (e.g. coolant fluids, dielectric fluids) until a prohibition in 1979 by the United States Congress and in 2001 by the Stockholm Treaty (Porta & Zumeta, 2002). However, a large portion of the produced PCBs are still in use and might be released into the environment by spills or leakage, additional to the already ubiquitous share of PCBs in water, air and soil (Rios et al., 2007).

Polycyclic Aromatic Hydrocarbons (PAHs) result from incomplete burning of various organic substances such as coal, oil, gas or even tobacco and charbroiled meat, but can also be manufactured and used for the production of pesticides, dyes or medicines. More than 100 different chemicals belong to the group of PAHs, of which many are toxic and accumulate in aquatic sediments and organisms (Bojes & Pope, 2007; Zeng & Vista, 1997).

In the present study, a 1.60 m sediment core was extracted from the Northern Adriatic (Brijuni Islands) and analyzed for down-core changes in species composition, abundance, and diversity of molluscan death assemblages. Retrieving a sediment core is a good method to sample unmixed, continuous sediment strata. This approach can be realized with minimum difficulty if certain important factors such as sediment composition, water depth, and handling of the equipment are considered from the onset of the coring operation (Glew et al., 2001). A piston corer can be used for water depths down to 140 m and is adequate for operations managed by small groups of two to three people (http://www.uwitec.at/, checked on 27 November 2014).

The extracted sediment core was sliced in an upright position, maintaining the original alignment of the fractions and the therein preserved animal hard parts. Time-averaged molluscan death

assemblages can be used for various purposes, for example comparing them to associated living assemblages and quantifying mismatches as indicators for recent ecological shifts. This can be a reliable and conservative evidence for human-induced changes in shallow-marine habitats (Ferguson, 2008; Kidwell, 2009; Olszewski & Kidwell, 2007). The collected data in combination with environmental data – including occurrence and amount of various organic and inorganic pollutants, sediment age and composition, and the local history of invasive fishing methods (e. g. bottom trawling) – were used to back-trace species communities before human impact on the ecosystem.

Material and Methods

Study area

The Northern Adriatic, a young marine area formed in the Holocene by the rising sea level, is one of the few modern, epicontinental seas that are comparable to Paleozoic and Mesozoic shelf environments (McKinney, 2007). The water surface circulation is primarily thermohaline and cyclonic (counterclockwise), in large part driven by the Po River, the biggest river in the area and the main cause for freshwater, sediment, and nutrient input into the sea (for an overview, see McKinney, 2007).

The productivity in the Northern Adriatic is among the highest in the Mediterranean Sea, which is in general oligotrophic (Zavatarelli et al., 1998). Hypertrophic zones exist off the Po Delta, in the northwestern region offshore Venice and in the northernmost region.

The sediment covering the Northern Adriatic seafloor consists of relict Pleistocene sand covered by Holocene mud (Fig. 1A, Goff et al., 2006; Pigorini, 1968). Recent sands cover only a small coastal zone, whereas Holocene terrigenous muds accumulate in a so-called prolittoral mud belt at an annual rate of ~4.5 mm (Fig. 1A, Van Straaten, 1970). Sediment cores show a succession from fluvial to brackish and marine facies (Cattaneo & Trincardi, 1999; Orogelec et al., 1991), and the thickness in Holocene mud layers varies regionally, from 10-12 m close to the Po River to only few centimeters offshore (Frignani et al., 2005).

High concentrations of Hg, Cu and Zn characterize modern deposits of less than one meter thickness in the Northern Adriatic that accumulated during the past thousand years (Covelli et al., 2006). Temporary sediment storage and resuspension mainly occurs during the winter storm period caused by northeastern cold winds (bora) and southeastern warm winds (sirocco) (Frignani et al., 2005). Other – unnatural – causes for resuspension are bottom trawling and dredging (Kaiser et al.,

2002; Thrush & Dayton, 2002), which have been applied in the Adriatic for nearly a century and destabilize the sediment system (De Madron et al., 2005; Palanques et al., 2001). Depth penetration of trawls ranges from 5-10 cm to 30 or 40 cm, depending on the trawl type (Hall-Spencer et al., 1999)

The benthic communities of the area mostly consist of polychaetes, infaunal echinoids and bivalves, crustaceans, and gastropods, which occur in distinct biocoenoses (Fig. 1B, Vatova, 1935; 1949; Gamulin-Brida, 1967; Orel & Mennea, 1969). As for the aforementioned sediment types, a west-east gradient was observed: a transition from an infauna-dominated to a combined infauna-rich and epifauna-rich part (e.g., Gamulin-Brida, 1967; Ott, 1992). Molluscan death assemblages in the area are largely composed of the bivalve families Corbulidae, Veneridae, Cardiidae and Galeommatidae and the gastropod families Cerithiidae, Rissoidae, Trochidae, Turritellidae and Nassariidae (Sawyer & Zuschin, 2010).

A wide range of crustacean and molluscan burrowing species inhabit the seafloor and contribute to bioturbation depths from 20 cm in the northwestern Adriatic to 1 m in the Gulf of Trieste (Atkinson & Froglia, 2000; Dworschak, 1998; Moodley et al., 1998; Pervesler & Dworschak, 1985). The many trails and holes and other *Lebensspuren* indicate their great abundance and their important role in sediment resuspension (Duplisea et al., 2001; Kollmann & Stachowitsch, 2001).

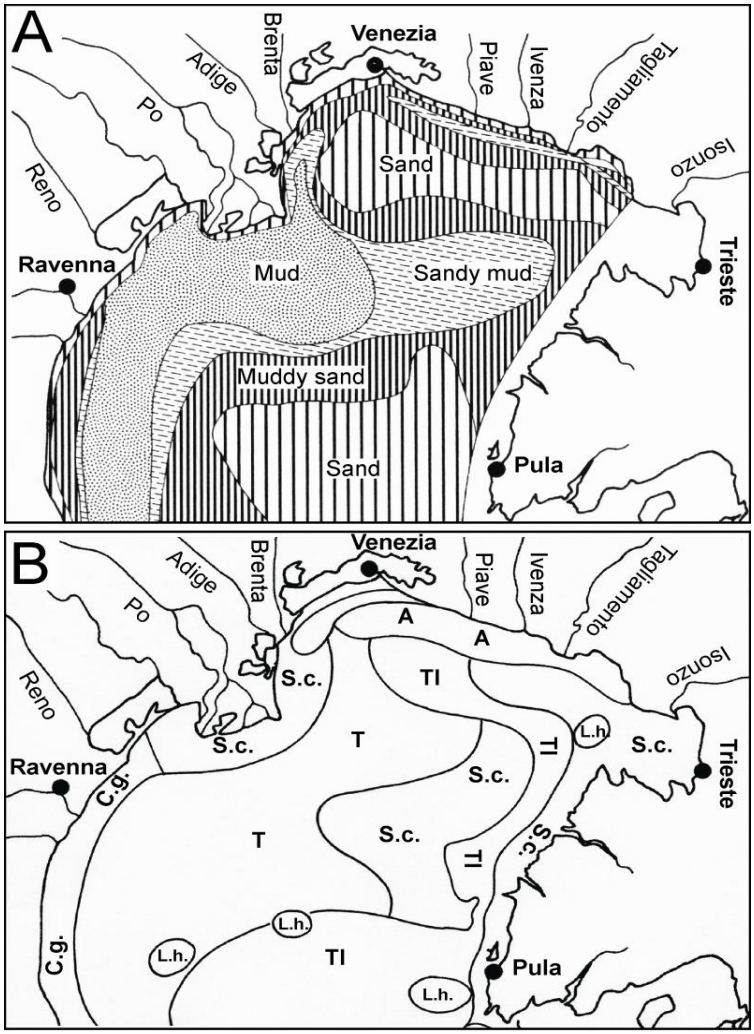

Fig. 1: Distribution and close correspondence of sediments and benthic assemblages in the northern Adriatic Sea. A) Grain-size distribution; B) Vatova´s benthic assemblages. A: *Amphioxus*, C.g.: *Chione gallina*, L.h.: *Lima hians*, S.c.: *Schizaster chiajei* association, T: *Turritella*, TI: *Tellina* (from Zuschin & Stachowitsch, 2009).

Sampling station

Sampling took place in the waters of the Brijuni Islands National park, which is situated southwest off the Istrian coast in the Adriatic Sea, western Croatia (Fig. 2). It is a group of 14 islands spread across a total area of 7.42 km^2 with two major islands, Mali Brijun and Veliki Brijun (Šoštarić & Küster, 2001; Fatovic-Ferencic, 2006). The island group has existed in its present-day state presumably for thousands of years, as the Adriatic basin was inundated 8000 to 10,000 years ago and the northernmost lagoons were formed approximately 6000 years ago (Brambati, 1992).

The islands are described as intensively settled from the mid-Neolithic onwards. The first major anthropogenic impact occurred in the late 19th century when, for example, dewatering of swamps was enforced to form a landscape suited for tourists (Bralic, 1990; Šoštarić & Küster, 2001). In the 20th century the area was chosen as presidential residence and declared a national park on November 9, 1983 and therefore remained mostly excluded from extensive public use. Moreover, the sea around the islands reportedly contains the cleanest water in the Istrian area (Fatović-Ferenčić, 2006).

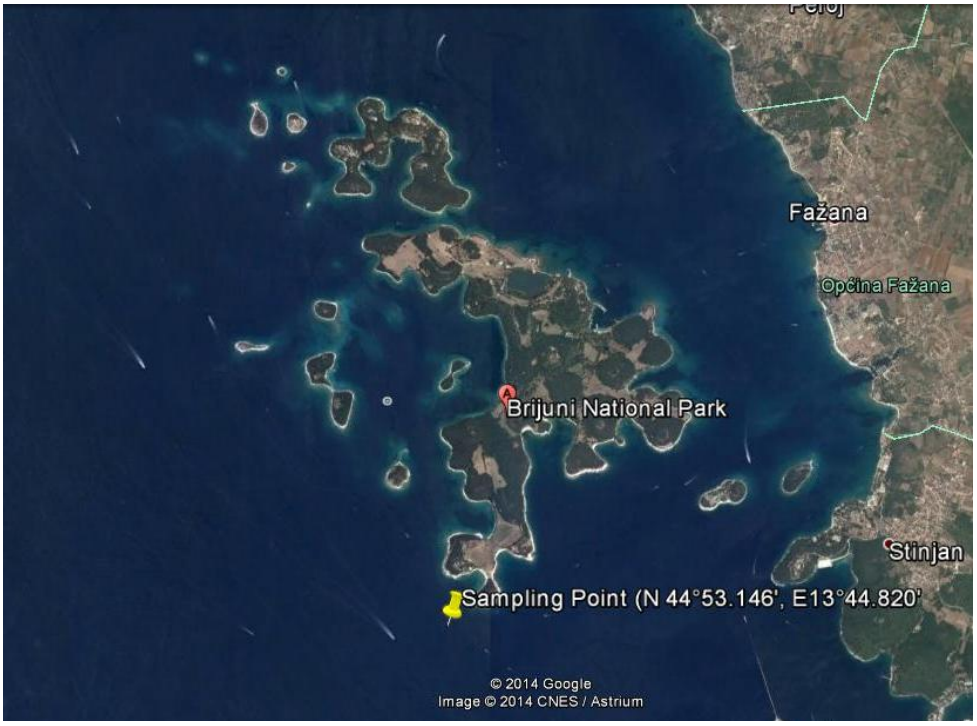

Fig. 2: Sampling position at Brijuni Islands National Park, (Google Earth map).

Sampling

The sediment core was extracted in summer 2013 on the Slovenian research vessel *Manta Bianca* using a UWITEC piston corer with hammer action (Fig. 3). Mobile weights (75 kg) were attached at the apex of the tripod and lifted and released to hammer the cylinder into the sediment (Fig. 3A & B). Furthermore, the coring device was equipped with a hydraulic core catcher to retain the sediment in the PVC liner when extracting the core. The piston pressed water into the rubber sleeve of the core catcher when the final depth was reached.

The drilling position was located at the coordinates 44°53,146' North and 13°44,820' East at a water depth of 44 m. The core was 160 cm long and had a diameter of 9 cm. The extracted sediment core was sliced directly on the boat into 38 subsamples of 2 cm for the uppermost 20 cm and of 5 cm for the remaining 140 cm of the core. The extrusion system of the coring device allowed for precise slicing and preserved the original stratification of the sediment by keeping the PVC liner upright during the slicing process (Fig. 3C).

A

B

C

Fig. 3: Piston corer with hammer action. Tripod for stabilization on seafloor during coring operation (A), mobile weights hammering the cylinder into the seafloor (B), extracted sediment in upright position ready for slicing (C).

Sediment analysis

A separate sediment core was extracted at the same drilling position and analyzed for grain size, sediment density and pollutants. Furthermore, the sediment was radiometrically dated at the Low-Level Counting Labor Arsenal of the University of Natural Resources and Applied Life Sciences, Vienna, by using Pb210 dating, which is based on the half life of the isotope Pb210 that forms as part

of the decay sequence of Uranium-238. The isotope has three different origins: “Unsupported Pb210” is formed in the atmosphere by the decay of Rn222, while so-called “supported Pb210” originates from the continuous Rn222 production arising from Ra226, which is naturally contained in the sediments. Enriched anthropogenic wastes possibly form a third source. The Pb210 sediment dating technique is based on the Pb210 excess activity values (“unsupported Pb210”) in uncontaminated sediments, which are calculated from the Pb210 activities in every layer and subtracting the estimated “supported Pb210” values from the estimated Pb activities (de Souza et al., 2012).

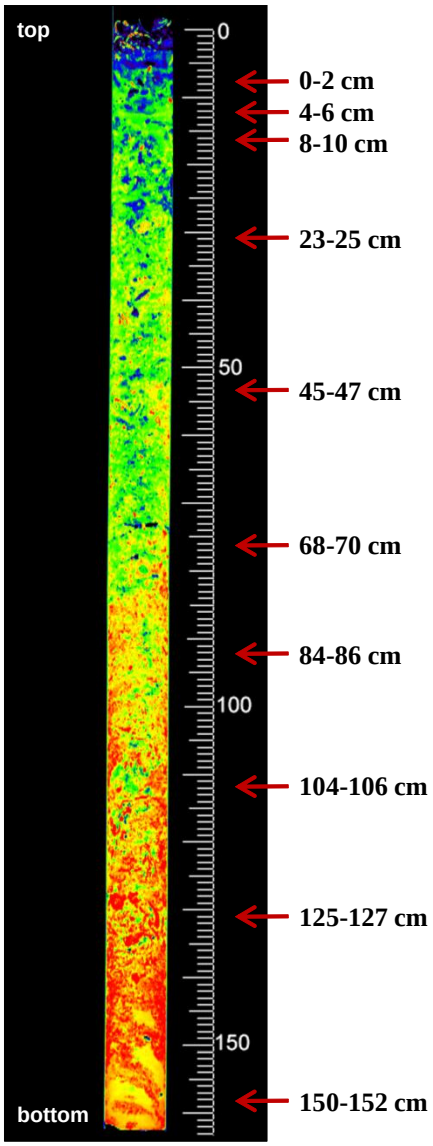

Fig. 4 Radiographic picure of sediment core

Grain size analysis was performed by means of a sedigraph (SediGraph III 5120 Particle Size Analyzer) for the small fractions (<63 µm) and dry sieving for fractions from <63 µm to >1 mm. Four types of sediment were defined: clay, silt, sand (excluding >1 mm) and the fraction >1 mm, which mostly consists of biogenic material.

Analyses for heavy metal content, nutrients and pollutants were performed by our cooperation partners from the ISMAR Institute in Venice. In a first step, a radiographic picture was taken to evaluate the sediment composition down the core and to choose fractions for further analysis. Different sediment structures and densities are revealed by a spectrum of false colors from blue (low density) to red (high density) (Fig. 4). Subsequently, the content of a range of heavy metals (Hg, Cu, Cr, Ni, Pb, As, Cd, Zn, Mn, Fe), organic pollutants (PCBs, PAHs), and nutrients (N, C, TOC) was determined at specific core sections: 1 cm, 5 cm, 9 cm, 24 cm, 24 cm, 46 cm, 69 cm, 85 cm, 105 cm, 126 cm and 151 cm core depth. Nutrients were indicated as percentage of dry weight (% dw). Total Carbon (Ctot), total organic carbon (TOC), and total nitrogen (Ntot) were measured at all sections chosen for the analyses along the core.

Sorting, identification and counting of shells

All samples were washed through five sieves, placed one on top of the other, with mesh diameters of 63 µm, 125 µm, 250 µm, 500 µm, and 1 mm and dried at 50°C. The material >1 mm was sorted

for biogenic components using a stereomicroscope and mollusks were identified – in most cases – to species level using specialist literature (Bosch et al., 1995; Cossignani et al., 1992; 2011; Gofas et al., 2011; Huber, 2010). Bivalve shells were sorted into left and right valves and double-valved specimens and were counted as the sum of double valves and the higher number of either right or left valves. Gastropods were counted if at least the apex was well preserved, and polyplacophorans were counted as the number of plates divided by eight.

Life habits and ecological categorization

Mollusk species were categorized according to their mobility, attachment, feeding mode and substrate relation. Furthermore, subcategories were chosen for substrate relation and feeding mode to provide more detailed information on the ecology of the animals. Species were assigned to categories following Beesley et al. (1998), Borja et al. (2000), Gofas et al. (2011a), Gofas et al. (2011b), Haydar (2010a, 2010b), Huber (2010), Koulouri et al. (2006), Oliver et al. (2010) and the World Register of Marine Species (WoRMS) (http://www.marinespecies.org/ checked on 4 December 2014). Mobility types are "actively mobile", "immobile" or "facultatively mobile". Attachment types are "unattached", "byssally attached" and "cemented" for species irreversibly fixed to rocks or other substrate. The various feeding and substrate types and additional subcategories were defined as summarized in Table 1.

Table 1. Categorization of feeding and substrate types

Feeding type	**Subcategories**	**Definition, comments**
Carnivore	Browsing	Species feeding on immobile animals such as bryozoans
	Micro	Species feeding on protozoans
	Macro	Predators
Chemosymbiotic		Species feeding on the metabolism products of chemosymbiotic bacteria within their bodies
Deposit feeding	Surface	Species feeding on particles at the sediment surface
	Subsurface	Species feeding on particles below the sediment surface
Filter feeding		Species feeding on particles suspended in water
Herbivore	Micro	Species feeding on microalgae
	Macro	Species feeding on seagrass and macroalgae
Scavenger		Species feeding on decaying organic matter
Symbiotic	Parasite	Species living as parasites in or attached to other animals
Substrate	**Subcategories**	**Definition, comments**

Epifauna	Species living on the substrate
Infauna	Species living in the substrate
Host	Species living in a symbiotic or parasitic relationship, using their hosts as "substrate"
Semi-infauna	Semi-burrowed species
Land	Land snails found in the core
Freshwater	Freshwater snails found in the core

Statistical analysis

Data were organized in spreadsheets and the program packages R (R core team 2013), PAST (Hammer et al. 2001) and PRIMER (Plymouth Marine Laboratories, UK; Clarke & Warwick 1994) were used for statistical analysis. Cluster analyses were performed with Bray-Curtis similarities and square-root transformed percentages. The uppermost sample (0-2 cm) was excluded from statistical analyses due to low abundance (3 individuals).

Effect of grain size on number of species, rarefied species richness, total abundance and selected feeding and substrate types was analyzed with linear regressions and a model selection approach. First all four size classes (clay, silt, sand, >1 mm) were included and non-significant covariates were subsequently dropped from the model, using the function 'lm' in R.

Influence of nutrients (N, TOC, C) and a variety of heavy metals (Cd, Ni, P, Mn, Fe, Cr, As, Li, Al, Cu, Hg, Pb, Zn) on number of species, rarefied species richness absolute abundance and selected ecology groups was analyzed using linear regression models ('lm' function in R). Only elements with an R^2 above 0.1 were used in the linear regression, therefore Cd, Ni, P and Mn were excluded.

Rarefied species richness and rarefaction curves for the total assemblage and sample rarefaction were designed in PAST using the functions "sample rarefaction" and "individual rarefaction" on the dataset.

For the purpose of this study, freshwater and land snails were always included without further information on substrate preferences or feeding behavior.

Results

Diversity and Abundances

Throughout the core, 23,012 individuals representing 192 mollusk species and 85 families were identified, including four land- and six freshwater gastropod species, which were found in the deeper parts of the core, starting from section 45-50 cm (abundance increasing downwards). Bivalves accounted for 74, gastropods for 113, polyplacophora for three, and scaphopods for two species.

The total number of specimens was lowest in the first sample at 0-2 cm depth and increased with depth until a maximum of 1557 specimens was reached at 125-130 cm. From there into the deeper part, a steady decrease was observed, with 134 individuals in the deepest sample (155-160). Numbers of bivalve and gastropod individuals show a similar pattern (Fig. 5).

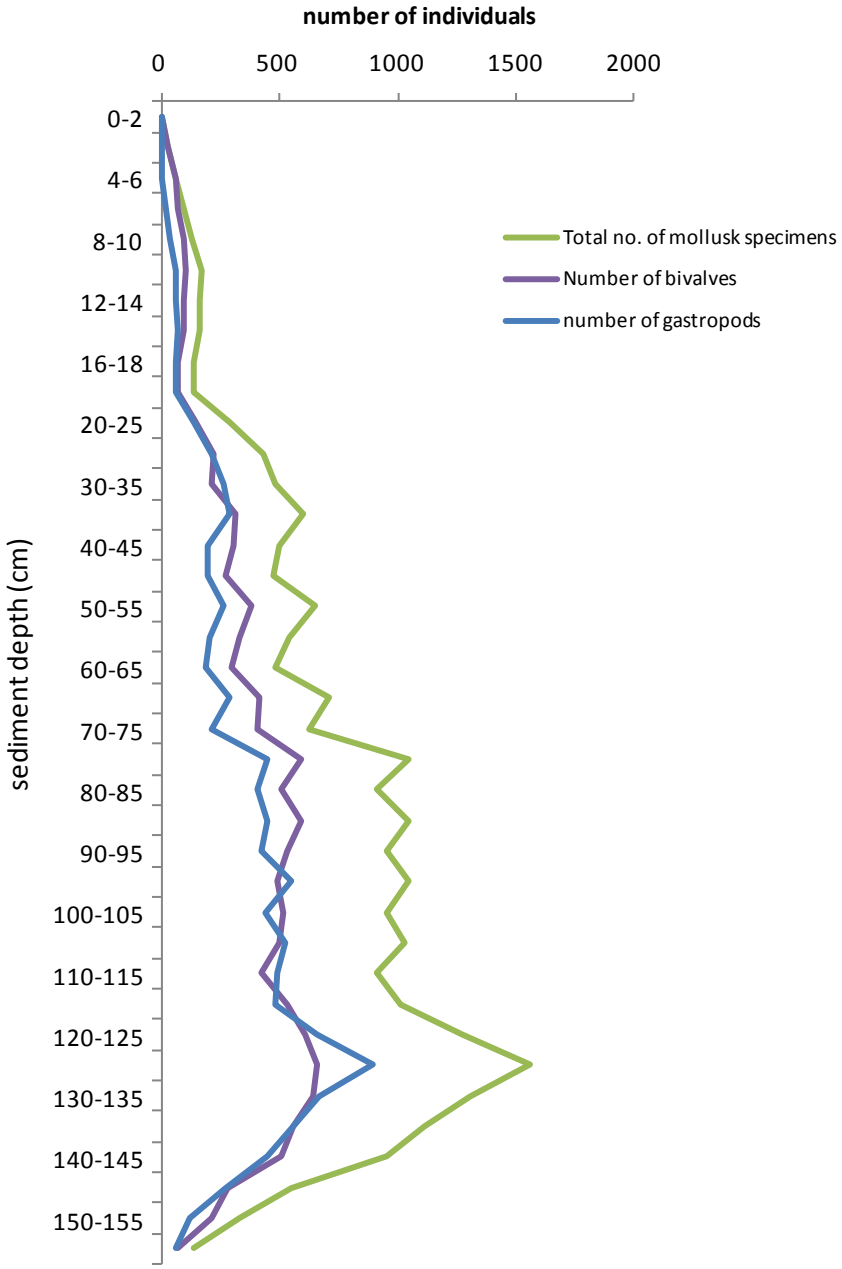

Fig.5. Absolute abundance of bivalves (blue), gastropods (purple) and all mollusks (green) along the core.

Mollusk families differed strongly in number of species and individuals. The gastropod families Rissoidae, Veneridae, Trochidae, Pyramidellidae and the bivalve family Pectinidae were rich in species as well as individuals, whereas several other families were represented with only one individual in one species (Phasianellidae, Scaphandridae, Velutinidae, Ischnochitonidae, Neritidae, Ungulinidae, Iravadidae, Pharidae and Costellariidae). A high number of families (39) contained two and more individuals in just one species (Fig. 6 & 7).

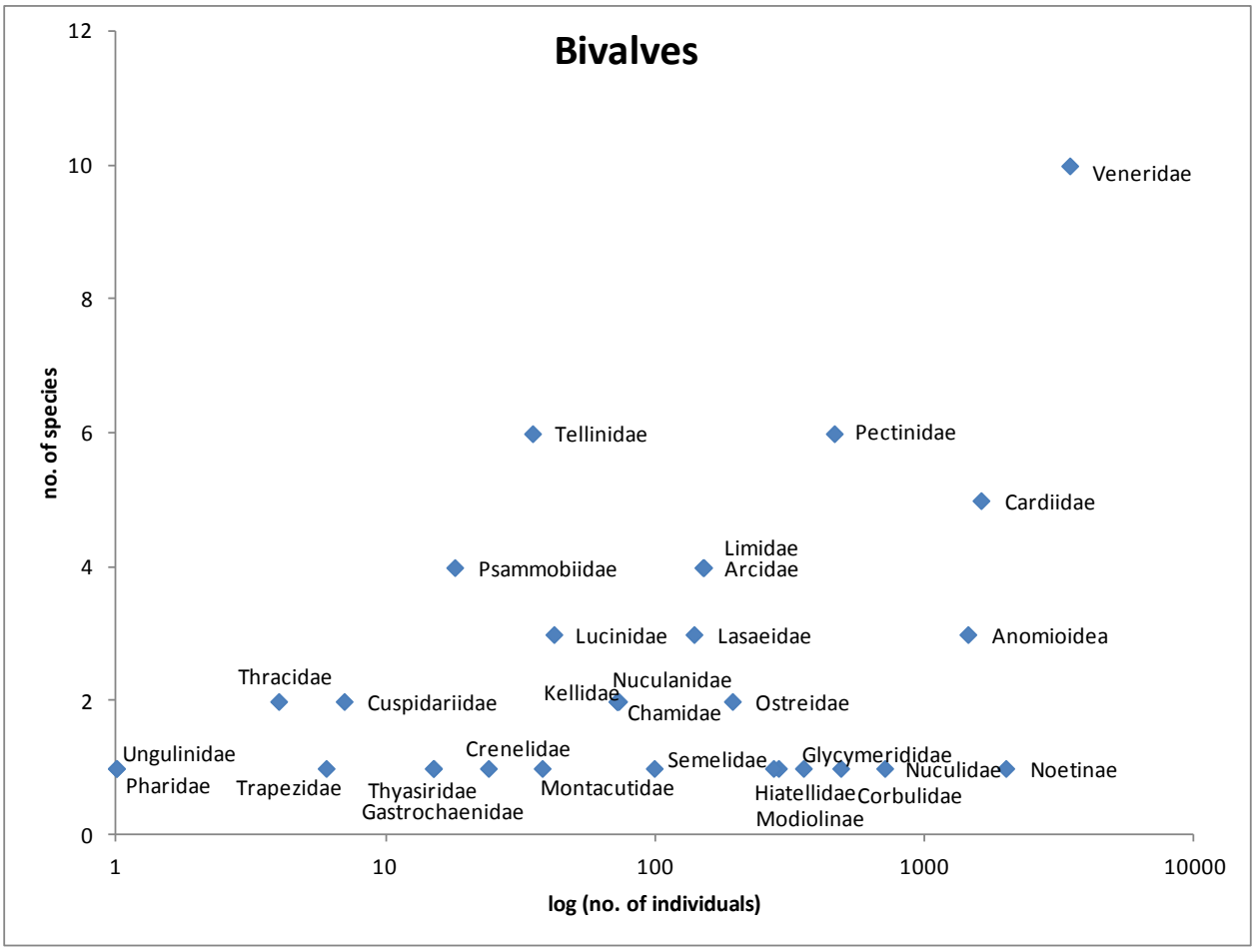

Fig.6. Bivalves: Number of individuals and species per family

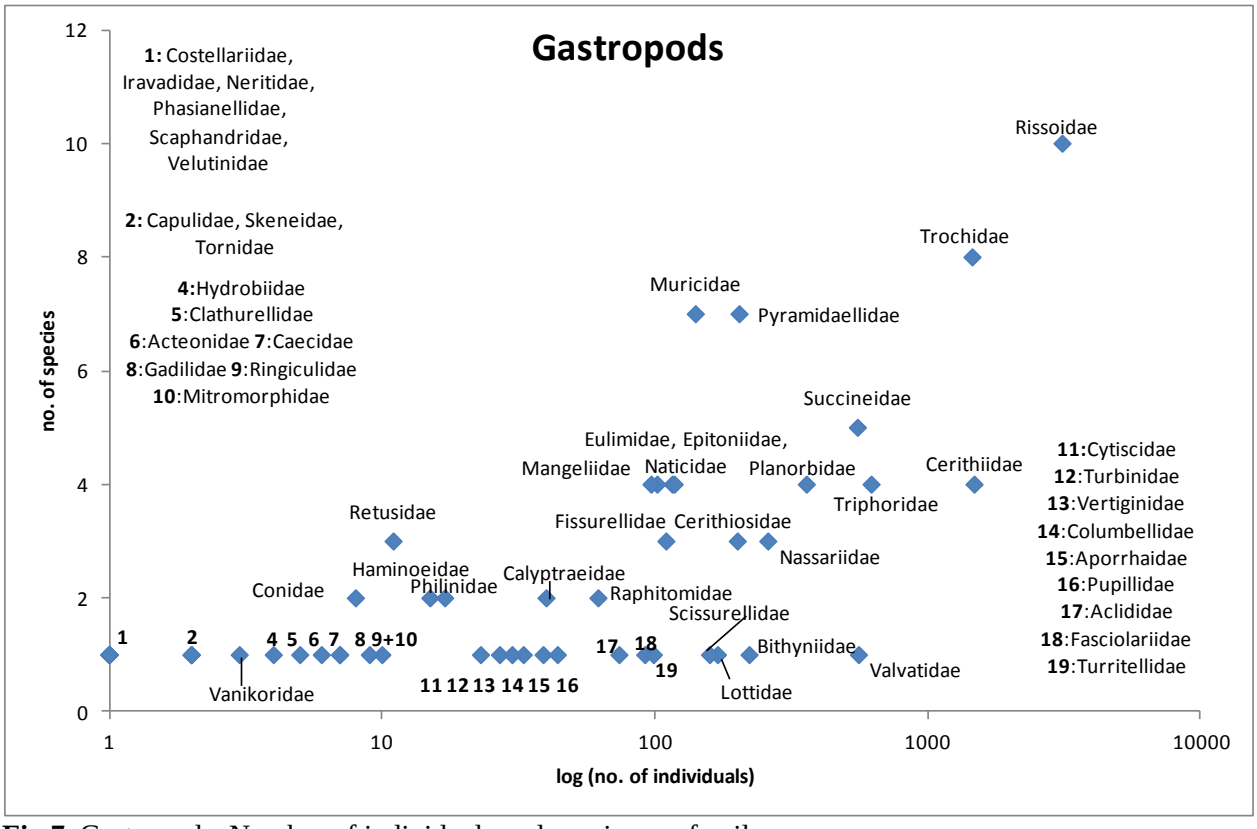

Fig.7. Gastropods: Number of individuals and species per family

The depth-distribution of gastropod species (relative abundances) displayed four dominant taxa: *Alvania* sp. 2, *Alvania* sp. 3, *Bittium reticulatum* and two or more species combined in *Jujubinus* spp. While *Jujubinus* spp. was prominent in the middle part of the core, *Alvania* sp. 2 and *Bittium reticulatum* were highly abundant in the top samples. *Alvania* sp. 3 was the most dominant gastropod in the lower half of the core (Fig. 8).

The relative abundance of bivalves sorted by sediment depth showed three highly abundant bivalve species and their alternating appearance in the core. While *Nucula* cf. *nucleus* occurred frequently only in the top layers, *Timoclea ovata* was prominent in the middle and lower part. *Striarca lactea*, however, was the most frequent bivalve in the lowermost part of the core (Fig. 9).

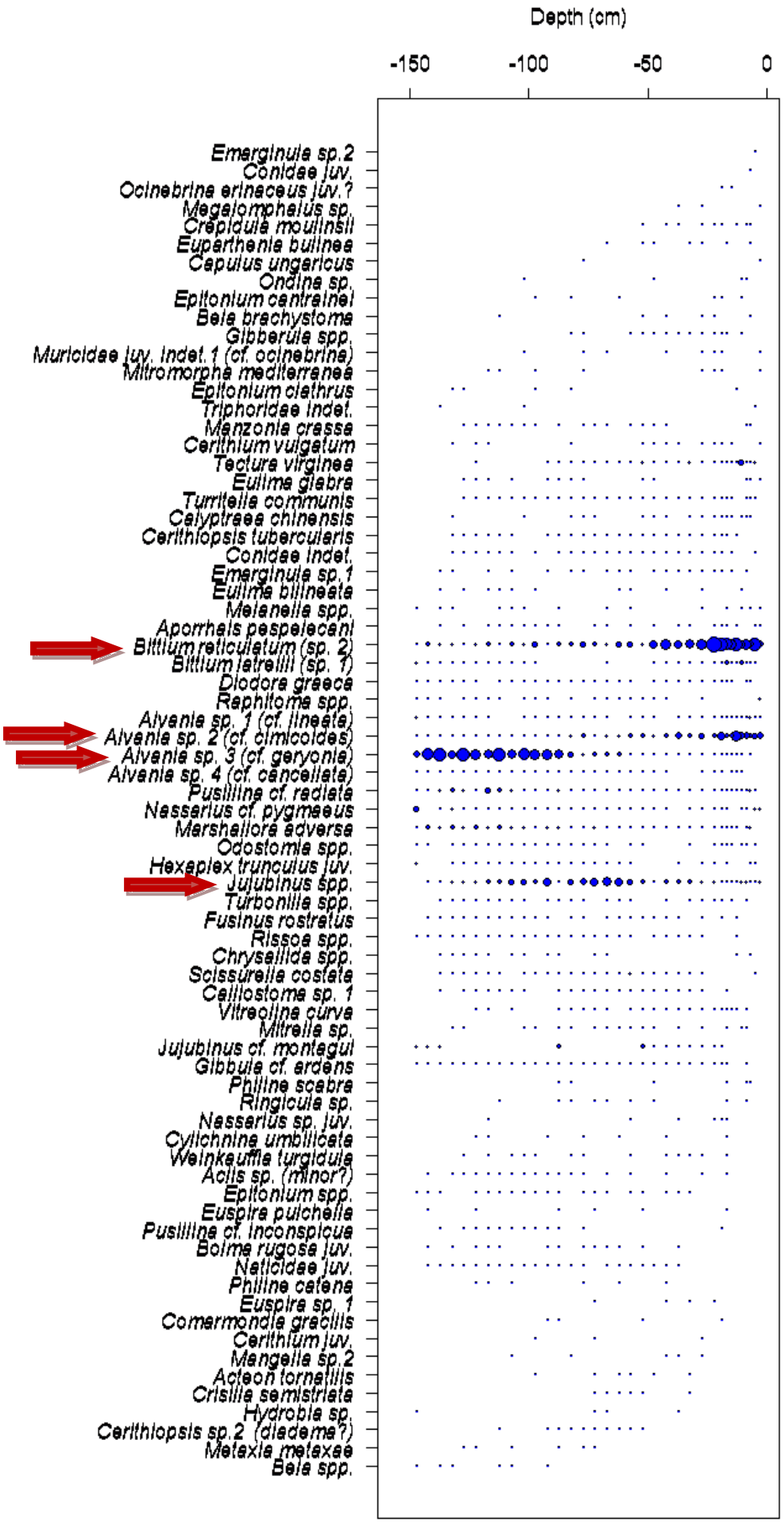

Fig.8. Relative abundance of marine gastropod species sorted by sediment depth.

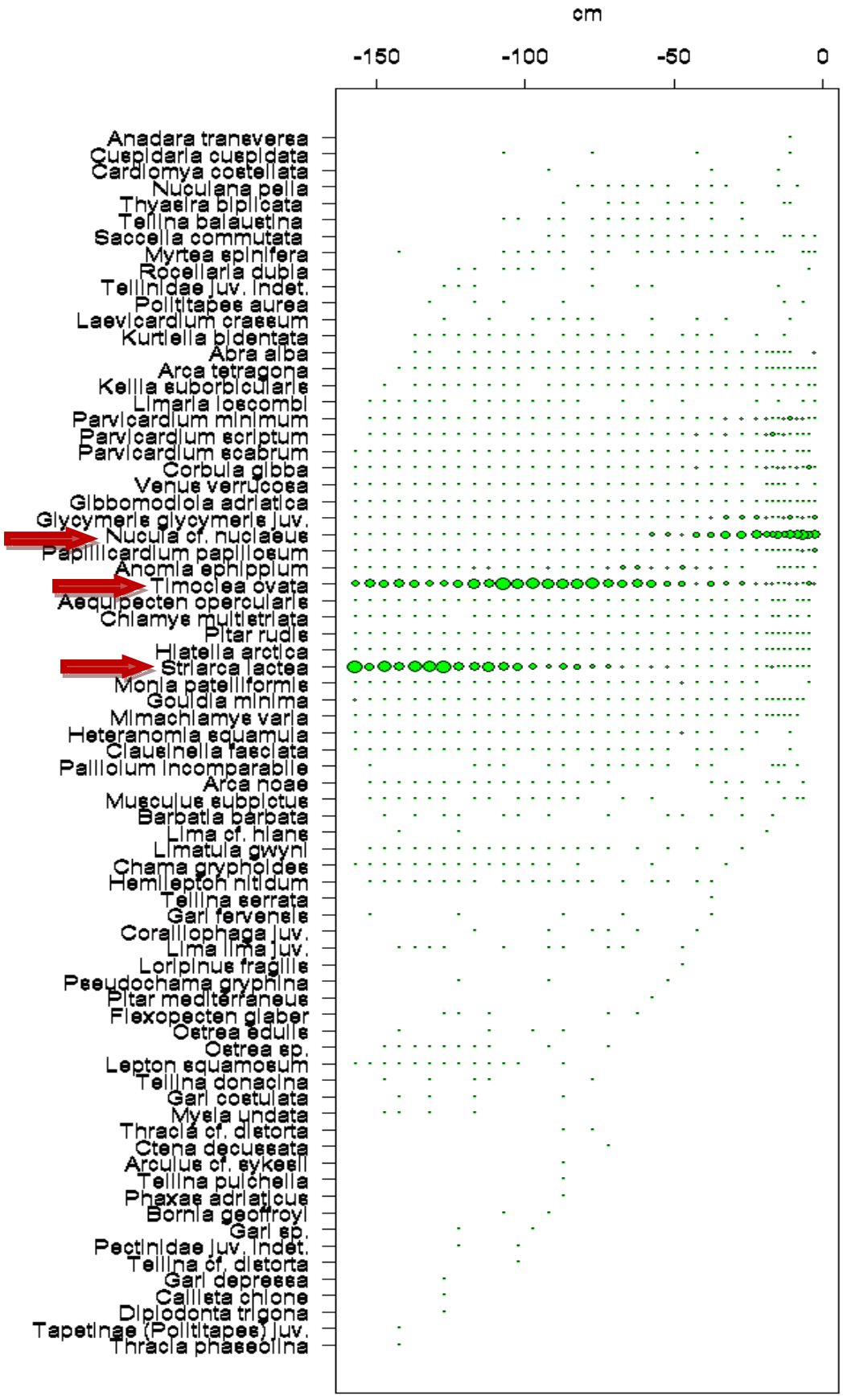

Fig. 9: Relative abundance of bivalves, sorted by sediment depth.

The number of rarefied species remained stable throughout the core at sample sizes of 50 and 100 individuals, which were available almost throughout the core. At larger sample sizes (>200 individuals), the diversity peaked at 35-40 cm, 55-60 cm and 85-90 cm became more obvious, but due to the lack of sufficient number of individuals not all layers could be compared. Samples with 1000 and more specimens were restricted to the deeper part of the core (Fig. 10).

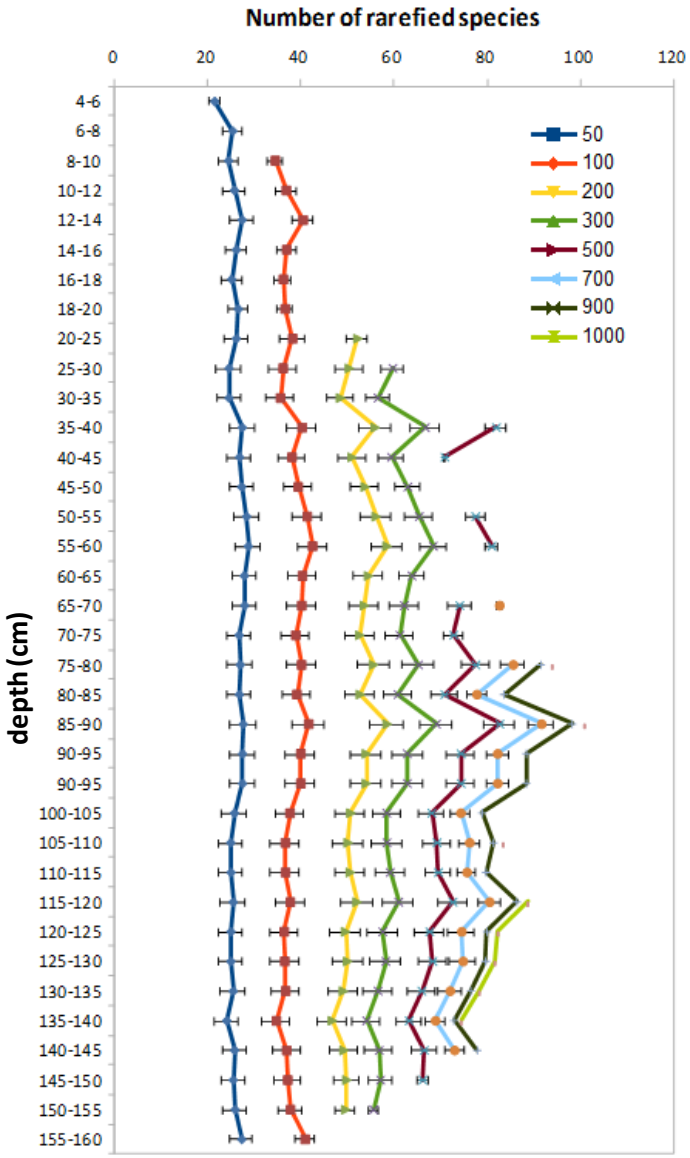

Fig. 10: Number of rarefied species along the core for different sample sizes.

The rarefaction curve of the total assemblage in the core (Fig. 11) shows a strong increase of species number with individuals for the first few thousand individuals, indicating high evenness, and still rises continuously towards the maximum number of 23,012 individuals in 192 species. The curve does not level off and therefore shows no saturation. The species accumulation curve (Fig.

12) reveals a similar pattern, which indicates that additional samples would still increase the number of species.

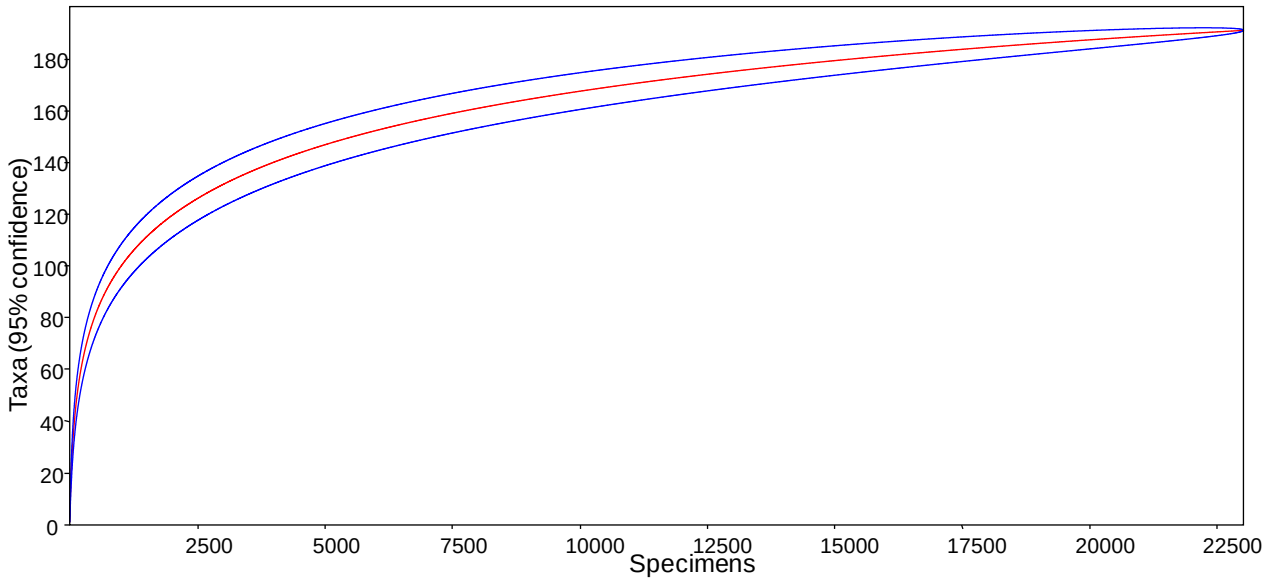

Fig. 11: Rarefaction curve of total assemblage with 95% confidence intervals.

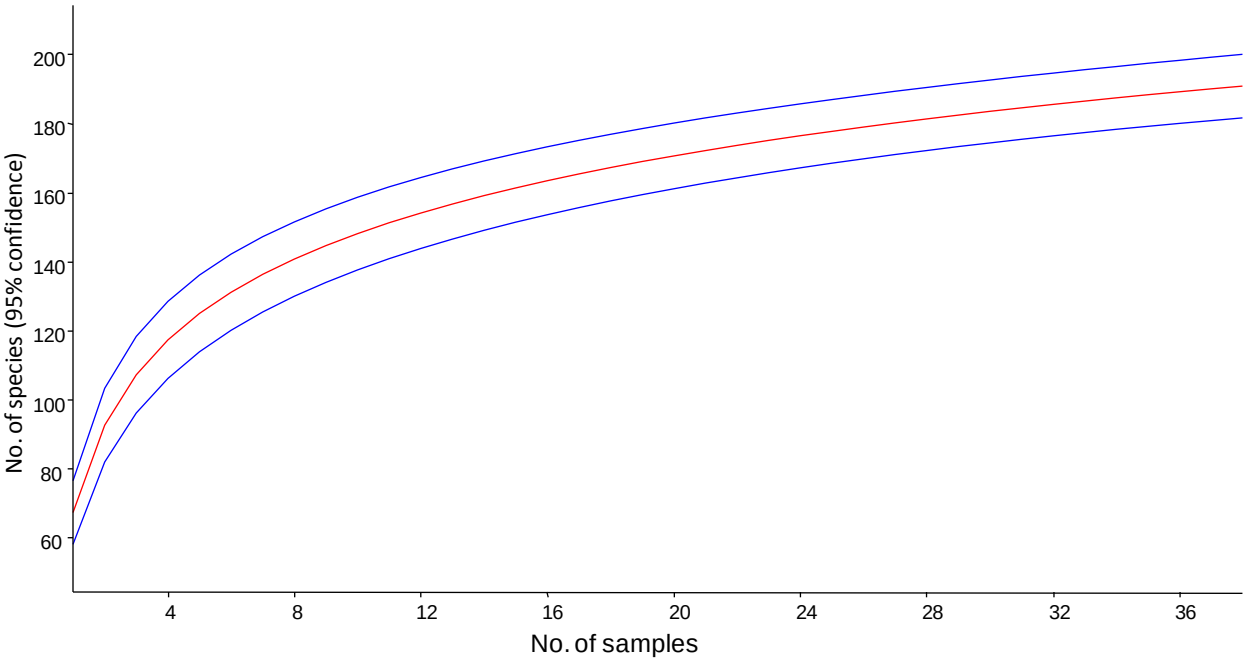

Fig. 12: Species accumulation curve with 95% confidence intervals.

Species composition

The most abundant bivalve was the venerid *Timoclea ovata* (2449 specimens), followed by the arcoid *Striarca lactea* (1995) (Fig. 13). Other highly abundant bivalve species were *Anomia*

ephippium (726), *Nucula* cf. *nucleus* (709) *and Corbula gibba* (487). These five bivalve species showed a distinct distribution pattern along the core (Fig. 14). *Timoclea ovata* and *Striarca lactea* abundances both showed strong peaks in the lower half of the core, though clearly separated from each other. While *Timoclea ovata*, an infaunal filter feeder, peaked at 75-80 cm with 166 individuals and discontinuously decreased with depth, *Striarca lactea*, an epifaunal filter feeder, steadily increased to a maximum of 201 individuals at 125-130 cm and rapidly decreased towards the low end of the core. Specimens of the epifaunal filter feeder *Anomia ephippium* occurred at very low numbers in the upper 35 cm, then suddenly increased and remained constant (20 to 50 individuals) for all lower samples. *Nucula* cf. *nucleus*, an infaunal soft-bottom deposit feeding species, was more abundant in the upper half of core samples than in the lower part. The pattern displayed a mild curve from 25-45 cm with abundances of 41 to 45 individuals and a second peak at 50-55 cm with 40 individuals. Abundances then slowly decreased with depth, although the species was present in all samples except the uppermost (0-2 cm). Also *Corbula gibba*, an infaunal filter feeder, was represented in all samples except 0-2 cm. In this case, the maximum abundance was 30 specimens at 75-80 cm. In general, abundances were low in the upper 35 cm and higher in the deeper samples, but no sharp peaks were observed (Fig. 14).

Alvania cf. *geryonia* (1490 specimens), *Bittium reticulatum* (1190) *Jujubinus* spp. (1007), *Marshallora adversa* (609), *Pusillina radiata* (608) and *Alvania* cf. *cimicoides* (582) were the six most abundant marine gastropods. Also two freshwater species – *Valvata macrostoma* (559) and *Oxyloma elegans* (554) – were among the most frequent gastropods (Fig. 13). The epifaunal micro-herbivores *Alvania* cf. *geryonia* and *Alvania* cf. *cimicoides* replace each other concerning their highest abundances along the core (Fig. 14). *Alvania* cf. *cimicoides* is abundant from 30 to 95 cm depth with a maximum of 41specimens, whereas *Alvania* cf. *geryonia* continuously increases from 30 cm depth towards a high peak of 166 specimens at 135 cm. Species of the genus *Jujubinus*, which also feed epifaunally on microalgae, were especially abundant from 60 to 100 cm depth (80 individuals at 75-80 cm) and again from 105 to 140 cm depth (79 at 125-130 cm). Those maxima are interrupted by a sharp decline at 95-100 cm (7 specimens). Another epifaunal microherbivore, *Bittium reticulatum*, showed the highest peak at 30-35 cm depth (93 specimens) and a second high peak at 125-130 cm, with several smaller peaks defining the abundance pattern of the species between those two peaks. The parasitic triphorid *Marshallora adversa*, which lives on sponges and seagrass, steadily increases with depth towards the highest number of identified individuals (56) at 130-135 cm. The epifaunal microherbivore *Pusillina* cf. *radiata* peaks at 125-130 cm (90 individuals) and steadily decreases towards the younger fractions until it is reduced to 1 individual at 8-10 cm (Fig. 14).

Freshwater and land snails occurred in high numbers in the deeper half of the core (Fig. 15). *Valvata macrostoma* was the most abundant freshwater species with a total number of 559 specimens and the highest peak at 125-130 cm (85 specimens). Further freshwater gastropods present were *Gyraulus* cf. *laevis* (309), *Bithynia* sp. (222), *Anisus* cf. *leucostoma* (42), *Gyraulus* cf. *albus* (6) and *Segmentina nitida* (3). The most abundant land snail was *Oxyloma elegans* (554), which was most abundant at 135-140 cm (66), followed by *Pupilla triplicata* (44) and *Vertigo antivertigo* (30) (Fig. 15).

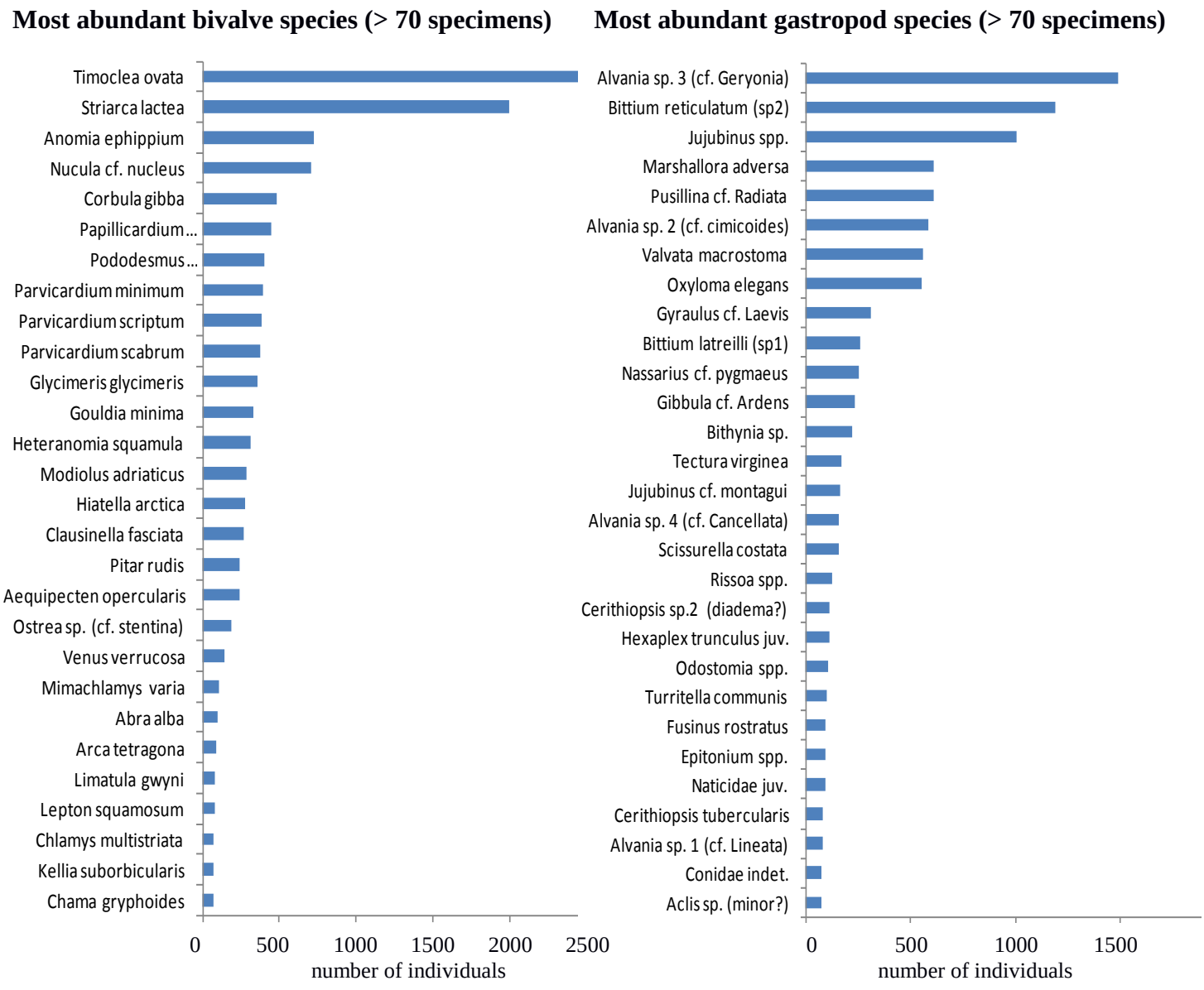

Fig. 13: Most abundant bivalve (left) and gastropod (right) species.

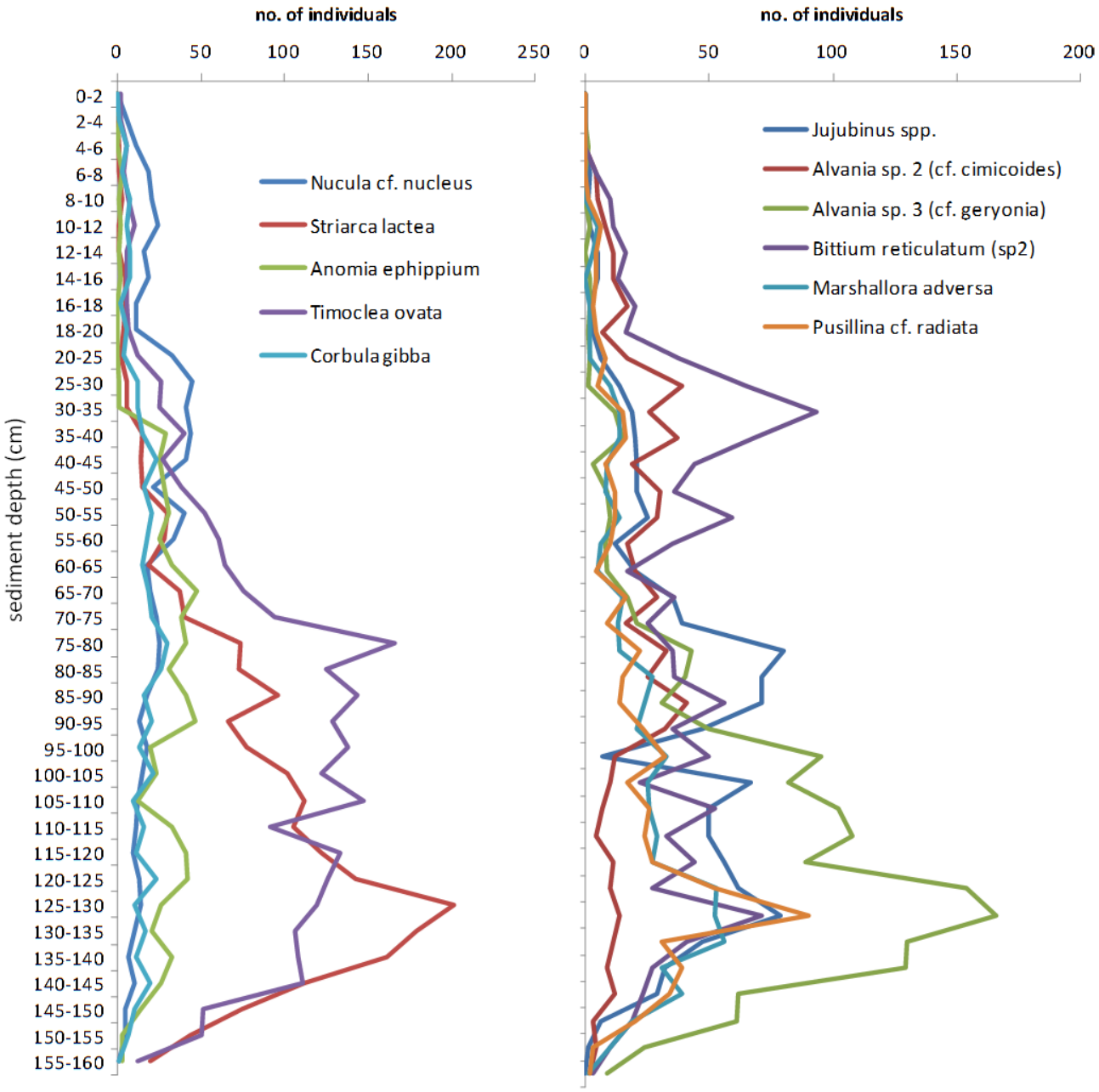

Fig. 14: Distribution of most abundant bivalve (left) and gastropod (right) species along the core.

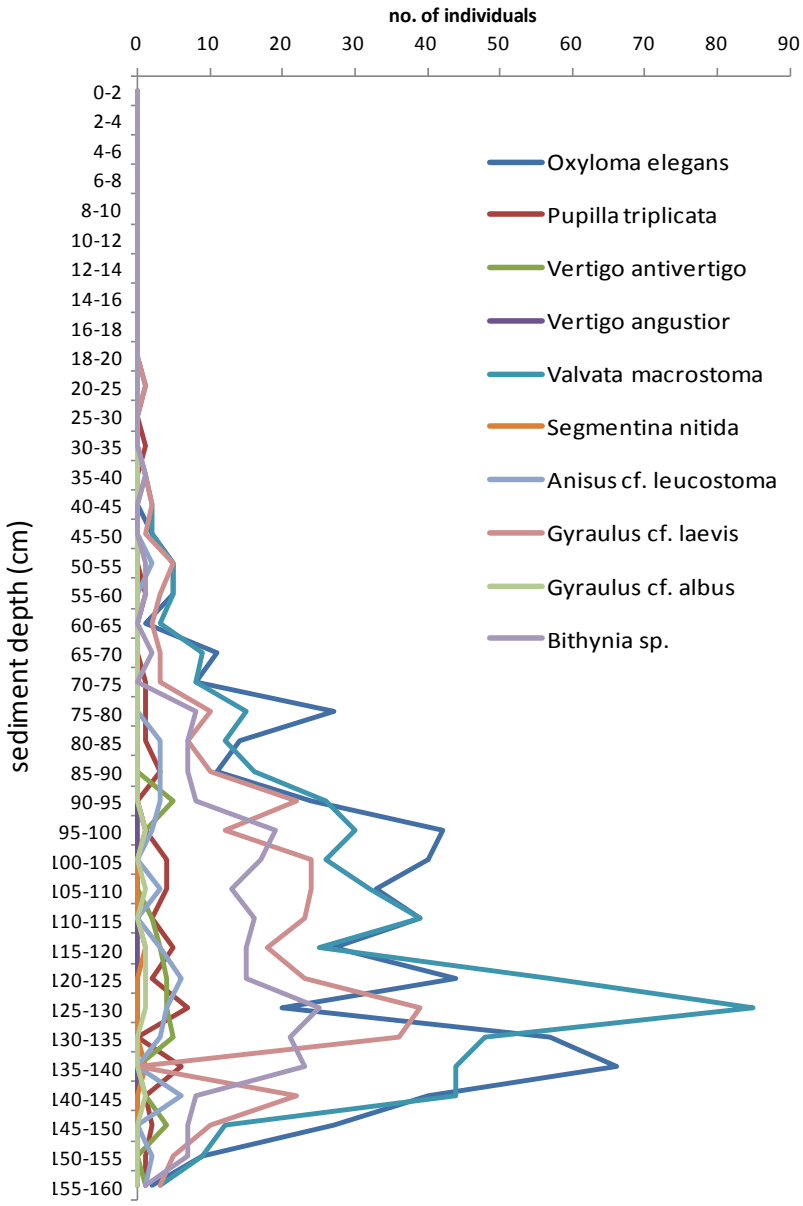

Fig. 15: Distribution of non-marine gastropod species along the core

Ecology

The substrate relations and feeding modes of mollusks changed down-core. Towards the younger fractions, a strong decrease in epifaunal species and filter feeders and an increase in infaunal and semi-infaunal species were visible. Throughout the core, epifaunal and infaunal species were the most abundant substrate groups and filter feeders were the most abundant feeding type (Fig. 16).
Parasitic species, which use their hosts as "substrate" (category "host/cryptic"), were more abundant in the deeper sediment layers of the core (Fig. 16). The relative (and absolute) abundance of deposit feeders increased towards the younger fractions while herbivore abundance decreased.
Concerning relative abundances of the most dominant ecological groups, large differences between minimum and maximum abundance were evident. Carnivores (1.56 %) and herbivores (3.13 %) were least abundant in the sample 4-6 cm close to the sediment surface, whereas filter feeders reached their maximum relative abundance here (64.06 %). The maximum percentage of carnivorous mollusks was at 8.59 % in the sample 20-25 cm, while filter feeders were at their minimum (36.08 %) at this depth. Herbivores were most abundant at 30-35 cm sediment depth (44.42 %). While herbivores strongly decreased and almost disappeared towards the younger fractions, filter feeders decreased, but remained abundant.
In the sample 2-4 cm, epifaunal mollusks reached their minimum abundance (14.29 %), whereas infauna was at the maximum relative abundance of 67.86 %. Note, however, that the sample size in this fraction was very small. The highest percentage of epifauna was 63.98 % at a sediment depth of 45-50 cm and the lowest percentage of infauna (16.76 %) was found at 125-130 cm.

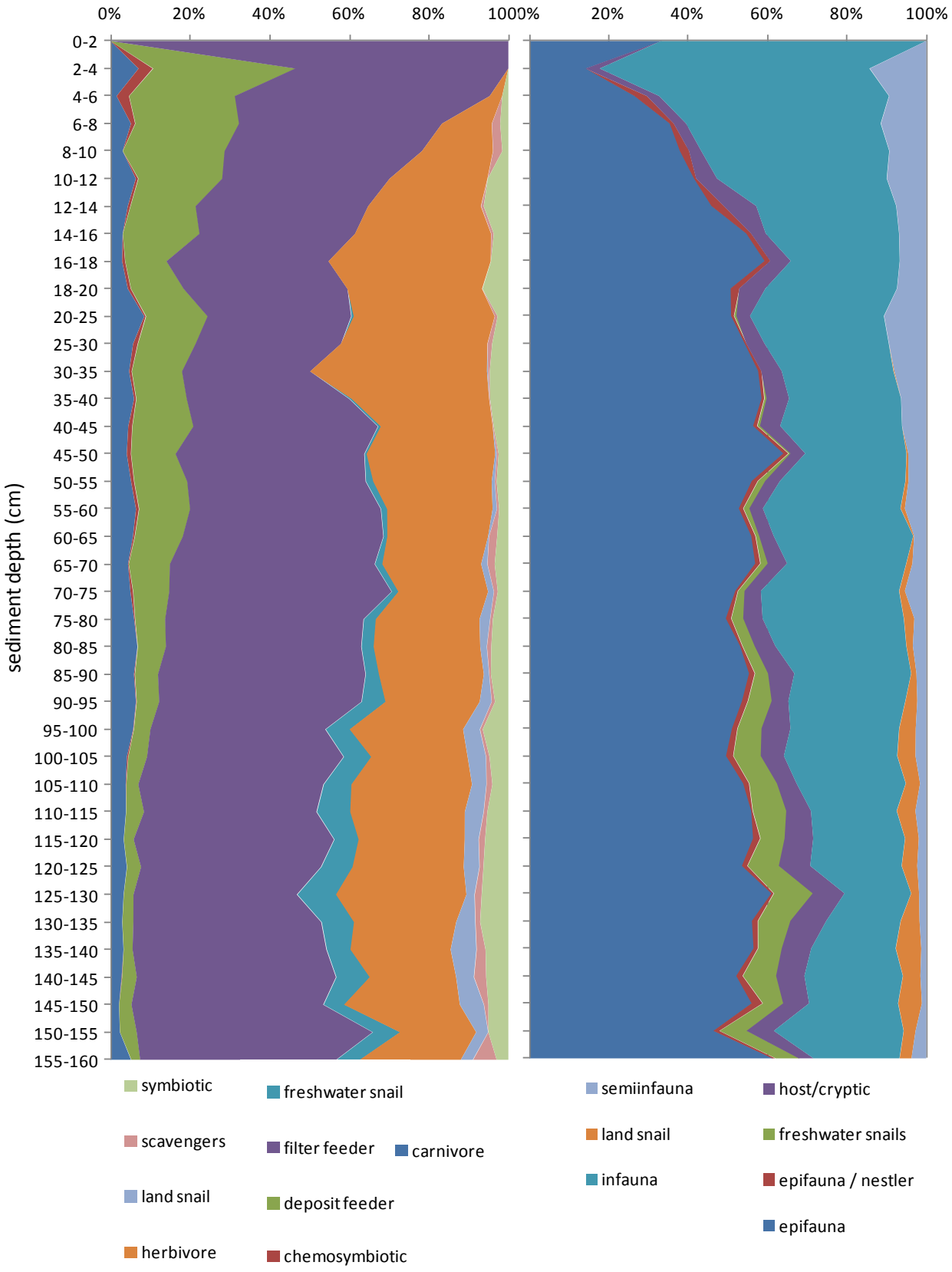

Fig. 16: Relative abundances of feeding modes (left) and substrate relations (right) along the core.

In a cluster analysis with square-root transformed percentages, the core could be divided into distinct groups each for species abundance, feeding modes and substrate relations. In all cases, these groups were clearly distributed along sediment depth (Fig. 17).

For species abundance, four clusters were identified at a 65 % similarity (Fig. 18, 19). The three uppermost samples plus sample 5 (10-12 cm) were outliers and are treated as a separate group (group A). Group B included sample 4 (8-10 cm) and all samples from 14 to 35 cm sediment depth. The most abundant species in group A was the infaunal deposit feeder *Nucula* cf. *nucleus* with a mean percentage of 18.1 %, followed by the infaunal suspension feeders *Glycimeris glycimeris* (7.4 %), *Timoclea ovata* (6.6 %) and *Papillicardium papillosum* (6.4 %). The only gastropod species among the ten most abundant species here was the epifaunal microherbivore *Bittium reticulatum* (2.6 %) (Fig. 20 A). In group B, however, *Bittium reticulatum* was the most common species at 12.4 %. *Nucula cf. nucleus* (10.5 %) and *Alvania* cf. *cimicoides* (6.9 %) were ranked second and third, followed by *Timoclea ovata* (4.7 %) and *Glycymeris glycymeris* (4.3 %). The two cardiid species *Parvicardium minimum* (4.0 %) and *Parvicardium scriptum* (3.9 %) were also abundant in this group, as was the corbulid *Corbula gibba,* an often studied bioindicator (Hrs-Brenko, 2006) (Fig. 20 B). In group C, a cluster determined for all samples from 35 to 95 cm sediment depth, the bivalve *Timoclea ovata* (11.1 %) was the most prominent species followed by the gastropod *Bittium reticulatum* (5.9 %) and the bivalve *Striarca lactea* (5.3 %). Also the anomiid *Anomia ephippium* was abundant (5.0 %). The remaining six of the ten most abundant species in this group contained three gastropod taxa (*Jujubinus* spp. (4.9 %), *Alvania* cf. *cimicoides* (3.9 %) and *Alvania* cf. *geryonia* (2.6%)) and three bivalve species (*Nucula* cf. *nucleus* (4.1 %), *Corbula gibba* (2.9 %) and *Parvicardium minimum* (2.6 %)) (Fig. 20 C). *Striarca lactea* (12.1 %), *Timoclea ovata* (11.0 %) and *Alvania* cf. *geryonia* (9.5 %) were the three most abundant species in group D, which consists of all samples from 95 to 160 cm. Two non-marine gastropods – the land snail *Oxyloma elegans* (3.5 %) and the freshwater species *Valvata macrostoma* (3.4 %) – were highly abundant. Seven of the ten most abundant species were gastropods, including the triphorid *Marshallora adversa* (3.1 %) and the rissoid *Pusillina* cf. *radiata* (2.9 %) (Fig. 20 D). *Timoclea ovata* and *Bittium reticulatum* were among the ten most abundant species in all four groups. *Corbula gibba* was abundant in groups A, B and C. *Glycymeris glycymeris* was abundant in groups A and B, and *Anomia ephippium* was abundant in groups C and D. Cardiid species were abundant in groups A (3 species), B (2 species) and C (1 species), but absent from the most abundant species in group D.

The cluster analysis on percentages of feeding modes again yielded four groups at a similarity of 89 % (Fig. 21, 22). Group A consists of the four outlying uppermost samples (2-10 cm), of which 54.6 % were *filter feeders* and 28.4 % were *deposit feeders*. Mollusks feeding on metabolites of

chemoautotrophic bacteria in their gills made up 1.9 %. *Parasites* (1.3 %) and *scavengers* (1.1 %) accounted for the remaining percentage because freshwater and land snails were absent from group A (Fig. 23 A). Group B is a cluster of ten subsamples at sediment depths from 10 to 45 cm. Most of the group is composed of *filter feeders* (39.8 %), *herbivores* (34.1 %) and *deposit feeders* (15.1 %). *Carnivores* (5.1 %) and *parasites* (4.6 %) make up less than ten per cent and *chemosymbiotic* mollusks (0.6 %), *scavengers* (0.4 %), *freshwater* (0.2 %) and *land snails* (0.02 %) each accounted for less than one percent (Fig. 23 B). Group C is a rather small group of six samples at 45-75 cm depth. As in groups A and B, *filter feeders* (49.6 %), *herbivores* (26.8 %) and *deposit feeders* (11.4 %) were the most abundant categories. The percentage of *carnivores* (5.2 %) was slightly higher and *parasites* (2.8 %) were less abundant than in group B. *Freshwater snails* (1.5 %) were more abundant than *scavengers* (1.03 %), and *land snails* (0.9 %) were equally abundant as *chemosymbiotic* animals (0.9 %) (Fig. 23 C). Group D is the largest cluster and includes all seventeen samples from 75 cm to the bottom of the core at 160 cm. *Filter feeders* (48.5 %) and *herbivores* (26.3 %) account for the largest part again, but are followed by *freshwater snails* (6.4 %) and *parasites* (5.2 %). Carnivores accounted for 4.3 per cent and deposit feeders for 4.1 per cent. The percentages of land snails (3.7 %) and scavengers (1.4 %) were higher than in the aforementioned groups, but chemosymbiotic bivalves make up only 0.06 % (Fig. 23 D).

Groups according to substrate relations (at a similarity of 91 per cent; Fig 24, 25) are distributed along the core in a similar manner as species abundance and feeding mode groups. However, group A included one more sample, and the sizes of the groups B, C and D are in between those of groups B, C and D in the previous two analyses. Infaunal and epifaunal specimens are the most abundant categories in all four groups. Group A consists of the five uppermost subsamples (2-12 cm). Mean percentages of *infauna* (52.9 %) and *epifauna* (31.2 %) account for over 80 % of individuals. 10.9 % are specimens assigned to the category *semi-infauna,* whereas the remaining five percent either used their hosts as substrate or were cryptic species and categorized as *host/cryptic* (3.6 %); individuals of the species *Hiatella arctica* formed the category *epifauna/nestler* (1.4 %). Freshwater and land snails are absent (Fig. 26A). In group B (9 samples, 12-45 cm), the order of *epifauna* and *infauna* was switched, with *epifauna* accounting for 54.2 % and infauna for 31.2 %. The order of *semi-infauna* (7.6 %), *host/cryptic* (5.3 %) and *epifauna/nestler* was maintained, and freshwater (0.2 %) and land snails (0.02 %) were present in very low proportions (Fig. 26 B). In group C (9 samples, 45-90 cm), the percentages of both *epifauna* (55.06 %) and *infauna* (32.1 %) are higher than in group B, and the categories *host/cryptic* (4.5 %) and *semi-infauna* (3.9 %) occur in reversed order. Non-marine gastropod shells are represented with 0.9 % (freshwater snails) and 0.7 % (land snails), and the category *epifauna/nestler* accounted for 0.3 % (Fig. 26C). Group D is the largest group with 14 samples (90-160 cm) and includes a large portion of freshwater snails (7.1 %), which

was the third largest subgroup after epifauna (54.5 %) and infauna (24.2 %). Parasites or cryptic mollusks make up 6.6 %, semi-infaunal animals 2.1 % and *epifaunal/nestler* 1.36 % (Fig. 26 D).

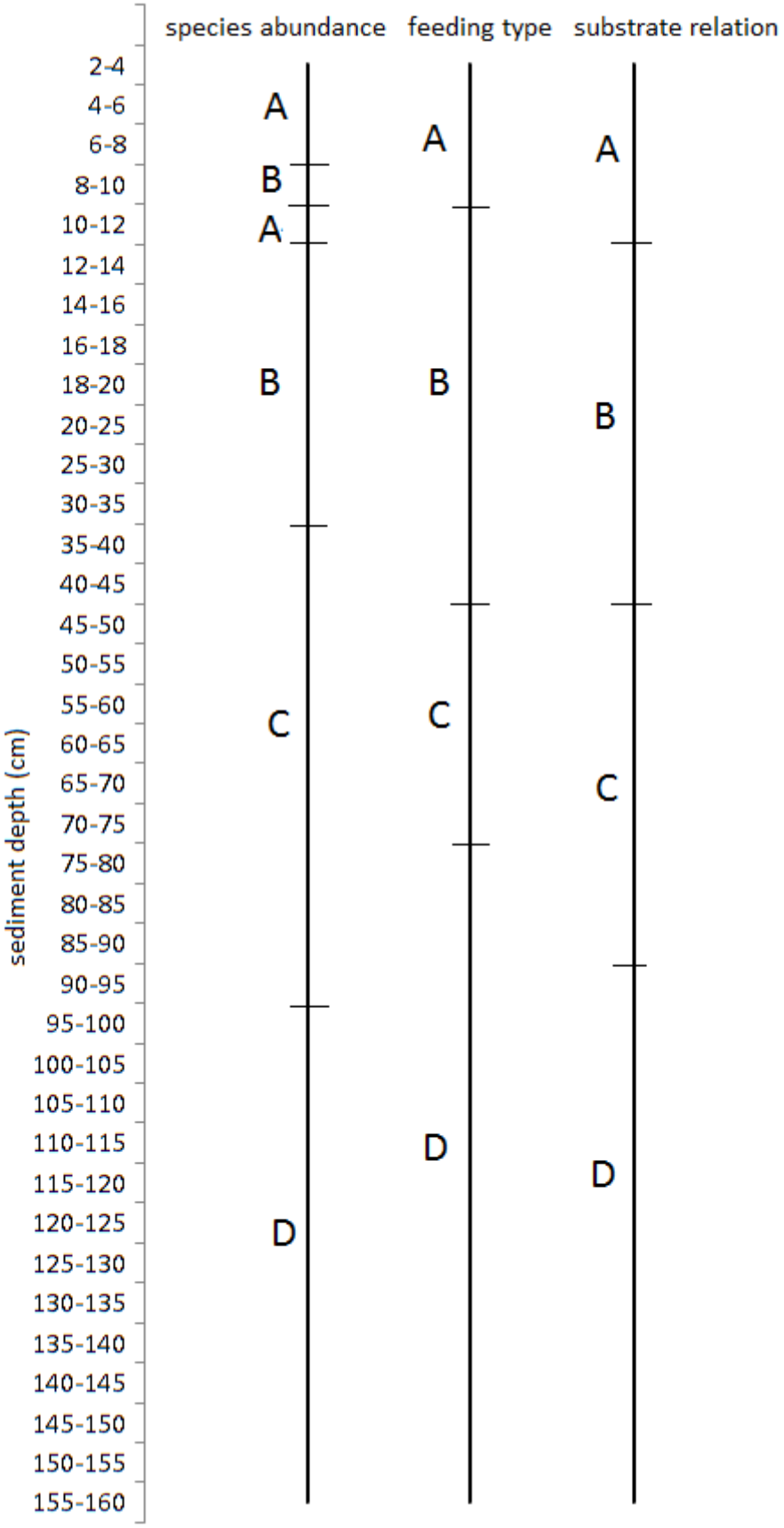

Fig. 17: Distribution of clusters A-D for species abundance, feeding mode and substrate relation along the sediment core.

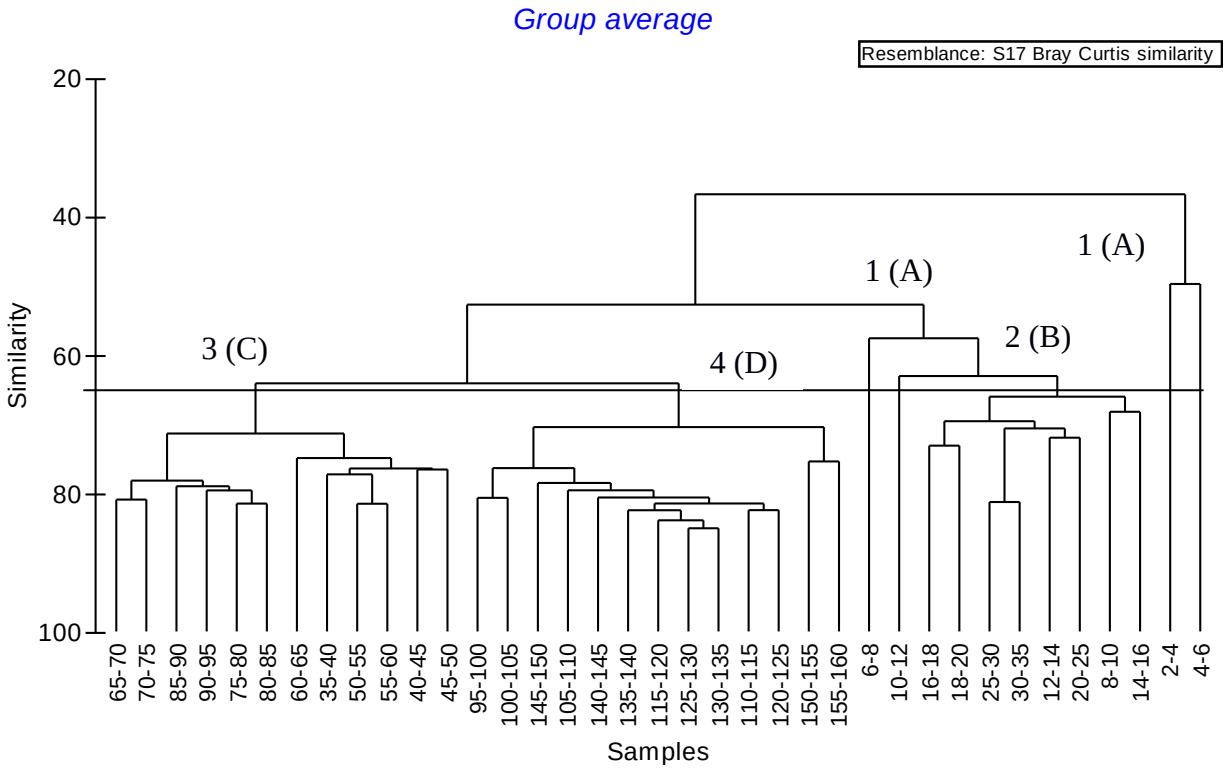

Fig. 18: Cluster analysis on square-root transformed species abundance data showing 3 clusters (2,3,4) and 4 samples, which are outliers (2-4, 4-6, 6-8, 10-12) and summarized in group 1 at a similarity level of 65%

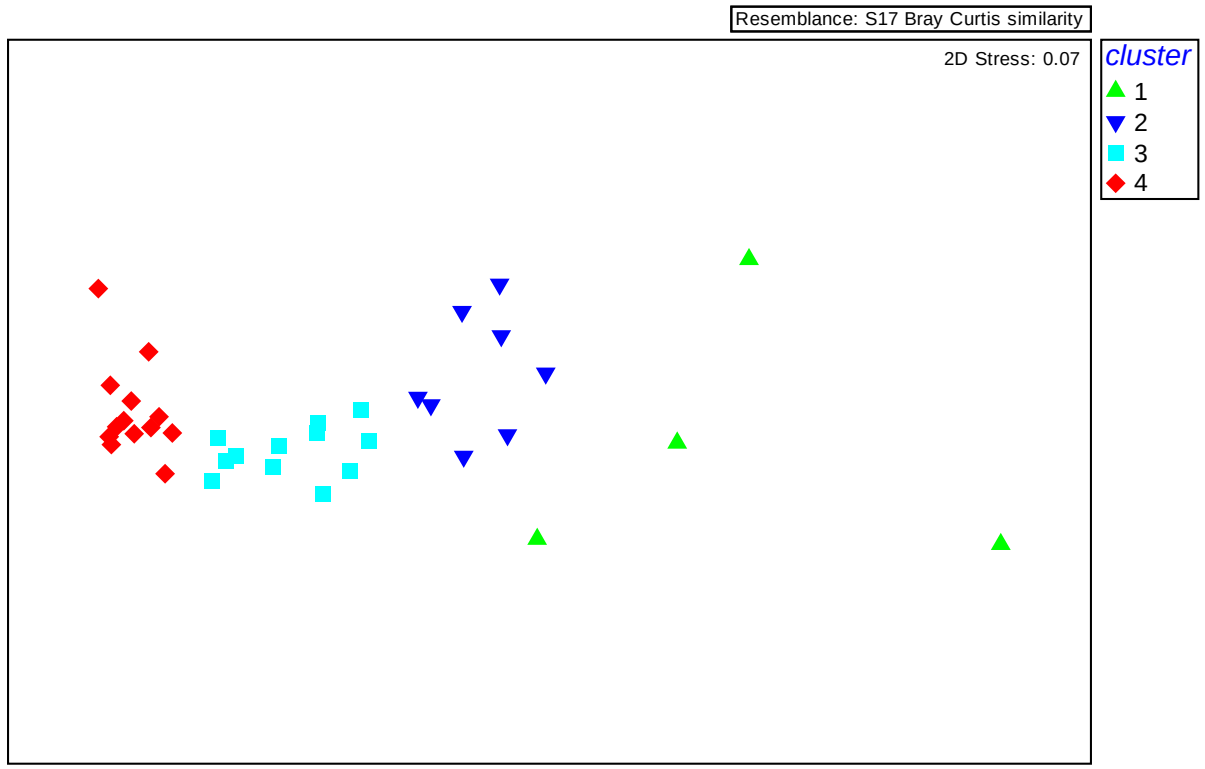

Fig. 19: nMDS Plot of species abundance. Grouping of samples according to cluster analysis (see Fig. 18).

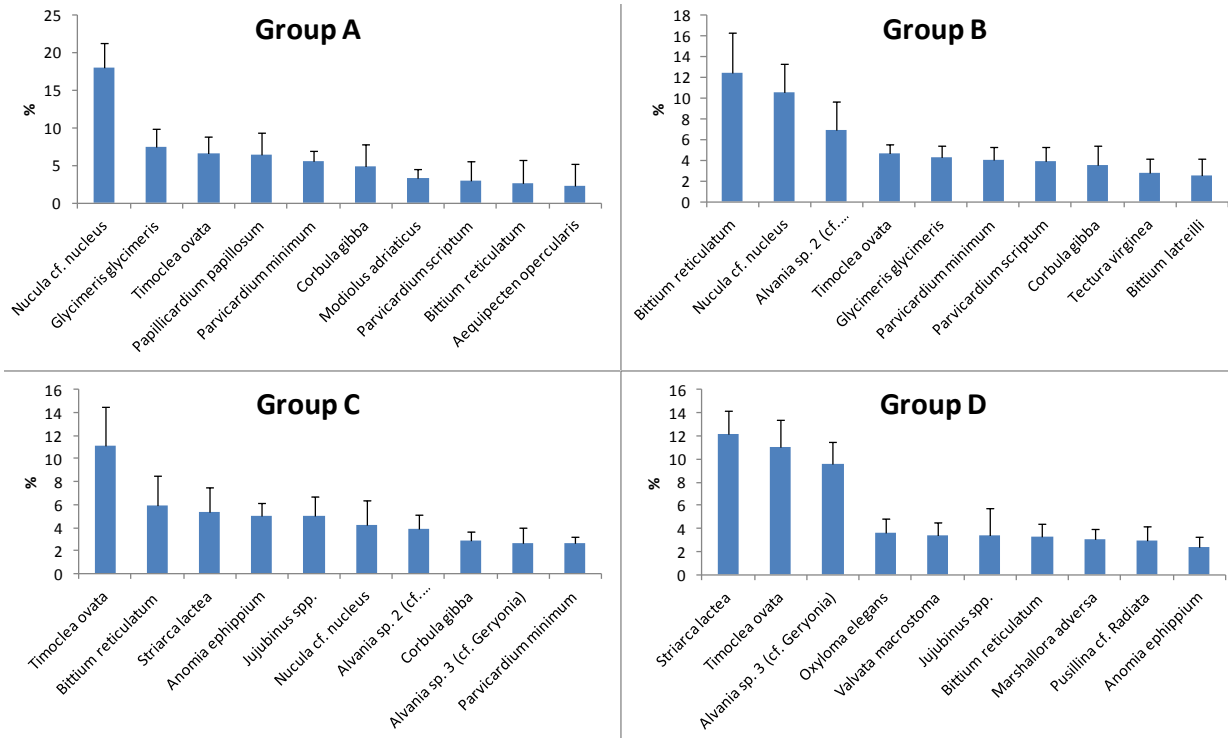

Fig. 20: Mean percentage of species per sample (with standard deviation) of the 4 clusters resulting from cluster analysis using square-root transformed abundance data (see Fig. 18).

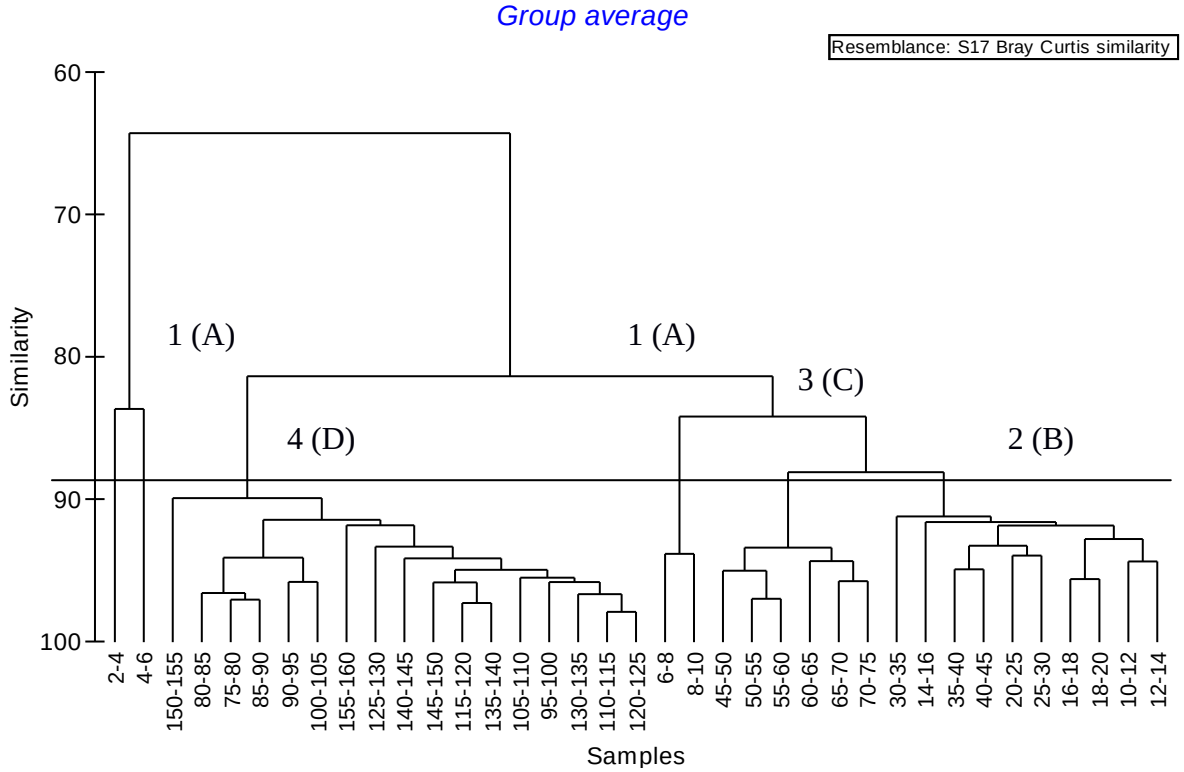

Fig. 21: Cluster analysis on square-root transformed feeding modes data showing 3 clusters (2, 3, 4) and 4 samples, which are outliers (2-4, 4-6, 6-8, 10-12) and summarized in group 1 at a similarity level of 89 %.

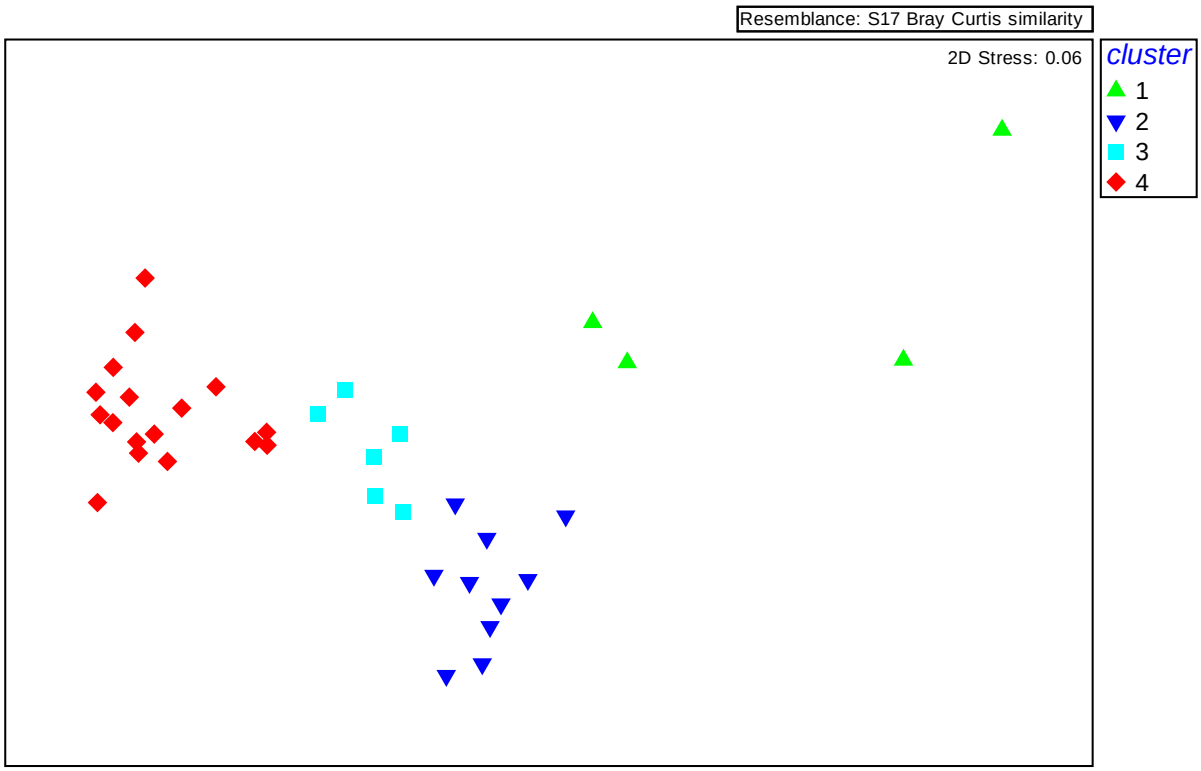

Fig. 22: nMDS Plot of feeding modes. Grouping of samples according to cluster analysis (see Fig. 21).

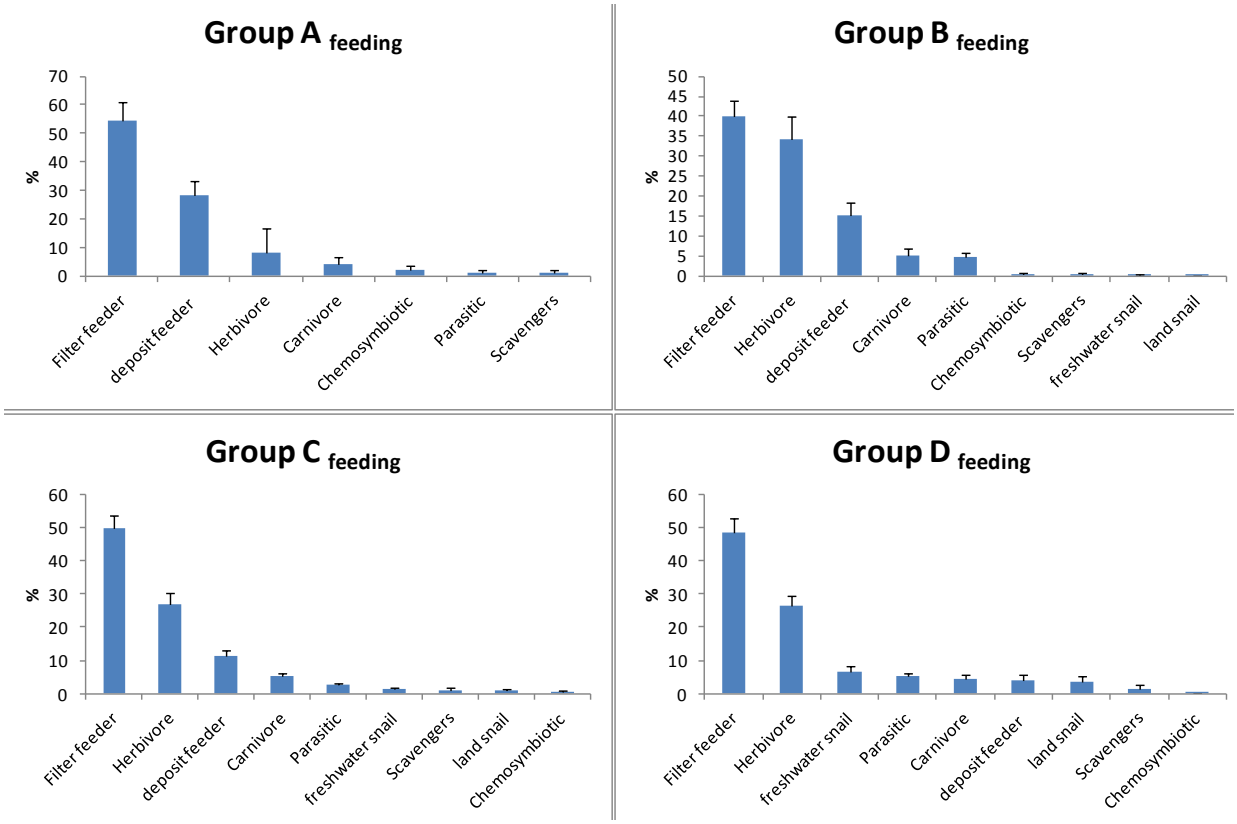

Fig. 23: Mean percentage of feeding modes per sample (with standard deviation) of the 4 clusters resulting from cluster analysis using square-root transformed abundance data (see Fig. 21).

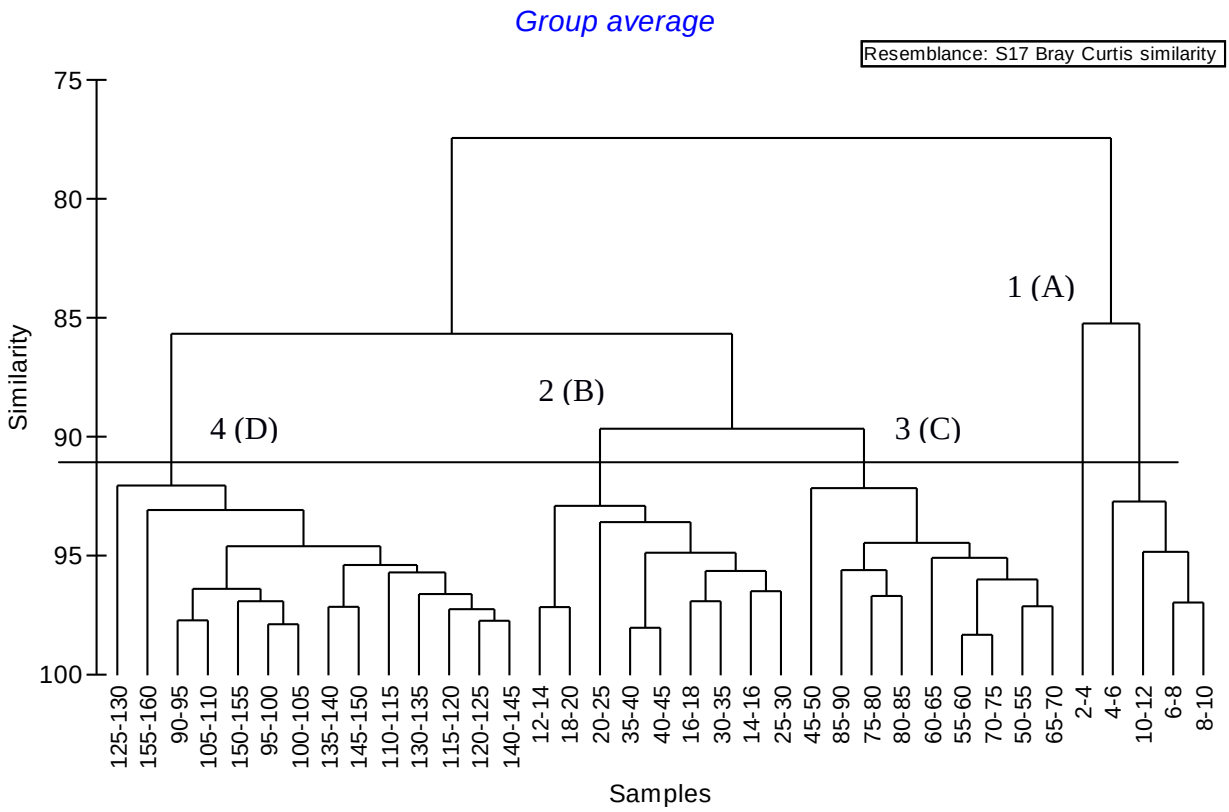

Fig. 24: Cluster analysis on square-root transformed substrate relation data showing 4 clusters at a similarity level of 91%. Cluster 1 includes one outlier (sample 2-4)

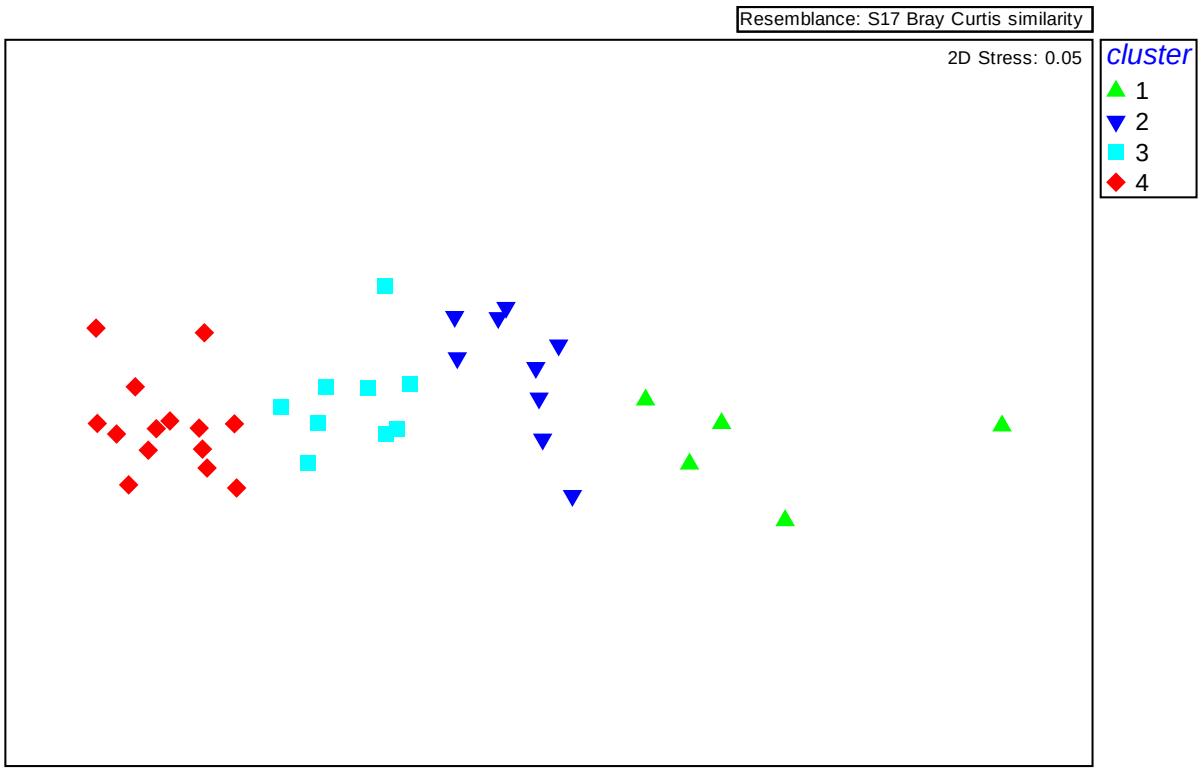

Fig. 25: nMDS Plot of substrate relation. Grouping according to cluster analysis (see Fig. 24).

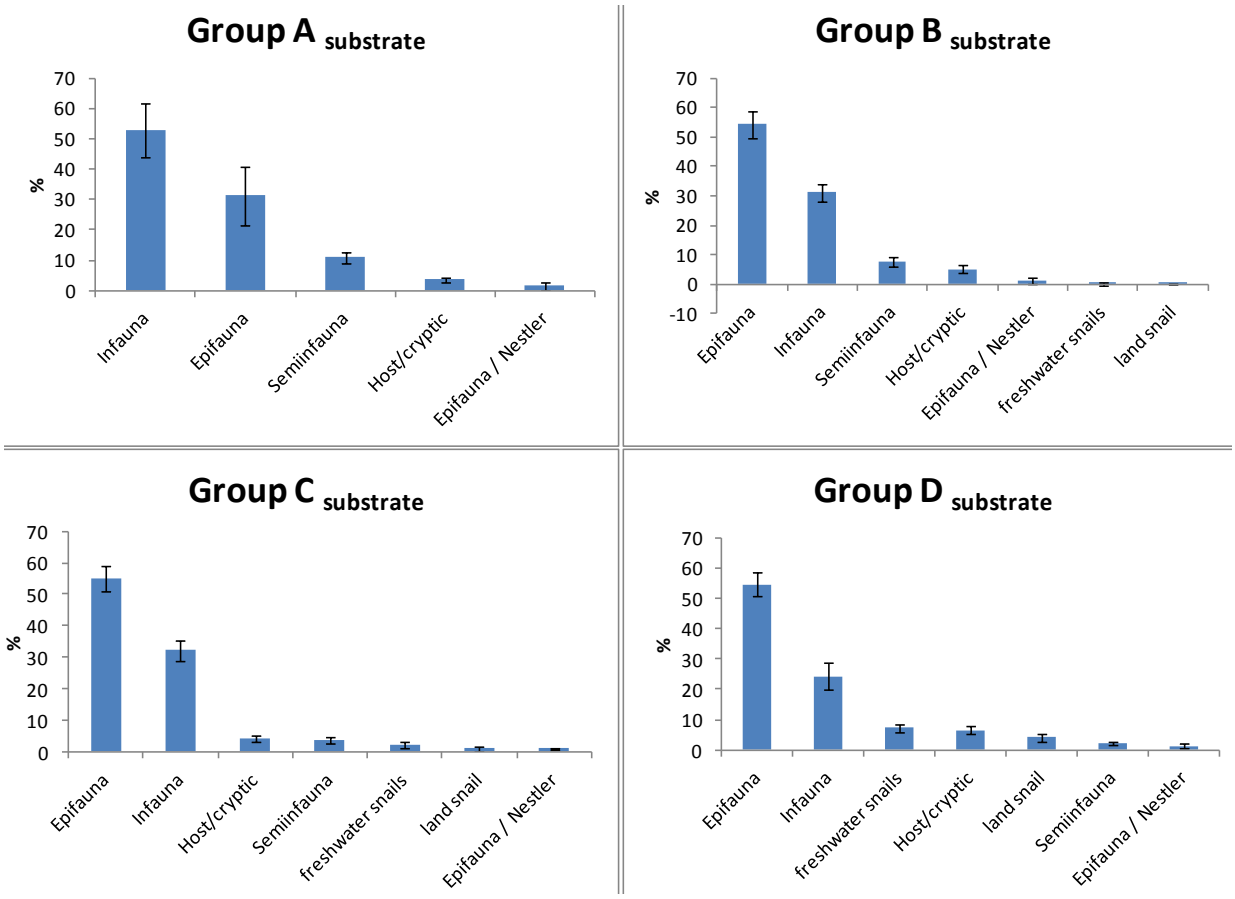

Fig. 26: Mean percentage of substrate relation per sample (with standard deviation) of the 4 clusters resulting from cluster analysis using square-root transformed abundance data (see Fig. 24).

Sediment composition, age and sedimentation rate

The percentage of clay decreased with depth, whereas the fraction >1 mm increased. A strong shift of sediments was visible in the lower third of the core, where the sandy fractions accounted for more than 80 % of the sediment mass. In the deepest 20 cm, another shift was visible. Fine sand and silt increased towards 90 %, coarse sand disappeared and clay accounted for the remaining 10 % (Fig. 27).

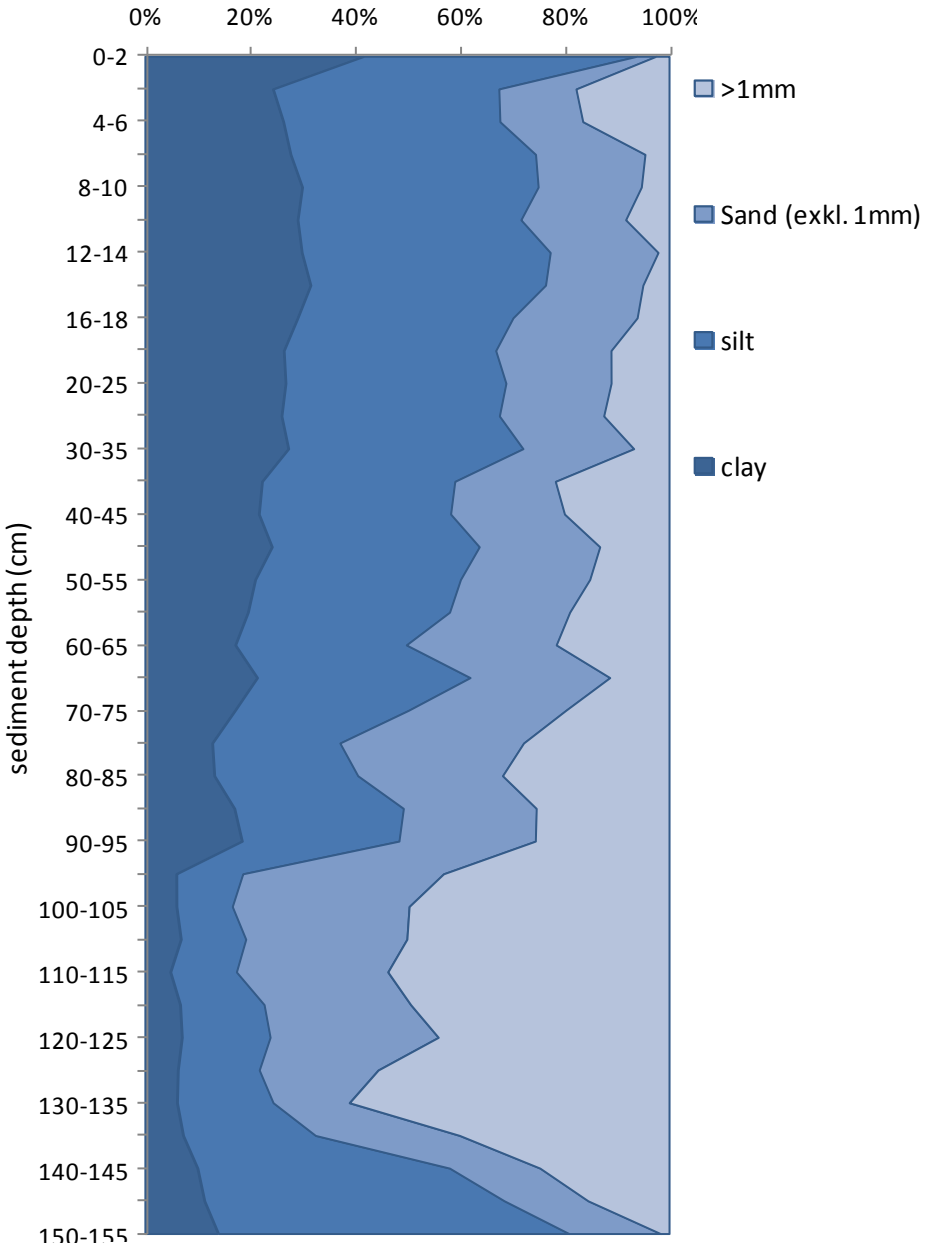

Fig. 27: Sediment composition along the core (from left to right: clay, silt, fine sand, coarse sand >1 mm) in mass per cent.

At a depth of 21 cm, an age of ~112 years was determined for the sediment core. This is roughly equivalent to a sedimentation rate of 1.2 mm/yr (Fig. 28). At the deep end of the core, terrestrial sediment was reached, which points to an age of 8000 to 10,000 years when the area was flooded in the Holocene. This suggests that sedimentation rates were low throughout the core and points to the occurrence of sediment resuspension and/or sedimentation gaps.

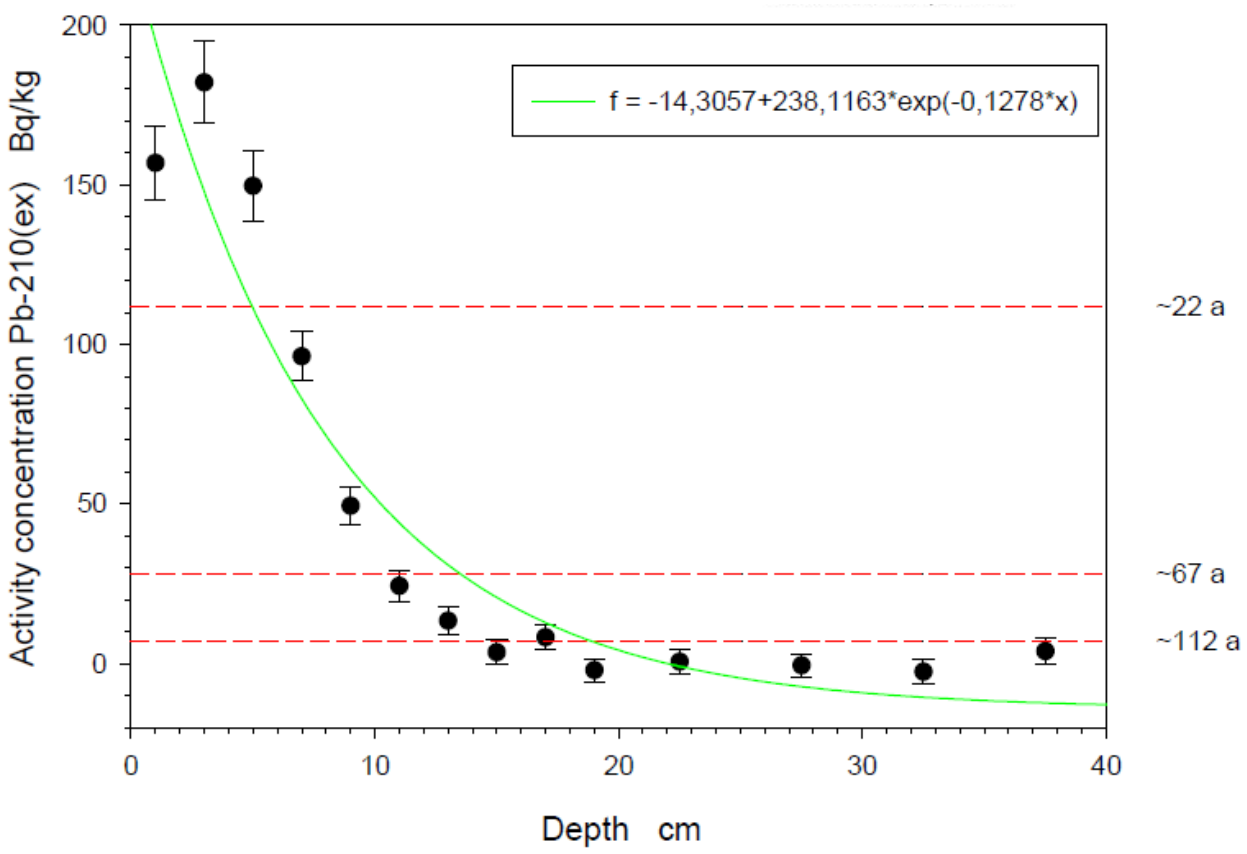

Fig. 28: Radiometric dating of the sediments.

Pollutants

Heavy metal values were high throughout the core, with some visible trends. The distributions of many heavy metal values along the core were similar to grain size distribution while others were distributed oppositional, which is especially obvious concerning the lower part of the core.

Fe and Al reached the highest values throughout the core with a Fe-concentration of 19,454 mg/kg at the deepest sampling point (150-152) and an Al-concentration of 17,648 mg/kg at a depth of 23-25 cm (Figs. 29 & 30).

Very high values of polycyclic aromatic hydrocarbons (PAHs) at the uppermost three sampling points were measured, with a maximum of 474.92 ng/gr at 5 cm depth. Polychlorinated biphenyls (PCBs) also reached their maximum value of 5.6ng/gr at 5 cm core depth. Both compound classes decreased to values below 20 ng/gr throughout the deep sections from 45 to 152 cm (Fig. 31).

A slight decrease with depth occurred for TOC (1.59-0.99 % dw) and Ntot (0.13-0.09 % dw), and a stronger decrease was recorded for Ctot (~6-4 % dw) (Fig. 32).

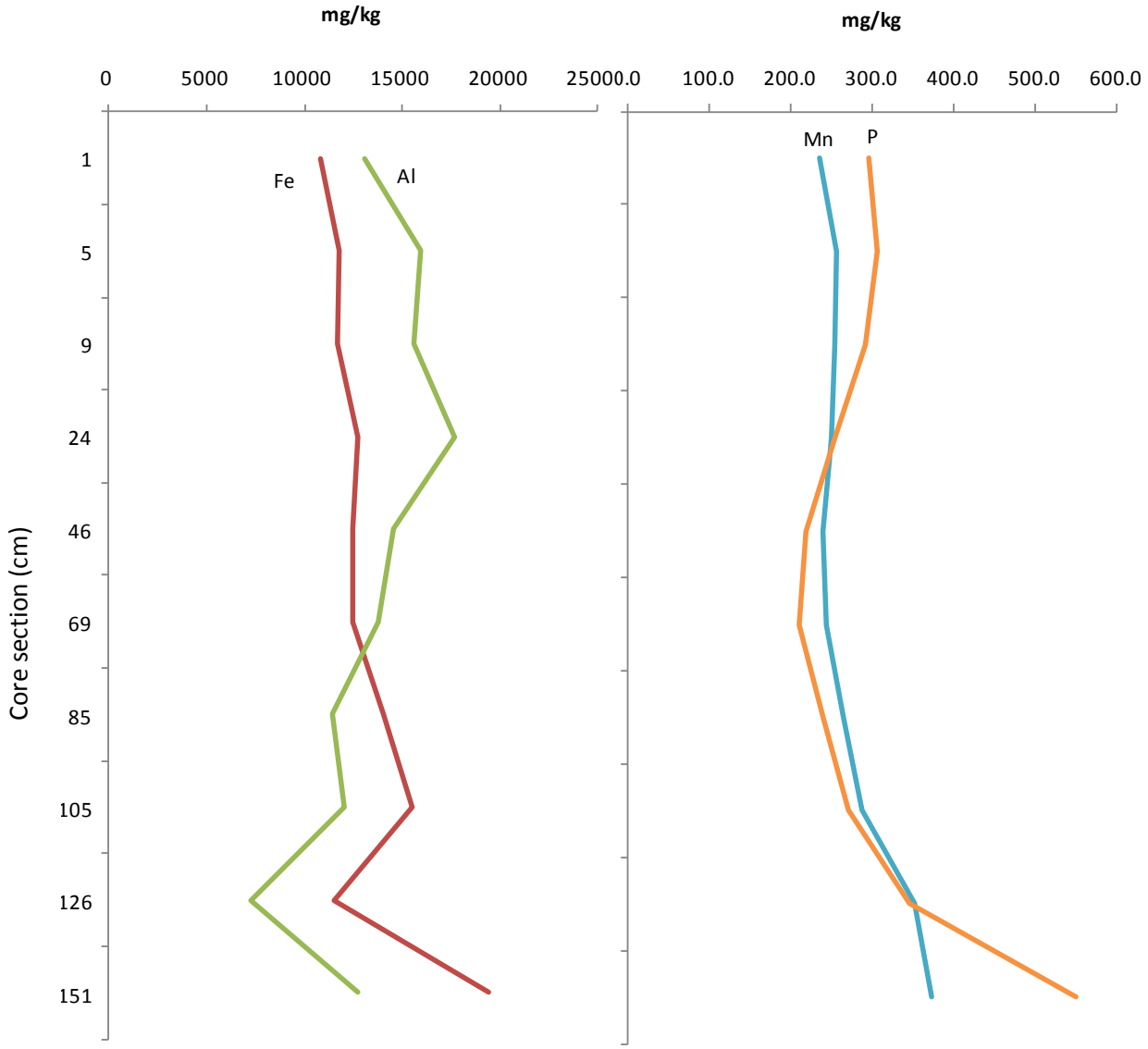

Fig. 29: Heavy metal concentrations along the core

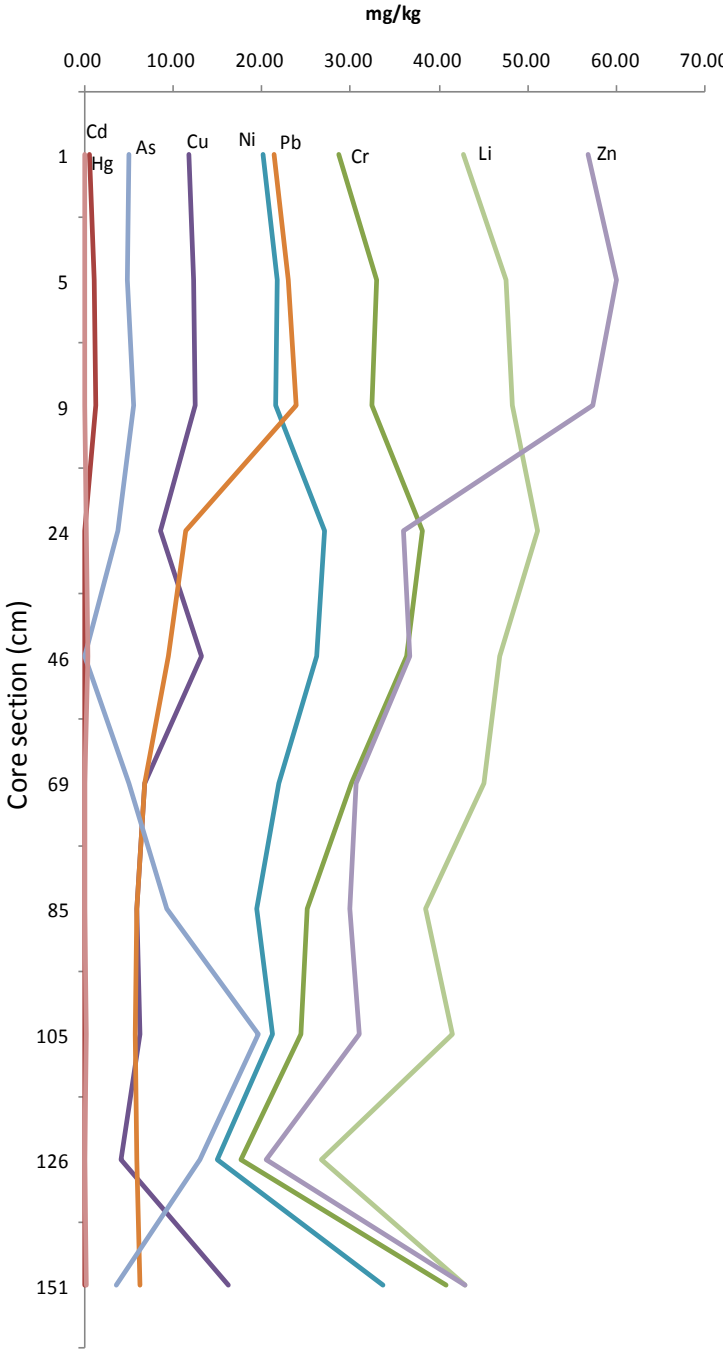

Fig. 30: Heavy metal concentration along the core.

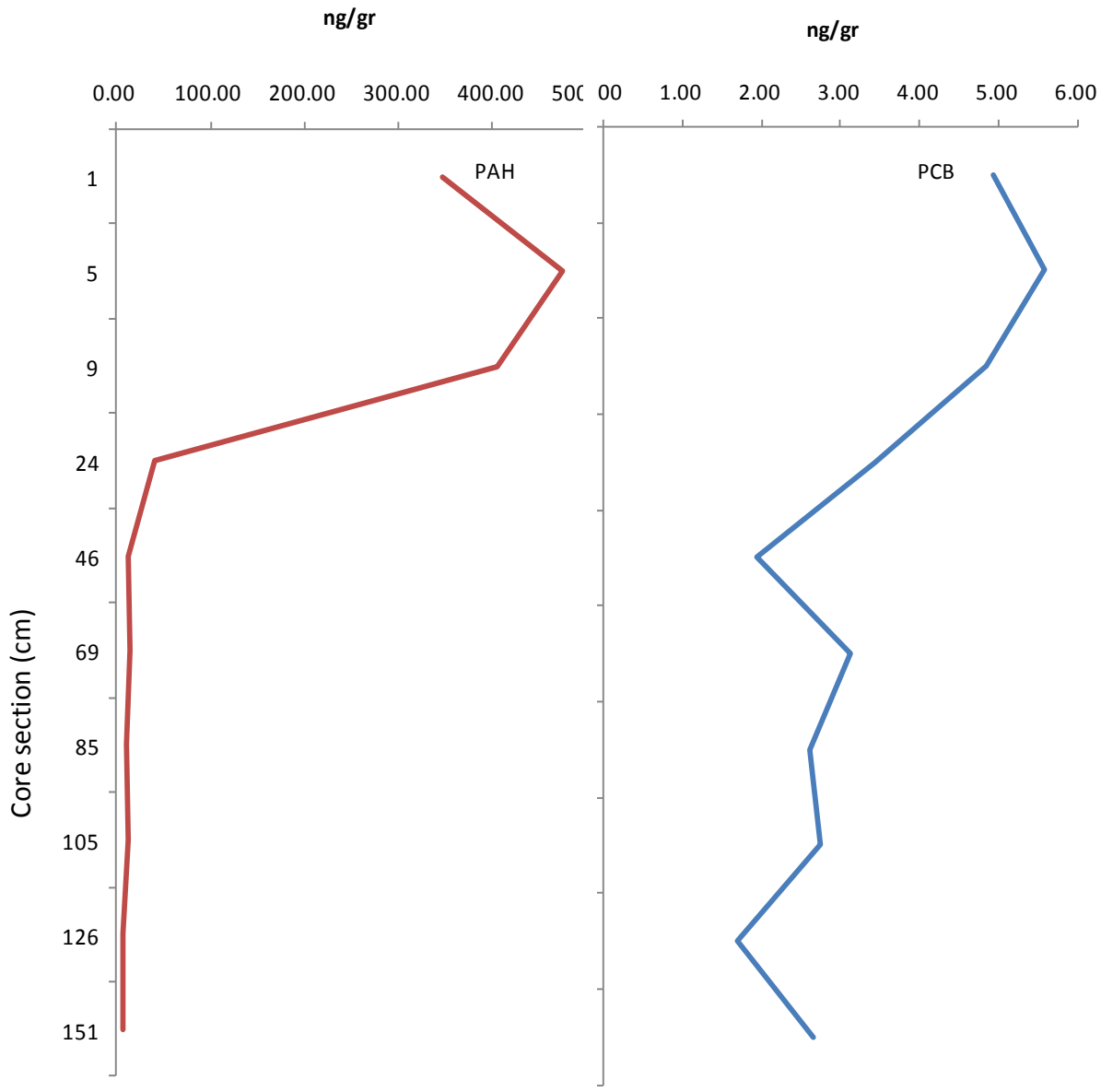

Fig. 31: PAH (left) and PCB (right) concentrations along the core.

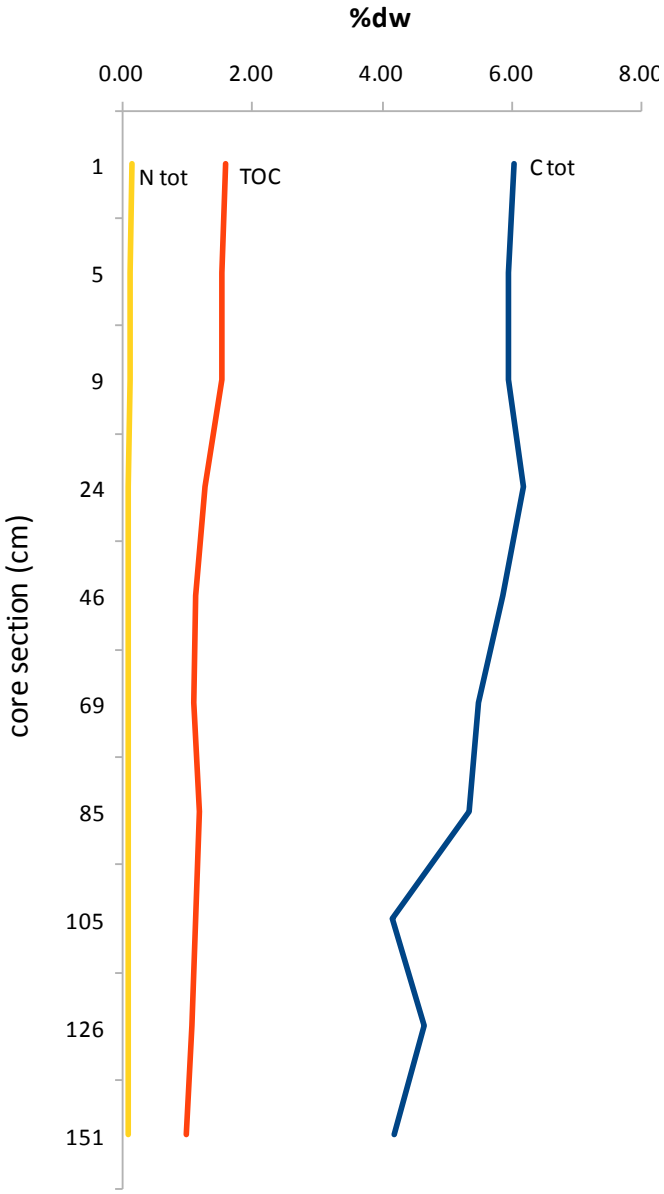

Fig. 32: Nutrient concentrations along the core.

Impact of pollutants on molluscan assemblages

The analyses of the effects of heavy metals, grain size and nutrients on the number of species, absolute abundance, rarefied species richness and selected ecological groups revealed that a range of heavy metal concentrations in the sediment seemed to impact the number of species (Tab. 2). The elements Pb and Hg impact absolute abundance and rarefied species richness (Tab. 3, 4). The percentage of clay negatively affected the number of species and the absolute abundance (Tab. 5, 6), but the percentage of infauna in the core was positively affected by the percentage of clay in the sediment composition (Tab. 10). The percentage of sand had a positive effect on rarefied species richness (Tab. 7) and a negative effect on the percentage of filter feeders (Tab. 8). Concerning nutrient values, only nitrogen showed significant p-values when all measured nutrient

concentrations were included in the model. Nitrogen concentration negatively affected the number of species and absolute abundance (Tab.12, 13), but had a positive effect on the percentage of infauna (Tab.17).

Table 2. Effect of heavy metals on number of species

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	144.596770	20.405072	7.086	0.00209 **
Zn	4.896565	0.696618	-7.029	**0.00216 ** **
Hg	40.493378	12.721956	3.183	**0.03344 ***
Cu	7.825938	2.921757	2.679	0.05531
Al	0.015761	0.004357	3.618	**0.02240 ***
As	-4.069480	1.133640	-3.590	**0.02297 ***
Cr	-10.166205	2.935864	-3.463	**0.02575 ***
Fe	0.011486	0.002563	4.482	**0.01097 ***

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 6.543 on 4 degrees of freedom
Multiple R-squared: 0.9825, Adjusted R-squared: 0.9518
F-statistic: 32 on 7 and 4 DF, p-value: 0.002353

Table 3. Effects of heavy metals on absolute abundance of individuals.

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	2457.990	155.417	15.816	9.79e-07 ***
Zn	-14.025	8.946	-1.568	0.16096
Pb	-59.899	17.062	-3.511	**0.00985 ** **
Hg	561.643	209.057	2.687	**0.03124 ***
Ni	-36.560	9.504	-3.847	**0.00632 ** **

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 91.85 on 7 degrees of freedom
Multiple R-squared: 0.9727, Adjusted R-squared: 0.957
F-statistic: 62.25 on 4 and 7 DF, p-value: 1.489e-05

Table 4. Effects of heavy metals on rarefied species richness.

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	41.2778	5.0788	8.127	1.95e-05 ***
Hg	29.5335	11.2893	2.616	**0.02799 ***
Pb	-2.3427	0.7013	-3.340	**0.00865 ** **

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 5.225 on 9 degrees of freedom
Multiple R-squared: 0.6179, Adjusted R-squared: 0.533
F-statistic: 7.277 on 2 and 9 DF, p-value: 0.01317

Table.5. Effects of grain size on number of species

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	60.9802	15.3297	3.978	0.000345 ***

Clay	-1.2927	0.3230	-4.003	**0.000321 *** **
Sand	1.3341	0.4608	2.895	**0.006581 ** **

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 14.74 on 34 degrees of freedom
Multiple R-squared: 0.6382, Adjusted R-squared: 0.6169
F-statistic: 29.98 on 2 and 34 DF, p-value: 3.122e-08

Table 6. Effects of grain size on absolute abundance

Effect	***Estimate***	***Std Error***	***t***	***Pr(>|t|)***
(Intercept)	1117.881	454.213	2.461	0.01925 *
Clay	-24.411	7.519	-3.247	**0.00268** **
>1 mm	5.722	6.907	0.828	0.41343
Silt	-4.996	6.026	-0.829	0.41301

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 192.4 on 33 degrees of freedom
Multiple R-squared: 0.8081, Adjusted R-squared: 0.7906
F-statistic: 46.32 on 3 and 33 DF, p-value: 6.288e-12

Table 7. Effects of grain size on rarefied species richness

Effect	***Estimate***	***Std Error***	***t***	***Pr(>|t|)***
(Intercept)	15.37184	3.95955	3.882	0.000487 ***
Sand	0.19332	0.05465	3.537	**0.001258** **
>1 mm	0.04811	0.03707	1.298	0.203666
Silt	0.15020	0.06192	2.426	**0.021100** *

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 1.254 on 32 degrees of freedom
Multiple R-squared: 0.3132, Adjusted R-squared: 0.2488
F-statistic: 4.863 on 3 and 32 DF, p-value: 0.006728

Table 8. Effects of grain size on percentage of filter feeders

Effect	***Estimate***	***Std Error***	***t***	***Pr(>|t|)***
(Intercept)	69.27012	13.92551	4.974	1.99e-05 ***
sand	-0.76415	0.36901	-2.071	**0.0463** *
silt	-0.09964	0.20123	-0.495	0.6238
clay	0.02008	0.25786	0.078	0.9384

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 10.28 on 33 degrees of freedom
Multiple R-squared: 0.1636, Adjusted R-squared: 0.08753
F-statistic: 2.151 on 3 and 33 DF, p-value: 0.1125

Table 9. Effects of grain size on percentage of deposit feeders

Effect	***Estimate***	***Std Error***	***t***	***Pr(>|t|)***
(Intercept)	10.8148	15.9820	0.677	0.503
Clay	0.4258	0.2645	1.609	0.117
>1 mm	-0.1512	0.2430	-0.622	0.538
Silt	-0.1277	0.2120	-0.602	0.551

Residual standard error: 6.768 on 33 degrees of freedom
Multiple R-squared: 0.388, Adjusted R-squared: 0.3323
F-statistic: 6.973 on 3 and 33 DF, p-value: 0.0009238

Table 10. Effects of grain size on percentage of infauna

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	18.6681	13.5189	1.381	0.1766
Clay	0.9014	0.3467	2.600	**0.0138 ***
>1 mm	0.1126	0.1757	0.641	0.5260
Sand	-0.2222	0.2811	-0.790	0.4350

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 8.975 on 33 degrees of freedom
Multiple R-squared: 0.4598, Adjusted R-squared: 0.4107
F-statistic: 9.362 on 3 and 33 DF, p-value: 0.000127

Table 11. Effects of grain size on percentage of epifauna

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	42.94192	12.51225	3.432	0.00163**
Sand	0.46526	0.33156	1.403	0.16989
Clay	-0.28902	0.23169	-1.247	0.22102
Silt	0.06586	0.18081	0.364	0.71798

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 9.233 on 33 degrees of freedom
Multiple R-squared: 0.2108, Adjusted R-squared: 0.139
F-statistic: 2.938 on 3 and 33 DF, p-value: 0.04757

Table 12. Effects of nutrient concentration on number of species

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	233.877	20.500	11.409	3.15e-06 ***
N	-2147.937	416.601	-5.156	**0.000868 *** **
TOC	66.057	43.577	1.516	0.168020
C	-9.077	5.751	-1.578	0.153133

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 9.212 on 8 degrees of freedom
Multiple R-squared: 0.9305, Adjusted R-squared: 0.9044
F-statistic: 35.68 on 3 and 8 DF, p-value: 5.596e-05#

Table 13. Effects of nutrients on absolute abundance

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	3237.0	545.6	5.933	0.000348 ***
N	-32648.7	11087.0	-2.945	**0.018574 ***
TOC	1864.5	1159.7	1.608	0.146558
C	-352.3	153.1	-2.302	0.050339

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.
Residual standard error: 245.2 on 8 degrees of freedom
Multiple R-squared: 0.7774, Adjusted R-squared: 0.6939
F-statistic: 9.311 on 3 and 8 DF, p-value: 0.00548

Table 14. Effects of nutrients on rarefied species richness

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	54.2108	12.4270	4.362	0.00241 **
N	-412.7669	252.5430	-1.634	0.14081
TOC	6.2653	26.4162	0.237	0.81848
C	0.1158	3.4864	0.033	0.97432

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 5.584 on 8 degrees of freedom
Multiple R-squared: 0.612, Adjusted R-squared: 0.4665
F-statistic: 4.206 on 3 and 8 DF, p-value: 0.04627

Table 15. Effects of nutrients on percentage of filter feeders

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	-1.451	29.891	-0.049	0.962
N	785.961	607.446	1.294	0.232
TOC	-8.969	63.539	-0.141	0.891
C	-1.459	8.386	-0.174	0.866

Residual standard error: 13.43 on 8 degrees of freedom
Multiple R-squared: 0.5037, Adjusted R-squared: 0.3176
F-statistic: 2.707 on 3 and 8 DF, p-value: 0.1157

Table 16. Effects of nutrients on percentage of deposit feeders

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	-24.875	17.919	-1.388	0.203
C	3.445	5.027	0.685	0.512
TOC	25.279	38.090	0.664	0.526
N	-155.909	364.148	-0.428	0.680

Residual standard error: 8.052 on 8 degrees of freedom
Multiple R-squared: 0.3836, Adjusted R-squared: 0.1525
F-statistic: 1.66 on 3 and 8 DF, p-value: 0.2517

Table 17. Effects of nutrients on percentage of infauna

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	-44.927	11.743	-3.826	0.00505 **
N	554.159	238.641	2.322	**0.04876 ***
TOC	18.805	24.962	0.753	0.47284
C	1.014	3.294	0.308	0.76615

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 5.277 on 8 degrees of freedom
Multiple R-squared: 0.9014, Adjusted R-squared: 0.8644
F-statistic: 24.37 on 3 and 8 DF, p-value: 0.0002235

Table 18. Effects of nutrients on percentage of epifauna

Effect	*Estimate*	*Std Error*	*t*	*Pr(>|t|)*
(Intercept)	97.549	10.799	9.033	1.8e-05 ***
N	-442.134	219.456	-2.015	0.0787
TOC	-22.072	22.955	-0.962	0.3644
C	3.846	3.030	1.269	0.2400

Signif. codes: '***' 0.001 '**' 0.01 '*' 0.05
Residual standard error: 4.853 on 8 degrees of freedom

Multiple R-squared: 0.8646, Adjusted R-squared: 0.8138
F-statistic: 17.03 on 3 and 8 DF, p-value: 0.0007811

Discussion

Information on benthic macrofauna communities can be used as an integrative measure for evaluating the condition and possibly taking actions to enhance the quality of an ecosystem (Pearson & Rosenberg, 1978). This is particularly the case when the collected data cover a period of several hundreds or thousands of years and provide an insight into community structures before human impacts (Lotze et al., 2006). Death assemblages (DA) in different sediment layers enable observing community structures over time, which might reflect ecological shifts due to natural or human-induced changes (Kidwell, 2009). The present study was conducted using methods of *conservation paleobiology* with the objective of investigating species communities and supplementary data of the past centuries, a period of major human activities in the Northern Adriatic Sea. As the extracted sediments cover an even longer timescale (Fig. 28), the preserved molluscan DAs enabled us to investigate thousands of years of shelly remains, which revealed distinct patterns of various faunistic trends. The observed categories *species abundance*, *feeding modes* and *substrate relation* show extremely similar trends throughout the core. Distinct clusters form at very similar core-depths for all three groups. This allows for a combined examination from a very old assemblage characterized by high abundances of freshwater and land snails to a group dominated by epifaunal filter feeders and grazers until the most recent cluster, which is characterized by infaunal filter feeders and deposit feeders. Remarkable down-core changes, however, were documented not only for mollusk species composition, abundance diversity, feeding modes and substrate relations but also for sediment composition, content of pollutants, and content of nutrients. Possible causes for these shifts are natural geological events as well as human-induced changes in the ecosystem.

Certain molluscan species which were present in our samples were considered biological indicators or species associated with indicator species for marine ecosystems in previous studies (Borja et al., 2000; Hrs-Brenko, 2006; Simboura & Zenetos, 2002). The absence or abundance of the hard parts of those species may allow specific insights into past conditions of the environment (Grotzinger et al., 2008; Hrs-Brenko, 2006; Nerlović et al., 2011; Weber & Zuschin, 2013).

Diversity and abundance

Large numbers of bivalve and gastropod species were found and sporadically also individuals of polyplacophorans and scaphopods. Including all subsamples and taxa, several thousand individuals in almost two hundred species were present in the sediment core. The total abundance of individuals as well as the number of species strongly decreased towards the younger subsamples (Fig. 5, Fig. 10) and major shifts in species composition were observed. In contrast, the rarefied species richness did not change strongly – at a constant number of individuals throughout the core, the number of species remained rather stable. This may indicate that evenness is not affected by the decreasing absolute number of individuals.

High abundances of epifaunal carnivores (Mangeliidae, Conidae, Raphitomidae) and macro-herbivores (Fissurellidae, *Smaragdia* sp.) as well as parasites in sponges (Triphoridae) and sea anemones (Epitoniidae) (Fig. 8) occurred in the deeper subsamples (Fig. 8). They hint at a former presence of sea grass meadows, algae and larger suspension feeders and carnivores which possibly disappeared or decreased over time due to changes in the environment, for example increasing clay content or high nutrient input (see Fig. 27, 32). A shift from high abundances of epifaunal filter feeders such as Arcidae and Noetinae (*Striarca lactea*) in the deep part to infaunal filter feeders such as Veneridae (*Timoclea ovata*) in the mid part and infaunal deposit feeders such as Nuculidae (*Nucula cf. nucleus*) and Nuculanidae in the upper part (Fig. 9) might be caused by changes in sediment composition and hypoxic conditions (Nerlović et al., 2011). *Nucula nucleus*, which was present only in the younger samples of the core, reportedly often co-occurs with the biological indicator *Corbula gibba* (N'Siala et al., 2008). The basket shell *Corbula gibba* was present throughout the core, but was more dominant in the samples from the top layer (Fig. 9, 20), whereas *Clausinella fasciata* was absent from the top 20 cm. *Corbula gibba*, a well-studied bioindicator, is often found in polluted areas as a tolerant opportunistic species which survives mass mortality events and prolonged conditions of low oxygen (Pearson & Rosenberg, 1977; Nerlović, 2011; Borja et al., 2000; Riedel et al., 2012). *Clausinella fasciata*, in turn, is sensitive to organic enrichment and present only under unpolluted conditions (Borja et al., 2000). Shifts in indicator species such as *Corbula gibba* and *Clausinella fasciata* reinforce the assumption of major environmental changes and stress in the youngest samples (corresponding to the 20th century) caused by sediment resuspension, increased nutrient input and hypoxia.

In the deep samples, large numbers of freshwater and terrestrial gastropods were found; these were completely absent from the upper 50 cm of the core (Fig. 15). This indicates that earlier, during the Holocene transgression, water depth was much shallower and terrestrial and freshwater influences were strong at this site.

Chemosymbiotic bivalves, even though found only in small numbers, were completely absent from the deepest samples until the beginning of the top half of the core, where they appeared in very low abundances and increased towards the samples close to the sediment surface. The increase of chemosymbiotic bivalves in the upper layers of the sediment core might be a consequence of low oxygen conditions in the younger ecological history of the Northern Adriatic Sea because animals that live in symbioses with chemoautotrophic bacteria are adapted to anoxic or hypoxic conditions (Dubilier et al., 2008; Stewart et al., 2005) and might benefit from the disappearance of other benthic species from the affected areas.

Ecology and species composition

A cluster analysis performed on species abundances and ecological groups yielded four distinct assemblages of sub-samples which were clearly distributed with depth along the core. Therefore, we may hypothesize that several environmental changes occurred over time in this particular area, resulting in four different compositions of molluscan taxa with different life habits. The oldest cluster (Group D) was formed by the deepest 65/70 cm (for species abundance and substrate relation) or 85 cm (for feeding types) of the core (Fig. 17). It is characterized by a high abundance of terrestrial and freshwater mollusks, which suggests shallow water at the beginning of the Holocene transgression followed by a great influx of an unknown freshwater source, possibly remains of the meanwhile dried-up swamps of the Brijuni islands (Bralic, 1990). Dominant ecological groups in this cluster were epifaunal filter feeders, infaunal filter feeders, epifaunal herbivores and parasites in sponges. The section of the core which contained group D was furthermore distinctly defined by high percentages of coarse sand and low content of pollutants, both of which are inextricably linked to species composition: suspension-feeding epifaunal species rely on hard substrata and are sensitive to sediment input and resuspension events (Zuschin & Stachowitsch, 2009).

Groups C and B were characterized by decreasing numbers of non-marine mollusks, which were almost entirely absent from group B, but still present at low percentages in group C. Epifaunal and infaunal filter feeders and herbivores were dominant in both groups, but the percentage of deposit feeders strongly increased from group D to group C and again from C to B, which means an increasing importance of deposit feeders up-core towards group B. This cluster covers the core section from approximately 10-45 cm depth, which was most probably already affected by human activities (an age for 112 years was determined for 22 cm) such as overfishing and input of pollutants in the Northern Adriatic (Jackson et al., 2001; Lotze et al., 2010). Group A covers the uppermost ten centimeters of the core and is characterized by a clear dominance of infauna (>50%)

and deposit feeders. The major shift between B and A is the sharp decrease in herbivores and the clear dominance of infaunal deposit feeders, which again suggests disturbances such as hypoxia and anoxia caused by nutrient input and sediment resuspension resulting from bottom trawling, two factors which are often discussed with respect to the Northern Adriatic Sea (Barmawidjaja et al., 1995; Crema et al., 1991; Stachowitsch, 1991).

Certain species were present only in the upper half (e.g. *Nuculana pella*), while others appeared only in the deeper half but were absent from the younger fractions *(*e.g. *Lepton squamosum).* Traces of increasing human impact up-core are probably reflected in the changes in species abundance between the determined clusters. Cluster A was dominated by infaunal filter feeding or deposit feeding bivalves, whereas only one gastropod species was among the ten most abundant taxa. The filter feeding, infaunal, facultatively mobile bivalve *Timoclea ovata* and the epifaunal herbivore gastropod *Bittium reticulatum* were the only two species found among the ten most abundant species in all four clusters, though ranked differently depending on depth (Fig. 20). *Corbula gibba* was a dominant species in clusters A, B and C, but decreased in abundance from A to C and was absent from D. Since *C. gibba* is able to survive or even prefers polluted areas and low oxygen concentrations (Hrs-Brenko, 2006; N'Siala, 2008), this abundance pattern points to increasing environmental stress from the bottom towards the top of the core.

Pollutants

A range of pollutants was found in all sampled layers, typically with a tendency to increase towards the top. An increasingly high concentration of nutrients in the younger samples might be explained by the position of the sampling point, which was quite close to shore (Fig. 2). Heavy metals were found throughout the core. Their distribution pattern reflects the changes in sediment composition, especially concerning the strong shift in the lower part of the core (Fig. 27) and the gradual increase towards the top, which parallels the increase of the fine fractions in the sediment. The pattern of PCBs shows a steep increase in the upper half of the core, clearly reflecting pollution during the past centuries (Rios et al., 2007). Also PAH values were extremely high in samples of the upper 25 cm, probably reflecting incomplete combustion of fuels or by oil spills at sea (Bojes & Pope, 2007). Some pollutant elements and nutrients which might at least partly originate from anthropogenic sources and accumulate in the sediment (Duysak & Ersoy, 2014; Pempkowiak et al., 1999; Wang et al., 2007) seem to influence the number of species as well as the rarefied species richness and the absolute abundance of mollusks in the core (Tab. 2-18). Grain size also seems to predict those variables, and the regression analyses additionally suggested an impact of grain size on infauna and filter feeders (Tab. 5-8, 10). The negative impact of fine sediment (clay) and nitrogen concentration

on number of species and absolute abundance, and the otherwise positive effect of those parameters on the percentage of infauna, again suggest that bottom trawling (causing resuspension of fine sediment), overfishing and nutrient input (causing hypoxic conditions) and as well as accumulations of microbes which might cause diseases significantly affect benthic communities over the long term (Haselmair et al., 2010; Jackson et al., 2001; Riedel et al., 2008, 2012).

Sediment age and composition

The extremely high abundance of individuals of several land and freshwater gastropods in the deepest samples (and the terrestrial sediment recorded at the deep end of the core) is indicative of a marine transgression, characterized by lag sedimentation and a high number of deposited shells at its early stage. Land snails were found in higher number in deeper sections and were followed by high abundances of freshwater species up-core, supporting this interpretation.
The increase of fine sediments towards the top can partly be explained by increasing water depth associated with quiet-water conditions in the course of the transgression. Changes in sedimentation rate and/or periods of sediment reworking and/or gaps in sedimentation are indicated because the sediment was dated to only 112 years at a depth of 22 cm, but the Holocene transgression started around 10,000 years ago. A steady sedimentation rate is therefore unlikely, but was calculated for 1.2 mm/yr for the top 22 cm which is rather low.

The gaps or periods of sediment reworking could partly explain the observed changes in species composition and ecological groups between cluster B, C and D. The changes observed in the top cluster might reflect human-induced environmental changes resulting from high input of pollutants and fine sediments through bottom trawling and through the Po and other rivers. Furthermore, the increasingly high numbers of non-marine species down-core can possibly be attributed to the geological shifts between clusters B and D.

Conclusion

Major down-core changes in molluscan death assemblages were observed on a millennial time scale. Distributed along the core, four groups characterized by distinct species abundances, feeding and substrate types were identified. Moreover, pollutant concentrations and sediment composition changed from the oldest towards the youngest samples. These results point to multiple ecological

shifts during the past thousands of years, whereby the youngest shift can possibly be attributed to human impact in the Northern Adriatic Sea.

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Figures

Fig. 1 from: Zuschin, M., & Stachowitsch, M. (2009). Epifauna-Dominated Benthic Shelf Assemblages: Lessons From the Modern Adriatic Sea. *Palaios*, *24*(4), 211–221. doi:10.2110/palo.2008.p08-062r

Appendix

Summary

Conservation paleobiology, a new research field, aims at investigating responses of the environment at a time scale that exceeds the standard annual or decadal investigations and therefore assesses pre-human baseline communities as references to current states. Paleontological methods are used to investigate the quality of modern day ecosystems.

In the present study, a sediment core of 1.60 m length was extracted from the seafloor near the Brijuni Islands, Croatia, located in the Northern Adriatic Sea, one of the most degraded marine ecosystems worldwide. The sediment core was sliced into subsamples and investigated for down-core changes of diversity, abundance, species composition, feeding modes and substrate relations of molluscan death assemblages. Sediment analyses included grain size, pollutants, heavy metals and sediment age, which were used to explain the ecological data along the core.

Down-core changes were observed concerning all aspects. Diversity and abundance increased towards the older, deeper subsamples, whereas concentrations of nutrients and organic pollutants as well as some heavy metals decreased. Sediment dating revealed low sedimentation rates at the top (approximately 1 mm / y) and an age of ca. 112 years at a depth of 22 cm. The deepest part of the core, however, hit terrestrial sediment, which indicates a total age of several thousand years and the presence of sediment gaps and events of sediment reworking. A cluster analysis revealed four distinct groups in species composition, feeding modes and substrate relations of mollusks from top to bottom of the core. The upper cluster is characterized by infaunal filter feeders and deposit feeders and a high percentage of the bivalve indicator species *Corbula gibba*, which is known to occur in high numbers in polluted marine areas. Clay and silt make up 65 % of the sediment mass and nutrient levels are quite high, which might be explained by anthropogenic input. Shifts in sediment composition were observed also for the deeper parts of the core. In the lower third, high percentages of coarse and fine sand are present, and clay and silt combined make up only 20 % of the total mass. The cluster in this part of the core is characterized by epifaunal filter feeders, herbivores and a high percentage of freshwater snails. Sponges, cnidarians, algae and seagrass were probably present as suggested by the species composition.

Concluding from sediment dating and observed down-core changes, conditions in cluster A (and possibly B) might be a result of human impact in the Northern Adriatic, whereas differences between cluster D and C as well as C and B might result from natural changes during the Holocene transgression and gradual deepening of the environment.

Zusammenfassung

Methoden der aufstrebenden Disziplin “Conservation paleobiology” ermöglichen die Erforschung von Umweltveränderungen über jene Zeitspanne, welche die anthropogenen Eingriffe der vergangenen Jahrhunderte auf das Ökosystem abdeckt und, darüber hinaus, die Erfassung von Artengemeinschaften und Umweltparametern, welche vor dem sogenannten Anthropozän herrschten.

Das Untersuchungsgebiet der vorliegenden Studie war die Nordadria, welche zu den ökologisch am stärksten degenerierten marinen Lebensräumen weltweit zählt. Ein 1,60 m langer Sedimentkern wurde dem Meeresboden unweit der Brijuni Inseln (Kroatien) entnommen und in mehrere Einzelproben unterteilt, in welchen die Mollusken-Totgemeinschaften untersucht wurden. Berücksichtigt wurden die Diversität, Häufigkeit und Artengemeinschaften der Schalenträger, sowie weiterführende Sedimentanalysen wie Korngrößen, Sedimentalter und der Gehalt von verschiedenen Schadstoffen und Schwermetallen welche zur Erklärung der ökologischen Daten herangezogen wurden. Es wurden Veränderungen mit der Tiefe in allen untersuchten Aspekten festgestellt. Diversität und absolute Häufigkeit nahmen mit Tiefe und Alter zu, während der Schadstoffgehalt abnahm. Die Sedimentdatierung ergab niedrige Sedimentationsraten (ca. 1 mm / a) und ein Alter von 112 Jahren bei einer Tiefe von 22 cm. Die tiefste Stelle des Kerns stieß auf terrestrisches Sediment, was auf ein Gesamtalter des Kerns von mehreren Jahrtausenden schließen lässt. Eine Cluster-Analyse ergab vier separate Cluster entlang der Tiefe des Sedimentkerns. Artenzusammensetzung, Substratbeziehung und Ernährungsweisen wurden hierfür herangezogen. Der oberste, jüngste Cluster ist durch einen großen Prozentsatz an infaunalen Suspensions- und Detritusfressern charakterisiert. Außerdem wurde eine hohe relative Abundanz der Muschelart *Corbula gibba* festgestellt, welche als Bioindikator für sehr verschmutzte und Sauerstoffarme marine Lebensräume gilt. Ton und Silt sind hier die dominanten Korngrößen und der Nährstoffgehalt ist relativ hoch, was durch anthropogene Einträge in die Nordadria erklärt werden kann. Die Korngrößen und Ökotypen im tiefsten Cluster unterscheiden sich stark von jenen weiter oben. Hier dominiert Sand, wohingegen Ton und Silt lediglich 20 % der Gesamtmasse ausmachen. Epifaunale Suspensionsfresser, Weidegänger und Süßwasserschnecken charakterisieren diesen Teil des Kerns, und die Artenzusammensetzung weist auf das Vorkommen von Schwämmen, Cnidariern, Seegräsern und Algen hin.

Die Veränderungen der Molluskentotgemeinschaften und des Sedimentes mit zunehmendem Alterlegen anthropogenen Einfluss im oberen Teil des Kerns nahe, während ökologische Veränderungen als Folge der Holozänen Transgression und der damit verbundenen graduellen Abtiefung des Environments im unteren Teil vorherrschen.

List of species

family	species	diet	preferential substrate	absolute abundance
Nuculanidae	*Nuculana pella*	deposit feeder / filter feeder	Infauna soft bottoms	19
Nuculanidae	*Saccella commutata*	deposit feeder / filter feeder	Infauna soft bottoms	53
Nuculidae	*Nucula* cf. *nucleus*	deposit feeder / filter feeder	Infauna soft bottoms	709
Arcidae	*Arca noae*	filter feeder	Epifauna	43
Arcidae	*Arca tetragona*	filter feeder	Epifauna	91
Arcidae	*Anadara transversa*	filter feeder	Semi-infaunal	1
Arcidae	*Barbatia barbata*	filter feeder	Epifauna	15
Noetinae	*Striarca lactea*	filter feeder	Epifauna	1995
Glycymerididae	*Glycimeris glycimeris*	filter feeder	Semi-Infauna	354
Crenellinae	*Musculus subpictus*	filter feeder	Host	24
Modiolinae	*Modiolus adriaticus*	filter feeder	Semi-Infauna / Nestler	286
Pectinidae	Pectinidae indet.	filter feeder	Epifauna	2
Pectinidae	*Aequipecten opercularis*	filter feeder	Epifauna	240
Pectinidae	*Mimachlamys varia*	filter feeder	Epifauna	109
Pectinidae	*Palliolum incomparabile*	filter feeder	Epifauna	30
Pectinidae	*Chlamys multistriata*	filter feeder	Epifauna	75
Pectinidae	*Flexopecten glaber*	filter feeder	Epifauna	5
Anomioidea	*Anomia ephippium*	filter feeder	Epifauna	726
Anomioidea	*Heteranomia squamula*	filter feeder	Epifauna	311
Anomioidea	*Pododesmus patelliformis*	filter feeder	Epifauna	406
Limidae	*Lima lima*	filter feeder	Epifauna / Nestler	10
Limidae	*Lima* cf. *hians*	filter feeder	Epifauna	3
Limidae	*Limaria loscombi*	filter feeder	Epifauna	56
Limidae	*Limatula gwyni*	filter feeder	Epifauna	82
Ostreidae	*Ostrea edulis*	filter feeder	Epifauna	5
Ostreidae	*Ostrea* sp. (cf. *stentina)*	filter feeder	Epifauna	188
Chamidae	*Chama gryphoides*	filter feeder	Epifauna	70
Chamidae	*Pseudochama gryphina*	filter feeder	Epifauna	3
Lucinidae	*Anodontia fragilis*	Chemosymbiotic	Infauna	2
Lucinidae	*Ctena decussata*	Chemosymbiotic	Infauna	1
Lucinidae	*Myrtea spinifera*	Chemosymbiotic	Infauna	39
Thyasiridae	*Thyasira biplicata*	Chemosymbiotic / filter feeder	Infauna	15
Lasaeidae	*Hemilepton nitidum*	filter feeder / commensal	Host / Cryptic	57
Lasaeidae	*Lepton squamosum*	filter feeder / commensal	Host / Cryptic	81
Lasaeidae	*Arculus* cf. *sykesi*	filter feeder / commensal	Host	1
Kellidae	*Bornia geoffroyi*	filter feeder / commensal	Host / Cryptic	2
Kellidae	*Kellia suborbicularis*	filter feeder / commensal	Host	70
Montacutidae	*Kurtiella bidentata*	filter feeder / commensal	Host	38
Cardiidae	*Papillicardium papillosum*	filter feeder	Infauna	448
Cardiidae	*Parvicardium scabrum*	filter feeder	Infauna	375
Cardiidae	*Parvicardium scriptum*	filter feeder	Epifauna	381
Cardiidae	*Parvicardium minimum*	filter feeder	Infauna	398
Cardiidae	*Laevicardium crassum*	filter feeder	Infauna	12
Semelidae	*Abra alba*	deposit feeder	Infauna	99

Tellinidae	*Tellina serrata*	deposit feeder	Infauna	1
Tellinidae	*Tellina pulchella*	deposit feeder	Infauna	1
Tellinidae	*Tellina donacina*	deposit feeder	Infauna	5
Tellinidae	*Tellina balaustina*	deposit feeder	Infauna	19
Tellinidae	Tellinidae indet.	deposit feeder	Infauna	7
Tellinidae	*Moerella distorta*	deposit feeder	Infauna	2
Psammobiidae	*Gari costulata*	deposit feeder	Infauna	6
Psammobiidae	*Gari fervensis*	deposit feeder	Infauna	8
Psammobiidae	*Gari depressa*	deposit feeder	Infauna	2
Psammobiidae	*Gari* sp.	deposit feeder	Infauna	2
Pharidae	Pharidae indet.	deposit feeder	Infauna	1
Veneridae	*Mysia undata*	filter feeder	Infauna	4
Veneridae	*Callista chione*	filter feeder	Infauna	2
Veneridae	*Gouldia minima*	filter feeder	Infauna	331
Veneridae	*Pitar rudis*	filter feeder	Infauna	242
Veneridae	*Pitar mediterraneus*	filter feeder	Infauna	1
Veneridae	*Venerupis aurea*	filter feeder	Infauna	11
Veneridae	*Venerupis* juv.	filter feeder	Infauna	1
Veneridae	*Venus verrucosa*	filter feeder	Infauna	140
Veneridae	*Timoclea ovata*	filter feeder	Infauna	2449
Veneridae	*Clausinella fasciata*	filter feeder	Infauna	264
Trapezidae	*Coralliophaga lithophagella*	filter feeder	Infauna hard bottom	6
Ungulinidae	*Diplodonta trigona*	filter feeder	Infauna/Semi-Infauna	1
Corbulidae	*Corbula gibba*	deposit feeder	Infauna	487
Gastrochaenidae	*Gastrochaena dubia*	filter feeder	Infauna hard bottom	15
Hiatellidae	*Hiatella arctica*	filter feeder	Epifauna / Nestler	274
Cuspidariidae	*Cuspidaria cuspidata*	carnicore	Infauna	4
Cuspidariidae	*Cardiomya costellata*	carnicore	Infauna	3
Thraciidae	*Thracia phaseolina*	filter feeder	Infauna	1
Thraciidae	*Thracia* cf. *distorta*	filter feeder	Infauna	3
Lottidae	*Tectura virginea*	Herbivore	Epifauna	170
Fissurellidae	*Diodora graeca*	Carnivore	Epifauna	69
Fissurellidae	*Emarginula* sp.1	Herbivore	Epifauna	40
Fissurellidae	*Emarginula* sp.2	Herbivore	Epifauna	1
Scissurellidae	*Scissurella costata*	Deposit	Epifauna	159
Phasianellidae	*Tricolia* sp.	Herbivore	Epifauna	1
Trochidae	*Calliostoma* sp. 1	Carnivore	Epifauna	50
Trochidae	*Calliostoma* sp. 2 (cf. *Zizyphinum)*	Herbivore	Epifauna	1
Trochidae	*Gibbula fanulum*	Herbivore	Epifauna	1
Trochidae	*Gibbula* cf. *ardens*	Herbivore	Epifauna	235
Trochidae	*Jujubinus* spp.	Herbivore	Epifauna	1007
Trochidae	*Jujubinus* cf. *exasperatus*	Herbivore	Epifauna	1
Trochidae	*Jujubinus* cf. *montagui*	Herbivore	Epifauna	162
Trochidae	*Callumbonella* cf. *suturalis*	Herbivore	Epifauna	1
Turbinidae	*Bolma rugosa* juv.	Herbivore	Epifauna	27
Skeneidae	Skeneidae indet. juv.	unknown	Epifauna	2

Rissoidae	*Alvania* sp. 1 (cf. *Lineata)*	Herbivore	Epifauna	80
Rissoidae	*Alvania* sp. 2 (cf. *cimicoides)*	Herbivore	Epifauna	582
Rissoidae	*Alvania* sp. 3 (cf. *Geryonia)*	Herbivore	Epifauna	1490
Rissoidae	*Alvania* sp. 4 (cf. *cancellata)*	Herbivore	Epifauna	159
Rissoidae	*Pusillina* cf. *inconspicua*	Herbivore	Epifauna	23
Rissoidae	*Rissoa* spp.	Herbivore	Epifauna	126
Rissoidae	*Pusillina* cf. *Radiata*	Herbivore	Epifauna	608
Rissoidae	Rissoidae indet.	Herbivore	Epifauna	2
Rissoidae	*Manzonia crassa*	Carnivore	Epifauna	38
Rissoidae	*Crisilla semistriata*	Herbivore	Epifauna	9
Aporrhaidae	*Aporrhais pespelecani*	Carnivore	Semiinfauna	39
Tornidae	*Circulus striatus*	Deposit+Symbiotic	host	2
Vanikoridae	*Megalomphalus* sp.	Deposit	Epifauna	3
Calyptraeidae	*Calyptraea chinensis*	Filter feeder	Epifauna	25
Calyptraeidae	*Crepidula moulinsii*	Filter feeder	Epifauna	15
Hydrobiidae	*Hydrobia* sp.	Deposit	Epifauna	4
Iravadiidae	*Hyala vitrea*	Deposit	Semiinfauna	1
Naticidae	Naticidae juv.	Carnivore	Infauna	91
Naticidae	*Euspira pulchella*	Carnivore	Infauna	7
Naticidae	*Euspira* sp.1	Carnivore	Infauna	17
Naticidae	*Euspira* sp.2 *(grossularia?)*	Carnivore	Infauna	3
Capulidae	*Capulus ungaricus*	Filter feeder	Epifauna	2
Cerithiidae	*Bittium reticulatum* (sp2)	Herbivore	Epifauna	1190
Cerithiidae	*Bittium latreilli* (sp1)	Herbivore	Epifauna	257
Cerithiidae	*Cerithium vulgatum*	Herbivore	Epifauna	27
Cerithiidae	*Cerithium* juv.	Herbivore	Epifauna	9
Turritellidae	*Turritella communis*	Filter feeder	Semiinfauna	99
Epitoniidae	*Epitonium cantrainei*	Symbiotic	Host	8
Epitoniidae	*Epitonium clathrus*	Symbiotic	Host	13
Epitoniidae	*Epitonium* cf. *Jolyi*	Symbiotic	Host	3
Epitoniidae	*Epitonium* spp.	Symbiotic	Host	92
Aclididae	*Aclis* sp. *(minor?)*	Symbiotic	Host	74
Eulimidae	*Eulima glabra*	Symbiotic	Host	21
Eulimidae	*Eulima bilineata*	Symbiotic	Host	21
Eulimidae	*Melanella* spp.	Symbiotic	Host	20
Eulimidae	*Vitreolina curva*	Symbiotic	Host	40
Caecidae	*Caecum trachea*	Herbivore	Epifauna	7
Velutinidae	*Lamellaria perspicua*	Symbiotic	Host	1
Muricidae	Muricidae indet.	Carnivore	Epifauna	7
Muricidae	Muricidae juv. indet.1 (cf. *ocinebrina)*	Carnivore	Epifauna	10
Muricidae	Muricidae juv. indet 2 (cf. *pagodula)*	Carnivore	Epifauna	2
Muricidae	*Hexaplex trunculus* juv.	Carnivore	Epifauna	115
Muricidae	*Ocinebrina erinaceus* juv.	Carnivore	Epifauna	2
Muricidae	*Ocinebrina* sp.	Carnivore	Epifauna	2
Muricidae	*Muricopsis* sp.1	Carnivore	Epifauna	3

Cystiscidae	*Gibberula* spp.	Carnivore	Epifauna	23
Costellariidae	*Vexillum ebenus*	Carnivore	Infauna	1
Fasciolariidae	*Fusinus rostratus*	Carnivore	Epifauna	92
Nassariidae	*Nassarius* cf. *pygmaeus*	Scavengers	Epifauna	251
Nassariidae	*Nassarius* sp. juv.	Scavengers	Epifauna	7
Nassariidae	*Nassarius* sp.	Scavengers	Epifauna	2
Columbellidae	*Mitrella* sp.	Carnivore	Epifauna	33
Clathurellidae	*Comarmondia gracilis*	Carnivore	Epifauna	5
Mangeliidae	*Bela* spp.	Carnivore	Epifauna	8
Mangeliidae	*Bela brachystoma*	Carnivore	Epifauna	10
Conidae	*Mangelia* sp.1 *(costulata?)*	Carnivore	Epifauna	6
Conidae	*Mangelia* sp.2	Carnivore	Epifauna	8
Mangeliidae	Conidae indet.	Carnivore	Epifauna	77
Mangeliidae	Conidae juv.	Carnivore	Epifauna	2
Raphitomidae	*Raphitoma* spp.	Carnivore	Epifauna	60
Raphitomidae	*Raphitoma* cf. l*eufroyi*	Carnivore	Epifauna	2
Mitromorphidae	*Mitromorpha mediterranea*	Carnivore	Epifauna	10
Cerithiopsidae	*Cerithiopsis tubercularis*	Carnivore	Epifauna	83
Cerithiopsidae	*Cerithiopsis* sp.1 *(nonfronii?)*	Carnivore	Epifauna	3
Cerithiopsidae	*Cerithiopsis* sp.2 *(diadema?)*	Carnivore	Epifauna	115
Triphoridae	*Monophorus* sp. 1	Symbiotic	Host	1
Triphoridae	*Marshallora adversa*	Symbiotic	Host	609
Triphoridae	*Metaxia metaxae*	Symbiotic	Host	9
Triphoridae	Triphoridae indet.	Symbiotic	Host	3
Pyramidellidae	*Odostomia* spp.	Symbiotic	Host	105
Pyramidellidae	*Ondina* sp.	Symbiotic	Host	6
Pyramidellidae	*Ondina vitrea*	Symbiotic	Host	1
Pyramidellidae	*Turbonilla* spp.	Symbiotic	Host	56
Pyramidellidae	*Folinella excavata*	Symbiotic	Host	2
Pyramidellidae	*Chrysallida* spp.	Symbiotic	Host	25
Pyramidellidae	*Euparthenia bulinea*	Symbiotic	Host	9
Acteonidae	*Acteon tornatilis*	Carnivore	Epifauna	6
Ringiculidae	*Ringicula* sp.	Carnivore	Epifauna	9
Haminoeidae	*Haminoea* sp. *(navicula?)*	Herbivore	Epifauna	2
Haminoeidae	*Weinkauffia turgidula*	Herbivore	Epifauna	15
Philinidae	*Philine catena*	Carnivore	Epifauna	8
Philinidae	*Philine scabra*	Carnivore	Epifauna	7
Retusidae	*Retusa semisulcata*	Carnivore	Epifauna	1
Retusidae	Retusa truncatula	Carnivore	Infauna	2
Retusidae	*Cylichnina umbilicata*	Carnivore	Infauna	8
Scaphandridae	*Scaphander lignarius* juv.	Carnivore	Infauna	1
Neritidae	*Smaragdia* sp.	Herbivore	Epifauna	1

Succineidae	*Oxyloma elegans*	land snail	land snail	554
Pupillidae	*Pupilla triplicata*	land snail	land snail	44
Vertiginidae	*Vertigo antivertigo*	land snail	land snail	30
Vertiginidae	*Vertigo angustior*	land snail	land snail	0
Valvatidae	*Valvata macrostoma*	freshwater snail	freshwater snail	559
Planorbidae	*Segmentina nitida*	freshwater snail	freshwater snail	3
Planorbidae	*Anisus cf. Leucostoma*	freshwater snail	freshwater snail	42
Planorbidae	*Gyraulus* cf. *Laevis*	freshwater snail	freshwater snail	309
Planorbidae	*Gyraulus* cf. *Albus*	freshwater snail	freshwater snail	6
Bithyniidae	*Bithynia* sp.	freshwater snail	freshwater snail	222
Dentaliidae	*Antalis* sp.	Carnivore	Infauna	17
Gadilidae	*Dischides politus*	Deposit	Infauna	7
Leptochitonidae	*Leptochiton* spp.	Herbivore	Epifauna	20
Chitonidae	*Chiton* spp.	Herbivore	Epifauna	15
Ischnochitonidae	*Ischnochiton rissoi*	Herbivore	Epifauna	1

Curriculum vitae

PERSONAL DETAILS

Name: Sara-Maria Schnedl
E-mail: saramaria.schnedl@gmail.com

EDUCATION

2005 – Present:	University of Vienna
Sep 05 – June 06	Byzantine and Modern Greek Studies
Sep 06 – Dec 09	Translation and Interpretation (German-English-Italian, Bachelor studies), successfully completed (Bakk.phil)
Mar 10 – Present	Interpreting (German-English-Italian, Master studies)
Sep 09 – Oct 12	Biology (Zoology), successfully completed (BSc)
Nov 12 – Present	Zoology (focus: marine biology, environmental paleobiology, Master studies)
1997-2005	Secondary School: Bundes- und Realgymnasium Rainerg. Wien 5, Graduation: 14 June 2005 (main focus: English, scholarly paper: *"Growing up in Literature and Fiction: A Comparison"*)
1993-97	Primary School Volkschule Schäfferg. Wien 4

EDUCATION ABROAD

Aug 2010 – Feb 20011	Visiting Semester at the *University of Crete*, Heraklion, Crete, Greece
July - Aug 09	Translation master class in Bath, England at *Bath English Language School*
July – Sep 08	Language courses in Tropea, Italy at *Piccola Università Italiana* and Rome, Italy at *Dilit*.
Feb 06 & Feb 07	Language course at *Dilit* in Rome, Italy
Sep 06	Language course at *Comitato Linguistico* in Perugia, Italy
Oct 02	Language course in Cambridge, England
Mar 00	Language course in Mandelieu, France

CONFERENCES

September 2014	7th International Meeting on Taphonomy and Fossilization, Ferrara, Italy (1 Talk, 1 Poster)

WORK EXPERIENCE IN AUSTRIA

Mar 14 – Jun 14	Study assistant at the *Department of Palaeontology, University of Vienna*
Feb 13 – May 14	*L&R Social Research*

Feb 11 – Mar 13	Tutor in English, Italian and German (*Kogler Nachhilfe*)
Sep 09 – Present	Volunteer work at *Ute Bock Association* in Vienna.
Sep 04 – Dec 05	Tutor in French and German *(BRG Rainergasse)*
June 08 – Dec 11	*Table Service Team* in Vienna
June 05 – July 05	*Österreichische Post AG*

WORK EXPERIENCE ABROAD

2 July 07 – 1 Aug 07	SEMARNAT (Animal Rehab Centre) in Guadalajara, Mexico.
8 Sep 03 – 19 Sep 03	*Promod* in Saint Malo, France.

LANGUAGES

German – mother tongue
English – C2
Italian – C2
French – basics
Modern Greek – basics
Spanish – basics