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Biodiversity assessment and drilling predation of bivalve death assemblages in the Northern Adriatic Sea

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1 Abstract

Historical ecology is a near-time approach of conservation paleobiology which uses organic and inorganic remains of the relatively recent past to examine ecological dynamics.

In this study, sediment grab samples of bivalve death assemblages were sampled at eight stations in the Northern Adriatic Sea, including protected and non-protected sites. A comparison of diversity, abundance, species composition and drilling predation by gastropods of the sampling sites was carried out. Sediment analysis, including grain size, pollutants and sedimentation rates, was integrated in the study and used to explain the ecological data. The sampling stations showed differences in species composition, diversity, nutrient and pollutant concentration, sediment grain size and drilling parameters. In total, 29,296 bivalve specimen were found.

The river-influenced stations Po, Po Buoy and Panzano revealed similar species compositions and strong nutrient and sediment input as well as increased pollution. The stations showed high numbers of bioindicator species which are characteristic for stressed ecosystems (e.g. *Corbula gibba, Anadara transversa*).

High diversity was found at stations Venice (2,244 individuals, 52 species, Shannon-Wiener Index 2.86) and Brijuni (2,133 individuals, 55 species, Shannon-Wiener Index 2.96), which share characteristics of low sediment and nutrient input, but differ in sediment grain size and grade of protection. The Po stations showed lowest diversity (Po: 459 Individuals, 20 Species, Shannon-Wiener Index 2.01; Po Buoy: 784 Individuals, 24 Species, Shannon-Wiener Index 1.90) probably due to the physiological constraints (e.g. High sedimentation rates, high input of pollutants and nutrients, freshwater input) that characterize this environment.

Drilling frequency (DF) did not correlate with nutrient content and diversity at all of the sampling stations. Only at station Panzano high nutrient content and highest DF (36.0 %) were found and at station Venice nutrient content and DF were low (DF= 11.6 %) and therefore correlated. The Po stations were the only stations where low diversity correlated with very low DFs (0.5 % at station Po, 2.2 % at station Po Buoy) all other stations showed no interrelations.

This study indicates, that diversity structures of bivalve death assemblages of the Northern Adriatic Sea are highly influenced by the environmental characteristics of the habitat, which can be modified by human impact directly and indirectly.

2 Zusammenfassung

Der Begriff “Historische Ökologie” bezeichnet einen Ansatz der Paläobiologie, welcher organische und anorganische Überreste der jüngeren Vergangenheit verwendet, um ökologische Veränderungen zu erkennen.

In dieser Studie wurden Schalen von Bivalven-Totgemeinschaften aus dem Gebiet der nördlichen Adria untersucht. Die Schalen stammen aus Sedimentproben von acht verschiedenen Gebieten der Nordadria, welche unterschiedlich stark vor menschlichem Einfluss geschützt sind. Die in den Sedimentproben enthaltenen Schalen wurden hinsichtlich ihrer Diversität, Häufigkeit der Arten und Artenzusammensetzung sowie auf Bohrlöcher räuberischer Gastropoden untersucht und verglichen. Zusätzlich wurden Sedimentanalysen, welche Korngrößen des Sediments, Schadstoff- und Nährstoffkonzentrationen sowie Sedimentationsraten umfassen, in die Studie miteinbezogen. Die Proben zeigten Unterschiede in der Artenzusammensetzung, Diversität, der Häufigkeit räuberischer Bohrspuren, der Nährstoff- und Schadstoffkonzentration und in der Sedimentkorngröße. Ingesamt wurden 29.296 Individuen gefunden.

Stationen wie Po, Po Boje und Panzano, welche in der Nähe von Mündungsgebieten größerer Flüsse liegen, zeigten eine hohe Ähnlichkeit bezüglich der Artenzusammensetzung sowie eine hohe Belastung durch Nährstoff- und Sedimenteintrag und Verschmutzung durch Schadstoffe. Zusätzlich wurde eine hohe Anzahl von Arten gefunden, welche charakteristisch für belastete Ökosysteme sind und somit als Bioindikatoren dienen.

Die beiden Stationen Venedig (2.244 Individuen, 52 Arten, Shannon-Wiener Index 2,86) und Brijuni (2.133 Individuen, 55 Arten, Shannon-Wiener Index 2,96) wiesen die höchste Bivalven-Diversität auf. Die beiden Stationen sind zwar ähnlich bezüglich des niedrigen Sediment- und Nährstoffeintrages, unterscheiden sich aber deutlich in Korngröße und vor allem in ihrem Schutzgrad. Die beiden Po-Stationen hingegen zeigten die niedrigsten Diversitäten (Po: 459 Individuen, 20 Arten, Shannon-Wiener Index 2,01; Po Boje: 784 Individuen, 24 Arten, Shannon-Wiener Index 1,90), welche wahrscheinlich auf die hohen Belastungen durch den Po, welche dieses Gebiet charakterisieren, zurückzuführen sind.

Bohrspuren, verursacht durch räuberische Gastropoden, wurden auf Korrelation mit Nährstoffkonzentration und Diversität an den jeweiligen Standorten untersucht, es wurde jedoch nicht an allen Stationen ein Zusammenhang gefunden.

Zusammenhänge von Raubdruck und Nährstoffkonzentration wurde nur bei den Stationen Panzano (hoher Nährstoffgehalt und maximale Bohrfrequenz von 36,0 %) und Venedig (Nährstoffgehalt und Bohrfrequenz mit 11,6 % gering) gefunden.

Bezüglich der Diversität waren die Po-Stationen die einzigen Stationen, die einen Zusammenhang von niedriger Diversität und niedrigem Raubdruck (Bohrfrequenz Station Po 0,5 %; Bohrfrequenz Station Po Boje 2,2 %) zeigten.

Diese Studie zeigt, dass die Diversität und Artenzusammensetzung von Bivalven-Todesgemeinschaften in der Nordadria zu einem großen Teil von den Umwelteinflüssen des jeweiligen Lebensraums abhängt. Diese Parameter können durch menschlichen Einfluss direkt oder indirekt geändert und beeinflusst werden.

3 Introduction

3.1 Northern Adriatic Sea

The Northern Adriatic Sea counts as one of the most degraded marine ecosystems world-wide and therefore can serve as a case study for ecosystem modification under human pressure (Lotze et al., 2006). The area is classified as a “sensitive ecosystem“ due to its characteristic as a semi-enclosed, shallow basin with high riverine input, soft bottoms, stratification, long water residence duration and high primary production (Ott, 1992; Stachowitsch, 1984, 1991).

Eutrophication, habitat conversion, overfishing and introduction of neobiota have long histories which intensified over the last few centuries and were becoming global in the last several decades (Jackson et al., 2001; Lotze et al., 2006; Worm et al., 2006; Halpern et al., 2012).

Early industrialization in European and Northern American (~ 1800) countries lead to accelerated ecological degredation of marine systems. Typical signs of degredation are declines in diversity, changes in total abundance, increase in resistant species, invasion of neobiota and decrease in benthic or other sensitive species (Yasuhara et al., 2012).

In the Northern Adriatic Sea, eutrophication became a frequent and widespread ecological problem after 1969 (Figure 1). The Po River, among other rivers, introduced waste water that was transported by counter-clockwise currents along the coasts of adjacent countries and lead to eutrophication and pollution (Barmawidjaja et al., 1995; N’siala et al., 2008). Eutrophication can cause hypoxic and anoxic conditions, which lead to abnormalities in response and behaviour of marine benthic species and influences survival, recruitment and growth (Haselmair et al., 2010; Nerlovic et al., 2011; Stachowitsch, 1984).

High concentrations of various pollutants are frequently found in marine systems and are further uptaken and/or accumulated in marine sediments and in benthic organisms. Sources of pollution are among others consumer waste, fuels, alloys, clearing sludge and fertilizers. Pollutants negatively affect marine and human health by entering the marine food chain via the atmosphere or water systems such as rivers (Duysak and Ersoy, 2014; Pempkowiak et al., 1999).

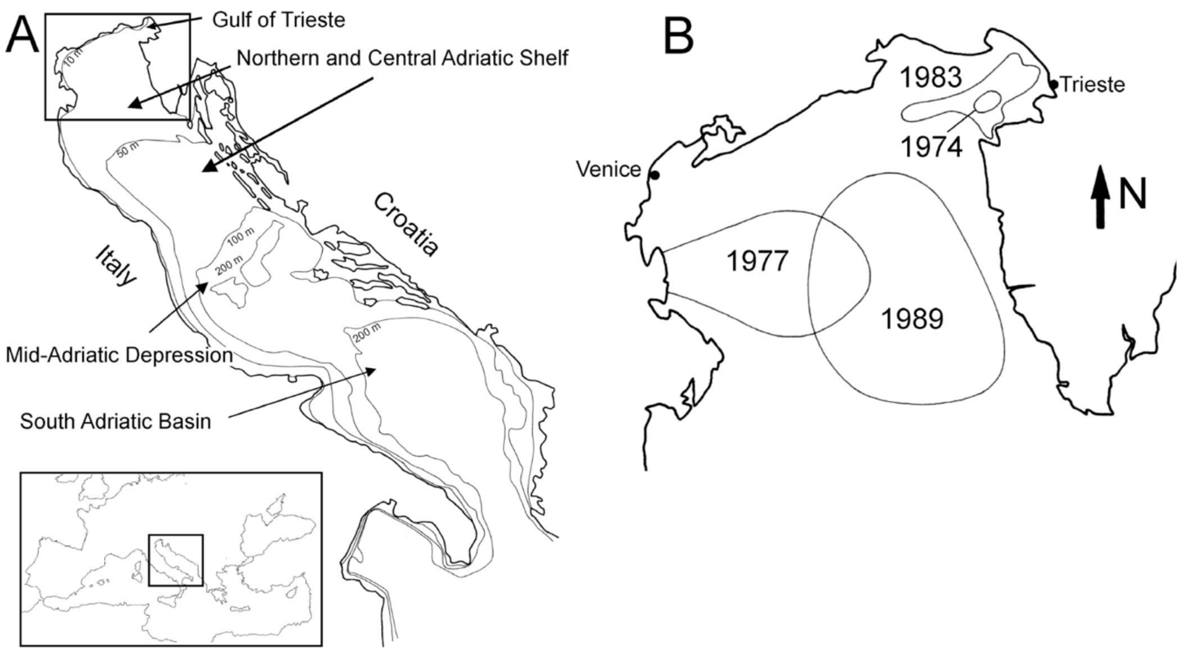

Figure 1: Morphology of the basin and anoxic events of the past in the Northern Adriatic Sea. A) Morphologic map showing the wide and shallow basin of the Northern Adriatic Sea B) Areas of bottom anoxia between 1974 and 1989 (from Zuschin and Stachowitsch, 2009)

3.2 Historical ecology

The conservation paleobiology perspective identifies phenomena beyond timescales of direct human experience by using organic remains, geochemical signals and associated sediments of the fossil record as data sources. One approach (near-time) of conservation paleobiology uses the relatively recent past (the last few million years) as a dynamic context for present-day conditions and is termed "Historical ecology". Historical ecology mainly focusses on ecological dynamics (e.g. changes of species abundance and distribution) (Dietl and Flessa, 2011).

3.2.1 Death assemblages

Periodical mortalities of benthic communities caused by depletion of oxygen as a result of eutrophication have occured for centuries (Crema, Castelli and Previdelli, 1991). Benthic animals can serve as important indicators for the degree and severity of marine pollution and degredation. Some benthic taxa (e.g. Echinoderms or crustaceans) are often missing in highly impacted areas whereas many molluscan species still can be found in high numbers (Nerlovic et al., 2011).

Moreover, molluscan hard parts often remain largely unchanged after death and can be identified to species level even after hundreds or thousands of years. Molluscs are a diverse group concerning habitat requirements and show a broad spectrum of sensitive to resilient species. Alterations of community composition and abundance caused by environmental changes such as pollution and hypoxia can reduce sensitive species, whereas tolerant species sometimes are still present in high abundances. Furthermore, indicator species can be used to study alterations in the ecosystem. Species such as *Corbula gibba*, a member of the Corbulidae family and commonly described as "basket shell", is known to inhabit unstable environments and is able to tolerate natural and anthropogenic disturbances. Hence, the species is considered as a bioindicator of environmental instability in soft bottom benthic habitats (Hrs- Brenko, 2006). By determining absence, presence or abundance of mollusc species, insights on disturbances on species composition can be gained (Dauer, 1993; Miller et al., 2002; Pearson and Rosenberg, 1978).

Molluscan death assemblages (DA) are the taxonomically identifiable empty shells that are collected from the seabed, typically from the uppermost 5– 20 cm of marine sediment. The DAs reflect input from past generations of organisms that have lived in the area, either temporarily or permanently. The relative abundances of species at a particular location can be altered by postmortem transport, incomplete preservation, differences in life span, or by the time-averaging of generations. Nevertheless, these dead individuals count as the direct empirical evidence of formerly existing populations (Kidwell, 2013). Molluscan DAs can serve as a window to the past, and the degree of variation between different community compositions over time functions as a proxy for ecological shifts (Grotzinger et al., 2008; Weber and Zuschin, 2013).

According to Kidwell (2013), DAs should not simply be seen as a representation of buried fossil assemblages, but as informants of historical data on the status of modern-day communities and ecosystems, which are under increasing anthropogenic influence (Worm et al. 2006; Halpern et al., 2008, 2012). DAs from surficial deposits are sources of biological information that reflect accumulation of species on a broad timescale from decades to millennia and are most relevant for evaluating anthropogenic impacts (Kidwell and Tomasovych, 2013). Direct observations on living systems are described as "[…] generally not sufficiently long running to evaluate many processes, commonly focus on only a few species of commercial or other interest, and monitoring usually does not start until human stresses are already underway or imminent" (Kidwell, 2013).

The Adriatic molluscan fauna and taxonomic composition is well known, which is an advantage for accurate identification of species (Cossignani et al., 1992; Riedl, 1963) and therefore makes studying molluscs as a record of ecological conditions attractive.

3.2.2 Drilling predation

In addition to molluscan death assemblages, studying predator-prey interactions help to evaluate its effect on diversity, evolution and distribution of a group. Predation is considered to be an important agent of natural selection and a key process in structuring benthic communities (Holt, 1977; Bohannan and Lenski, 2000). The usage of drill holes and repair scars, especially those attributed to naticid and muricid gastropods, can serve as a tool to quantify predation in the fossil record and in modern DAs of molluscs (Hoffmeister and Kowalewski, 2001).

In the Northern Adriatic, a low predation pressure as a general background condition and a predation intensity far below that of the tropics and subtropics is proposed by recent literature (McKinney, 2007; McKinney and Hageman, 2006). Other studies, however, state an activity of predatory gastropods in the Adriatic that can be as high as in other regions of comparable latitudes (Sawyer et al., 2009). In areas such as in the Gulf of Trieste, which is described as high-biomass epifauna (Zuschin et al., 1999), sub-tidal intensities of drilling predation on mollusks reach typical modern levels of about 20 % (Sawyer and Zuschin, 2010).

3.3 Study aim

For this survey, grab samples of bivalve death assemblages were taken from eight shallow sediment locations in the Northern Adriatic Sea.

The main aim of this study is to identify highly stressed ecosystems using species composition analysis and drilling predation. The following hypotheses are tested:

- The environments differ in species composition (e.g. due to their degree of protection)
- Drilling predation positively correlates with diversity
- Drilling frequencies are higher in eutrophic than in more oligotrophic habitats

4 Study Area

The Northern Adriatic Sea, with a size of > 300 km and a shallow average depth of ~ 50 m is one of the worlds's largest modern epicontinental seas (Zuschin and Stachowitsch, 2009). Moreover, high total human population and a long history of intense human impact makes it also one of the most degraded systems (Lotze et al., 2006).

Groups of benthic organisms occur in distinct biocenoses and mostly consist of polychaetes, infaunal echinoids and bivalves, crustaceans and gastropods (Vatova, 1949; McKinney, 2007). Infaunal assemblages typical for modern shelf associations can be found in the eutrophic western part of the Northern Adriatic, whereas the oligotrophic eastern part is predominated by suspension-feeding epifauna (McKinney, 2007).

The Po River is responsible for the primary sediment, nutrient and freshwater input into the Adriatic Sea. Freshwater input into the Adriatic basin by the Po River is not only featuring a primarily thermohaline, cyclonic (counterclockwise) circulation of surface water, but also accounts for one-third of the entire freshwater input into the Mediterranean together with other smaller rivers (Artegiani et al., 1997, McKinney, 2007). Average surface water temperature of the Northern Adriatic is 7 °C during winter and 24 °C during summer, average salinity amounts to 30-35 ‰ (Gacic, 2001; Janekovic, 2010).

4.1 Sediment distribution and nutrient input

The sediment supply to the Adriatic basin is strongly asymmetric with extensive sediment input on the northern and western coasts in contrast to low input on the eastern Croatian side (Milligan and Cattaneo, 2007). The sediment covering the Northern Adriatic seafloor consists of relict Pleistocene sand covered by Holocene mud (Pigorini, 1968; Goff et al., 2006). Recent sand covers a small coastal zone, shelfal relict sands the seafloor and in between a so called prolittoral mud belt is developed through deposition of recent terrigenous muds with a maximum accumulation rate of about 4.5 mm per year (Van Straaten, 1970) (Figure 2A).

Sediments are not in steady-state equilibrium. In shallow areas, for example in the Adriatic north of the Po River prodelta, sediment storage may be temporary and undergo resuspension which influences productivity. Natural induced temporary sediment storage and resuspension mainly occurs during the winter storm period by factors such as northeastern cold winds (bora) and southeastern warm winds (scirocco) (Frignani et al., 2005).

Man- induced reasons for resuspension of sediment, bottom trawling and dredging, are destabilizing the sediment. Bottom trawling has been applied for nearly a century and results in penetration to sediment depth ranging from 5-10 cm to about 40 cm (Kaiser et al., 2002; Thrush and Dayton, 2002; De Madron et al., 2005; Palanques et al., 2001; Hall-Spencer et al., 1999). Redistribution on typically sediment starved modern shelfs strongly affect benthic community structures (Riggs et al., 1998).

Along with the Po River, not only sediments but also nutrients reach the Adriatic basin. The productivity of the Northern Adriatic is among the highest in the Mediterranean, which as a whole is distinctly oligotrophic (Turley, 1999). Even comparatively nutrient-poor areas are productive by Mediterranean standards (Zuschin and Stachowitsch, 2009). Eutrophic and even hypertrophic zones are found off the Po delta which makes the western part of the basin mesotrophic. The northwestern region off Venice is strongly influenced by seasonal nutrient flushing from the coastal lagoons. In the Gulf of Trieste, which lies in the northernmost part, the input of pelitic sediments and nutrients find their origin from various small Istrian and Friulian rivers, land drainage and groundwater (Olivotti et al., 1986; Harding et al., 1999) (Figure 2B).

Through riverine influence, the distribution of modern fine-grained sediments of fluvial origin correspond to areas of high nutrient supply whereas nutrient deprived areas (Figure 2B) are characterized by Pleistocene relict sands (Zuschin and Stachowitsch, 2009).

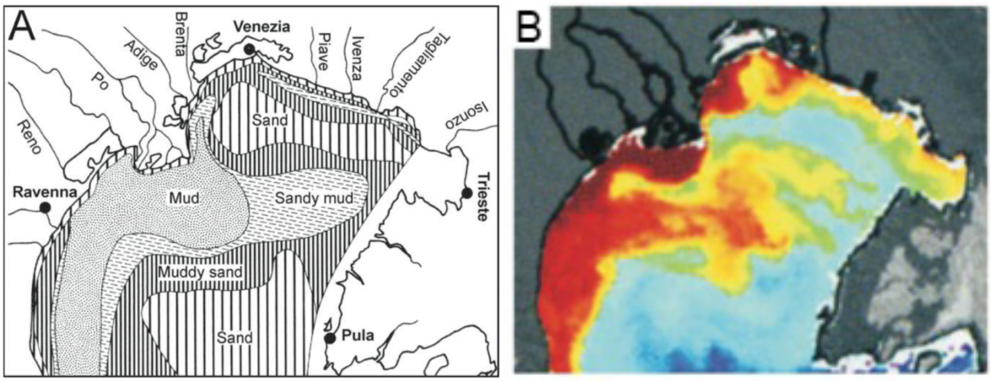

Figure 2: Distribution and coherence of sediments and nutrients in the Northern Adriatic Sea. A)Grain-size distribution B) Chlorophyll *a* levels (a proxy for nutrient availability, highest concentrations coloured in red) on 14 August 2001 (from Zuschin and Stachowitsch, 2009)

4.2 Pollutants

Input of large loadings of metals, organic chemicals and pathogens into the ocean lead to accumulations of pollutants in marine sediments. Long term storage and resuspension of toxic substances in the sediment contribute to significant long term degredation of marine ecosystems (Burton, 2002).

During the past thousand years, high concentrations of Mercury (Hg), Copper (Cu) and Zinc (Zn) accumulated in modern deposits of less than one meter thickness in the Northern Adriatic (Covelli et al., 2006).

When it comes to organic pollutants, persistent organic pollutants (POPs), which are widespread on land and in aquatic environments, are of great concern. POPs are synthetic organic compounds that are chemically stable and not easily degradable in the environment or by organisms (Rios et al., 2007). Some of these are highly toxic and have a wide range of chronic effects, including endocrine disruption, mutagenicity and carcinogenicity (Tanabe, 2004). They are typically hydrophobic and lipophilic which leads to their partition to solids, notably organic matter. They also partition into lipids in organisms rather than entering the aqueous milieu of cells, become stored in fatty tissue and accumulate in foodchains. Due to the POPs ability to enter the gas phase under certain temperature they may volatilise from soils, vegetation and water bodies into the atmosphere and travel long distances before being redeposited as they are not easily broken down. POPs therefore can accumulate in areas far from where they were used or emitted (Jones and De Voogt, 1999). 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).

Polychlorinated biphenyls (PCBs) are mixtures of up to 209 individual chlorinated compounds, of which 113 are known to be present in the environment (Pascal et al., 2005; NWF, 1994). They were produced for fluids needed in electric apparatus (e.g. Coolant fluids, dielectric fluids) until a prohibition of production in 1979 by the United States Congress and in 2001 by the Stockholm Treaty (Porta and Zumenta, 2002). Nevertheless, at least half of the PCBs produced are still in use, especially in older electrical equipment, or in storage. Thus, a huge reservoir of PCBs remains with the potential to be released into the environment either through spills or leakage from transformers and other devices.

Additionally, the migration of these chemicals from sediments with high concentrations of PCBs provides an ongoing supply to the water phase (Brasher and Wolff, 2004; Barreira et al., 2005).

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of over 100 different chemicals that result from incomplete burning of various organic substances such as coal, oil, gas or garbage, usually appearing in mixtures. However, they can also origin from natural synthesis by organisms or from natural events such as forest fires, volcanism and petroleum seeps (Notar et al., 2001). PAHs can also be manufactured and used for the production of pesticides, plastics, dyes or medicines. They are major pollutants emitted from shipping industry and oil exploitation and are assumed to potentially have long-term effects on the environment (Martínez-Gómez et al., 2010). Many PAHs are toxic, and tend to bioaccumulate in aquatic organisms. There are 16 PAH compounds that are classified by the USA's Environmental Protection Agency (USEPA) as priority pollutants and as high priority substances in the European Water Framework Directive based on their toxicity for humans (Bojes and Pope, 2007; Martínez-Gómez et al., 2010; Wessel et al., 2010).

PAHs appear in high concentrations in costal areas which are urbanized, as human activity and industrial processes come along with population. The Adriatic is a relatively shallow land-locked water body, with densely populated coastal communities and high agricultural and industrial activity. Furthermore, some areas of the Northern Adriatic are extensively utilized for tourist and mariculture purposes. Riverine input from big rivers such as the Po or the Isonzo River might lead to leakage of industrial and agricultural drainage and contamination of the marine environment (Notar et al., 2001; Perugini et al., 2007).

5 Sampling Stations

Seven sampling stations*, Piran II, Piran Buoy, Po, Po Buoy, Brijuni, Venice,* and *Panzano* were chosen according to different sediment types, nutrient conditions and degrees of protection (Figure 3). Always two of the sampling points correspond to each other, one is impacted by human activity such as fishing and dredging and the other one is protected. For sampling station Panzano, however, no counterpart was sampled. Additionally, grab samples were taken at *Position D* for additional biomass and used for more information on biodiversity and drilling predation of molluscan death assemblages. For *Position D* also no counterpart was examined.

Figure 3: Map of sampling stations (Google maps, on 13. 11. 2015)

Station Piran II is located off Piran (Slovenia) in 24 m depth (N 45° 33' 47.52"/ E 13° 32 ' 13.32”). The sampling point is characterized by sandy mud with low sediment and nutrient input and is not protected from dredging by fisheries.

Station Piran Buoy is located within the protected perimeter of the oceanographic buoy operated by MBS Piran in 24 m depth, close to station Piran II (N 45° 32' 55.92" / E 13° 33' 3.24"). The shelf environment of sampling point Piran Buoy is protected from dredging.

Station Po (N 44° 50' 31.86" / E 12° 32' 19.80") and Station Po Buoy (N 44° 43' 49.92" / E 12° 26' 24.78") are located close to the Po estuary (Italy) and therefore are highly affected by riverine input of sediment and nutrients. Sampling depths were 23 m and 21 m, respectively. The sediment mainly consists of fine grained sediment (silt and clay). Furthermore, Station Po Buoy is located within the protected circuit of the oceanographic buoy “S1” operated by ISMAR.

Station Brijuni is located within the boundaries of the Brijuni islands marine national park (Croatia) in 45 m depth (N 44° 53' 9.00" / E 13° 44' 49.26"). The shelf surface consists of relict sands. Fishing and dredging is prohibited.

Station Venice is located close to Venice (Italy) in 22 m depth (N 45° 22' 30.84"/ E 12° 46' 32.82"). The area is highly affected by fishing and dredging and consists of oligotrophic relict sand.

Station Panzano is located in the Gulf of Triest of Italy, close to the Isonzo River mouth (N 45° 44' 7.44" / E 13° 36' 1.68"). This station is characterized by pelitic sediments due to riverine input. Sampling depth was 11 m.

Station Position D is located south-east of station Venice and is characterized by sandy sediment. Samples were taken in a depth of 30 m. (N 45°17'3.87" / E 12°55'48.15").

6 Material and methods

6.1 Sampling

The sampling took place in the basin of the Northern Adriatic Sea and was conducted in summer 2014. On board of the Slovenian research vessel Manta Bianca, grab samples of marine surface sediment were taken. At each of the stations, eight grab samples were extracted using a Van Veen grab sampler covering an area of about 992 cm^2, corresponding to a volume of about 12,076 cm^3. Every sample covered sediment from top layers up to 20 cm depth.

All of the grab samples extracted were washed through a sieve with a mesh size of 1 mm. After sieving, living and dead biomass was sorted and the samples of death assemblages were dried for further evaluation, whereas living individuals were preserved in ethanol. Even though at each sampling station eight grab samples were extracted, only one of the grab samples was further analysed, as this was found to be sufficient to get enough and representative shell material to evaluate the composition of death assemblages. Two exceptions were made at the stations Po and Po Buoy, where two grab samples were analysed each as the diversity of the samples was very low.

6.2 Analysis of environmental parameters

Environmental data for the analysis of inorganic (Hg, Pb, As) and organic pollution (PCBs, PAHs), nutrients (C tot, TOC, N tot) and sediment age and composition was sampled with 1.5 m long cores all of the sampling stations, except station Position D, and further processed in laboratories of the Venice ISMAR institute. Nutrients were indicated as percentage of dry weight (%ss). Grain size analysis was performed with a sedigraph (SediGraph III 5120 Particle Size Analyzer) and dry sieving. Sediment types are clay, silt, sand (excluding > 1 mm) and the fraction > 1 mm, mostly consisting of biogenic material.

Radiometrical dating of the sediment cores by using ^{210}Pb dating was conducted by the Low-level Counting Labor Arsenal of the University of Natural Resources and Applied Life Sciences, Vienna. Based on these data, it was possible to calculate annual sedimentation rates of the different sampling stations.

6.3 Identification of species and counting

Using a stereomicroscope and special literature (Cossignani et al., 1992, 2011; Gofas et al., 2011; Scaperotta et al., 2009, 2010, 2011, 2012, 2013), the bivalves were identified according to morphological features and if possible, classified to species level. Some bivalve species were hard to distinguish as a matter of similar taxonomic features and therefore summarized (*Modiolus* spp., *Limaria* spp., *Ostrea* spp., *Mytilus* spp.). Individuals that could not be identified to species but family level were categorized as indeterminable but considered within the biodiversity assement (Veneridae indet., Tellinidae indet., Pectinidae indet.).

After identification of bivalve species, the shells where counted to get total individual numbers for the biodiversity assessment and to assess the number of shells that have been drilled.

6.3.1 Biodiversity assessment

The biodiversity assessment of molluscan death assemblages will give insight on the differences in diversity of benthic communities in different environments throughout the Adriatic. Using the shells of molluscs as bioindicators, states of environments can be interpreted.

For the assessment of biodiversity, the total abundance of species in the samples was calculated. Bivalve shells were only counted when the hinge was still present to avoid overestimation of number of individuals. The total number of individuals was then calculated by dividing the shells that were not articulated into half and adding them to the articulated shells. On this way it was possible to estimate the number of individuals of a species within a sample.

6.3.2 Drilling predation

Well preserved shells, preserving at least 90% of the original shape were also examined for traces of drilling predation. In this study, it was of interest to determine the effects of drilling predation on molluscan commmunities in the Northern Adriatic as a whole and therefore it was not distinguished from which predatory clades the boreholes derived. Only drillholes that are circular in cross section with smooth sides, penetrate perpendicular from the outside of the shell surface, and penetrate one valve only in articulated shells were considered to be predatory in nature (Carriker and Yochelson, 1968; Rohr, 1991; Baumiller, 1996; Kaplan and Baumiller, 2000; Leighton, 2001). To evaluate drilling intensities the number of individuals of preserved shells was calculated. This was done by dividing the number of disarticulated valves by two and adding them to the double valved specimens.

To examine the complexity of predator-prey interactions in the Northern Adriatic, five indices of drilling predation were calculated which gives insights on regional variability of drilling intensities that can be compared to diversities of different habitats. Predation pressure can vary across environmental gradients and also may change with anthropogenic impact.

Drilling frequency (DF) was calculated by dividing the total number of drilled shells by the total number of individuals examined. Drill frequency (DF) is a measure to quantify the overall drilling rate of bivalves by predatory gastropods. By dividing the total number of incomplete drill holes by the number of shells examined, a measure for failure of predatory attacks can be calculated, which is the Incomplete drilling frequency (IDF). Multiple drilling frequency (MDF) was calculated by the number of multiple drilled shells divided by the total number of preserved shells. Edge drilling frequency (EDF), the percentage of shells that were drilled at the shell edge, was calculated by dividing the edge drilled shells by the total number of preserved shells. Prey effectiveness (PE) accounts for the prey's ability to resist drilling predation by drilling gastropods and therefore served as a measure of predation failure. PE is obtained by dividing the number of incomplete drills by the total number of attacks (incomplete plus complete drill holes) (Vermeij, 1987; Kowalewski, 2002).

6.4 Statistical analysis

For the biodiversity assessment, individuals of broken and complete shells were added to get an estimation of total individuals present in the samples.

Bivalve species that account to ≥ 1 % of individuals in the total assemblage and species that account to ≥ 5 % at the individual stations were used to compare abundances between stations. Species that account to < 1 % of all pooled individuals or to < 5 % at different stations were summed up and termed "REST".

As the number of individuals differed strongly between samples, rarefaction curves were used to compare diversities and drilling predation data.

Rarefaction parameters were calculated by using PAST 3.07 (Hammer et al., 2001) and exported to Excel for Mac 2011 to draw the rarefaction curves.

The dendrogram for hierarchical clustering based on the Bray-Curtis similarity index was done by using PAST 3.07 (Hammer et al., 2001).

The community composition was analysed with non-metric multidimensional (Non-metric MDS) scaling based on the Bray-Curtis similarity index. Graphs were performed using PAST 3.07 (Hammer et al., 2001).

Calculation of Shannon-Wiener Index for diversity, as a measure of eveness, was done by using PAST 3.07 (Hammer et al., 2001).

Drilling predation parameters such as DF, IDF, EDF, MDF, PE were calculated at various taxonomic levels using Microsoft Excel for Mac 2011.

7 Results

A total of 29,296 individual bivalves was counted (broken and complete individuals), identified to species level, counted and used for biodiversity comparison.

In there, 15,699 complete individual bivalves (calculated from 761 articulated and 29,685 disarticulated valves) were counted.

In total, the shells represented 89 bivalve species from 35 bivalve families. Within this working frame, four new species were found in the grab samples which have not been found in core samples and were added to the species list (*Similipecten similis, Acanthocardia tuberculata, Donax trunculus* and *Kurtiella tumidula*).

7.1 Biodiversity assessment

7.1.1 Total fauna

In total, 29,296 bivalve specimen were found. *Gouldia minima, Corbula gibba* and *Parvicardium scabrum* are the most abundant species with 30.2 %, 17.5 %, 13.8 %, respectively. All other species contribute < 10 % each and account for 38.5 % in total (Figure 4).

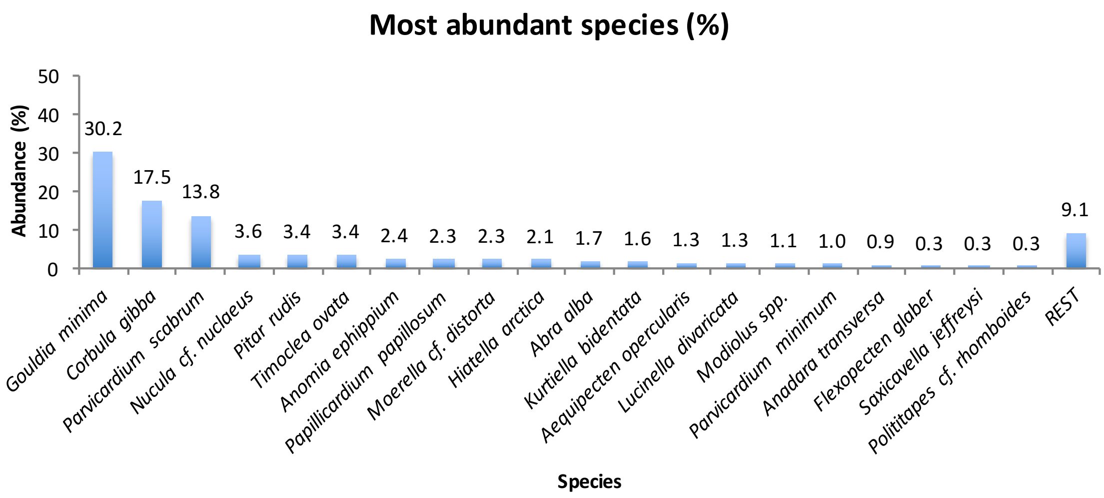

Figure 4: Most abundant species pooled across all eight stations

7.1.2 Sampling stations

7.1.2.1 Piran II

At station Piran II, 6,324 bivalve individuals were counted in total. 55 different species were found. Most abundant species are *Gouldia minima*, *Corbula gibba* and *Parvicardium scabrum* with 46.6 %, 11.7 % and 18.4 % abundance, respectively. Species with < 10 % abundance accredit for 23.3 % when pooled together (Figure 5).

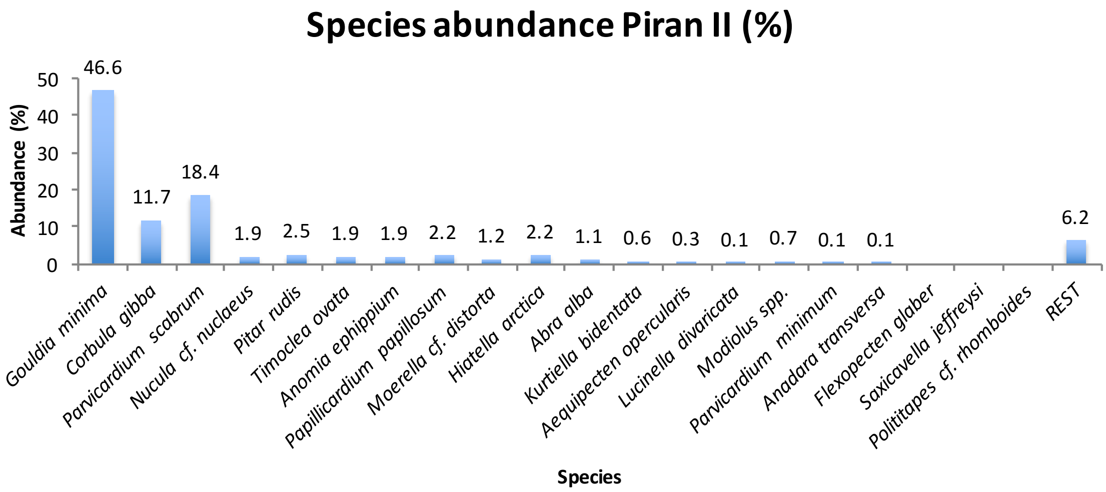

Figure 5: Most abundant species at station Piran II

7.1.2.2 Piran Buoy

At Piran Buoy, a total of 12,903 bivalve specimens was counted and 63 different bivalve species identified. This represents the station with the highest number of identified individuals and species. Dominant species are *Gouldia minima* with 44.9 %, *Corbula gibba* with 16.2 % and *Parvicardium scabrum* with 13.6 % (Figure 6). Species with < 10 % abundance account for 25.3 % in total.

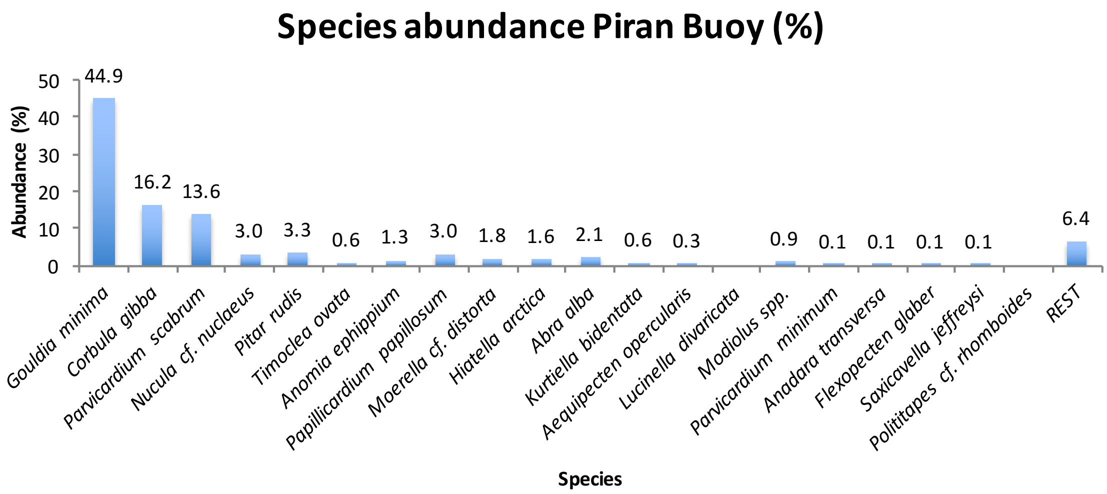

Figure 6: Most abundant species at station Piran Buoy

7.1.2.3 Po

At station Po, 459 bivalve individuals were found (Grab 4 and Grab 5 added together). This represents the lowest individual number of all stations. In the sample 20 different species were identified. The most abundant species are *Corbula gibba* with 30.7 %, *Kurtiella bidentata* with 17.4 %, *Anadara transversa* with 16.3 % and *Saxicavella jeffreysi* with 15.7 % total abundance. All other species together account for 19.9 % (Figure 7).

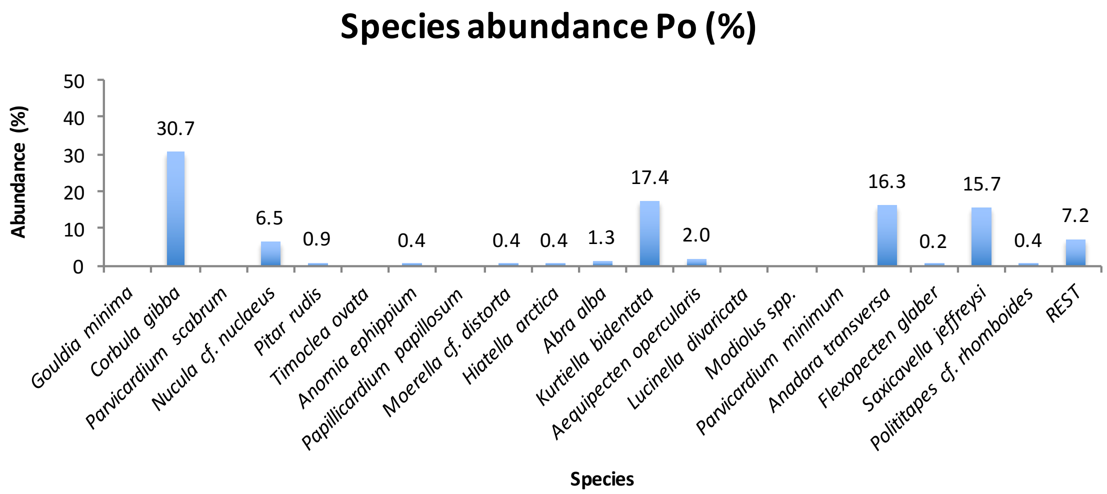

Figure 7: Most abundant species at station Po

7.1.2.4 Po Buoy

At station Po Buoy, 784 bivalve specimens were counted (Grab 1 and Grab 2 summarized) and 24 different bivalve species were found. Most abundant species are *Corbula gibba*, *Kurtiella bidentata* and *Anadara transversa* with 44.1 %, 11.1 % and 19.6 % respectively. Species with < 10 % abundance account for 25.2 % (Figure 8).

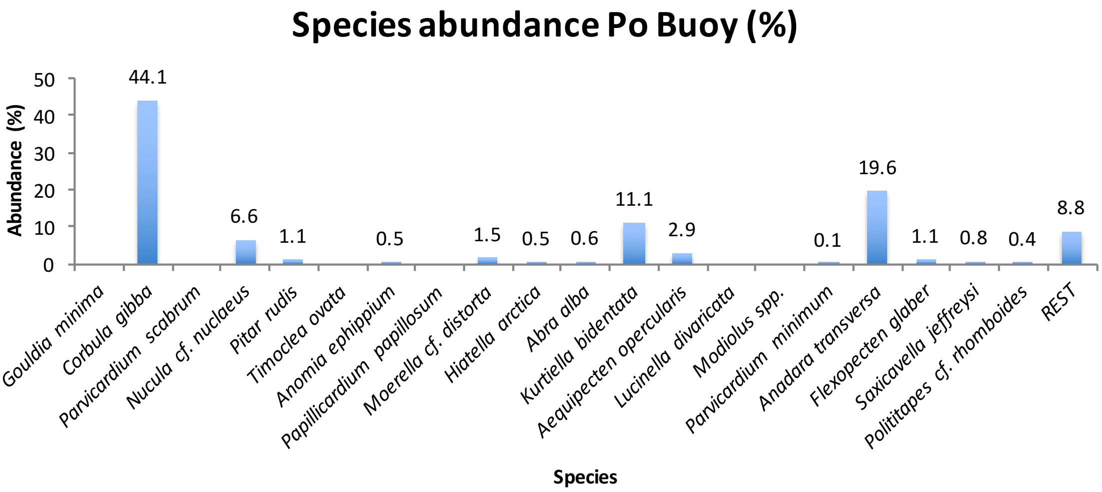

Figure 8: Most abundant species at station Po Buoy

7.1.2.5 Brijuni

At station Brijuni, a total of 2,133 bivalve individuals was counted. Out of the 55 species that were identified, the most abundant species are *Corbula gibba*, *Nucula cf. nuclaeus, Timoclea ovata* and *Parvicardium minimum* with abundances of 10.5 %, 14.4 %, 10.8 % and 11.1 %, respectively. Species with < 10 % abundance account for a total of 53.2 % (Figure 9).

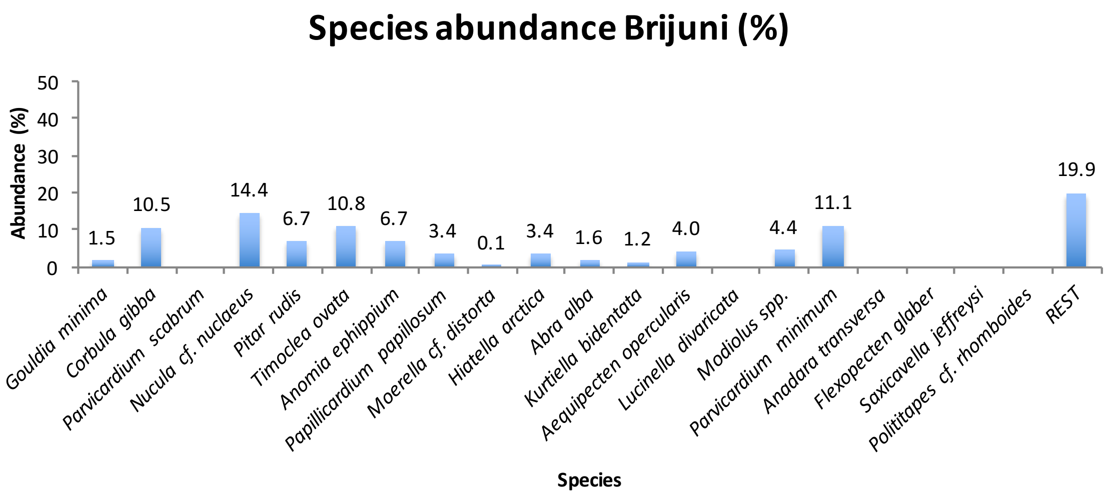

Figure 9: Most abundant species at station Brijuni

7.1.2.6 Venice

At station Venice, 2,244 bivalve individuals were detected. In total, 52 bivalve species were found. The two most abundant species are *Parvicardium scabrum* and *Lucinella divaricata* with 19.6 % and 16.5 %, respectively. All other species contribute < 10 % and account for 63.9 % in total. Station Venice is the only station where *Lucinella divaricata* was found in high numbers (Figure 10).

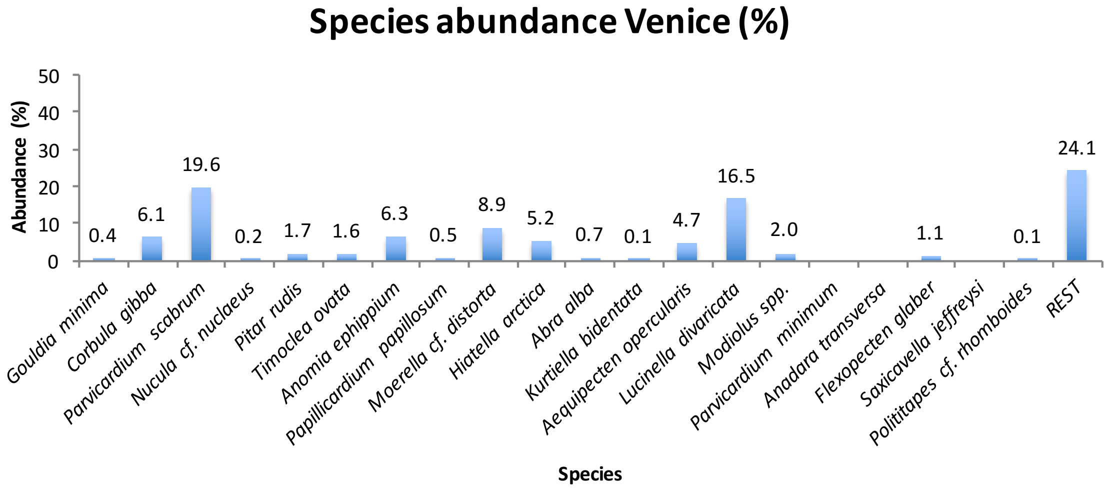

Figure 10: Most abundant species at station Venice

7.1.2.7 Panzano

At station Panzano, 846 bivalve individuals were counted and 37 different species identified. Most abundant species are *Corbula gibba* with 41.1 % and *Kurtiella bidentata* with 12.5 %. Species with < 10 % abundance account for 46.4 % (Figure 11).

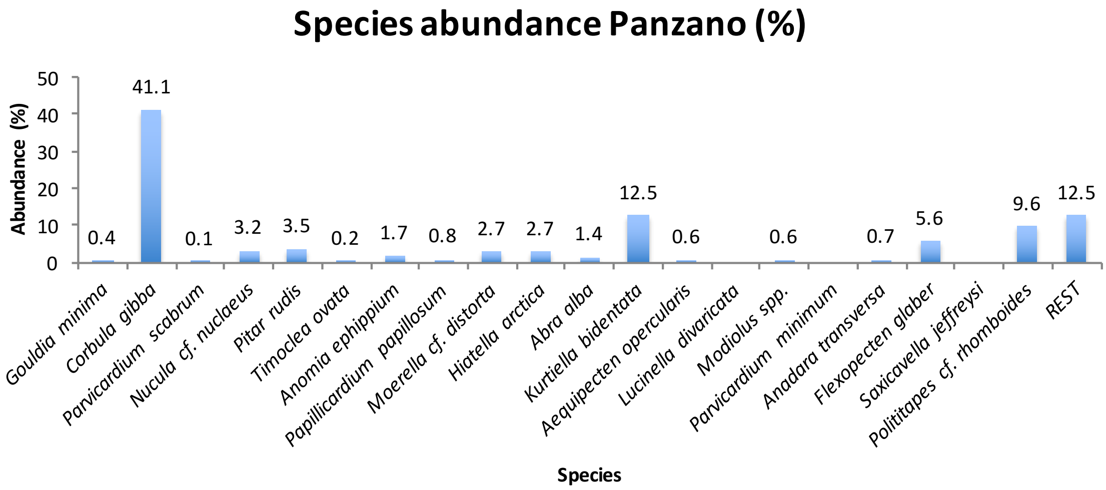

Figure 11: Most abundant species at station Panzano

7.1.2.8 Position D

At station Position D, a total number of 3,603 bivalves were counted. In the sample 55 different bivalve species were identified. Most abundant species at this station are *Corbula gibba*, *Parvicardium scabrum* and *Timoclea ovata* with 30.6 %, 18.5 % and 14.9 %, respectively. All other species accounted for < 10 % of abundance in the sample and made up a total of 36 % (Figure 12).

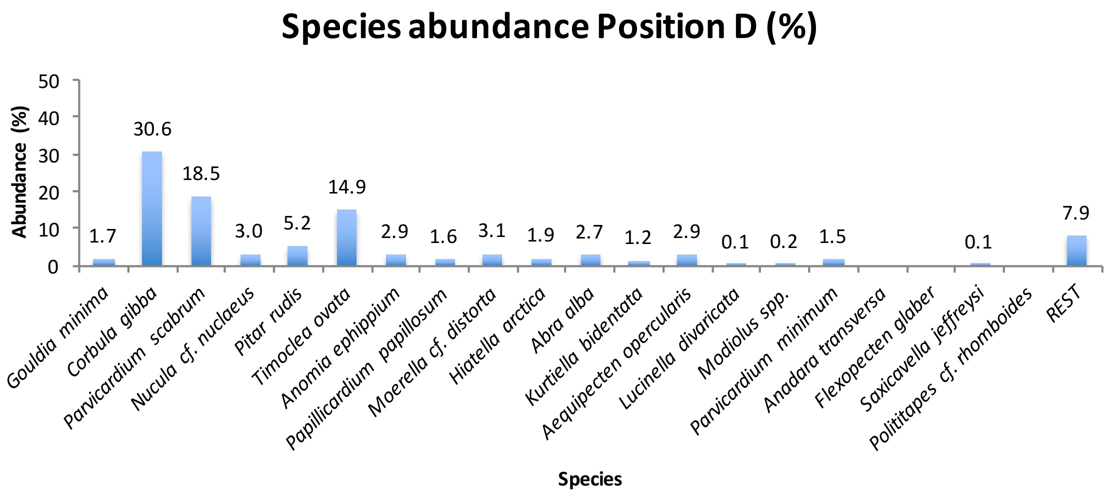

Figure 12: Most abundant species at station Position D

7.2 Shannon-Wiener Index

The number of species at the sampling stations ranged from 459 individuals at station Po to 12,903 individuals at stations Piran Buoy. At station Po, only 20 species were found whereas station Piran Buoy showed the highest species numbers with 63 species. At station Po Buoy, Shannon-Wiener Index was lowest among all stations with 1.90. Stations Brijuni and station Venice showed highest values for Shannon-Wiener Index with 2.96 and 2.86, respectively (Table 1).

Station	Individuals	Number of species	Shannon-Wiener Index
Piran II	6,324	55	1.99
Piran Buoy	12,903	63	2.06
Po	459	20	2.01
Po Buoy	784	24	1.90
Brijuni	2,133	55	2.96
Venice	2,244	52	2.86
Panzano	846	37	2.31
Position D	3,603	55	2.42

Table 1: Number of Species, Number of Individuals and Shannon-Wiener Index of the sampling stations

7.3 Rarefaction

The rarefaction curve at a sample size of 400 individuals (Figure 13) shows an increase of species number of individuals for the first few hundred individuals at all of the sampling stations, indicating high eveness.

At individual numbers of 400, Brijuni and Venice show highest species richness with 36 and 37 species, respectively. The samples from stations Piran and Piran Buoy show similar results as Position D and Panzano with 30, 31, 31 and 30 species, respectively.

The stations off the Po delta show the lowest number of species with 21 species at station Po Buoy and 19 species at station Po.

The curves in Figure 13 do not level off, which indicates that additional sampling would increase the number of species at all of the stations.

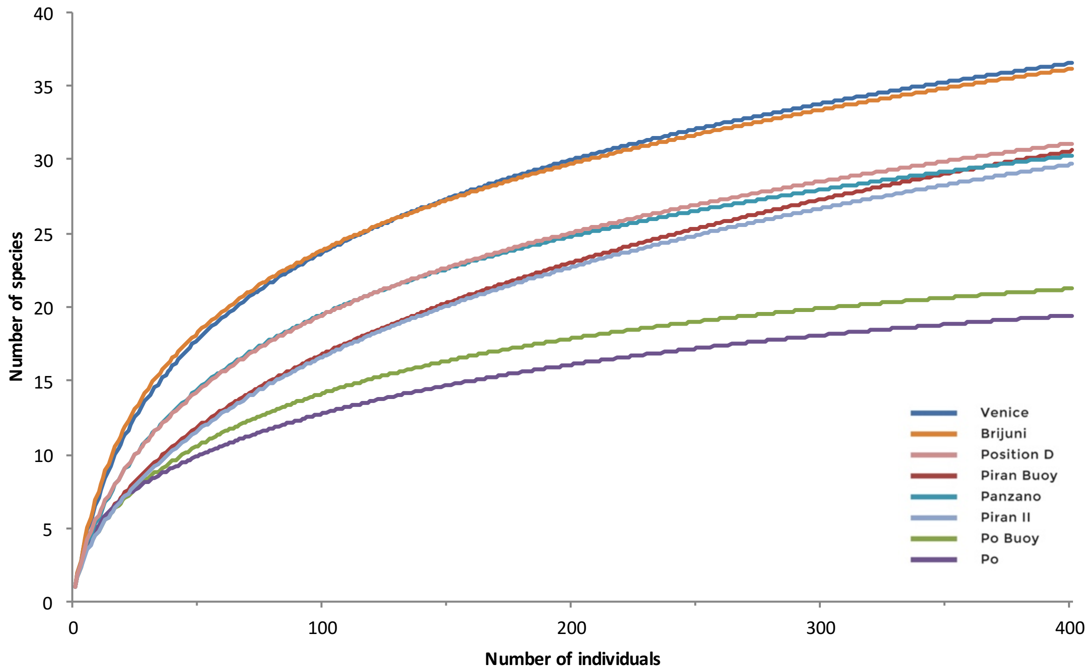

Figure 13: Rarefaction curve of total individuals, sampling size 400 individuals

7.4 Cluster analysis

At a Bray-Curtis similarity of 0.32, two clusters can be distinguished (Figure 14). In one cluster, stations Panzano, Po Buoy and Po are united. The second cluster includes stations Venice, Piran Buoy, Piran II, Position D and Brijuni.

At a similarity of 0.56, the stations Panzano, Po Buoy and Po still cluster, whereas the other stations split up. Brijuni, Position D and Venice are outliers. Only the two stations close to Piran (Piran Buoy and Piran II) cluster at a Bray-Curtis similarity level of 0.88.

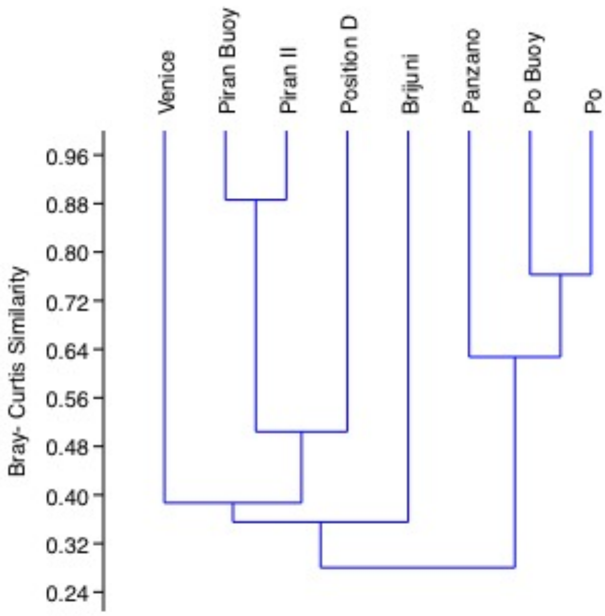

Figure 14: Cluster analysis of sampling stations performed with Bray-Curtis similarity index

7.5 Non-metric MDS

The non-metric multidimensional ordination of the sampling stations shows a differentiation into distinct groups (Figure 15). Sampling stations Po Buoy, Po and Panzano show a high Bray-Curtis similarity and group together. The sampling stations off Piran (Piran Buoy and Piran II) form another distinct group. Three sampling stations, Position D, Brijuni and Venice do not cluster at all and therefore are distinct from all other stations.

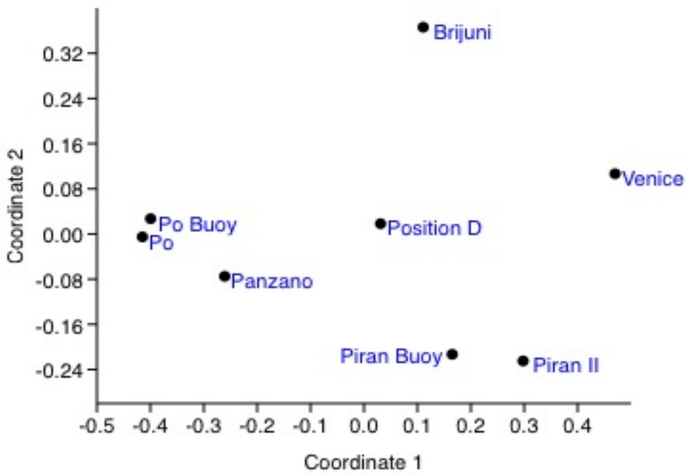

Figure 15: Non-metric MDS of sampling stations using Bray-Curtis similarity index

7.6 Environmental Parameters

7.6.1 Sedimentation rates

Annual sedimentation rates were fluctuating between 0.15 cm/ year at station Brijuni and 2.3 cm/ year at station Po. Generally, the sampling stations off the Po delta show the highest sedimentation rates with distance, compared to the other stations (Table 2).

Station	Sedimentation rate (cm/ year)
Piran II	0.16
Piran Bouy	0.26
Po	2.30
Po Buoy	1.80
Brijuni	0.15
Venice	N.A.
Panzano	0.24
Position D	N.A.

Table 2: Annual sedimentation rates at the sampling stations

7.6.2 Grain size analysis

Grain size distribution of sediments at the sampling stations off Piran and Brijuni show that all four types of grain sizes are represented. Nevertheless, stations Piran Buoy and Brijuni show a higher content of pelitic sediments with grain sizes smaller than 0.063 mm (Clay and silt) compared to station Piran II. The sediment at station Piran II consists, beside smaller fractions of clay and silt, to a large fraction of sand (more than 50 %). At station Venice the sediment consists almost exclusively of sand (Figure 16).

The distribution of grain sizes in the uppermost 20 cm of sediment at stations off the Po Delta (Po and Po Buoy) and sampling station Panzano mainly consist of clay and silt and therefore show high similarity (Figure 17).

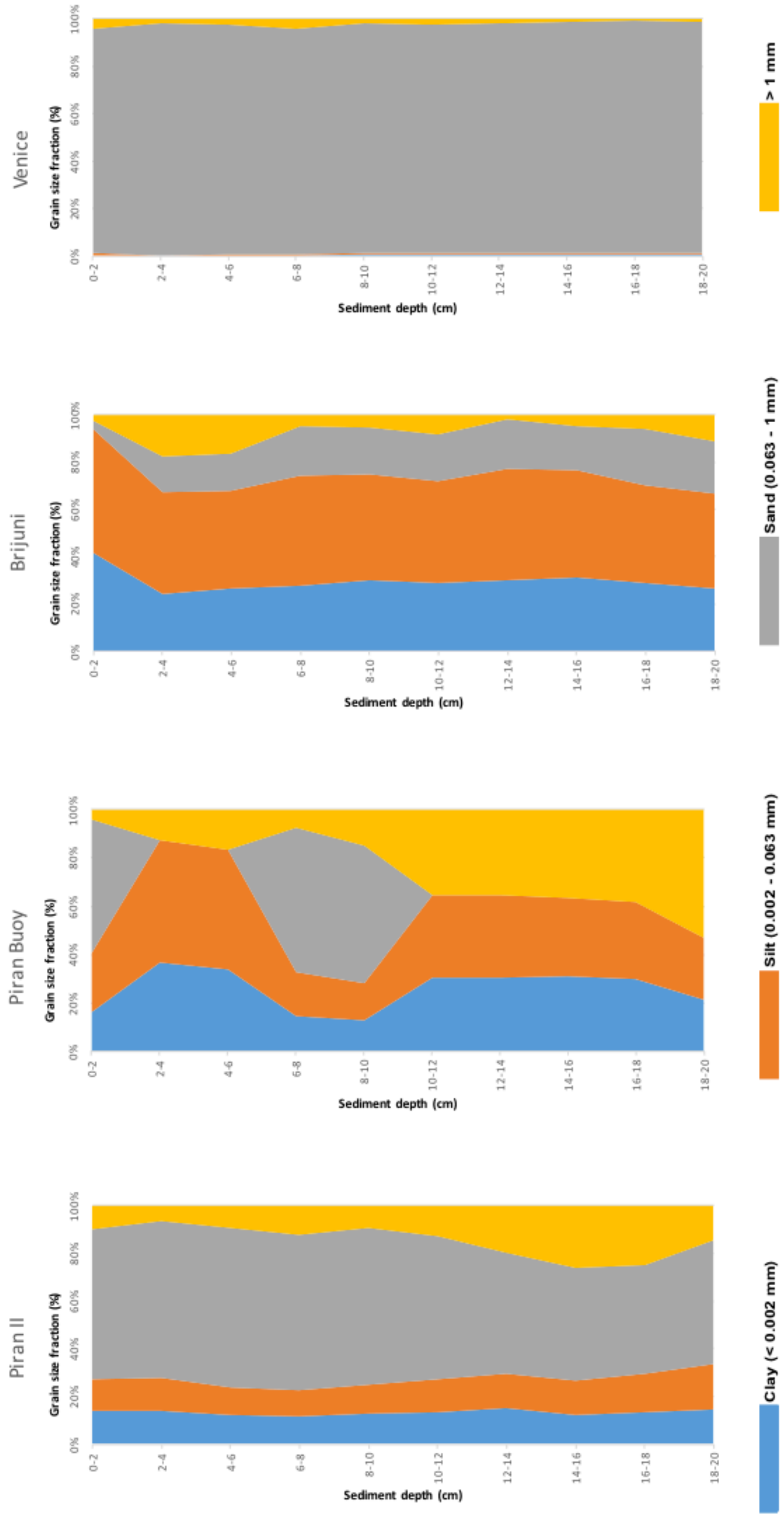

Figure 16: Grain size distribution of sediments from stations Piran II, Piran Buoy, Brijuni and Venice

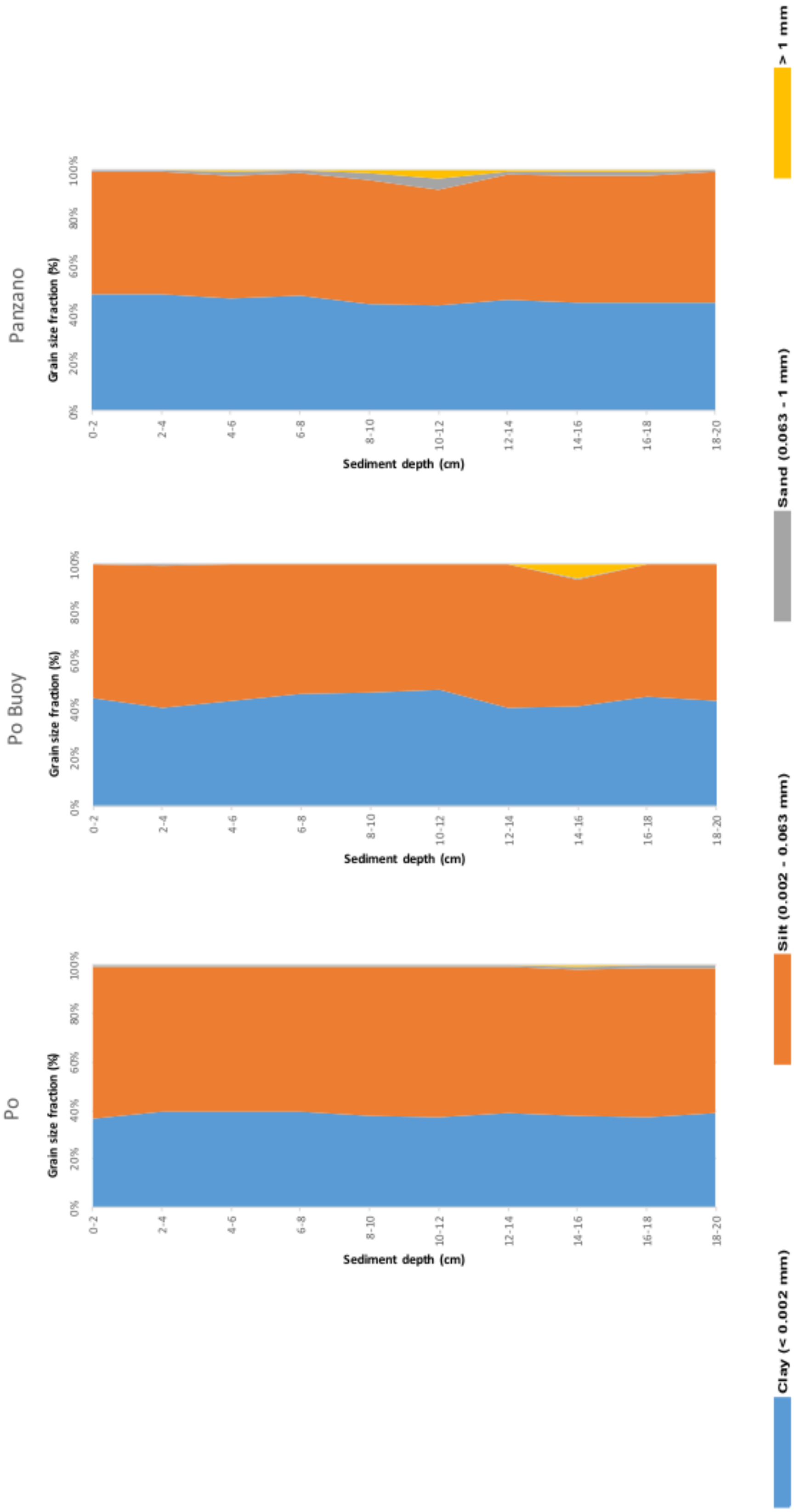

Figure 17: Grain size distribution of sediments from stations Po, Po Buoy and Panzano

7.6.3 Nutrients

Total Carbon (C tot), which is the total amount of inorganic and organic C in a sediment sample, was highest at station Piran II, Piran Buoy and Panzano with a proportion of almost 10 % of dry weight (%ss). Lowest concentration was found at stations Po Buoy and Po (Figure 18).

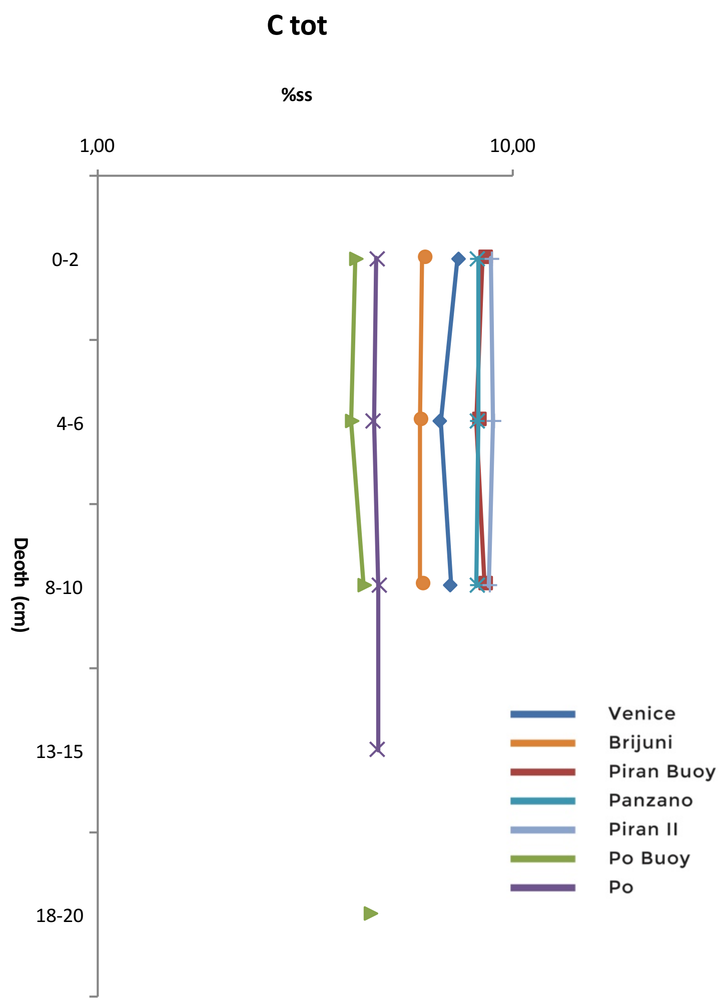

Figure 18: C tot concentration at the sampling stations

Total organic carbon (TOC) was found to be highest at the Po stations and at station Brijuni (from 1.5 % to 1.8 % of dry weight) with no striking variance in concentrations with depth (Figure 19). At station Venice, TOC was lowest (around 0.1 % of dry weight).

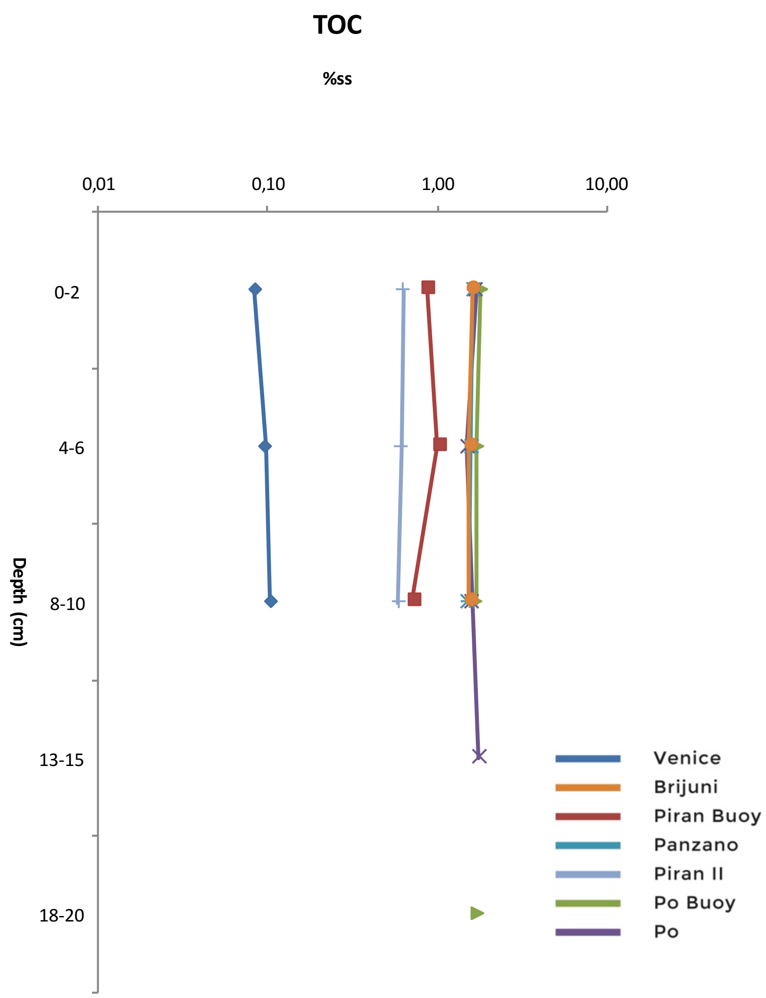

Figure 19: TOC concentration at the sampling stations

Total Nitrogen (N tot) concentration was highest at stations Panzano, Po Buoy, Po and Brijuni (Figure 20). Concentrations diverged between 0.11 % and 0.14 % of dry weight. At station Venice, N tot concentrations were found to be lowest (0.01 % to 0.02 % of dry weight). At the stations close to Piran (Piran Buoy and Piran II) an increase of N tot concentration from 10 cm depth to the sediment surface can be observed.

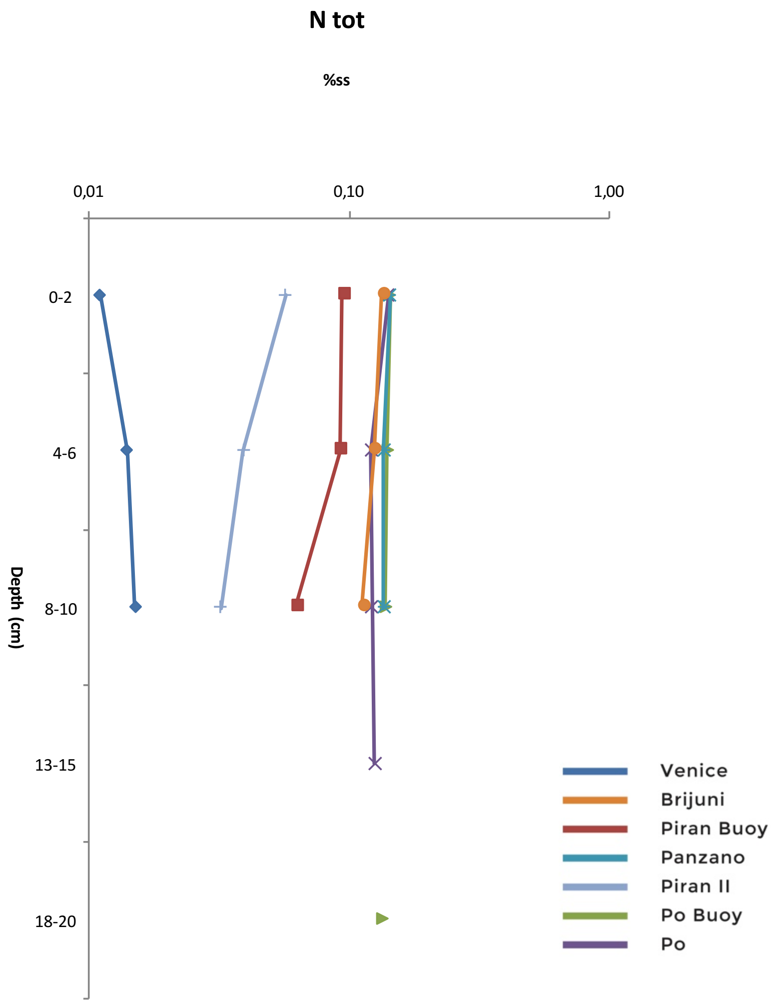

Figure 20: N tot concentration at the sampling stations

7.6.4 Pollutants

7.6.4.1 Heavy metals

Concentrations of Mercury (Hg) in the surface samples were quite distinct (Figure 21). Sampling stations Venice showed the lowest concentration of Hg, with 0.1 mg/ kg in the uppermost layer (0-6 cm) and an increase in concentration in deeper layers covering a sediment depth of 8-10 cm (0.05 mg/ kg). With concentrations of 8.22 to 11.75 mg/ kg from the uppermost layer to layers in a depth of 10 cm, the sediment at Panzano shows the highest Hg contamination.

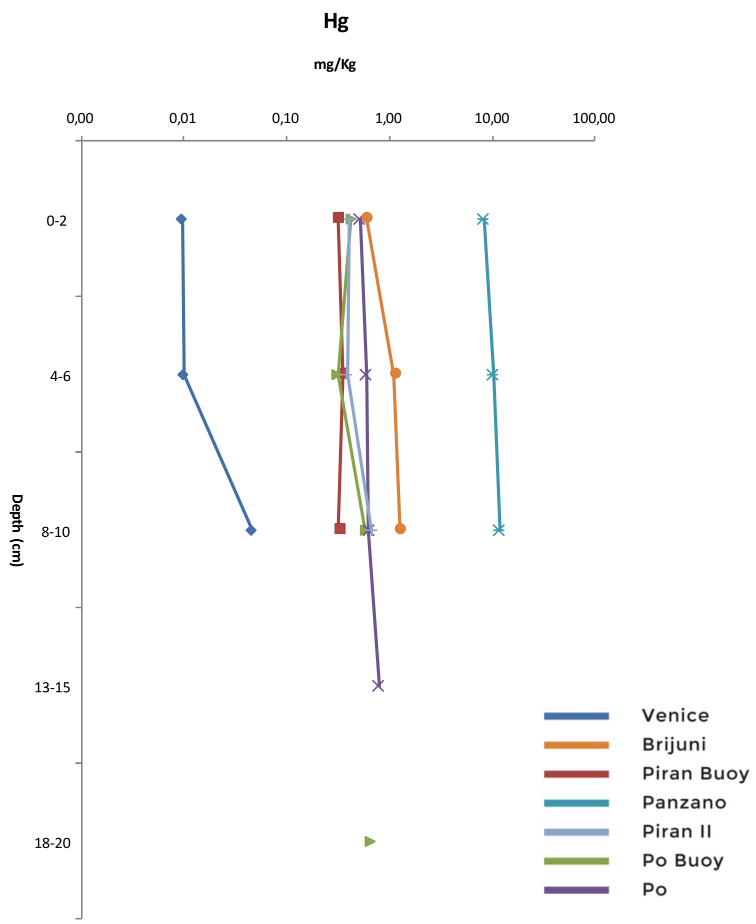

Figure 21: Hg sediment concentration at the sampling stations

Concentrations of Lead (Pb) showed highest values at stations Panzano, Po Buoy and Po (ranging from 26.72 mg/ kg at station Po to 27.99 mg/ kg at Panzano). Lowest values were found at station Venice, where the concentration in the top sediment were 4.24 mg/ kg. In general, no significant increase or decrease in Pb concentrations with depth can be observed (Figure 22).

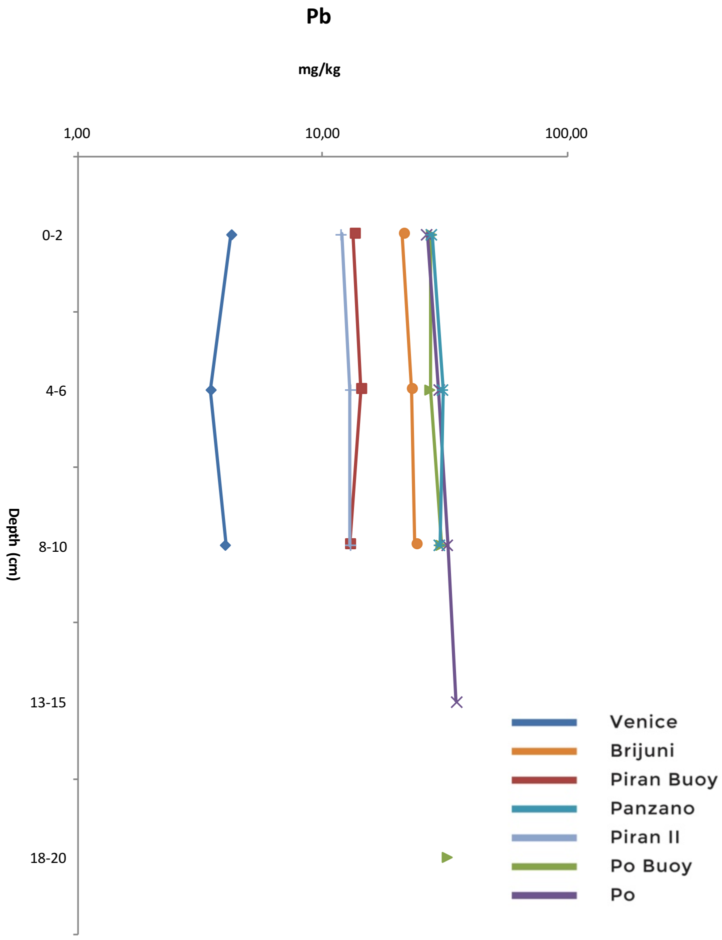

Figure 22: Pb sediment concentration at the sampling stations

Sediment concentrations of Arsenic (As) were highest at station Venice with top sediment concentrations of 16.36 mg/ kg. Lowest concentration in the top sediment occurred at station Piran II with 3.62 mg/ kg (Figure 23).

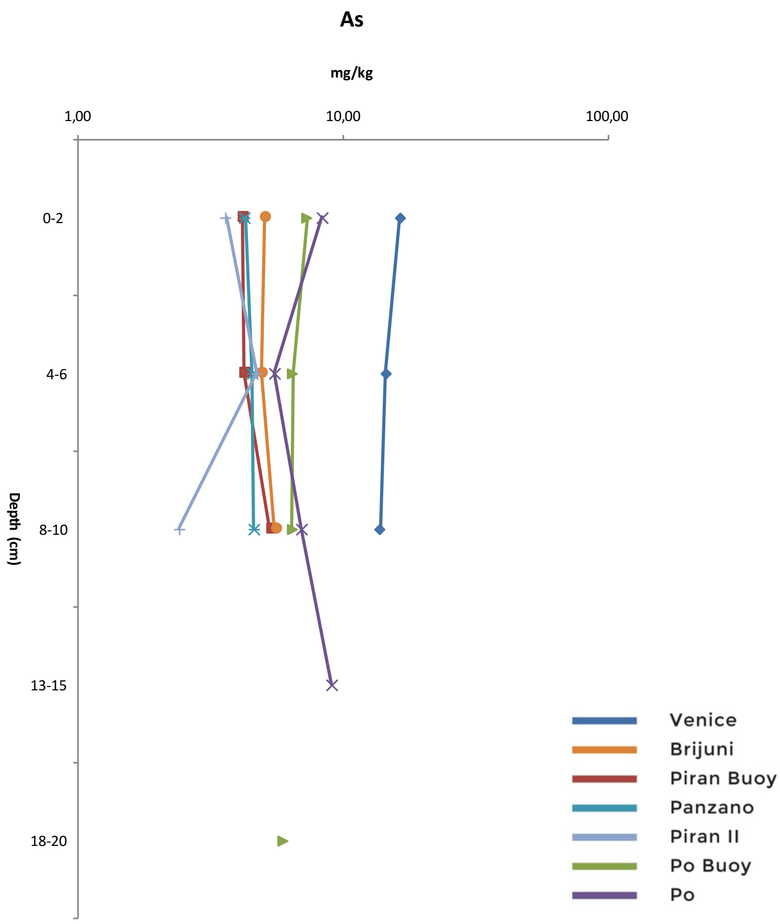

Figure 23: As sediment concentration at the sampling stations

7.6.4.2 Persistent organic pollutants

PCB concentrations in the sediments were fluctuating between 2.98 ng/ g in a depth of 8-10 cm at Piran II and 10.98 ng/ g in deeper surface layers (13-15 cm) at station Po (Figure 24). No significant change in concentrations with sediment depth are determinable.

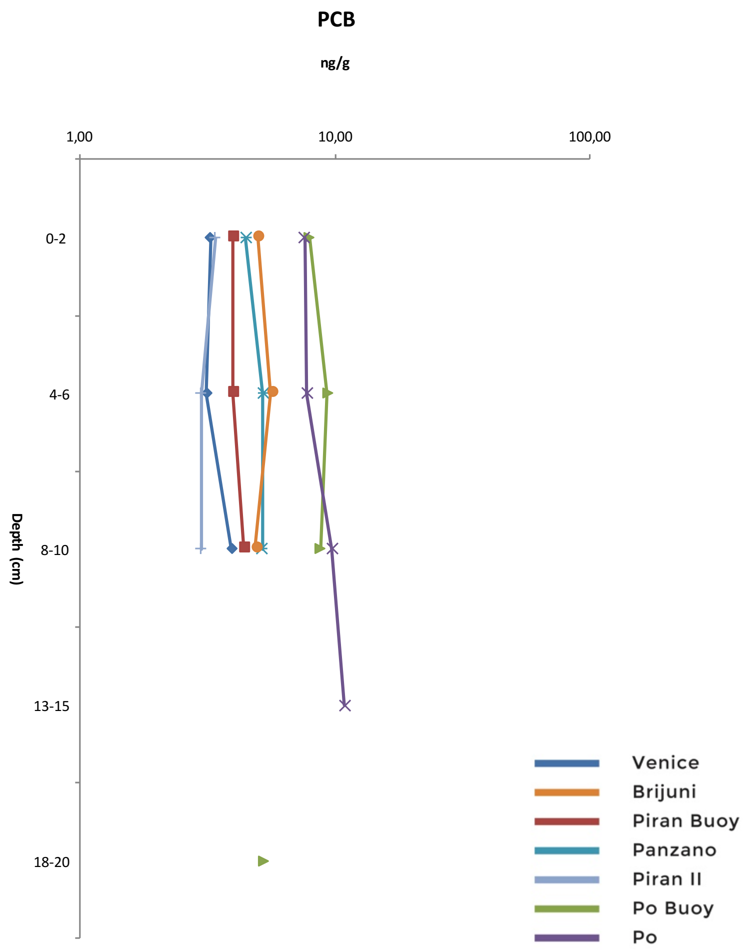

Figure 24: PCB sediment concentration at the sampling stations

The values of PAHs concentration in the sediment ranged between 6.23 and 9.80 ng/ g at stations Venice, which showed the lowest concentration and Brijuni with the highest constant values ranging from 347.20 ng/ g to 404.59 ng/ g (from sediment surface to a depth of 10 cm). The other stations showed rather inconspiciously fluctuating values in the area of about 50 to 300 ng/ g. The only outlier represents sampling station Piran II, where levels of PAH concentration increase dramatically from 48.78 ng/ g to 4184.42 ng/g in a sediment depth of 8-10 cm. (Figure 25).

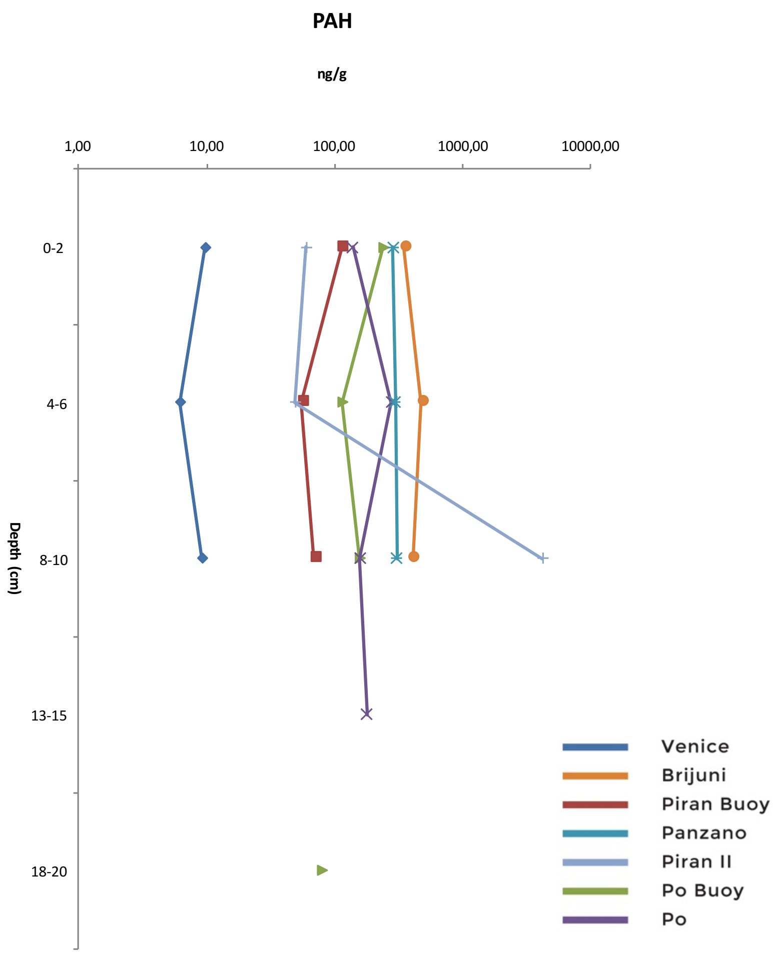

Figure 25: PAH sediment concentration at the sampling stations

7.7 Drilling predation

7.7.1 Total Fauna

In total, 15,699 individuals with ≥ 90 % of shell preserved were counted among all eight sampling points. For the total fauna, the mean drilling frequency (DF), incomplete drilling frequency (IDF) and prey effectiveness (PE) were 26.0 %, 1.3 % and 4.8 % respectively.

Nine of the 35 families were never drilled but also have been found only in low numbers (≤ 40).

DFs from the attacked families ranged from 2.9 % (Laseidae) to 39.1 % (Veneridae and Ostreidae).

Eight of the 35 families showed incomplete drill holes. IDFs ranged from 0.1 % (Veneridae) to 6.4 % (Corbulidae).

Families which have been drilled incompletely showed PE values ranging from 0.2 % (Cardiidae) to 20.7 % (Corbulidae) (Table 3).

The five most abundant species found within the samples were *Nucula cf. nucleaus*, *Parvicardium scabrum*, *Gouldia minima*, *Timoclea ovata* and *Corbula gibba*. All of them were drilled with DFs ranging from 12.8 % (*Timoclea ovata*) and 46.0 % (*Gouldia minima*). IDFs are ranging from 0.0 % (*Parvicardium scrabrum*) and 6.4 % (*Corbula gibba*). PE values are within a spectrum of 0.3 % (*Parvicardium scabrum, Gouldia minima*) and 20.7 % (*Corbula gibba*) (Table 3).

Total Fauna

	S	*n*	D	ID	DF %	IDF %	PE %
Class							
Bivalvia		15,699	4,076	205	26.0	1.3	4.8
Family							
Bivalvia							
Nuculanidae	2	167	20	2	12.0	1.2	9.1
Nuculidae	1	689	207	3	30.0	0.4	1.4
Arcidae	4	419	19	0	4.5	0.0	0.0
Noetiidae	1	74	14	0	18.9	0.0	0.0
Glycymerididae	2	21	2	0	9.5	0.0	0.0
Mytilidae	3	135	38	0	28.1	0.0	0.0
Pectinidae	5	317	27	0	8.5	0.0	0.0
Propeamussidae	1	1	0	0	0.0	0.0	-
Anomioidea	3	633	219	1	34.6	0.2	0.5
Limidae	3	4	0	0	0.0	0.0	-
Ostreidae	1	23	9	0	39.1	0.0	0.0
Lucinidae	4	1,113	293	1	26.3	0.1	0.3
Thyasiridae	1	27	0	0	0.0	0.0	-
Montacutidae	8	421	86	0	20.4	0.0	0.0
Laseidae	2	35	1	0	2.9	0.0	0.0
Kellidae	1	17	5	0	29.4	0.0	0.0
Carditidae	1	82	27	0	32.9	0.0	0.0
Chamidae	1	37	10	0	27.0	0.0	0.0
Basterotiidae	1	62	0	0	0.0	0.0	-
Cardiidae	8	3,170	463	1	14.6	0.0	0.2
Mactridae	1	49	11	0	22.4	0.0	0.0
Semelidae	3	82	12	0	14.6	0.0	0.0
Tellinidae	3	245	40	0	16.3	0.0	0.0
Psammobiidae	2	8	0	0	0.0	0.0	-
Solecurtidae	1	13	0	0	0.0	0.0	-
Donacidae	1	9	2	0	22.2	0.0	0.0
Veneridae	11	5,098	1993	6	39.1	0.1	0.3
Ungulinidae	1	1	0	0	0.0	0.0	-
Corbulidae	2	2,942	718	187	24.4	6.4	20.7
Pharidae	1	15	0	0	0.0	0.0	-
Gastrochaenidae	1	25	1	0	4.0	0.0	0.0
Hiatellidae	1	428	79	5	18.5	1.2	6.0
Pandoridae	1	2	0	0	0.0	0.0	-
Cuspidariidae	2	7	2	0	28.6	0.0	0.0
Thraciidae	1	52	7	0	13.5	0.0	0.0
Most abundant species							
Bivalvia							
Nucula cf. nuclaeus		689	207	3	30.0	0.4	1.4
Parvicardium scabrum		2,279	361	1	15.8	0.0	0.3
Gouldia minima		3,890	1,790	5	46.0	0.1	0.3
Timoclea ovata		648	83	1	12.8	0.2	1.2
Corbula gibba		2,941	718	187	24.4	6.4	20.7

Table 3: Taxonomic summary of drill hole data pooled across all samples for classes, families and the 5 most abundant species of bivalves

The drill hole data of the most abundant species in the death assemblage (n ≥ 50) show that all of the abundant species were drilled, except one species (*Saxicavella jeffreysi*). DFs are ranging between 1.4 % (*Arca noae*) and 46.0 % (*Gouldia minima*). Only seven out of the 29 abundant species were found to be drilled incompletely with IDFs ranging from 0.1 % (*Gouldia minima*) to 6.4 % (*Corbula gibba*). PE values are spanning between 0.3 % (*Parvicardium scabrum*) and 33.3 % (*Saccella commutata*) (Table 4).

Total Fauna

	n	D	ID	DF %	IDF %	PE %
Species n>50						
Bivalvia						
Nuculana pella	85	16	0	18.8	0.0	0.0
Saccella commutata	82	4	2	4.9	2.4	33.3
Nucula cf. nuclaeus	689	207	3	30.0	0.4	1.4
Arca noae	71	1	0	1.4	0.0	0.0
Arca tetragona	110	5	0	4.5	0.0	0.0
Anadara transversa	237	13	0	5.5	0.0	0.0
Striarca lactea	74	14	0	18.9	0.0	0.0
Modiolus spp.	94	28	0	29.8	0.0	0.0
Aequipecten opercularis	218	20	0	9.2	0.0	0.0
Flexopecten glaber	63	1	0	1.6	0.0	0.0
Anomia ephippium	562	192	0	34.2	0.0	0.0
Heteranomia squamula	62	21	0	33.9	0.0	0.0
Lucinella divaricata	315	50	0	15.9	0.0	0.0
Kurtiella bidentata	403	86	0	21.3	0.0	0.0
Centrocardita aculeata	82	27	0	32.9	0.0	0.0
Saxicavella jeffreysi	62	0	0	0.0	0.0	-
Acanthocardia paucicostata	50	1	0	2.0	0.0	0.0
Parvicardium exiguum	88	18	0	20.5	0.0	0.0
Parvicardium scabrum	2,279	361	1	15.8	0.0	0.3
Parvicardium minimum	251	9	0	3.6	0.0	0.0
Papillicardium papillosum	442	59	0	13.3	0.0	0.0
Abra alba	53	9	0	17.0	0.0	0.0
Moerella cf. distorta	236	38	0	16.1	0.0	0.0
Gouldia minima	3,890	1790	5	46.0	0.1	0.3
Pitar rudis	354	91	0	25.7	0.0	0.0
Timoclea ovata	648	83	1	12.8	0.2	1.2
Corbula gibba	2,941	718	187	24.4	6.4	20.7
Hiatella arctica	428	79	5	18.5	1.2	6.0
Thracia phaseolina	52	7	0	13.5	0.0	0.0

Table 4: Drill hole data of bivalve species n≥ 50 pooled across all samples

7.7.1.1 Drill frequency (DF)

In all of the the death assemblages of the seven sampling points, drilled shells have been found. DFs are ranging between 0.5 % (Po) and 36.0 % (Panzano), with most of the stations having DFs >10% (Table 5).

Station	Total (Preserved shells)	Drills (total)	DF (%)
Piran Buoy	5,770	2,027	35.1
Piran II	3,342	974	29.1
Po	369	2	0.5
Po Buoy	695	15	2.2
Brijuni	1,512	391	25.9
Venice	1,426	165	11.6
Panzano	602	217	36.0
Position D	1,983	285	14.4
Total	15,699	4,076	26.0

Table 5: Mean Drill frequency of all sampling stations

7.7.1.2 Incomplete drill frequency (IDF)

In seven out of eight death assemblages, shells with incomplete drill holes were found. IDFs are ranging between 0.28 % (Venice) and 3.99 % (Panzano). In the death assemblage of sampling station Po, no bivalve shells with incomplete drills have been found (Table 6).

Station	Total (Preserved shells)	Incomplete drills (total)	IDF (%)
Piran Buoy	5,770	92	1.59
Piran II	3,342	23	0.69
Po	369	0	0.00
Po Buoy	695	2	0.29
Brijuni	1,512	13	0.86
Venice	1,426	4	0.28
Panzano	602	24	3.99
Position D	1,983	47	2.37
Total	15,699	205	1.31

Table 6: Mean Incomplete drill frequency of all sampling stations

7.7.1.3 Multiple drill frequency (MDF)

In six out of eight samples, bivalve shells with more than one drill hole were found. MDFs are ranging between 0.1 % at sampling point Venice and 0.8 % at sampling point Brijuni. In the samples taken close to the Po Delta (Sampling station Po and Po Buoy), no bivalve shells with multiple drills were found. (Table 7).

Station	Total (Preserved shells)	Multiple drills (total)	MDF (%)
Piran Buoy	5,770	11	0.2
Piran II	3,342	9	0.3
Po	369	0	0.0
Po Buoy	695	0	0.0
Brijuni	1,512	12	0.8
Venice	1,426	2	0.1
Panzano	602	1	0.2
Position D	1,983	7	0.4
Total	15,699	42	0.3

Table 7: Multiple drill frequency of all sampling stations and of the total assemblage

7.7.1.4 Edge drill frequency (EDF)

At all the sampling stations, shells with edge drills have been detected. The EDFs are ranging between 0.3 % at sampling station Po and 2.8 % at sampling station Venice (Table 8).

Station	Total (Preserved shells)	Edge drills (total)	EDF (%)
Piran Buoy	5,770	96	1.7
Piran II	3,342	64	1.9
Po	369	1	0.3
Po Buoy	695	5	0.7
Brijuni	1,512	43	2.8
Venice	1,426	5	0.4
Panzano	602	11	1.8
Position D	1,983	20	1.0
Total	15,699	245	1.6

Table 8: Edge drill frequency of all sampling stations and of the total assemblage

7.7.1.5 Prey effectiveness (PE)

PE values between the different stations are ranging from 0.0 % at sampling station Po, where no incompletely drilled shells have been found, to 14.2 % at sampling station Position D (Table 9).

Station	Total attacks	Incomplete drills (total)	PE (%)
Piran Buoy	2,119	92	4.3
Piran II	997	23	2.3
Po	2	0	0.0
Po Buoy	17	2	11.8
Brijuni	404	13	3.2
Venice	169	4	2.4
Panzano	241	24	10.0
Position D	332	47	14.2
Total	4,281	205	4.8

Table 9: Prey effectiveness of all sampling stations and of the total assemblage

7.7.2 Sampling stations

7.7.2.1 Piran II

Within the grab sample of sampling point Piran II all of the most abundant families (n ≥ 20) were found to be drilled (Table 10). The DFs ranged from 10.0 % (Arcidae) to 41.1 % (Veneridae). Only three of the abundant families were drilled incompletely with IDFs ranging from 0.2 % (Veneridae) to 4.5 % (Corbulidae). Among the incompletely drilled families, PEs ranged from 0.5 % (Veneridae) to 20.7 % (Corbulidae).

Piran II

Families n≥20	**S**	***n***	**D**	**ID**	**DF** (%)	**IDF** (%)	**PE** (%)
Nuculanidae	2	25	7	0	28.0	0.0	0.0
Nuculidae	*1*	87	26	0	29.9	0.0	0.0
Arcidae	3	40	4	0	10.0	0.0	0.0
Anomioidea	*2*	107	25	0	23.4	0.0	0.0
Lucinidae	*3*	26	4	0	15.4	0.0	0.0
Montacutidae	*4*	37	9	0	24.3	0.0	0.0
Carditidae	*1*	26	7	0	26.9	0.0	0.0
Cardiidae	*6*	786	141	0	17.9	0.0	0.0
Tellinidae	*2*	37	10	0	27.0	0.0	0.0
Veneridae	*6*	1,580	649	3	41.1	0.2	0.5
Corbulidae	*1*	400	69	18	17.3	4.5	20.7
Hiatellidae	*1*	101	12	2	11.9	2.0	14.3

Table 10: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Piran II

The most abundant bivalve species (n ≥ 20) of station Piran II were all drilled (Table 11). DFs were ranging from 6.9 % (*Arca tetragona*) to 43.4 % (*Gouldia minima*). Three out of the abundant species were drilled incompletely with lowest IDFs of 0.2 % (*Gouldia minima*) to highest values of 4.5 % (*Corbula gibba*). The corresponding PE values were spanning from 0.5 % (*Gouldia minima*) to 20.7 % (*Corbula gibba*).

Piran II

Species n≥20	***n***	**D**	**ID**	**DF** (%)	**IDF** (%)	**PE** (%)
Nuculana pella	23	7	0	30.4	0.0	0.0
Nucula cf. nuclaeus	87	26	0	29.9	0.0	0.0
Arca tetragona	29	2	0	6.9	0.0	0.0
Anomia ephippium	98	24	0	24.5	0.0	0.0
Kurtiella bidentata	34	9	0	26.5	0.0	0.0
Centrocardita aculeata	26	7	0	26.9	0.0	0.0
Parvicardium scabrum	663	120	0	18.1	0.0	0.0
Papillicardium papillosum	87	16	0	18.4	0.0	0.0
Moerella cf. distorta	35	9	0	25.7	0.0	0.0
Gouldia minima	1,395	605	3	43.4	0.2	0.5
Pitar rudis	68	23	0	33.8	0.0	0.0
Timoclea ovata	94	17	0	18.1	0.0	0.0
Corbula gibba	400	69	18	17.3	4.5	20.7
Hiatella arctica	101	12	2	11.9	2.0	14.3

Table 11: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Piran II

7.7.2.1 Piran Buoy

In the death assemblage of sampling point Piran Buoy, only one of the most abundant families (n ≥ 20) was not drilled (Table 12). DFs of the other families ranged from 6.2 % (Arcidae) to 45.7 % (Veneridae). Five of the abundant families within the sample were drilled incompletely with IDFs ranging from 0.1 % (Veneridae, Cardiidae) to 8.9 % (Corbulidae). Among the families with incomplete drills PEs ranged from 0.4 % (Cardiidae) to 21.1 % (Corbulidae).

Piran Buoy

Families n≥20	S	*n*	D	ID	DF (%)	IDF (%)	PE (%)
Nuculanidae	2	34	5	0	14.7	0.0	0.0
Nuculidae	*1*	222	64	1	28.8	0.5	1.5
Arcidae	3	65	4	0	6.2	0.0	0.0
Noetiidae	*1*	25	0	0	0.0	0.0	-
Pectinidae	*3*	30	3	0	10.0	0.0	0.0
Anomioidea	*3*	162	62	0	38.3	0.0	0.0
Lucinidae	*4*	30	9	0	30.0	0.0	0.0
Montacutidae	*3*	76	19	0	25.0	0.0	0.0
Carditidae	*1*	56	20	0	35.7	0.0	0.0
Chamidae	*1*	23	7	0	30.4	0.0	0.0
Cardiidae	*7*	1,191	250	1	21.0	0.1	0.4
Tellinidae	*3*	32	8	0	25.0	0.0	0.0
Veneridae	*7*	2,638	1,205	2	45.7	0.1	0.2
Corbulidae	*1*	965	322	86	33.4	8.9	21.1
Hiatellidae	*1*	123	30	2	24.4	1.6	6.3

Table 12: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Piran Buoy

Within the abundant species of the grab sample from Piran Buoy (n ≥ 20) only two species were not drilled. DFs of drilled species ranged from 12.5 % (*Papillicardium papillosum*) to 47.6 % (*Gouldia minima*) (Table 13). Only five of the abundant species were found incompletely drilled with at least one incompletely perforated bore hole. IDFs ranged from 0.1 % (*Parivicardium scabrum*) to 8.9 % (*Corbula gibba*), PE values from 0.2 % (*Gouldia minima*) to 21.1 % (*Corbula gibba*).

Piran Buoy

Species n≥20	***n***	**D**	**ID**	**DF** (%)	**IDF** (%)	**PE** (%)
Nuculana pella	23	5	0	21.7	0.0	0.0
Nucula cf. nuclaeus	222	64	1	28.8	0.5	1.5
Arca noae	55	-	0	0.0	0.0	-
Striarca lactea	25	-	0	0.0	0.0	-
Anomia ephippium	129	49	0	38.0	0.0	0.0
Heteranomia squamula	25	7	0	28.0	0.0	0.0
Kurtiella bidentata	72	19	0	26.4	0.0	0.0
Centrocardita aculeata	56	20	0	35.7	0.0	0.0
Chama gryphoides	23	7	0	30.4	0.0	0.0
Parvicardium exiguum	68	14	0	20.6	0.0	0.0
Parvicardium scabrum	865	204	1	23.6	0.1	0.5
Papillicardium papillosum	240	30	0	12.5	0.0	0.0
Moerella cf. distorta	30	7	0	23.3	0.0	0.0
Gouldia minima	2,435	1,159	2	47.6	0.1	0.2
Pitar rudis	116	29	0	25.0	0.0	0.0
Timoclea ovata	53	9	0	17.0	0.0	0.0
Corbula gibba	965	322	86	33.4	8.9	21.1
Hiatella arctica	123	30	2	24.4	1.6	6.3

Table 13: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Piran Buoy

7.7.2.2 Po

With a total individual number of 459 bivalves, the grab samples of station Po contained the lowest number of individuals of all stations. Furthermore, only two out of five most abundant families (n ≥ 20) were found to be drilled (Table 14). DF values were lowest within the family of Corbulidae with 0.8 % and highest in the family of Arcidae with 1.4 %. None of the families featured incomplete drill holes.

Po

Families n≥20	**S**	***n***	**D**	**ID**	**DF (%)**	**IDF (%)**	**PE (%)**
Nuculidae	1	21	0	0	0.0	0.0	-
Arcidae	1	70	1	0	1.4	0.0	0.0
Montacutidae	1	58	0	0	0.0	0.0	-
Basterotiidae	1	51	0	0	0.0	0.0	-
Corbulidae	1	122	1	0	0.8	0.0	0.0

Table 14: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Po

Two of the most abundant species (n ≥ 20) in the grab samples Po contained drills (Table 15). DFs from *Corbula gibba* were 0.8 % and from *Anadara transversa* 1.4 %. None of the abundant species was incompletely drilled.

Po

Species n≥20	***n***	**D**	**ID**	**DF (%)**	**IDF (%)**	**PE (%)**
Nucula cf. nuclaeus	21	0	0	0.0	0.0	-
Anadara transversa	70	1	0	1.4	0.0	0.0
Kurtiella bidentata	58	0	0	0.0	0.0	-
Saxicavella jeffreysi	51	0	0	0.0	0.0	-
Corbula gibba	122	1	0	0.8	0.0	0.0

Table 15: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Po

7.7.2.3 Po Buoy

Among the most abundant bivalve families (n ≥ 20) of sampling station Po Buoy, three families were drilled with DFs from 2.0 % (Arcidae) and 2.5 % (Montacutidae, Corbulidae). Only individuals from the family of Corbulidae were found incompletely drilled with an IDF of 0.6 % and a PE value of 20.0 % (Table 16).

Po Buoy

Families n≥20	**S**	***n***	**D**	**ID**	**DF (%)**	**IDF (%)**	**PE (%)**
Nuculidae	*1*	42	0	0	0.0	0.0	-
Arcidae	*1*	147	3	0	2.0	0.0	0.0
Pectinidae	2	28	0	0	0.0	0.0	-
Montacutidae	*1*	81	2	0	2.5	0.0	0.0
Corbulidae	*2*	318	8	2	2.5	0.6	20.0

Table 16: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Po Buoy

In the grab sample of station Po Buoy, three drilled species were found (Table 17). The drilled species *Anadara transversa*, *Kurtiella bidentata* and *Corbula gibba* showed DFs of 2.0 %, 2.5 % and 2.5 %, respectively. Only *Corbula gibba* was drilled incompletely with an IDF of 0.6 % and a PE value of 20.0 %.

Po Buoy

Species n≥20	***n***	**D**	**ID**	**DF (%)**	**IDF (%)**	**PE (%)**
Nucula cf. nuclaeus	42	0	0	0.0	0.0	-
Anadara transversa	147	3	0	2.0	0.0	0.0
Kurtiella bidentata	81	2	0	2.5	0.0	0.0
Corbula gibba	317	8	2	2.5	0.6	20.0

Table 17: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Po Buoy

7.7.2.4 Brijuni

All of the abundant families (n ≥ 20) of sampling station Brijuni contained bore holes (Table 18). The family of Arcidae showed the lowest DF with 6.4 %, whereas the Noetiidae family had the highest DF (45.2 %). Families Nuculanidae, Nuculidae, Veneridae, Corbulidae and Hiatellidae contained incompletely perforated shells with IDFs ranging from 0.3 % (Veneridae) to 5.7 % (Nuculanidae).

Brijuni

Families n≥20	**S**	***n***	**D**	**ID**	**DF** (%)	**IDF** (%)	**PE** (%)
Nuculanidae	2	35	4	2	11.4	5.7	33.3
Nuculidae	1	236	90	2	38.1	0.8	2.2
Arcidae	2	47	3	0	6.4	0.0	0.0
Noetiidae	1	31	14	0	45.2	0.0	0.0
Mytilidae	2	45	22	0	48.9	0.0	0.0
Pectinidae	5	76	18	0	23.7	0.0	0.0
Anomioidea	2	143	62	0	43.4	0.0	0.0
Montacutidae	2	29	4	0	13.8	0.0	0.0
Cardiidae	3	299	31	0	10.4	0.0	0.0
Veneridae	7	289	69	1	23.9	0.3	1.4
Corbulidae	1	168	45	7	26.8	4.2	13.5
Hiatellidae	1	59	21	1	35.6	1.7	4.5

Table 18: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Brijuni

All of the abundant species (n ≥ 20) of Brijuni were drilled, whereas only five species were incompletely drilled (Table 19). *Parvicardium minimum* showed the lowest DF with 3.6 % and *Modiolus spp*. the highest DF of 50.0 %. IDFs ranged from 0.6 % (*Timoclea ovata*) to 5.9 % (*Saccella commutata*), PEs from 2.2 % (*Nucula cf. nuclaeus*) to 33.3 % (*Saccella commutata*).

Brijuni

Species n≥20	***n***	**D**	**ID**	**DF** (%)	**IDF** (%)	**PE** (%)
Saccella commutata	34	4	2	11.8	5.9	33.3
Nucula cf. nuclaeus	236	90	2	38.1	0.8	2.2
Arca tetragona	46	3	0	6.5	0.0	0.0
Striarca lactea	31	14	0	45.2	0.0	0.0
Modiolus spp.	44	22	0	50.0	0.0	0.0
Aequipecten opercularis	57	14	0	24.6	0.0	0.0
Anomia ephippium	132	55	0	41.7	0.0	0.0
Kurtiella bidentata	25	4	0	16.0	0.0	0.0
Parvicardium scriptum	47	14	0	29.8	0.0	0.0
Parvicardium minimum	193	7	0	3.6	0.0	0.0
Papillicardium papillosum	57	10	0	17.5	0.0	0.0
Gouldia minima	24	11	0	45.8	0.0	0.0
Pitar rudis	72	17	0	23.6	0.0	0.0
Timoclea ovata	167	37	1	22.2	0.6	2.6
Corbula gibba	168	45	7	26.8	4.2	13.5
Hiatella arctica	59	21	1	35.6	1.7	4.5

Table 19: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Brijuni

7.7.2.5 Venice

Grab samples of sampling station Venice showed only one family that was not drilled (Arcidae) (Table 20). Drilled families had DFs from 2.1 % (Cardiidae) to 31.1 % (Corbulidae). The family of Corbulidae was the only family that contained individuals with incomplete perforation. This resulted in an IDF of 4.4 % and a PE value of 12.5 %.

Venice

Families n≥20	S	*n*	D	ID	DF (%)	IDF (%)	PE (%)
Arcidae	3	36	0	0	0.0	0.0	-
Mytilidae	2	30	7	0	23.3	0.0	0.0
Pectinidae	3	54	4	0	7.4	0.0	0.0
Anomioidea	2	106	20	0	18.9	0.0	0.0
Lucinidae	1	301	48	0	15.9	0.0	0.0
Cardiidae	5	377	8	0	2.1	0.0	0.0
Mactridae	1	26	5	0	19.2	0.0	0.0
Tellinidae	2	107	9	0	8.4	0.0	0.0
Veneridae	9	101	16	0	15.8	0.0	0.0
Corbulidae	1	90	28	4	31.1	4.4	12.5
Hiatellidae	1	78	7	0	9.0	0.0	0.0
Thraciidae	1	52	7	0	13.5	0.0	0.0

Table 20: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Venice

Sampling point Venice contained one abundant species (n ≥ 20) that was not drilled at all (*Arca tetragona*) (Table 21). All other abundant species showed drills and had DFs ranging from 2.2 % (*Parvicardium scabrum*) to 31.1 % (*Corbula gibba*). From the family of Corbulidae, only one representative, *Corbula gibba*, showed incomplete perforation (IDF= 4.4 %; PE= 12.5 %).

Venice

Species n≥20	*n*	D	ID	DF (%)	IDF (%)	PE (%)
Arca tetragona	24	0	0	0.0	0.0	-
Modiolus spp.	20	4	0	20.0	0.0	0.0
Aequipecten opercularis	37	4	0	10.8	0.0	0.0
Anomia ephippium	101	20	0	19.8	0.0	0.0
Lucinella divaricata	301	48	0	15.9	0.0	0.0
Parvicardium scabrum	364	8	0	2.2	0.0	0.0
Spisula subtruncata	26	5	0	19.2	0.0	0.0
Moerella cf. distorta	106	9	0	8.5	0.0	0.0
Callista chione	38	1	0	2.6	0.0	0.0
Timoclea ovata	25	7	0	28.0	0.0	0.0
Corbula gibba	90	28	4	31.1	4.4	12.5
Hiatella arctica	78	7	0	9.0	0.0	0.0
Thracia phaseolina	52	7	0	13.5	0.0	0.0

Table 21: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Venice

7.7.2.6 Panzano

All abundant families and species (n ≥ 20) of sampling station Panzano were drilled. On family level, DFs ranged from 2.6 % (Pectinidae) to 53.8 % (Montacutidae). Only the family Corbulidae was drilled incompletely (Table 22).

On species level, *Flexopecten glaber* had the lowest DFs with 3.4 % and *Kurtiella bidentata* the highest with 55.1 %. *Corbula gibba*, the only representative of the Corbulidae family and the only species drilled incompletely within the sample showed an IDF of 8.6 % and a PE value of 16.0 % (Table 23).

Panzano

Families n≥20	S	*n*	D	ID	DF (%)	IDF (%)	PE (%)
Pectinidae	3	38	1	0	2.6	0.0	0.0
Montacutidae	2	91	49	0	53.8	0.0	0.0
Veneridae	5	68	17	0	25.0	0.0	0.0
Corbulidae	1	266	121	23	45.5	8.6	16.0

Table 22: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Panzano

Panzano

Species n≥20	*n*	D	ID	DF (%)	IDF (%)	PE (%)
Flexopecten glaber	29	1	0	3.4	0.0	0.0
Kurtiella bidentata	89	49	0	55.1	0.0	0.0
Pitar rudis	21	7	0	33.3	0.0	0.0
Polititapes cf. rhomboides	41	10	0	24.4	0.0	0.0
Corbula gibba	266	121	23	45.5	8.6	16.0

Table 23: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Panzano

7.7.2.7 Position D

Only one family among the abundant families (n ≥ 20) from grab sample Position D was found without drill holes (Pectinidae). All the other families had DFs ranging from 5.5 % (Nuculanidae) to 52.1 % (Anomioidea). The family of Corbulidae was the only one that was found to have incomplete drill holes. IDF was 7.7 % and PE value 27.5 % (Table 24).

Position D

Families n≥20	S	*n*	D	ID	DF (%)	IDF (%)	PE (%)
Nuculanidae	2	55	3	0	5.5	0.0	0.0
Nuculidae	1	60	21	0	35.0	0.0	0.0
Pectinidae	3	72	0	0	0.0	0.0	-
Anomioidea	2	96	50	0	52.1	0.0	0.0
Montacutidae	3	44	3	0	6.8	0.0	0.0
Cardiidae	6	484	32	0	6.6	0.0	0.0
Semelidae	2	21	2	0	9.5	0.0	0.0
Tellinidae	2	34	3	0	8.8	0.0	0.0
Veneridae	7	403	36	0	8.9	0.0	0.0
Corbulidae	1	613	124	47	20.2	7.7	27.5
Hiatellidae	1	44	7	0	15.9	0.0	0.0

Table 24: DF, IDF and PE of the most abundant bivalve families (n ≥ 20) from sampling station Position D

On species level, three out of 15 abundant species (n ≥ 20) did not show any signs of drilling predation attacks within the samples of sampling station Position D (*Saccella commutata*, *Aequipecten opercularis*, *Parvicardium minimum*) (Table 25). The drilled abundant species had DFs from 4.2 % (*Timoclea ovata*) to 51.8 % (*Anomia ephippium*). The only species that was drilled incompletely was *Corbula gibba* with an IDF of 7.7 % and a PE value of 27.5 %.

Position D

Species n≥20	***n***	**D**	**ID**	**DF** (%)	**IDF** (%)	**PE** (%)
Nuculana pella	20	3	0	15.0	0.0	0.0
Saccella commutata	35	0	0	0.0	0.0	-
Nucula cf. nuclaeus	60	21	0	35.0	0.0	0.0
Aequipecten opercularis	69	0	0	0.0	0.0	-
Anomia ephippium	85	44	0	51.8	0.0	0.0
Kurtiella bidentata	42	3	0	7.1	0.0	0.0
Parvicardium scabrum	385	29	0	7.5	0.0	0.0
Parvicardium minimum	47	0	0	0.0	0.0	-
Papillicardium papillosum	42	3	0	7.1	0.0	0.0
Moerella cf. distorta	33	3	0	9.1	0.0	0.0
Gouldia minima	28	12	0	42.9	0.0	0.0
Pitar rudis	50	9	0	18.0	0.0	0.0
Timoclea ovata	307	13	0	4.2	0.0	0.0
Corbula gibba	613	124	47	20.2	7.7	27.5
Hiatella arctica	44	7	0	15.9	0.0	0.0

Table 25: DF, IDF and PE of the most abundant bivalve species (n ≥ 20) from sampling station Position D

8 Discussion

The environmental conditions at the sampling stations within this study showed strong variations. The sampling stations are located in different parts of the Northern Adriatic basin (i.e. On the west and on the east coast, but also in the center). Variations in sedimentation rates, sediment grain size, nutrient availability, environmental pollution by organic and inorganic contaminants and difference in degree of protection lead to variations in species composition, diversity and trends of drilling predation between the stations.

8.1 Biodiversity assessment, Rarefaction and Shannon-Wiener Index

The biodiversity assessment showed varying results concerning number of species and individuals at the different sampling stations. Station Piran Buoy showed the highest number of individuals (12,901 individuals) by far, compared to the other stations, and is also the sampling point with the highest number of species (63 species). Important in this aspect is the protection of the area from dredging as it is located in the perimeter of the oceanographic buoy operated by MBS Piran, which should have a positive influence on the biodiversity of the sampling station. The non-protected site of Piran II is next to the protected are of Piran Buoy, which means the stations share characteristics in environmental parameters such as sediment grain size, sedimentation rate and concentration of nutrients and pollutants, but still individual and species numbers were much lower (6,324 individuals, 55 species).

At the stations close to the Po delta, lowest numbers of individuals and species were found. At station Po, only 20 species and 459 individuals and at station Po Buoy 24 species and 784 individuals occurred in our samples. This is not very surprising, as this environment is only suitable as a habitat for species that are able to cope with high sedimentation rates, turbidity, freshwater influence and high nutrient and pollutant concentration. Nevertheless, station Po Buoy which is a protected site, shows higher numbers of individuals and species when compared to station Po that is not protected.

Even though the stations at Piran and Po are very different when looking at species and individual numbers, values for the Shannon-Wiener Index were found to be similar. Compared to other stations the values are low (1.90 at station Po Buoy to 2.06 at station Piran Buoy), indicating low species eveness.

The stations Brijuni and Venice showed similarities regarding the number of species, number of individuals and Shannon-Wiener Indices. At Brijuni, 55 species, 2,133 individuals and, compared to the other stations, the highest Shannon-Wiener Index of 2.96 was observed. At Venice, 52 species, 2,244 individuals and the second highest index of 2.86 was deteced. This indicates that the two stations show similar high diversity, even though the habitats are quite different regarding environmental parameters (e.g. Sediment grain size, pollution) and degree of protection.

The rarefaction curves also show that Brijuni and Venice show similar high species richness, and moreover the highest richness among all stations when compared at the same number of individuals (Figure 13). On the other hand, the stations close to the Po delta show by far the lowest species richness. Stations Piran Buoy, Piran, Panzano and Position D are grouping together, indicating similar species richness at 400 individuals.

The three most abundant species are *Gouldia minima, Parvicardium scabrum* and *Corbula gibba* with 30.2%, 17.5% and 13.8% abundance respectively (Figure 4). The venerid *Gouldia minima* is a filter feeding bivalve that lives unattached in shallow areas of fine sands, mud and gravel. The cardiid *Parvicardium scabrum*, is a filter feeder living unattached in fine sediments. The corbulid *Corbula gibba* is a filter and detritus feeding species that, in contrast to the other two abundant species, is facultatively mobile and can live bysally attached. The three species are all representatives of the soft bottom infauna, living in sediments of mud, sand and gravel (Gofas et al. 2011).

Furthermore, *Corbula gibba* is a well-studied bioindicator and is known to be able to survive mass mortality events, prolonged conditions of low oxygen environments and is often found in polluted areas (Pearson and Rosenberg 1978, Nerlovic 2011, Borja et al. 2000, Riedel et al. 2012). *Corbula gibba* was found at all stations with abundances ranging from 6.1 % (Venice) to 44.1 % (Po Buoy). Especially at station Po, Po Buoy and Panzano this species shows high abundances (30.7 %, 44.1 % and 41.1 %, respectively) which could be due to the fact that the sampling stations are located at the deltas of large rivers which bring along enhanced sediments, nutrient and pollutants.

Another species that was found in high numbers exclusively at the Po stations is *Anadara transversa.* The species is a semi-infaunal filter feeder which is actively mobile and can remain unattached buried within the sediment, but is also able to attach by means of a byssus in soft bottom substrate (Gofas et al. 2011).

This species from the family of Arcidae was first recorded in the Mediterranian in 1972 in the Bay of Izmir (Turkey) as *Arca amygdalum*, where it was probably introduced from Chinese waters (Demir, 1977). In the Adriatic Sea, the invasive species was first recorded in 2000 (Morello & Solustri, 2001). Vectors of introduction and spreading to and throughout the Adriatic are most likely transfer as non target species within mussel clams from mussel farms and shipping traffic of commercial and fishing vessels. *Anadara transversa*, similar to *Corbula gibba*, has been reported to succeed in heavily contaminated areas and degraded benthic ecosystems (Zenetos, 1994). This, again, could be a reason for the high abundances at station Po Buoy (19.6%) and Po (16.3%), where riverine influence is considerable.

Striking for the sampling stations close to rivers was also the appearance and abundance of *Kurtiella bidentata.* Abundances at Panzano, Po and Po Buoy were 12.5%, 17.4%, and 11.1%, respectively. Even though no current literature for *Kurtiella bidentata* as a bioindicator for polluted and disturbed ecosystems is available, the species could have an advantage over others in environments with high sedimentation rate, nutrient concentration and pollution.

Clausinella fasciata, in turn, is a bivalve species that is sensitive to organic enrichment and is known to be present only under unpolluted conditions (Borja et al. 2000). The species was exclusively found (although only in very low numbers) at stations which are not influenced by the input of large freshwater rivers, i.e. at sampling stations Piran II, Piran Buoy, Brijuni, Venice and Position D (Species List, Appendix).

The lucinid bivalve *Lucinella divaricata* lives infaunal in softbottom in a symbiosis with chemoautotrophic bacteria (Gofas et al., 2011). Animals that live in symbiosis with chemoautotrophic bacteria are adapted to anoxic or hypoxic conditions (Dubilier et al., 2008; Stewart et al., 2005). This species was only found in high abundances at sampling station Venice (16.5 %), where bottom trawling is commonly and extensively used for fishing. According to Riemann and Hoffmann (1991), bottom trawling leads to increase in turbidity, sediment redistribution and increase of nutrients and as a consequence to increased oxygen consumption.

At stations Position D and Brijuni, the venerid *Timoclea ovata* was found in relatively high numbers, with abundances of 14.9% and 10.8% respectively, compared to the other stations. The filter feeding species is facultatively mobile and lives unattached in sand and gravel sediments (Gofas et al., 2011). Additionally, notably high abundances of *Nucula cf. nucleaus* (14.4%) and *Parvicardium minimum* (11.1%) were found at station Brijuni. *Nucula cf. nucleaus* is a detritus and filter feeding species without a siphon that lives actively mobile and unattached in soft bottom substrata. *Parvicardium minimum* is a filter feeding species that lives facultatively mobile and unattached in soft bottoms. The two species might prefer habitats with very low sedimentation rates and low nutrient content, as is the case in Brijuni.

8.2 Cluster analysis and non-metric MDS

Bray-Curtis similarity analysis showed a clear picture of distinct clusters (Figure 14).

At a low similarity of 0.32, two big cluster groups can be distinguished which are seperating the stations influenced by rivers from those without fluvial impact. Bivalve species that inhabitat environments of bigger river estuaries need to have special adaptions and tolerances, for instance in terms of salinity, sedimentation, turbidity, nutrients and pollutants. This could be the reason for the clear seperation into the two groups, leading to different species compositions.

At a similarity of 0.56, the river influenced stations still cluster, whereas the other stations split up, except the two stations close to Piran which still cluster at a similarity level of 0.88. Stations Piran II and Piran Buoy are located directly next to each other, whereas the Po stations are located farther away from each other and do not cluster at this similarity level anymore. This could indicate, that species composition similarity is influenced more by close distance than by riverine influence.

In contrast to the Bray-Curtis cluster analysis, where only groups of species are built and species compositions can be compared, the Non-metric MDS additionally exemplifies environmental gradients (Figure 15). In this study, a clear grouping of different sampling stations can be determined. On the one hand, there are the river- influenced stations: Po, Po Buoy and Panzano. The three sampling stations are characterized by high sedimentation rates, high nutrient input, pelitic sediment and high risk of pollution. Stations Piran II and Piran Buoy are clustering as well, based on their close distance and similarities in environmental conditions. Stations Brijuni, Venice and Position D do not cluster and therefore do not share any close similarities between them or to other stations.

Based upon this information and the knowledge of environmental factors such as grain size, nutrient concentration and sedimentation rates, clear gradients can be established.

On the x- axis, grain size is changing from the river- influenced stations with high sedimentation rates and pelitic sediments (left) to stations with low sedimentation and larger grain sizes (right), represented by station Venice. Sediment input comes along with nutrients, also here a gradient can be established from eutrophic areas close to river deltas (Po stations and Panzano) to oligotrophic relict sand as there can be found at the sampling station in the shelf area of Venice (Figure 2).

8.3 Environmental parameters

The sedimentation rates at the sampling stations differ a lot. The stations close to the Po delta, Po and Po Buoy, show highest sedimentation rates with 2.3 cm/ year and 1.8 cm/ year, respectively. This is due to the high riverine input of the Po River, which brings along large amounts of fine grained sediment. Sedimentation rates rates are rather low in the eastern part of the basin, where they are lowest at the station Brijuni (0,15 cm/ year).

Riverine sediment input is also reflected in the grain size distribution. The stations influenced by bigger rivers (Po, Po Buoy and Panzano) are characterized by fine grained sediment, which is flushed into the basin, whereas the sediment at other stations is composed by a mixture of different grain sizes. Only station Venice is characterized by larger grainsize, with almost exclusively relict sand.

Nutrient concentrations in sediments differed between the stations and are also influenced by grain size and river-influence. The river influenced stations Po, Po Buoy and Panzano showed highest concentrations in TOC and N tot.

Enormous sediment and nutrient concentrations are brought into the basin through rivers. High amount of organic carbon is washed into the delta and is taken up by organisms. The relatively low amount of shells that have been found at the Po stations could explain the low values for C tot (inorganic and organic carbon) at these stations. Shells of mollusks contain carbonate and thereby represent a fraction of inorganic C in the sediment. This fraction of inorganic C is missing at the Po stations as a matter of low amount of shells due to low individual numbers.

Interestingly, high concentrations of TOC and N tot were also found at station Brijuni. Reasons for this could be increasing clay content or enhanced nutrient input, maybe caused by the close position of the station to the shore and increased anthropogenic influence.

At station Venice, a very low content of TOC and N tot was observed. Sampling station Venice is not only farther away from the coast, but also not influenced by rivers. Moreover, sand particles show low surface to volume ratio as of their large size, and therefore the probability for adsorption processes is lower.

In contrast, clay particles have, due to their low size, a high surface to volume ratio. The high surface area favours adsorption and bonding of (anthropogenic) chemicals and nutrients on particulate matter.

Rivers such as the Isonzo or Po, have large catchment areas and are crossing highly industrialized and agricultural areas. Therefore, it is not very surprising that sediment contamination is high at the stations influenced by rivers – namely, Panzano, Po and Po Buoy.

Heavy metals such as Hg (Mercury), Pb (Lead) and As (Arsenic) were detected.

Background concentrations of Hg in marine sediments are about 0.01 – 0.3 mg/ kg. These values are exceeded at almost all the stations, but the highest values occur in sediments at station Panzano, where concentrations reach levels up to 11.75 mg/ kg. Station Panzano is situated in the Gulf of Trieste, which is a semi-enclosed gulf in the north– eastern part of the Adriatic Sea. Until 1995, a former mercury mine was operated in Idrija, Slovenia, which drained polluted sediment into the Isonzo River. The Isonzo River is the most important source of freshwater and inorganic suspended matter and discharges into the Gulf of Trieste (Širca et al., 1999).

Pb concentration in sediments were also found to be highest at the river-influenced stations. Important sources are, among other, production of Pb through mining and smelting activities and production of everyday products such as paints, batteries, weights and projectiles.

Interestingly, together with the river-influenced stations, station Brijuni show high values of Hg and Pb too. This could be due to the same reasons as high nutrient content, increasing anthropogenic activity, clay content and close distance to the shore.

Values for As contamination show opposite results. Whereas Pb and Hg values were lowest at station Venice, probably due to reduced adsorption space of sandy sediment, As concentrations are highest. Sources of As are copper smelters, coal burning, pesticides and, interestingly, glass production. Venice, primarily the island of Murano, is known to be a historical production place for Venetian glass. Many heavy metal oxides are used to e.g. improve the chemical resistance, eliminate bubbles or to obtain coloured or special glass. The waste products of the glassworks are one of the main sources of anthropogenic pollutants in the Venetian lagoon as liquid effluents can contain many contaminants (Giusti and Zhang, 2002).

The river-influenced stations showed also high concentration of organic contaminants. PCB was highest at the Po stations. Even though PCB's are banned nowadays, they are still present in the environment due to their high stability and are known to accumulate in sediments (Rios et al., 2007; Jones and De Voogt, 1999).

PAHs are among the most widely distributed organic contaminants and result from agricultural, industrial and shipping activity and from incomplete combustion of fuels or from oil spills (Martínez-Gómez et al., 2010; Notar et al., 2001; Perugini et al., 2007). Highest values were detected at stations Brijuni, Panzano and Po Buoy, probably due to leakage of industrial and agricultural drainage by rivers and populated coastal communities, which affect stations close to shore. Furthermore, Heath et al. (2006) state that the Gulf of Trieste has been significantly modified by urbanization and industrialization after the First World War, which explains the second highest PAH values at Panzano among all sampling stations.

Outliers of PAH concentration, such as exceedingly high concentrations at station Piran II in a sediment depth of 8-10 cm (4184,42 ng/ g) could, for instance, be an indicator for an oil spill that might have occured abot 50 to 65 years ago.

8.4 Drilling Predation

Predation and the influence of predation on biodiversity over evolutionary timescales is an essential paleoecological issue (Vermeij, 1987) and anthropogenic impact such as nutrient increase or bottom trawling might influence drilling frequency.

In this study, drilling frequency was highest at sampling station Panzano with 36.0%. At this station, nutrient input through the Isonzo River is relatively high, confirming the hypotheses of increased nutrient content leading to increased predation.

Nevertheless, the stations close to the Po delta were found to have very low DFs. The Po samples also contained the smallest bivalve assemblages of all stations. The environment is influenced by high sedimentation rates, muddy sediments, freshwater discharge and high nutrient input, which are physiological constraints that impede life for organisms. At station Po Buoy, DF was 2.2% and at station Po, it was even lower with a minimum of 0.5%. One explanination for the low predation intensities despite high nutrient contents may be the fact that not only prey but also predators, in this case drilling gastropods, may be sensitive to freshwater and sediment input.

At the stations close to Piran, Piran II and Piran Buoy, relatively high DFs of 29.1% and 35.1%, were found, respectively. The shelf area is characterized by sandy mud and minor nutrient input.

In the area of station Venice, the sediment composition mainly consists of oligotrophic relict sands. The assemblage of this stations also showed low predation frequencies (DF= 11.6%), confirming the hypothesis that low nutrient content leads to low predation frequencies.

Death assemblages of station Brijuni show intermediate results of a DF of 25.9%. The area of Brijuni islands is formed by relict sands that are rather low in nutrients. Sedimentation rate is lowest among all other stations (0.15 cm/ year).

The DF results show, that not at all sampling stations high nutrient availability is related to high DFs (e.g. station Po and station Po Buoy). At Panzano in the Gulf of Trieste a high biomass fauna occurs (Zuschin et al., 1999) and DF was found to be highest. Typical modern levels of drilling predations (around 20%), as stated by Sawyer and Zuschin (2010) are exceeded at this station.

Measures of diversity and DFs correlated only at some of the sampling stations. Most of the abundant bivalve families (n≥ 20) included drilled specimens. Even species that were relatively rare were attacked, which leads to the conclusion that the predators appear to be generalists (Sawyer and Zuschin, 2010)

At station Brijuni a high diversity but a moderate DF of 25.9% was found. The most abundant species, *Nucula cf. nucleaeus* showed a DF of 38.1%, whereas the second most abundant species, *Parvicardium minimum* showed the lowest DF (3.6%) among all species at this locality.

At station Venice, which also showed the second highest diversity, a rather low DF was found (11.6%). The two most abundant species, *Parvicardium scabrum* and *Lucinella divaricata* showed different DFs of 2.2% and 15.9%, respectively.

At station Po, only low levels of diversity and low DFs were found and only two of the abundant species (n≥ 20), *Corbula gibba* and *Anadara transversa* were found to be drilled with DFs of 0.8% and 1.4%, respectively.

At station Po Buoy, the situation looks similar with low diversity and low DFs. Three drilled species, *Anadara transversa*, *Kurtiella bidentata* and *Corbula gibba* were found (with DFs of 2.0%, 2.5% and 2.5% respectively).

At the stations located close to Piran, rather low diversity but high DFs of 35.1% (Piran Buoy) and 29.1% (Piran II) occurred. In both of the grab samples, *Gouldia minima* was the most abundant species and also drilled the most with DFs ranging from 43.4% (Piran II) to 47.6% (Piran Buoy).

Last but not least, Position D, which showed intermediate diversity, also showed rather low DFs (14.4%). Predominant species such as *Corbula gibba* showed a DF of 20.2%, whereas *Anomia ephippium* showed the highest DF of 51.8%.

Interestingly, *Corbula gibba*, which was present and abundant (n≥ 20) in all of the grab samples, was also among the most abundant species that was found to be incompletely drilled in all death assemblage, except at station Po. IDFs ranged from 0.6% at station Po Buoy to 8.9% at Piran Buoy with respective PE's of 20.0% and 21.1%. *Corbula gibba*, a bioindicator that is known to be able to endure low oxygen conditions and pollution might be protected from drilling by a thick shell. Bivalves of this taxonomic group have a conchiolin layer in their shell, which acts like a deterrent to predators.

Diversity did not correlate with predation intensities at all of the sampling stations. At the Po stations, low diversity is accompanied by low predation intensities. At all of the other stations, no significant relationship between DF and diversity was found.

At stations Brijuni and Venice, where diversity was high, intermediate to low drilling activity was detected. According to Connell (1961), in modern benthic communities, intermediate predation intensities are supposed to increase diversity, probably caused by reduced competition for space.

9 Conclusion

Within this study, environmental conditions appear to have major influence on species composition, number of individuals and predation intensities.
Bivalve assemblages that inhabit river-influenced locations in the Northern Adriatic Sea, where sedimentation rates, nutrient and pollutant input and freshwater influence are high and grain size is small, must be adapted to physiological constraints. Especially at locations at the river mouth of the Po River, this results in low diversity.

Corbula gibba and *Anadara transversa*, both bivalve species that are known as bioindicators for stressed ecosystems, were found in high numbers at river-influenced stations.

Stations Venice and Brijuni showed highest diversity, even though the habitats are different in their environmental characteristics and especially in the degree of protection. The reason for this could be the low sedimentation rate at both of the stations, which lead to accumulation of old shells of many different species. Furthermore, the two environments are characterized by stable environmental conditions (e.g. no fluctuation in sedimentation rates and salinity) which favor high diversity. Nevertheless, when comparing neighbouring stations Piran Buoy and Piran II, and Po Buoy and Po, degree of protection could make a difference as more species and more individuals have been found at the stations which lay in the protected perimeter of oceanographic buoys (Piran Buoy and Po Buoy).

Drilling predation did not correlate with nutrient availability and diversity at all of the stations. Especially at the Po stations, environmental conditions may be to harsh for prey (resulting in low diversity) and even for predators (resulting in low DF).

In this study, the main influences shaping modern bivalve death assemblages may be environmental characteristics and physical constraints at the different sampling stations. The environmental conditions are naturally set but also intensively modified by human impact, which even lead to signs of pollution and degredation at locations which are environmentally protected. The data set in this study should be seen as another evidence for the importance of monitoring and protection of natural systems, with a special focus on rivers and coastal areas.

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11 Appendix

		Total individuals at stations (n)								
Family	**Species**	**Po**	**Po Buoy**	**Panzano**	**Venice**	**Piran Buoy**	**Piran II**	**Brijuni**	**Position D**	**Total**
Nuculanidae	*Nuculana pella*	0	0	5	21	31	29	1	26	113
Nuculanidae	*Saccella commutata*	0	0	0	0	14	3	43	36	96
Nuculidae	*Nucula cf. nuclaeus*	30	52	27	4	392	121	308	109	1,043
Arcidae	*Arca noae*	0	0	0	13	72	4	0	1	90
Arcidae	*Arca tetragona*	0	0	0	27	4	35	53	11	130
Arcidae	*Anadara transversa*	75	154	6	1	9	8	0	0	253
Arcidae	*Anadara gibbosa*	0	0	0	0	0	0	1	0	1
Noetiidae	*Striarca lactea*	0	0	0	1	28	16	34	4	83
Glycymerididae	*Glycymeris glycymeris*	0	0	0	14	1	0	0	3	18
Glycymerididae	*Glycymeris violacescens*	0	0	0	7	0	1	1	0	9
Mytilidae	*Mytilus* spp.	0	2	0	0	1	0	1	0	4
Mytilidae	*Musculus subpictus*	0	15	12	23	17	13	6	4	90
Mytilidae	*Modiolus* spp.	0	0	5	45	115	46	93	7	311
Pectinidae	*Aequipecten opercularis*	9	23	5	105	33	21	85	106	387
Pectinidae	*Mimachlamys varia*	0	0	6	3	16	6	12	3	46
Pectinidae	*Talochlamys multistriata*	0	0	0	0	0	0	9	0	9
Pectinidae	*Flexopecten glaber*	1	9	47	25	9	3	1	1	96
Pectinidae	*Palliolum incomparabile*	0	0	0	0	0	0	6	0	6
Pectinidae	Pectinidae indet.	0	0	0	0	24	0	38	0	62
Propeamussiidae	*Similipecten similis*	0	0	0	0	0	0	0	2	2
Anomioidea	*Anomia ephippium*	2	4	14	142	173	118	143	104	700
Anomioidea	*Heteranomia squamula*	0	0	1	5	28	11	11	14	70
Anomioidea	*Monia patelliformes*	0	0	1	0	8	0	0	0	9
Limidae	*Limaria loscombi*	0	0	0	0	0	0	2	0	2
Limidae	*Limaria* spp.	0	0	1	37	28	5	29	2	102
Limidae	*Limatula gwyni*	0	0	0	3	0	0	0	0	3
Limidae	*Limatula subauriculata*	0	0	0	2	0	0	0	0	2
Ostreidae	*Ostrea* spp.	0	0	9	2	14	2	0	0	27
Lucinidae	*Loripinus fragilis*	0	0	2	0	38	22	0	2	64
Lucinidae	*Ctena decussata*	0	0	0	0	1	0	0	0	1
Lucinidae	*Lucinella divaricata*	0	0	0	371	5	7	1	2	386
Lucinidae	*Myrtea spinifera*	0	0	1	0	8	7	18	13	47
Thyasiridae	*Thyasira biplicata*	6	4	2	0	5	4	13	10	44
Montacutidae	*Coracuta obliquata*	0	0	0	0	0	1	4	0	5
Montacutidae	*Kurtiella bidentata*	80	87	106	3	81	39	26	45	467
Montacutidae	*Kurtiella tumidula*	0	0	0	0	0	0	0	1	1
Montacutidae	*Tellimya ferruginosa*	0	0	0	1	0	1	0	0	2
Montacutidae	*Litigiella glabra*	0	0	0	0	4	0	0	1	5
Montacutidae	*Montacuta goudi*	0	0	0	2	0	0	0	0	2
Montacutidae	*Scacchia oblonga*	0	0	2	2	0	0	0	1	5
Montacutidae	*Lepton squamosum*	0	0	0	0	1	1	0	0	2
Laseidae	*Arculus cf. sykesii*	0	0	0	0	0	0	0	2	2
Laseidae	*Hemilepton nitidum*	1	2	0	0	23	9	2	2	39
Kellidae	*Kellia suborbicularis*	0	0	1	6	1	1	9	2	20
Carditidae	*Centrocardita aculeata*	0	0	0	0	58	28	0	0	86
Carditidae	*Chama gryphoides*	0	0	0	0	30	14	0	1	45
Basterotiidae	*Saxicavella jeffreysi*	72	6	0	0	7	0	1	4	90
Cardiidae	*Acanthocardia paucicostata*	6	15	21	1	48	28	1	20	140
Cardiidae	*Acanthocardia tuberculata*	0	0	0	3	0	0	0	0	3
Cardiidae	*Parvicardium scriptum*	0	0	0	1	1	0	69	0	71
Cardiidae	*Parvicardium exiguum*	0	0	0	0	69	18	0	2	89
Cardiidae	*Parvicardium scabrum*	0	0	1	440	1,761	1,166	1	665	4,034
Cardiidae	*Parvicardium minimum*	0	1	0	0	7	4	236	55	303
Cardiidae	*Papillicardium papillosum*	0	0	7	12	382	140	72	56	669
Cardiidae	*Laevicardium crassum*	0	0	0	4	8	8	3	11	34
Mactridae	*Spisula subtruncata*	1	0	1	77	18	8	0	22	127
Semelidae	*Abra alba*	6	5	12	16	265	68	35	99	506
Semelidae	*Abra nitida*	15	21	18	0	4	0	1	0	59
Semelidae	*Abra prismatica*	0	0	0	0	0	0	0	10	10
Tellinidae	*Moerella cf. distorta*	2	12	23	199	238	76	3	112	665
Tellinidae	*Tellina serrata*	0	0	0	0	2	0	1	1	4
Tellinidae	Tellinidae indet. (Tellina/Moerella)	0	0	0	0	3	40	0	0	43
Tellinidae	*Arcopagia balaustina*	0	0	0	1	1	3	2	0	7

Family	Species	Po	Po Buoy	Panzano	Venice	Piran Buoy	Piran II	Brijuni	Position D	Total
		Total individuals at stations (n)								
Psammobiidae	*Gari costulata*	0	0	0	3	0	0	0	0	3
Psammobiidae	*Gari fervensis*	0	0	0	0	8	0	0	0	8
Solecurtidae	*Azorinus chamasolen*	0	0	5	0	33	6	1	3	48
Donacidae	*Donax trunculus*	0	0	0	12	0	0	0	0	12
Veneridae	*Mysia undata*	0	1	1	0	12	3	5	13	35
Veneridae	*Gouldia minima*	0	0	3	9	5,790	2,950	32	60	8,844
Veneridae	*Pitar rudis*	4	9	30	39	432	161	143	188	1,006
Veneridae	*Callista chione*	0	0	0	58	0	0	0	0	58
Veneridae	*Polititapes cf. rhomboides*	2	3	81	3	0	0	0	0	89
Veneridae	*Polititapes aureus*	0	0	0	0	22	25	21	12	80
Veneridae	*Clausinella fasciata*	0	0	0	2	3	1	7	13	26
Veneridae	*Dosinia lupinis*	0	1	0	11	0	0	0	0	12
Veneridae	*Venus verrucosa*	0	0	0	4	29	18	5	1	57
Veneridae	*Venus casina*	0	0	0	2	0	0	0	0	2
Veneridae	*Timoclea ovata*	0	0	2	36	80	118	231	536	1,003
Veneridae	Veneridae indet.	1	0	0	54	56	0	3	0	114
Ungulinidae	*Diplodonta brocchii*	0	0	0	0	0	3	0	0	3
Corbulidae	*Corbula gibba*	141	346	348	138	2,094	743	224	1,101	5,135
Corbulidae	*Lentidium mediterraneum*	0	1	0	0	0	0	0	0	1
Pharidae	*Phaxas adriaticus*	3	7	15	31	25	7	4	31	123
Gastrochaenidae	*Rocellaria dubia*	0	0	0	9	29	11	2	1	52
Hiatellidae	*Hiatella arctica*	2	4	23	116	201	141	73	69	629
Pandoridae	*Pandora inaequivalvis*	0	0	1	0	0	1	0	1	3
Cuspidariidae	*Cuspidaria cuspidata*	0	0	1	0	1	0	3	1	6
Cuspidariidae	*Cardiomya costellata*	0	0	0	0	0	0	3	0	3
Thraciidae	*Thracia phaseolina*	0	0	0	98	2	1	1	1	103
	TOTAL OF STATIONS	**459**	**784**	**846**	**2,244**	**12,903**	**6,324**	**2,133**	**3,603**	**29,296**

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Date of Birth:	11.07.1990 in Linz, Upper Austria

EDUCATION

September 2015 – Present **HTL Mödling**

- College for Interior Design and Restoration of Furniture

September 2013 – Present **University of Vienna**

- Course of study: Master Environmental Sciences
- Interdisciplinary approach to the investigation of processes that control the earth environment
- Language: English

October 2009 – February 2013 **University of Vienna**

- Course of study: Biology
- Thematic priority: Ecology
- Bachelor graduation (February 2013)

September 2000 – July 2008 **B(O)RG Dornbirn Schoren (Secondary school)**

- Artistic branch
- Graduation (Matura): May 2008, Summa Cum Laude

September 1996 – July 2000 **Volksschule Dornbirn Markt (Primary school)**

WORK EXPERIENCE

April 2015 **Project „Haa Organic Vegetable Farming Support Initiative“, Bhutan**

- Representative for Dr. Rudolf Knünz at the 3rd Project Board Meeting at the Development Bank Limited, Thimphu, Bhutan
- Meeting with Food Corporative Bhutan
- Interviewing of farmers from Haa District

July–August 2014 **Internship Land Vorarlberg**

- Filming and Photographing for teaching material purposes

August–September ‘11/12/13	**Internship Doppelmayr Zoo, Wolfurt**
	• Farming activities, animal fostering
July–August 2008	**Internship Pensionsversicherungsanstalt, Dornbirn**
	• Administrative work
Winterseason 2008/2009	**Skischool Lech am Arlberg**
	• Ski- an snowboard instructor
July–August 2007	**Internship Bregenzer Festspiele, Bregenz**
	• Walch Catering at the Restaurant “Bühne 3“
July 2006	**Internship Veterinarian (Dr. Planner Winsauer), Dornbirn**
	• Supervision of the animal boarding facility
Winterholidays 2006-2012	**Ski- and snowboard instructor Skischool Lech am Arlberg**
	• Guidance of groups up to 12 children and teenagers
	• Private lessons for adults and children

STAYS ABROAD

July–September 2010	Africa (Rwanda, Tansania)
	• Uhuru Peak, Kilimanjaro (5895m)
	• Mount Meru (4562m)
July–September 2009	Indonesia (Bali, Lombok) and Australia (Perth)
August–Dezember 2008	Central America (Nicaragua, Costa Rica, Panama)
	• One month stay at Spanish Institute COSI, Costa Rica

LANGUAGES

Excellent, job experience:	**German** (Mothertongue)
	English (Fluent in reading, speaking and writing; TOEFL score: 103)
Advanced:	**Spanish**

OTHER QUALIFICATIONS

- Data handling: Mac OS, Microsoft Office (Word, Access, Excel, PowerPoint, Outlook), Touch typing system
- AutoCAD 2015
- Driving license A, B
- Certified “Schneesportlehrerpraktikantin“ (Certified ski- and snowboard instructor)
- Certified PADI Advanced Open Water Diver

INTERESTS

Nature, photography, mountaineering and travelling.