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Foraminifera as Bio-Indicators of Anthropogenic Impact in the Bay of Seine, France

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of Seine, France*

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Abstract

Benthic foraminifera are increasingly used as environmental indicators of natural and anthropogenic stress in all possible marginal marine environments. This study on living (Rose Bengal stained) foraminifera was carried out at 5 stations collected in the Eastern Bay of Seine and Seine Estuary, France. Sampling was took place biannually in spring and fall from 2008 to 2011 on 6 sampling cruises yielding 28 sediment cores. Here a status report is presented on the estuarine ecosystem as recorded from a selected set of sediment samples that reflect habitats and physico-chemical conditions within the area. A relatively low diversity assemblage of benthic foraminifera was recovered, as a response to the variable habitat conditions within the estuary and seasonal events. A total of 33 species were found alive (rose Bengal stained), while maximum diversity never exceeded 19 species at one site. Of the 33 species 14 are more abundant than 5% at all stations. Two key species were identified as potential bioindicators and analyzed with regard to their distribution and correspondence with environmental parameters (sediment grain size, freshwater input, water depth). The benthic foraminifera *Elphidium excavatum* and *Ammonia beccarii* were found to be key species dominating the assemblages of the samples. Diversity trends to increase with distance to the river mouth and in particular in positions off the extuary axis. As the estuarine setting causes environmental pressure, the relationship between the key indicator taxa for pollution and natural environment stress is discussed. This study emphasizes the need for more detailed research on the situation in the Seine Estuary and Eastern Bay of Seine but also on general relationships between anthropogenic impact on coastal environments and natural pertubations.

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Chapter 1

Introduction

1.1 Context of this study

This master thesis has been initiated as a cooperation between the Steinmann Institute (University of Bonn) and the BIAF (University of Angers). Furthermore, it was embedded into the COLMATAGE project which contributed to the scientific initiative “Groupement d’Intérêt Public Seine-Aval” (GIP SEINE-AVAL; engl.: Association of public interest of the Lower Seine) ¹.

The GIP SEINE-AVAL program has been started in 1996 to bring together scientists, administrative staff, and governmental executives. It is the main sponsor and promoter of scientific projects taking place in the Lower Seine region, and especially the Seine Estuary. The program’s objective is improving the knowledge on the functioning and the different factors interacting in the ecosystem of the estuary. It aims particularly at the better understanding of mechanisms ruling the dynamics of the Seine Estuary and the interactions in between the river and the English Channel at different scales. The association insists on the necessary interdisciplinarity for this comprehension.

COLMATAGE is a French acronym which stands for “Coupling of bio-morpho-sedimentology and dynamics in long-term of benthic and ichthyological habitats in the Lower Seine”. The COLMATAGE is a multidisciplinary project integrating participants of seven research groups and is lead by Prof. Dr. Jean-Claude Dauvin from the University Lille 1. Its working period is scheduled from the year 2007 until the end of 2011 during which three main aspects ought to be elaborated:

1. acquisition of extensive sedimentary data, ichthyological and faunal data in the area of the eastern Bay of Seine and lower estuary up to la Risle. The funding has been realized together with the GIP SEINE-AVAL
2. joint analysis of morpho-sedimentary evolutions, habitats, benthic and ichthyological populations in the intertidal and subtidal zone
3. typological cartography of the of the marine estuarine habitats in the bio-sedimentary gradient of the Bay of Seine through assistance of the mini ROV Seabotix

This thesis deals with the analysis of the microscopic benthic sediment dwellers named “Foraminifera” and defines their distribution patterns in the Seine Estuary in order to evaluate the present ecological health of the Seine Estuary. The work of this study took place at the BIAF, Angers University which is an experienced geo-

¹Internet homepage of GIP SEINE-AVAL <http://seine-aval.crihan.fr/>

logical and oceanographical laboratory specialized in analysing and applying recent foraminifera for ecological assessment all over the world since long time².

1.2 Aims and goals of this study

In accordance with the COLMATAGE schedule, a time series of samples was collected in the lower Seine Estuary and eastern Bay of Seine. They were subsequently analysed for live of the unicellular microorganisms called foraminifera (kingdom: Protozoa, phylum: Foraminifera).

The principle aims were:

- to produce an inventory of live foraminiferal assemblages at 5 selected stations in the lower Seine Estuary and eastern Bay of Seine collected during six seasonal cruises during the years 2008-2011
- to interpret and compare the live stock from different sampling dates with each other
- to assess the natural and anthropogenic impact on the living foraminifera
- to attempt in appointing species with possible potential for an foraminiferal bio-indicator of anthropogenic impact
- to contribute to the data set for an integrated foraminiferal/macrofaunal bio-indicator index developed by the macrofaunal working group of Caen University and BIAF, Angers University

The samples of the first two cruises were analysed by Yannick Bayona (2009), the consecutive two by Jonathan Lulé (2010) and the final two as well as the overall interpretation is covered by this study.

1.3 Foraminifera and ecological applications

Modern and extensive research by geologists and paleontologists has picked up at least 180 years ago with the first taxonomic classifications of the Frenchman Alcide d'Orbigny (1802-1875), who was among the first scientists who benefited from technologically improvements in binocular microscopes.

Foraminifera are ubiquitous, unicellular protists present in virtually all marine environments and play an important role in the marine carbon cycle (Langer 2008).

²Internet homepage of the BIAF http://ead.univ-angers.fr/~geologie/index_en.htm

The organisms typically produce a test. Its form and composition (morphology) are the primary means by which Foraminifera are identified and classified (Loeblich and Tappan 1988). While more than 20,000 live morphological species are recognized today (Lipps and Finger 2010), the number is about to rise since DNA sequencing has become a widespread method which can reveal previously hidden species Pawlowski et al. (2011). Both living and fossil foraminifera, reach back as far as the Cambrian period, more than 500 million years ago. Three main test wall-types are distinguished: The test may be made of organic material (organic forms), mineral particles collected in sediment substrate and cemented together (agglutinated forms), or secreted transparent calcium carbonate (perforate or hyaline forms). A test may consist of one chamber or multiple chambers added during ontogeny. If the latter, different arrangement patterns in space are another main classification factor. Modern Foraminifera are found in all marine and brackish environments where they may have planktic (see reviews of Schiebel and Hemleben 2005 and Spezzaferri and Spiegler 2005) or benthic modes of life (Murray 2006). Because of their high taxonomic diversity, abundance throughout geologic time and evolutionary trends, fossil foraminifera are useful for relative dating methods like biostratigraphy (Koutsoukos 2005, Aubry and Van Couvering 2005), which plays an important role in the rising profile of geologic sequence stratigraphy used in hydrocarbon exploration (Jones and Simmons 1999). After dying off, the test does not decay and rests on the ocean bottom in the sediment where it has high potential to become fossilized. Faunal associations and isotopic compositions of the foraminiferal tests are proxies for salinity and temperature of sea water and the paleo-atmospheric conditions in general as described by Jorissen et al. (2007). Assessing biology and ecology of recent foraminifera is the key to calibrating proxies and enables scientists to reconstruct paleo-environments Gooday (2003), Martínez-Botí et al. (2011), Rossi et al. (2011). Research on present day foraminiferal ecology revealed ecological dependencies and specific requirements of taxa. Driving factors on organism distribution patterns in marginal marine environments is the critical threshold of various limiting factors: bio-availability of food, oxygen in the sediment (Jorissen et al. 1995), light, temperature, salinity and hydrodynamics like currents or the waxing and waning of tides (Murray 2006).

In the past decades since the 1950s scientists use life foraminifera as proxies for environmental health and the impact of aquatic pollution (Frontalini and Coccioni 2011). Although many chemical and organic pollutants can be analyzed nowadays it is often not clear what impact a given dose can have. According to Barbieri et al. (2006) Foraminifera are first choice environmental proxies and indicators as they show “*short life cycles and the possibility of genetic reorganization by sexual*

reproduction [which] enable rapid reaction to environmental changes; this makes foraminifera ideal bio-indicators for short- to long-term changes of marine environments, from global to extremely local scales."

Water pollution has been an environmental concern since the onset of the Industrial Revolution in the 19th century. Anthropogenic activities (i.e., agriculture, mining, industrialization, urbanization) have contaminated surface, ground, and coastal waters with excessive nutrients and potential toxins. The suspended contaminants from the water column inevitably accumulate in the riverbed sediments which function as a pollutant sink (Amiard-Triquet and Dauvin 2009, Amiard et al. 2009). Foraminifera react quite immediately to changing physico-chemical aspects of their surroundings both of natural and anthropogenic origin. Hence, in numerous sites of the world foraminifera have been applied to investigate impact of various pollutants as well as laboratory experiments with artificial exposure (see Yanko et al. 1994 and Alve 1995 for review). That is for example organic sewage outflow (Watkins 1961, McGann et al. 2003, Mojtahid et al. 2008), paper pulp (Resig 1960), mandated release of freshwater at dams (Buzas-Stephens et al. 2011), chemical pollution (see for review Martínez-Colón et al. (2009)), heavy metals Alve (1991), Bergin et al. (2006), Martínez-Colón et al. (2009), oil spills (Morvan et al. 2004, Ernst et al. 2006, Sabeau et al. 2009), thermal effluents (Samir and El-Din 2001, Arieli et al. 2011) and aquaculture (Angel et al. 2000, Vidović et al. 2009).

Results of progressively rising pollution-degrees are test abnormalities (Geslin et al. 2000, Samir and El-Din 2001), dominance of opportunistic/tolerant species and the event of totally barren substrates (see Figure 1.1 and review in Alve 1995). Studies of sampling series are designed to obtain the standing crop (living fauna) over a specified time range with periodic intervals. Case studies in southern England (Murray and Alve 2000, Alve and Murray 2001) have revealed that the interpretation of foraminiferal reproduction cycles usually cannot be related to seasonal changes even if sampling intervals are kept short and foraminiferal census respects individuals down to 63 μm . Many studies suggest a coherence of food availability (i.e. bacteria, diatoms) with rapid reproduction rates (Walton 1955, Murray and Alve 2000, Murray 2001) which in turn corresponds to raised influx of nutrients (i.e. occasionally caused by pollution; see Buzas-Stephens and Buzas (2005), Carnahan et al. (2009), Martínez-Colón et al. (2009), Buzas-Stephens et al. (2011), Frontalini and Coccioni (2011)).

Experiments in laboratories have shown that foraminifera act very sensitive to small amounts of pollution (e.g. test deformation) but lethal thresholds are fairly high for some particular opportunistic genuses like *Ammonia* and *Haynesina* (Le Cadre and Debenay 2006).

In order to restore natural conditions in polluted estuaries, and marginal marine places in general, the initial or pre-industrialized state has to be known. Foraminifera qualify quite good to examine the geologic record of the last few hundreds of years. First attempts were made by Scott et al. (1995), Cearreta et al. (2002), Alve et al. (2009) which resulted in a practical means to compare post-industrial condition with pre-industrial conditions and the information on the maximum possible health status.

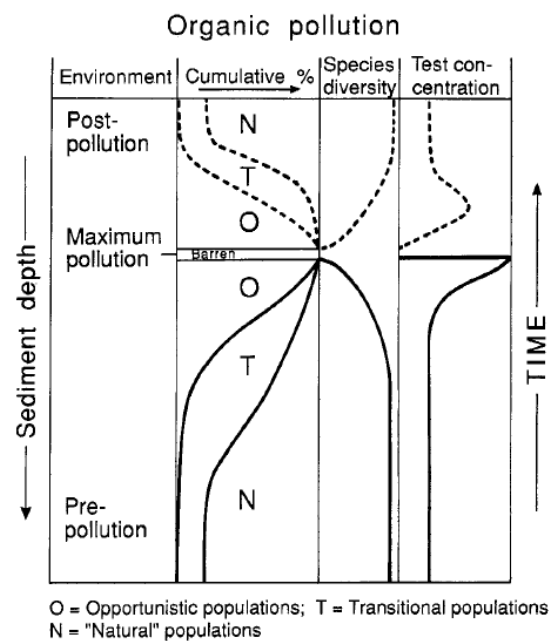


Figure 1.1: Theoretical development of the benthic foraminiferal community in a sediment core prone to a waxing and waning pollution source. from Alve (1995)

1.4 Biotic indices and comparison macrofauna/microfauna

Dauvin et al. (2012) defines a benthic indicator species "[...] as *“sentinel species”*, which is a particular species that by its presence or its relative abundance warns of possible unbalances in the surrounding environment or distortions in community functions [...]". Defining a universal set of indicator species would be the logical focus of efforts for scientists. As it turns out, modern indices focusing on particular species or species groupings seem to be not or only few generalizable, as they have to be adapted to the concerned region's peculiarities (Blanchet et al. 2008), which is obviously limiting their usefulness. A common problem is that foraminifera in general show a surprisingly high tolerance to pollution and therefore pollution sensitive species seem to be rare (Jorissen 2010). In fact, other limitations appear with

the specific ecology, seasonality (abundance spikes: pre- or post life-cycle), spatial variability and climatic gradients. This principle is valid for macrofauna as well as for foraminifera. Thus, well established foraminiferal indices such as the FORAM Index (Hallock et al. 2003) are not generally suitable, as they aim on communities native in warm corral reef environments. Also pinpointing a single, globally dispersed taxon for a worldwide pollution indicator is not feasible.

For improving bio-monitoring significance, scientists currently aim for harmonising long-applied macrofaunal bio-indices ³ (AMBI, BOPA, BENTIX, etc.) with microfauna like foraminifera (Jorissen 2010). Existing benthic macrofaunal indices are well tested and widely applicable but show significant drawbacks in various matters: (1) requirements for large sediment volumes for statistically significant numbers of inhabitants, (2) difficulty to establish the initial ecological state of the study area and (3) lack of specialists for taxonomical identification. These are all cases when micropaleontology shines.

1.5 Previous studies

Bayona (2009) found during his study of the Bay of Seine assemblages of September 2008 and 2009 three distinct clusters derived from density distribution. A very poor group close to the river mouth dominated by *Elphidium excavatum*, a mediocre populated group the Bay of Seine dominated by *Psammosphaera fusca* and a very dense and diverse populated community stretching north to south perpendicular in respect to the tidal outlet which was also highly dominated by *Elphidium excavatum*. He his thesis Bayona points out the two main factors having influence on foraminiferal faunas: the strong hydrodynamics (tidal currents and river flow) and the associated granulometries. These show most impact at the proximal stations at the river mouth and decrease in the stations perpendicular to the river stream. Bayona's data will be incorporated in time-series comparisons in this study and continue it further.

Initial results on macrofauna, elaborated by the GIP SEINE AVAL workgroups, has shown that the bivalve *Abra alba* (Wood, 1802) and the tube building polychaete worm *Lagis koreni* Malmgren, 1866 dominate the estuary interannually with a solid spatio-temporal stability despite a seasonal variation of the distribution and density of the communities (Thiébaud et al. 1997).

Debenay (2009) sampled 2003 and 2004 tidal flats and marshes of three estuaries in northern France for foraminiferal assemblages: the Authie Estuary, Somme Estuary and Seine Estuary. The comparison of densities reflected the contrast-

³e.g. echinoids, nematodes, bivalves, ophiuroids, crustaceans, etc...

ing anthropogenic influence (see Table 1.1). Most important species on the intertidal banks have been identified: *Criboelphidium magellanicum*, *Elphidium excavatum williamsoni*, *Elphidium gerthi*, *Haynesina germanica* and *Elphidium excavatum*. Debenay remarked that especially *Elphidium excavatum williamsoni* showed lower densities but *Ammonia tepida* higher densities in the Seine Estuary compared to the less impacted environments. *Ammonia tepida* is a very opportunistic taxon which Debenay used as a proxy to describe the higher anthropogenic impact of the industrialized Seine Estuary. The faunal analysis has shown that grainsize and annual cycles do not affect living specimens directly. Diversity trends could not be shown. Rather more complex inter-annual patterns rule densities and seasonal cycles usually do not repeat which is a commonly observed phenomenon (see also Alve and Murray 2001). Arminyot du Châtelet et al. (2011) took foraminiferal samples from Boulogne-sur-Mer, France (170 km northeast of the Seine Estuary). The sampling covered the enclosed harbor basin and adjacent Liane River estuary and revealed strong correlation of several species to industrial heavy metal contamination. *Elphidium excavatum* and *E. magellanicum* were found to be well represented in the outer basins and Liane River where grain sizes were raised and heavy metal contamination comparably low. The inner harbor setting included stillwater, high proportions of silt and heavy metal pollution legacy. *Haynesina germanica* and *Bolivina pseudoplicata* showed to be particularly tolerant of Cr, Cu, Zn and organic carbon where individual thresholds for *Elphidium excavatum* and *E. magellanicum* were exceeded.

Table 1.1: Foraminifera from three estuarine's tidal flats in northern France. from Debenay (2009)

Location	Pollution Status	Species Richness S (living)	Species Richness S (dead)	Average density per 50 cm ³ (total fauna)
Authie	pristine	6±3	31±13	25,200±19,000
Somme	average	4±3	43±18	3,600±4,800
Seine	chronic	2±1	20±7	1,200±1,550

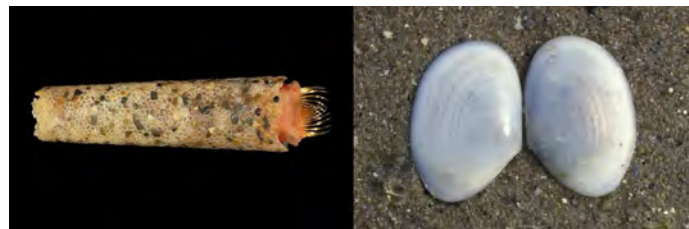


Figure 1.2: On the left: *Arba alba* (Wood, 1802); vernacular name: white furrow shell; small, up to 25 mm long. On the right: *Lagis koreni* Malmgren, 1866; vernacular name: trumpet worm, on picture ca. 20 mm long. From WoRMS (Appeltans et al. 2011)

Chapter 2

Methods

2.1 Regional setting

The samples for this study stem from the French Seine Estuary, which is one of the most important French estuaries. It is situated in the Normandy draining into the large, but shallow Bay of Seine, which in turn shares its shores with the English Channel (see Figure 2.3). The Seine Estuary is constituted by the lower 160 km of the Seine River from the dam in Poses to the mouth close to Le Havre. According to commonly accepted model which has been put forward by Cameron and Pritchard (1963) and was recently put forward again by Valle-Levinson (2010), an estuary can generally be defined as "(a) a semienclosed and coastal body of water, (b) with free communication to the ocean, and (c) within which ocean water is diluted by freshwater derived from land".

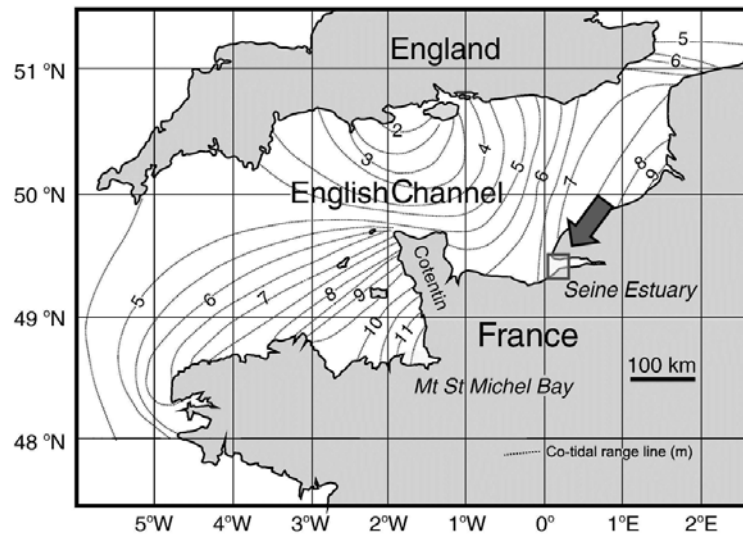


Figure 2.1: Location of the Seine Estuary with tidal range iso-lines after S.H.O.M. (1968). Altered after Tessier et al. (in press)

The Seine river is the main discharging agent draining a watershed area of 79,000 km². This area is inhabited by 16 million people, and accounts for some 50% of the river traffic in France, 40% of the country's business activity, and 30% of its agricultural farmland. Additionally, the Seine passes through Paris and Greater Paris area which has major influence on the river with contaminants and purified waters. Further downstream north of Paris, two metropolitan areas, namely Rouen and Le Havre with 400,000 and 200,000 inhabitants respectively have influence not only with their big harbors receiving larger overseas freighters on a daily basis (i.e. GPMH: Grand Port Maritime du Havre; GPMR: Grand Port Maritime de Rouen).

The GPMR is Europe's fourth largest harbor measured in turnover and needs, together with the GPMH., to maintain its shipping navigation channels which is realized by dredging. Only recently the GPMH opened a new container terminal outside of the original harbor basin ("Port 2000") in order to receive increasing numbers of freighters (see Vandebroek (2006) and Figure 2.2). Accordingly, the GPMH dredging activities have risen for at least one third in volume. Since the 19th century urbanization and human interference in the estuary has continually increased - a development that still continues. Dams, dykes, reclamation and dredging of the freighter navigation channel have significantly altered the hydrosedimentary characteristics with a tendency to channel erosion and coarser sands in the whole estuary Lesueur et al. (2003). Through that magnified erosion more than 100 km² of intertidal environments and faunal habitats have been lost (Lafite and Romana 2001, Amiard-Triquet and Dauvin 2009). A study keeping track of the changes of the sedimentary characteristics is given by Lesourd et al. (2001). Simultaneously with changing the shape of the environment, physico chemical conditions have antithetically decreased. A significantly raised influx of nutrients (e.g. Nitrate and Phosphorous, modeled by Billen et al. 2001), metals Cd and Hg, hydrocarbons (PAHs) and polychlorinated biphenyls is reviewed by Amiard et al. (2009). Moreover, strong oxygen depletion can be measured downriver of the highly urbanized areas Paris and Rouen, severing conditions for benthic infauna. Thus, Debenay (2009) and Armynot du Châtelet and Debenay (2010) consider the Seine Estuary a chronically polluted estuary.

The freshwater flow of the Seine River is measured at the dam of Poses and is relatively small (compared to other European rivers) with about 450 m³/s over the last 50 years (Deloffre and Lafite 2009). Historical data shows that peak water volumes (more than 2200 m³/s) arrive in autumn and winter, while low water sometimes hardly reaches 100 m³/s in the summer months around September.

The Seine is a macrotidal tide-dominated estuary with a tidal range of 3-8.5 m. The estuarine turbidity maximum (ETM) is the place where riverine and marine waters collide. It represents a hydrographic limit where salinity abruptly changes. A submerged eddy entrains and suspends sediments. According to Brenon and Le Hir (1999) the turbidity maximum in the Seine Estuary results from the superposition of two processes: (a) the dynamical accumulation of suspended sediment, related to water flow, dependent on sediment behaviour and bathymetry, (b) salinity gradients, only related to river flow and bathymetry, which modify the estuary's structure. The ETM shifts from high to low tide about 20 km up and downstream and also about 5 km downstream during high water times. During low tide it shifts from KP



Figure 2.2: Bird’s eye view on the northern shore of the Seine Estuary. Note the heavily industrialized harbor area and especially the recently built cargo terminal (“Port 2000”) reaching into the estuary water body. Photo provided by the P.A.H. homepage <http://www.havre-port.net>

352.5 (low river input) to KP 362.5 (high river input) and during high tide from KP 332.5 (low river input) to KP 347.5 (high river input). Sampling station 40 is located very close to KP 365 (estuary mouth). So during times of low tides and high water runoff (winter to spring months) the ETM might have an impact on the physical conditions of station 40.

Sediment-load is not only expelled from the estuary but also pushed back by marine inflows drawn in by onshore wind Tessier et al. (in press) and such a very much changing marine influence on the area can be expected. All these effects together compose a very active hydrodynamics system with ever changing parameters.

2.2 Field methods

2.2.1 Sampling

Five stations were sampled by the COLMATAGE workgroup in the lower Seine Estuary and the adjacent eastern Bay of Seine. Their distribution is depicted in Figure 2.3 and more details are given in Table 2.1. A transect west to east (Station 11, 15, 40) along tidal currents and riverine effluents and a second north south transect, perpendicular to the river mouth and the previous transect (Station 7, 15, 28). The station pattern was chosen to reflect expected medium-scale conditions like the proximity to

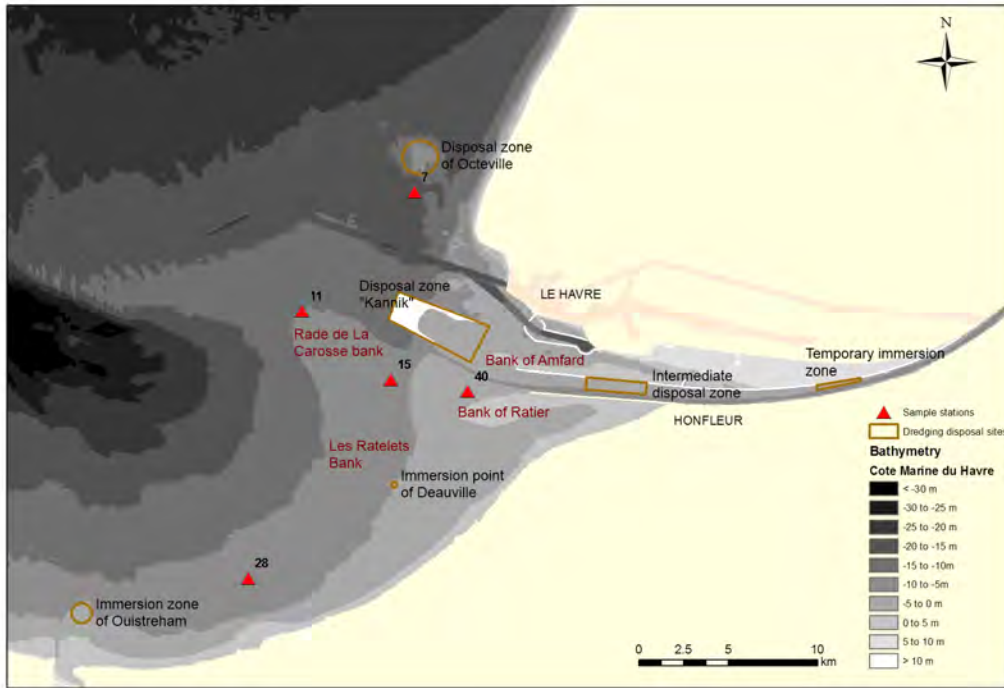


Figure 2.3: Bathymetry map of the Seine Estuary and the adjacent Bay of Seine. Sampling stations, dredging disposal sites and important sandbanks are indicated. Depth data from SHOM, GPMR and GPMH. Compiled by Nicolas Bacq, responsible for information administration scientific data at in the GIP SEINE-AVAL.

anthropogenic facilities and exposure effects of the low saline river water and health of the environment in the ship navigation channel. As previous time-series studies on North Atlantic coasts have shown that many species have reproduction peaks in winter (~February) and autumn (~September, see Debenay et al. 2006; Murray and Alve 2000), six consecutive cruises in September 2008, September 2009, December 2009, April 2010, September 2010 and March 2011 were carried out and yielded 28 sediment cores. In December 2009 only three of five stations could be cored. The sediment surface sampling was conducted from shipboard using a Bowers & Conelly multicorer (2 tubes) of which one core was reserved for foraminiferal analysis. Interior diameter of the applied plexiglas tubes was 5.9 cm. The recovered cores had a length of 2 to 5 cm and were sliced in varying intervals which resulted in 92 subsamples of different volumes (for details see Table B.2). Although deep infaunal foraminifera in intertidal environments are reported in up to 30 cm depth (Goldstein et al. 1995), the uppermost 5 cm are sufficient to be considered for ecological census studies (Alve and Murray 2001). After cutting the sediment slices were kept in polyethylene jars.

Benefits of the multicorers are the conservation of the initial integrity of the cut sediment and the hermetic enclosure during pulling up onto the vessel. This makes multicorers especially suitable for depth analysis, where disturbance and mixing is not desired and makes the use of grab samplers unfavourable (Murdoch and Azcue 1995). Replicate cores in order to assess effects of patchiness like proposed by Murray (2006) were not taken.

During the September 2008 cruise separate samples were taken by a Reineck box corer (Reineck 1963) and sieved by the workinggroup of Professor Jean-Claude Dauvin at the STATION MARINE DE WIMEREUX. Details of the procedure are given in subsection 2.3.1 below.

Table 2.1: GPS positions of sampled stations

Station	7	11	15	28	40
description	North	Estuary channel distal	Estuary channel medial	South	Estuary channel proximal
Latitude	49°31,840'N	49°28,151'N	49°26,175'N	49°20,066'N	49°25,902'N
Longitude	0°01,103'E	0°03,932'W	0°00,266'E	0°06,025'W	0°03,838'E
depth [m]	18.2	10.4	7.5	12.5	3.5

2.2.2 Staining

Immediately after slicing was accomplished, the cores were stored in plastic containers. Live foraminifera were stained and fixed by adding 95% ethanol and Rose Bengal stain in 1 g/L concentration (Walton 1952, Murray and Bowser 2000).

Staining with Rose Bengal is a terminal method that indicates living specimens but concurrently kills them of. The Method is widespread, quickly accomplished, inexpensive and numerous field-tested since the introduction by Walton (1952). Rose Bengal is a substance that is absorbed onto enzymes and colors them rose to deep red. Hence, the assumption is made that only living foraminifera contain non-decayed enzymes in their tests. Foraminiferal protoplasm will go red after a short exposure to the Rose Bengal solution while empty (i. e. dead) tests remain unstained or are liable to a slight superficial pinkness. Thus, it should be easy to distinguish stained from unstained specimens and according to Lutze and Altenbach (1991) leads to 96% correct identifications if carefully employed.

Anyhow, Rose Bengal has been the subject of numerous debates on accuracy (see review of Bernhard 2000). For example some residual proteins or bacteria which are disintegrating the dead protoplasm persist in the dead tests, the inner organic lining

of a empty test could be stained or live protoplasm does not incorporate the stain at all. Furthermore, in some cases the cytoplasm could persist in dead cells for long time (2 weeks or more) before being degraded which could result in perceiving dead organisms as alive. All these side-effects could bias the detection. For this reason the strict determination rules proposed by de Stigter et al. (1998) were applied (see subsection 2.3.3).

2.3 Laboratory methods

2.3.1 Granulometrical analysis

In 2008 a granulometrical analysis has been conducted at the STATION MARINE DE WIMEREUX by the work group of Professor Dauvin (University of Lille). Subsamples from the top of the sediment cores were washed on a 50 μm sieve to remove inherent salt. The fraction subordinate to the sieve was captured dried together with the sievings at 70°C for 48h.

Then, the sediment was passed through 3 sets of 6 sieves while fixed on a vibratory plate. The first set was processed for 10 minutes had meshes of 5 mm, 2 mm, 1.6 mm, 1.25 mm, 1 mm and 0.8 mm. The second and third were processed 20 minutes each. Meshes of the second set: 0.63 mm, 0.5 mm, 0.4 mm, 0.315 mm, 0.25 mm, 0.2 mm. Third set respectively: 0.16 mm, 0.125 mm, 0.1 mm, 0.08 mm, 0.063 mm, 0.05 mm. Sievings were weighed in grams and are given in Table B.1.

The data has been processed with GAEA WinSieve 1.18, a laboratory database programm for applied geology. Two cumulative curves were generated with the “Detailed Modified Wentworth” classification system (see Figure B.1 and Figure B.2).

2.3.2 Sieving

All subsamples were washed (i.e. wet sieved) carefully in the laboratory over a series of nested sieves. Subsamples from the first 4 cruises had a classical foraminiferal pattern of 500 μm , 150 μm and 63 μm , while the later cruises were sieved additionally with a 315 μm and 125 μm refining the foraminiferal bearing fraction. The sediment was washed gently until the entire fine fraction <63 μm (clay) was removed and went into the sink. The first and uppermost 500 μm sieve eliminates the fraction of large seashell debris, plants and macrofauna. The following 500 μm to 63 μm contain the foraminifera. Sievings were collected in small plastic vials and conserved until further by ethanol. The sieves were submerged after cleaning in methylene blue, an ink-like substance that quickly colours everything still tucked

in the mesh. This allows carried-over foraminifera easily to be identified as deep blue or greenish. A (wet) sieving method was not applied. Bayona (2009) tried floatation with trichloroethylen for a faster picking process (see Scott et al. (2001), Murray (2006)) but statistical comparison of residue and floated material suggested refraining from further application, as many species incorporating heavy sediment grains were present.

2.3.3 Picking

Rose Bengal stained specimens then were wet picked with a brush under Leica binoculars. Of the first 4 cruises only the 150 μm fraction was sieved, yielding a range from 500-150 μm . The more detailed sieved subsamples from the last two sampling periods were picked in the 315 μm , 150 μm and 125 μm fractions, also yielding a 500-150 μm range plus additionally a smaller 150-125 μm range thereunder.

Sediment portions were given into a transparent 10x10 cm plastic picking tray and systematically scanned for stained specimens. Then, picked specimens were placed in Celka plummer slides backed with white cardboard as indication for live specimens. Water-soluble guar gum glue was used for keeping the species in their preset cells, while they are facultative movable by wetting them with the brush.

Wet-picking was chosen for the reason that Rose Bengal stain shows deeper coloration and also thick-walled specimens still reveal a light rose tone which in dry state would prove to be unrecognizable. Moreover, it preserves fragile genera like the soft-walled allogromids. Wet-picking is proposed to become the standard method for future ecological studies (Schönfeld 2011).

Only the most complete and deepest colored specimens and specimens with all chambers except the last one intensively coloured were considered alive to avoid false positives (Murray and Bowser 2000). Due to colour fading in some subsamples this color restrictions had to be adapted. This phenomenon already occurred in samples picked by Bayona (2009) and Lulé (2010) which was handled concurrently.

2.3.4 Taxonomic identification

Foraminifera show numerous and varying forms. Today, about 5,000 recent and 50,000 fossil species are recognized (Lipps and Finger 2010). Given these numbers it becomes clear that the majority of work has been done on foraminifera buried in geologic sedimentary layers. Main motivation point is the application of them as biostratigraphic tools that indicate relative ages of rocks. This is mainly used by petroleum companies that fund this scientific application. Thus, it is logic that

taxonomy of these organisms is solely based on morphological characteristics of their hard parts that endure in rocks (i.e. the test).

The taxa representing the majority in the Seine Estuary (*Ammonia* and *Elphidium*), numerous morphological variations appear in the species. *Ammonia* as well as *Elphidium* are genres very widespread around the world. Their same species appear with different morphologies in publications. These smaller morphologic variations are usually referred to ecophenotypes (or morphotypes) that might adapt to changing environmental conditions (Feyling-Hanssen 1972, Painter and Spencer 1984, Jorissen 1988). Jorissen (1988) outlines their basis of recognition and discusses the smooth transitions between single recognized morphospecies. This makes a reliable and quick identification especially difficult. Today, with the development of ubiquitous DNA sequencing, genetic studies to resolve the morphospecies enigma are initiated (see Langer (2001), Schweizer et al. (2011)). DNA sequencing is possible only for case studies but not very practical for extant application in ecological studies.

Thus, in this study, only very distinctive morphotypes have been appointed because of lack of time and consistency with previous identifications of Bayona (2009) and Lulé (2010). For example *Elphidium excavatum clavatum* and *Elphidium excavatum williamsoni* are given in the census tables, whereas all the further morphotypes of *Elphidium* are grouped in the species *Elphidium excavatum*.

Very often the prefix “forma” is used to designate morphospecies (e.g. *Elphidium excavatum forma clavatum*), but also just adding the morphospecies’ name after the species name is quite common and also recommended by WoRMS¹ taxonomists (e.g. *Elphidium excavatum clavatum*). In fact, numerous authors attribute morphotypes to similar forms of different forma taxa. Bayona (2009) reviewed and picked up this complicated taxonomic situation and tried to regroup the *Elphidium* and *Ammonia* (sub-) species for his initial study on the Seine Estuary.

Recognition and identification in this has been accomplished using well-established taxonomic atlases like Loeblich and Tappan (1988, 1994), Jones et al. (1994). For ICZN² accepted nomenclature the online database WoRMS (Hayward et al. 2011) has been consulted. The continuous checks of authoritative taxonomic editors makes it especially reliable and up to date.

¹<http://www.marinespecies.org/foraminifera/index.php>

²<http://iczn.org/>

2.3.5 Statistics

Statistical methods applied on faunal data are commonly used to explore patterns of appearance and correlations of particular species with environmental conditions. Once all data of the six collections (Sep 08, Sep 09, Dec 09, Apr 10, Sep 10, Mar 11) were complete, Canonical Correspondance Analysis and Cluster Analysis were used to compare the “behavior” of the stations over time. For this purpose the free paleontological statistics program PAST (Hammer et al. 2001) was applied.

When using percentage-values are used, one has to bear in mind that they are subject to the constant sum constraint – where the increase in abundance of one species leads to a decrease in others. Hence, to overcome this problem, the arcsin-transformation was applied which is a common procedure in ecological studies. The desired value q is calculated by taking the arcsin of square root of the percentage-value x (50% written as 0.5).

$$q = \arcsin \sqrt{x}$$

2.3.6 Biotic indices

Biotic indices are univariate expressions in single numbers that evaluate and simplify certain aspects of biocenoses and also thanatocenoses. They facilitate the way to compare samples with each other. Some indices alternate between two extreme endmembers that give information on the communities’ condition.

Species richness S

Number of foraminiferal species in a sample.

Number of individuals N

Number of foraminiferal tests in a sample.

Standardized individuals per 50 cm³

Workers on surface foraminiferal surface fauna commonly use containers with different volumes and also core diameters vary. In order to compare volumes (e.g. downcore slices) of different dimensions within the own study or with others, sediment volumes have to be normalized to 50 cm³ and consequently the number of counted foraminifera individuals.

In the following equation applies $V_{standardized}= 50\text{cm}^3$, V_{sample} is the odd volume of the sample taken and N_{sample} is the counted individuals in V_{sample} .

$$N_{50\text{cm}^3} = \frac{V_{standardized}}{V_{sample}} \times N_{sample}$$

Standardized individuals per 100 cm²

Similar like the 50 cm³ standardization mention above, living foraminiferal communities are compared on a 100 cm² surface area (i.e. 0-1 cm subsample of a core). The individual number N of the sediment-seawater interface is picked and counted. In the following equation applies $A_{standardized}= 100 \text{ cm}^2$, $A_{core}=5.9 \text{ cm}$ (see subsection 2.2.1) and N_{sample} equals the counted individuals in the surface sample.

$$N_{100\text{cm}^2} = \frac{A_{standardized}}{A_{core}} \times N_{sample}$$

Ammonia-Elphidium foraminiferal index (A-E index)

The *Ammonia-Elphidium* index, first introduced by Sen Gupta et al. (1996) and proofed by Thomas et al. (2000), is an expression of the relative abundances of two common taxa in many coastal foraminiferal assemblages (less than 20 m water depth). As *Ammonia* has proven to be more tolerant to oxygen depletion than *Elphidium* (Moodley and Hess 1992), the A-E index is used as a proxy for hypoxia and anoxia. Also the A-E index correlates according to Sen Gupta and Platon (2006) with organic carbon in the surface sediment. Furthermore, Sen Gupta and Platon (2006) put forward that the index is universally applicable on genus level and thus a separation of species is unnecessary.

Nevertheless, Sen Gupta and Platon (2006) argue, when co-varying factors like salinity are present the A-E index should be handled with care, as lowered salinity may raise the A-E index.

$$A - E \text{ index} = \frac{N_{Ammonia}}{N_{Elphidium}}$$

Shannon H

Another measure of species diversity is the information function H (Shannon 1948), where p_i is the proportion of the i th species ($p = \%/100$) and \ln is the natural logarithm. The contribution to H of each species depends on its proportion p_i so rare species make little contribution. H reaches its maximum when all species are equally present.

$$H = - \sum_i p_i * \ln(p_i)$$

2.3.7 Microscopy

Well preserved individuals of the most abundant and some rare species were photographed with a scanning electron microscope (SEM) type JEOL JSM-6301-F in the first analysis cycle (2008/2009) of this time series study. This work was achieved by J. Bayona (2009) in collaboration with SCIAM members and here reproduced and extended. The digital SEM pictures were later digitally assembled via paint.NET 3.5.8 (Rick Brewster, Washington State University) and arranged on plates (see Appendix A Plates on page 65).

Light photographs were acquired from individuals picked from the latest sampling cycle (2010/2011) with analySIS FIVE (SIS/Olympus^l) software. Samples are prepared on black Plummer slides and are automatically moved under a Leica^l Z16APO monocular microscope using a motorized xy-stage. The microscope is the second generation of a concept developed by Bollmann et al. (2004) at ETH Zürich. A detailed description of the custom array is reviewed by Clayton et al. (2009). In maximum resolution a pixel is equivalent to a length of 1.68067 μm . Further photograph postprocessing is equivalent to SEM pictures (see above).

2.4 Other methods

2.4.1 Seine runoff data

Accordingly with the power generation at the dam of Poses the debit of the Seine is measured. Historic measurements of average daily debit reaches back until 1941. Up-to-date data are available to the public with about 1 month delay on the GIP Seine-Aval homepage³. Data is collected by automatic probes in the dam of Poses.

³<http://seine-aval.crihan.fr/web/pages.jsp?currentNodeId=150>; date of access: 26th September 2011

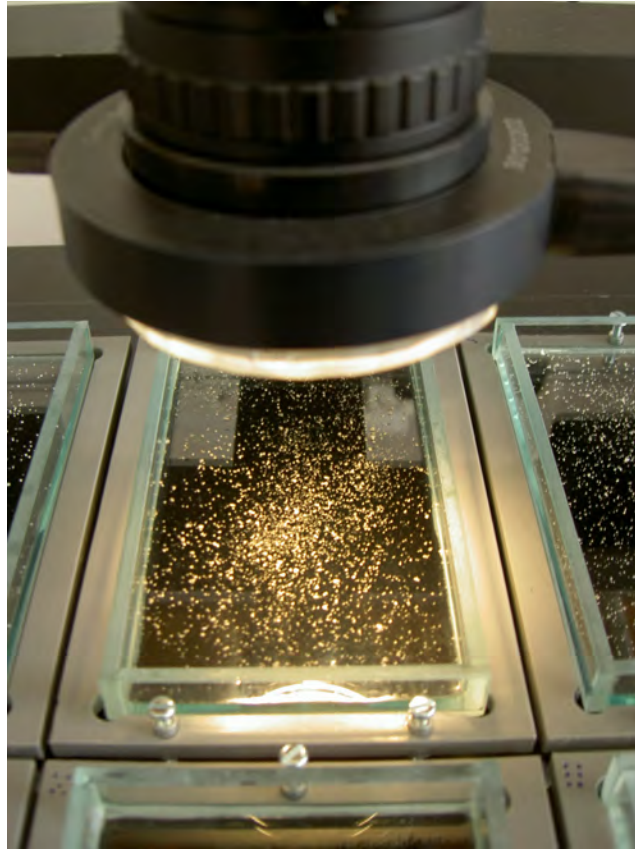


Figure 2.4: Exemplary photo of the automated light microscope (objective lens with rim light and stage with glass plates). Kindly provided by Professor Ralf Schiebel (BIAF).

Poses is the upper delimitation of the Seine Estuary. It is 160 km upstream from the Bay of Seine and this means given numbers may be altered regarding the estuary mouth. It has to be taken into account that global freshwater flux to the Bay of Seine is influenced by downstream feeder rivers and the Craie aquifer (GIPSeine-Aval 2008). These secondary factors play a role of changing importance. According to GIPSeine-Aval (2008), the Craie aquifer can contribute during wet and normal times of the year a water volume of up to 25% of the Seine riverine runoff. In summer its contribution is prevalent negligible. Rainfall is another factor adding up to freshwater input to the Seine Estuary and Bay of Seine. Analyses of its impact to the foraminiferal communities in other (smaller) estuaries like the Vie Estuary (Debenay et al. 2006) has proven a diminished impact and therefor is here being omitted.



Figure 2.5: The dam of Poses, 160 km upstream of Le Havre. Photo from GIPSeine-Aval (2008).

Chapter 3

Results

3.1 Runoff analysis

The daily freshwater debit data of the Seine river permits tracing the hydrologic regime throughout the whole sampling period. The amount of freshwater has influence on water depth, position of the turbidity maximum and salinity of the estuary and equally the adjacent Bay of Seine.

Runoff data is visualized in Figure 3.1. The data set spans January 2008 to July 2011. Water discharge was measured in very short intervals of 1 day (explicit numbers not shown). But a more concise interval of one month allows a better overview (see Table 3.1). Patterns repeat but deviate by reason of alternating meteorologic situations and shifted rain periods. The minimal debits are generally observed between August and September while the maximum debits usually between January and March.

In 2008 minimal monthly average debit was reached in August ($296.6 \text{ m}^3/\text{s}$), maximum in April ($988.5 \text{ m}^3/\text{s}$) and a annual mean of $520.5 \text{ m}^3/\text{s}$. The following year 2009 received much less runoff. The minimum of 2009 was reached in August ($181.2 \text{ m}^3/\text{s}$), the maximum in February ($637.6 \text{ m}^3/\text{s}$) and an annual mean of $338.8 \text{ m}^3/\text{s}$. The third year (2010) is characterized by a minimum of $180.5 \text{ m}^3/\text{s}$ in July. The 2009/2010 winter maximum value of $689.1 \text{ m}^3/\text{s}$ was received in February 2010, the 2010 mean reached $415.1 \text{ m}^3/\text{s}$. The 2010/2011 winter runoff maximum reaches its spiking maximum in January 2011 with $1193.6 \text{ m}^3/\text{s}$, which is earlier and higher than the previous years.

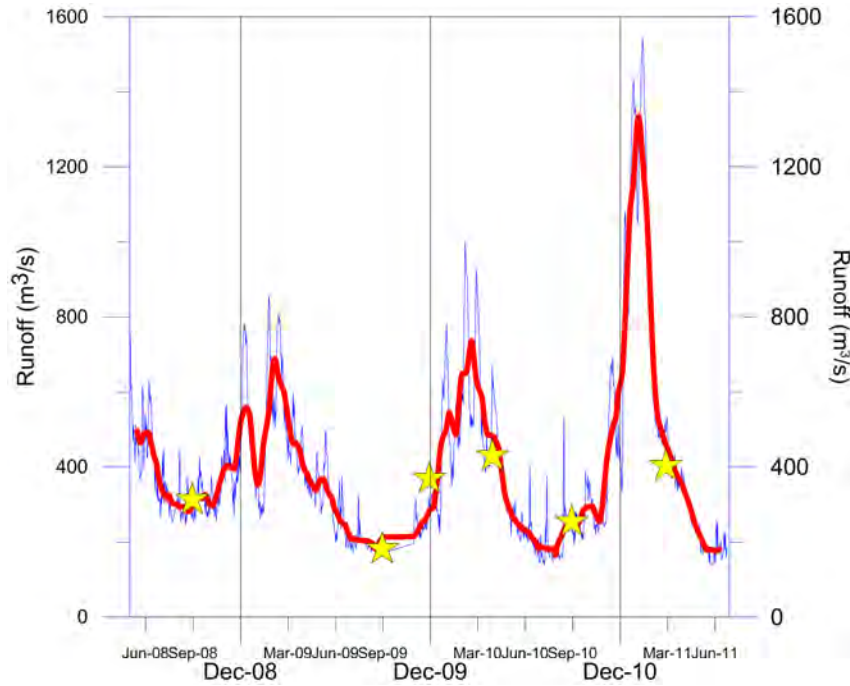


Figure 3.1: Runoff data measured at the dam of Poses. blue plot: 1-day interval; red plot: 30-day mean; yellow asterisk mark sampling times.

Table 3.1: 30-day mean runoff data measured at the dam of Poses in cubic meters per second (m^3/s ; see subsection 2.4.1). Sampling months are marked with asterisks, winter maximum months are magenta colored. Missing values are due to malfunctions and maintenance periods of the dam and probe.

	2008	2009	2010	2011
January	572.9	462.8	514.5	1193.6
February	673.5	637.6	689.1	521.4
March	838.7	464.5	548.8	404.2 ★
April	988.5	363.8	430 ★	295.9
May	525.3	348.0	255.5	187.7
June	452.9	250.1	213.8	182.1
July	320.0	210.9	180.5	177.1
August	296.6	181.2	229.2	
September	314.6 ★	182.3 ★	255.3 ★	
October	317.9	-	277	
November	401.2	249.7	481.6	
December	544.3	370.1 ★	906.2	
Mean	520.5	338.8	415.1	

3.2 Grain size analysis

The results of the grain size analysis conducted on the 2008 sampling are picked up for integration into overall considerations. The results of the 18 different sieve bottoms stretching an interval from 5 mm to 0.05 mm are shown in Table B.1. The granulometric raw data is presented in absolute numbers (gram) and relative percentiles. In order to compare the stations with each other and to adapt to international standards, cumulative plots utilizing the Wentworth classifications (Wentworth 1922) have been calculated (see Figure B.1 and Figure B.2). Cumulative grain-size curves plot grain size against cumulative weight percent frequency. Its shape is virtually independent of the sieve interval used. Also, data that can be derived from the cumulative curve allow calculation of several important grain-size statistical parameters. The slope of the central part of this curve reflects the sorting of the sample. A very steep slope indicates good sorting while a very gentle slope depicts poor sorting.

The following classification numbers have been calculated by the software GAEA WinSieve 1.20 and are shown in Table 3.2: percentage of sand, silt and clay within the Wentworth classification, sorting, mean (or 50% quantile in cumulative plot), skewness and kurtosis.

As the dry sieve intervals go down to 0.05 mm, the lower tails of the sum plots, %silt and %clay are modeled and convey less significance. For a correct empirical statement a wet sieving (laser granulometry etc.) would have extended the curve properly. As three sampling stations are located in very turbulent waters, the presence of less fine grained material can be assumed and hence wet sieving negligible. The sum plots show that stations 7 and 28 (north and south of the estuary) have lower proportions of sand (68.1% and 85.8% respective), while stations 11, 15, 40 consist almost only of a sandy facies (98.6%, 94% and 98% respective). The central station 15 has a slightly lower sand fraction ratio (94.3%).

Based on these values three different facies are observable:

- Station 7 dominated by sandy to ?muddy sediments situated in the north of the estuary. Sorting is relatively poor.
- Station 28 dominated by sandy to silty grain sizes. Sorting is good.
- Stations 11, 28 and 40 dominated almost exclusively by sandy grain sizes in the estuary channel along a west/east axis. Sorting is good to very good.

Table 3.2: Grain-size statistical parameters of the five sampling stations (September 2008).

station	7	11	15	28	40
description	North	Estuary channel distal	Estuary channel medial	South	Estuary channel proximal
% sand	68.1	98.6	94.3	85.8	98
% silt	< 30.4	< 0.9	5.1	11.4	2.0
% clay	< 29.0	< 0.9	0.3	0.8	0.1
sorting	3.797	1.193	1.304	1.544	1.470
mean	0.090	0.219	0.184	0.172	0.192
kurtosis	0.097	2.929	0.000	0.000	0.000

3.3 Foraminiferal fauna analysis

3.3.1 Overview

A total of 9063 living (stained) foraminifera from 315 μm and 150 μm sieves were collected out of 28 cores. In the faunal analysis the 125 μm is not considered for consistency reasons and will be discussed separately in section 3.8. A total of 33 benthic species were identified within living (stained) assemblages (see Census Appendix C and alphabetical species list Appendix D on page 123) in the Seine Estuary and Eastern Bay of Seine over a 3-year period in different seasons. Thereof 17 species were hyaline, 7 porcelaneous and 9 agglutinated already reported in reviews on the North Sea (Murray 2006). None of the sampling stations exceeded 19 different living taxa. Peak diversity and abundance were not necessarily on the sediment surface nor was the deepest infauna reached in most cores.

3.3.2 Diversity and Density

Densities and diversities varied strongly in the different places. Species richness over time was lowest at station 40, closest to the riverine freshwater input (1-7, avrg. of 5). The stations further downstream (S15 and S11) showed slightly increasing diversities with averages of 6 and 8. Highest average diversities of 13 and 15 taxa were found in the marginal positions north and south of the main stream channel (stations 7 and 28) where the estuary width increases a lot. Generally, highest richnesses in the whole area were observed at the end of summer (see Table 3.3a for more details).

Density ranged from 4 to 1013 living (stained) specimens within standardised 50 cm^3

sediment which is several orders of magnitudes between contemporaneous sample locations (Table 3.3b). Density was lowest in winter and early spring (March) until it started recovering from April on. For a more precise correlation of annual salinity shifts with densities (or surface abundances) two annual sampling periods (spring and autumn) were shown to be insufficient.

Density and diversity of living foraminifera was correlated in many cases (see Figure B.3), which is a common characteristic reported by Murray and Alve (2000) from the Hamble Estuary in southern England.

3.3.3 Wall types

Hyaline specimens were greatly predominating the biocenosis (Table 3.3c). The two stations in the estuary channel (S11 and S15) show highest dominance of hyaline foraminifera with an average above 90%. The peripheral station in north and south (S7 and S28) still show significantly raised numbers of hyaline foraminifera with an average above 80%. Agglutinated tests are highly enriched in density and proportion (from 19 to 94%) in the most distant station from the estuary mouth. Besides that, agglutinated species were generally stronger prevalent in autumn and winter 2009 than in the other years.

3.3.4 Species ranking

An overall species ranking covering all 28 cores and specimen $>150\text{ }\mu\text{m}$ is presented in Figure 3.2 below. To separate the dominant fauna from accessory species, only taxa which constitute more than 5% in the 0-1 cm surface layers of each core are considered important for the variance and statistics. The concerned taxa are marked with asteriks in Figure 3.2: 14 of the 33 species match this requirement. The majority of the stained tests belong to *Elphidium excavatum* (and its non-differentiated morphotypes). It was the dominant species of the Seine Estuary and Eastern Bay of Seine comprising 63.14% of the total assemblage. That is in clear distance to the following species *Ammonia beccarii* with 15.62%. Third was *Psammosphaera fusca* (8.09%) which is half as much as *Ammonia beccarii*. Then follow *Quinqueloculina seminula* (3.15%), *Elphidium excavatum clavatum* (2.71%), *Eggerelloides scaber* (1.42%), *Psammosphaera* sp. (1.35%), *Psammospheara bowmanni* (1.01%), *Bulimina elongata* (0.77%), *Criboelphidium magellanicum* (0.64%), *Hemisphaerammina* sp. (0.46%), *Gavelinopsis praeegeri* (0.30%), *Nonion scaphum* (0.09%) and Agglutinated sp. (0.06%).

These especially high abundances of *Elphidium* and *Ammonia* species (more than 78% together) makes them worthwhile to follow their particular presence and ab-

sence patterns and the implicated causes for this behavior.

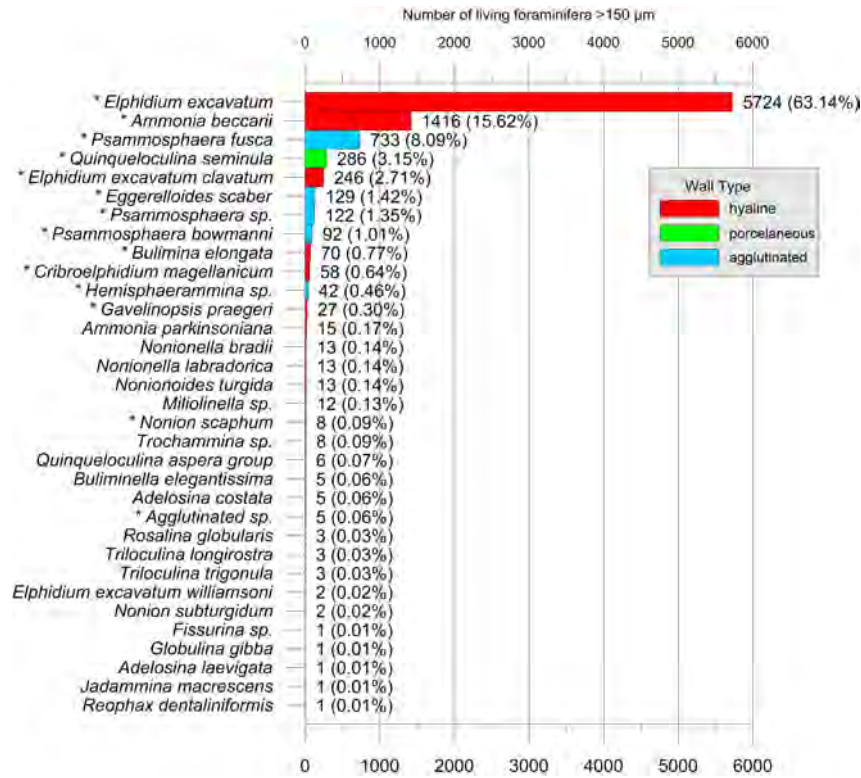


Figure 3.2: Species ranking of the 315 µm and 150 µm fraction covering all sampling periods. Asteriks mark the most significant species (see text)

Table 3.3: Key data of the recorded samples**(a) Species diversity S in whole cores**

station	S7	S11	S15	S28	S40	max. per season
description	North	Estuary channel distal	Estuary channel medial	South	Estuary channel proximal	
September 2008	19	9	10	16	4	23
September 2009	12	7	7	15	5	16
December 2009	No data	No data	6	9	5	11
April 2010	16	8	3	13	5	19
September 2010	18	8	7	14	7	21
March 2011	12	6	4	9	1	17
mean station	15±3	8±1	6±2	13±2	5±1	

(b) Species density N per 50 cm³ in whole cores

station	S7	S11	S15	S28	S40	mean season
description	North	Estuary channel distal	Estuary channel medial	South	Estuary channel proximal	
September 2008	1013	91	174	991	36	461±433
September 2009	219	53	76	241	59	130±80
December 2009	No data	No data	6	77	5	29±32
April 2010	675	18	20	222	122	211±190
September 2010	311	13	204	261	37	165±112
March 2011	199	6	35	86	4	66±61
mean station	483±288	36±29	86±69	313±226	44±31	

(c) Wall types % in whole cores (hyaline, porcelaneous, agglutinated)

station	S7	S11	S15	S28	S40	mean season
description	North	Estuary channel distal	Estuary channel medial	South	Estuary channel proximal	
September 2008	86, 9, 5	16, 4, 80	93, 3, 4	89, 0, 11	97, 3, 0	76, 4, 20
September 2009	83, 2, 15	6, 0, 94	80, 0, 20	72, 1, 27	97, 1, 3	68, 1, 32
December 2009	No data	No data	38, 6, 56	75, 4, 21	78, 0, 22	64, 3, 33
April 2010	88, 0, 12	52, 8, 40	100, 0, 0	81, 3, 16	98, 0, 2	84, 2, 14
September 2010	80, 15, 5	69, 0, 31	99, 0, 1	92, 1, 7	98, 1, 1	88, 3, 19
March 2011	84, 3, 13	56, 25, 19	99, 0, 1	84, 3, 13	100, 0, 0	85, 6, 9
mean station	84, 6, 10	40, 7, 53	94, 1, 5	82, 2, 16	95, 1, 5	

3.3.5 Community structure analysis

The foraminiferal fauna investigation is one of the main objectives of this study. That involves spatial, temporal and depth analysis of the foraminiferal distribution in the sediment column.

For the varying core depth's sake the 0-1 cm surface layer is the most suitable means for comparability. Epifaunal and shallow infaunal species gather here. Like stated above, only species contributing more than 5% were considered.

Abundance (per 100 cm²), diversity, Shannon H, AE-index and river runoff are combined in Figure B.3 on page 90. Proportions of the most important taxa in the 0-1 cm layer is shown in Figure B.5 on page 98. The vertical distribution of the most important species is given in Figure B.6 on page 102 for the North-South transect (S7-S15-S28) and in Figure B.7 on page 104 for the West-East transect (S11-S15-S40). And finally for the spatial approach to surface abundance see Figure B.4.

Station 7 (north) is in a position with relatively high abundances (2008 maximum, 454 minimum) and species richnesses (17 max., 9 min.). Times of low debit in September show a non repetetive pattern: whereas 2008 has the highest abundances (2008 individuals), the following September has the lowest measured abundance of 454 individuals. September 2010 has slightly higher abundances of 611 foraminifera per 100 cm². The April 2010 sampling took place 2 months after the winter 2009/2010 flood during waning runoff and had a population of 1785 individuals per 100 cm². The March 2011 core was collected two months after the high water with 486 living individuals per 100 cm².

Primarily, the most abundant species during the first 4 sampling periods are first *Elphidium excavatum* and second *Ammonia beccarii*. The dominance of *E. excavatum* and *A. beccarii* reaches a climax in April 2010 when highest river inflow (430 m³/s, Table 3.1) of all sampling cycles were measured.

Downcore distribution of standing crop is stable downcore during low river influx (September 2008,9,10). In April 2010 and March 2011 the sediment surface is densely populated but diminishes quickly from 1 cm downwards.

Station 11 (estuary channel distal) is the most western position and is a scarcely populated foraminiferal habitat. The highest abundance and species diversity is reached in September 2008 with 219 individuals per 100 cm² and 8 different species. Lowest is encountered in September 2010 with 11 individuals per 100 cm² and 2 species. In September 2009 abundance reaches 154 individuals and 6 species, April 2010 69 individuals and 4 species, September 2010 11 individuals and 2 species populate the sediment surface. In March 2011 33 individuals of 5 species are present.

The most westward positions sampling station is dominated by *P. fusca* and *Psammosphaera* sp. in September 2008 and 2009. During high runoff times *Psammosphaera* is outnumbered by *A. beccarii* and *E. excavatum*.

Deeper in the sediment a decreasing density is observable. This is also true for times of very sparse densities like March 2011.

Station 15 (estuary channel medial) is the center position in the middle of the NS and WE transects. Most living foraminifera are found in the September 2008 sample (472 individuals per 100 cm²) attributed to 8 species. The most empty surface was encountered in April 2010 with 15 individuals among 2 species.

The center station is mainly dominated by *E. excavatum* and *A. beccarii*. In March 2011 *E. beccarii* is the only living foraminiferal species. In September 2009 *P. fusca* and *Psammosphaera* sp. show up in considerable amounts subordinate to *E. excavatum* and *A. beccarii*.

Most remarkable distribution in depth is the inverse distribution of September 2010. Densities increase sixfold from surface to 5 cm depth.

Station 28 (south) is a comparatively densely populated place. The most dense population was found in September 2008 (2209 individuals per 100 cm²) accompanied by a species richness of 13. The lowest foraminiferal numbers contained the December 2009 sample (110 individuals per 100 cm²) assigned to 5 species.

The faunal community is always dominated by *E. excavatum* and *A. beccarii*. Secondly agglutinated species like *Psammosphaera* and *E. scaber* show up in all intervals. In the December 2009 core they are present in the 1-3 cm interval but not on the surface. In some cases (December 2009 and March 2011) *Q. seminula* has minor densities.

Station 40 (estuary channel proximal) shows almost all sampling intervals the poorest test densities. The maximum is reached in September 2010 (124 individuals per 100 cm², 4 species) and the minimum in April 2010: 4 individuals per 100 cm² of only a single species.

In many subsamples of the estuary mouth station a minuscule faunal density has been recorded. *E. excavatum* dominates the habitat at all times. Only in September 2009 and December 2009 a smaller amount of *P. fusca* is found in the strata deeper than the surface layer.

Summed up:

- The stations north and south of the estuary mouth (7 and 28) show high densities and are relatively strong diversified (Figure B.6)
- The stations of the transect parallel to the estuary mouth (40, 15 and 11)

clearly show lower densities and diversity

- Lower runoff is related to higher foraminiferal abundances
- Diversity correlates with density but not necessarily (see S7 April 2010, S15 September 2010)
- Density does not necessarily decrease downcore (see S15 September 2009, S28 December 2009, S40 September 2009, S40 April 2010). This might be due to surface erosion effects
- High foraminiferal abundances are only reached by the *Elphidium excavatum* and *Ammonia beccarii* populations
- Generally, agglutinated and porcelaneous species are present only in accessory amounts
- Populations of *P. fusca*, *P. bowmanni*, *Psammosphaera* sp. and *Hemisphaerammina* sp. increase in sampling stations with larger distance to the estuary mouth and might become the majority at some times (see S11 September 2008 & 2009)
- *Q. seminula* does not live at stations 15 and 40. This species might be a indicator for marine influence

3.3.6 Morphotype distribution

For the extant and widespread species *Elphidium excavatum* (Terquem, 1875) at least 6 distinct morphotypes are recognized in the literature (Feyling-Hanssen 1972, Painter and Spencer 1984, Jorissen 1988, Goubert 1997). Differentiation is made considering morphometrical aspects like the number and average length of sutural bridges, number of chambers visible and number of umbilical bosses. As an impetus for this differentiation an ecophenotypic adaptation to water temperatures and salinities is being hypothesized by Goubert (1997). In this present study only the most distinct morphotypes *E. excavatum clavatum* and *E. excavatum williamsoni* are distinguished and counted because of high overlapping of morphotypes. Possible further morphotypes are collectively incorporated into *Elphidium excavatum* (without morphospecies extension). During observation *E. excavatum clavatum* did not show a significantly different microhabitat preference (see Figure B.8). Elevated abundances of *E. excavatum clavatum* usually coincided with elevated living stock of *E. excavatum* (see Sep 2008, Sep 2009, April 2010).

3.4 Diversity indices

Shannon index (H), A-E Index and species richness (S) are means for giving estimations on the diversity of the different picked species. Again, only surface communities have been regarded for broadest comparability. Data is presented in Figure B.3 a-e together with Seine runoff and foraminiferal abundance data to make possible trends plausible. The A-E Index was only compilable when specimens of *Ammonia* and *Elphidium* were present.

Species diversity S varies with species abundance like already stated above. Shannon H often covaries with diversity S but not in every case. Divergences emerge when less species appear though in more equal distributions. The A-E Index in turn rises when diversity and abundance drop, which can be expected regarding the theory of Alve (1995) (see Figure 1.1). This behavior is in accordance with the perception of *Ammonia beccarii* being a highly tolerant to opportunistic species, thriving when less tolerant species (in this case *E. excavatum*) retreat.

Nevertheless, in some situations when the A-E index climbed (indicator for less favourable situations) while Shannon H also rose (indicator for higher diversity and equal distribution on species). This behavior stays unclear with the given parameters.

3.5 Cluster analysis (R-mode, species grouping)

A hierarchical cluster analysis (CA) has been conducted based on species appearance (Figure 3.3). Cluster analysis is a multivariate statistical method that generates a dendrogram of relation and groups species with similar abundance within samples (here: cores). The higher the distance of a dendrogram node (bifurcation), the lower the similarity of the successive species groups originating from the node will be. For data input the 0–1 cm >150 μm of the statistically significant foraminifera (see subsection 3.3.4) has been processed in PAST 2.11 (Hammer et al. 2001) utilizing “Ward’s method” algorithm. R-mode comparison demands in the statistics spread sheet samples in columns and species in rows. An upper distance limit for groups being considered as cluster was imposed with a value of 1.0. Then, clusters were colored accordingly. Given the maximal distance limit 4 clusters and 4 single entities can be distinguished:

Cluster 1 *Psammospaera* sp. and *Elphidium excavatum clavatum*

Cluster 2 *Elphidium excavatum williamsoni*, *Bulimina elongata*, *Psammospaera bowmanni* and *Criboelphidium magellanicum*

Cluster 3 *Quinqueloculina seminula*, *Hemisphaerammina* sp. and Agglutinated sp.

Cluster 4 *Eggerelloides scaber*, *Gavelinopsis praegeri*, *A. beccarii*

single entity *Nonion scaphum*

single entity *Psammosphaera fusca*

single entity *Ammonia beccarii*

single entity *Elphidium excavatum*

Species that do not belong to a cluster (i.e. the bifurcation is below the distance limit) do not show a similar appearance compared to any other species.

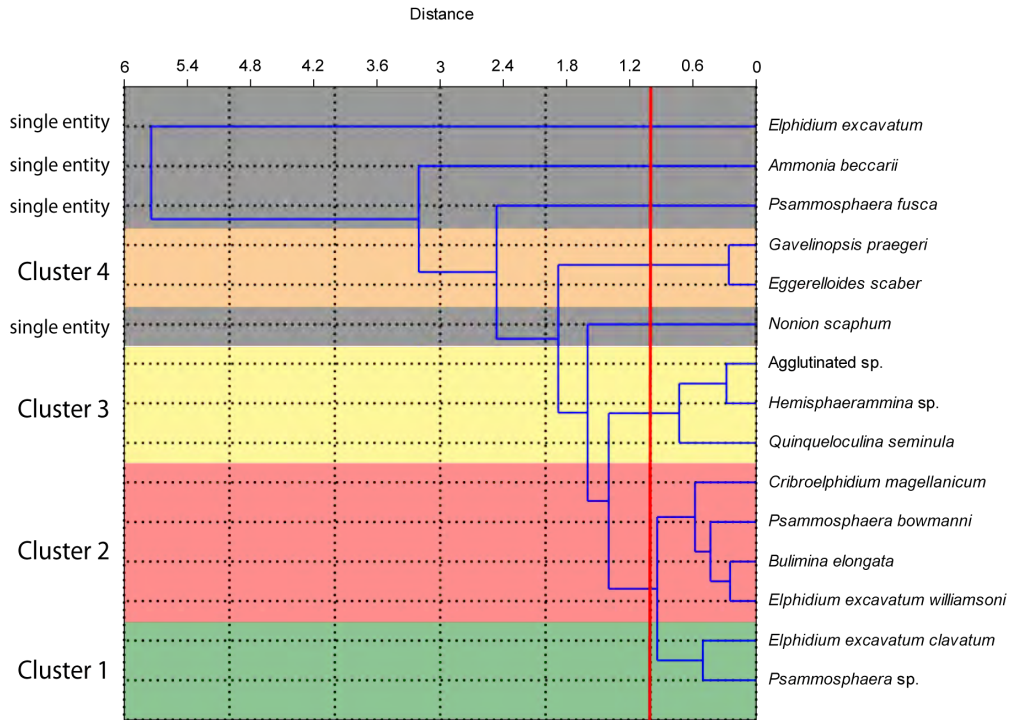


Figure 3.3: Cluster analysis dendrogram, R-mode, Ward's method

3.6 Cluster analysis (Q-mode, sample grouping)

A second cluster analysis was carried out in Q-mode data arrangement to detect possible groupings of samples (Figure 3.4). The process used the same arcsin transformed percentage-values but in a transposed matrix in comparison to R-mode analysis: species are arranged in columns, samples in rows. By using Ward's method

algorithm and a similarity limit of at least 1.0, 6 clusters and 2 single entities were grouped. The cluster groups are marked with individual colors in the dendrogram (see Figure 3.4).

Cluster 1 S7 September 2008, S7 April 2010, S15 September 2008, S15 September 2010, S28 September 2008, S28 December 2009, S28 September 2010

Cluster 2 S7 September 2010, S11 March 2011

Cluster 3 S11 April 2010, S15 September 2009, S28 September 2009, S28 April 2010

Cluster 4 S7 September 2009, S7 March 2011, S11 September 2010, S28 March 2011

Cluster 5 S15 March 2011, S40 September 2008, S40 September 2009, S40 December 2009, S40 April 2010, S40 September 2010, S40 March 2011

Cluster 6 S11 September 2008, S11 September 2009

single entity S15 December 2009

single entity S15 April 2010

The dendrogram combines Station 7 and 28 in cluster 1 and cluster 4. These stations are characterized by a strong species richness and a high foraminiferal density compared to the other stations of our study. Disregarding general abundance and dominance of *Elphidium excavatum* and *Ammonia beccarii*, the northern station shows much higher densities of *Quinqueloculina seminula* with up to 13% for north (S7) but only up to 4% in the south (S28). This coincides with finer granulometry of Station 7.

Station 11, the most freshwater influenced position in the east, is grouped in cluster 6. But nevertheless it shares similarity with the northern and southern stations 7 and 28 during some seasons (see cluster 2, 3 and 4). This station is characterized by a particular fauna, essentially by agglutinated species (*Psammosphaera fusca*, *Hemisphaerammina* sp.) which thrived during September 2008 and 2009 and *P. fusca* dominated with 72% the whole community. Then stations differ by the total absence of the usually dominant species *Elphidium excavatum*. Station 11 shares with the other stations parallel to the estuary axis a relatively coarse grain size. This makes the grain size unlikely to be a promoting factor for agglutinated species whereas this cannot be verified as the influence of currents transporting foraminifera specimens is not clear.

Moreover, the dendrogram shows that Station 15, in the central position of the channel, is not distinctly associated to other locations. This is expressed by alternating conjunction to the adjacent stations upstream (cluster 5), north and south (cluster 1, cluster 3) and the for formation of non-grouped entities (December 2009, April 2010).

Station 40, the most marine station, constitutes cluster 5 solely with the exception of S15 in March 2011. Thus, the assemblages and abundances encountered there persistantly separate from other regions.

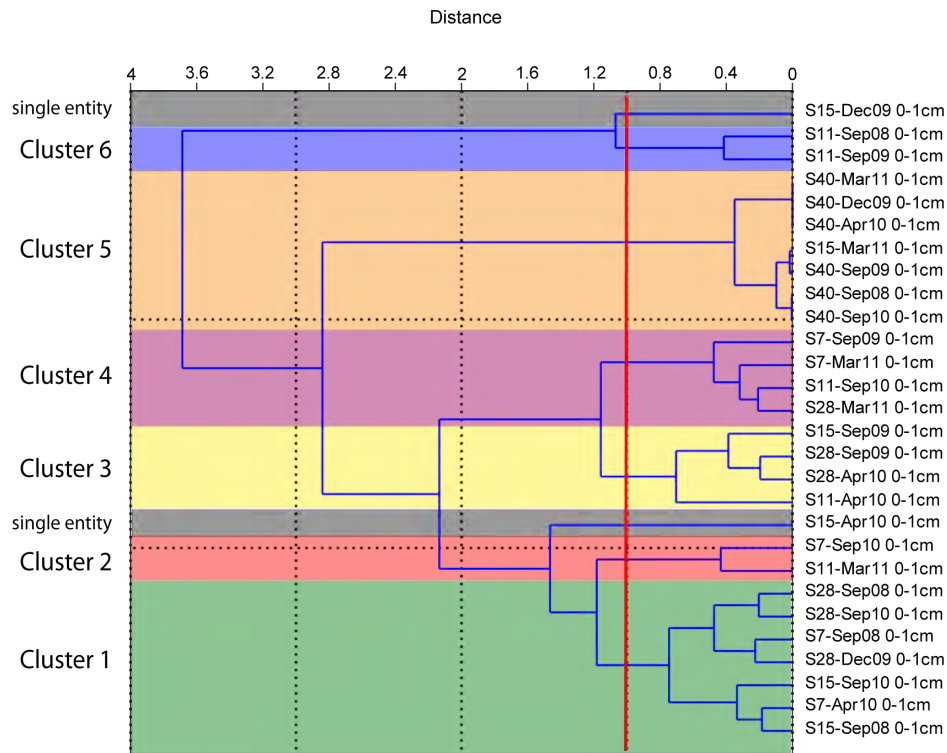


Figure 3.4: Cluster analysis dendrogramm, Q-mode, Ward's method

3.7 Canonical correspondance analysis

To get a perspective on the relationships between foraminifera and different parameters, a canonical correspondance analysis was conducted with PAST 2.11. Three environmental variables were used to compile triplots:

1. the average runoff during the sampling month (see Table 3.1). An average value might help to correct for slow response of the foraminiferal communities to changing environments;

2. the water depth at the respective sites (see Table 2.1);
3. the fraction of the sand sediment grain size at the respective station (analysis of 2008, see Table 3.2). Whereas it has to be taken into account that sand banks and grain sizes can vary quickly as the work of Lesourd et al. (2001, 2003) suggests.

Transponing the dataset matrix places once surface samples and once species in a triplot. Vectorial directions of parameters stay the same in both plots. The CCA reports on the respective dependency of a sample/species to a given environmental parameter. Positioning of values in the direction of a parameter vector signifies greater the influence of the respective parameter whereas opposite directions denote an anti-correlation. Here, the grainsize vector (“sand %”) roughly plots in the opposite direction of water depth. Hence, it can be deduced that communities in greater distance are probably ruled by deep water and fine substrates, whereas proximal communities (in respect to the estuary outlet) have to adapt to shallow waters and coarse sediment grains.

3.7.1 CCA samples

Results are illustrated in an ordination diagram (on page 108). The green triplot spans a field in which the surface samples are placed with respect to their respective affinity to the three environmental variables. Groups of the Q-mode cluster analysis (section 3.6) are added to visualize possible triggers for clustering.

Station 11 September 2008 and 2009 (cluster 6) are positioned antagonistic to river runoff which might be caused by the marine saltwater influence of the Bay of Seine. Station 15 April 2010 shows strong correlation with runoff, whereas in September 2009 that case is turned round. During other seasons positions are not very distinctly patterned but rather plot in direction of the sand vector. The stations 7 and 28 (clusters 1, 2, 3, 4) plot rather in direction of water depth than sand. Their relation to freshwater input stays changeful and unsettled. Placement of Station 40 (cluster 5) suggests an influence of coarse substrate (sand%) to the community's composition. This is possibly due to the elevated transport power for coarse grains in the main channel.

3.7.2 CCA species

Also a separate canonical correspondence analysis was carried out on species classification (Figure B.10) utilizing the same environmental parameters. The dominating species *Elphidium excavatum* and *Ammonia beccarii* are not very exposed positioned. *E. excavatum* shows a shift towards sand, whereas *A. beccarii* is deferred towards

water depth which is an unexpected result. *A. beccarii* is renown to colonize temporary dry intertidal environments with pronounced stress (Langer et al. 1989). That shows parameters acting on the distribution of this species, which is consistent with the conception of Murray (2001) who considers the patterns of distribution of benthic foraminifera are controlled by those environmental factors that have reached their critical threshold. The group *Psammosphaera* and *Hemisphaerammina* anti-correlate with Seine freshwater input with *P. bowmanni* especially showing a shift towards water depth. The group *Quinqueloculina seminula*, *Elphidium excavatum clavatum*, *Elphidium excavatum williamsoni*, *Criboelphidium magellanicum*, Agglutinated sp. and *Eggerelloides scaber* is moderately associated to river runoff and water depth. *Bulimina elongata* can bears the most definite defined occurrence. It shares the pattern of the former group but in a much more pronounced manner.

3.8 The 125 μm fraction

In September 2010 and March 2011 supplementary the 125 μm fraction has been analysed which yielded 229 individuals in September 2010 and 54 individuals in March 2011. A comparison of the September 2010 and March 2011 samples $>150 \mu\text{m}$ to the $>125 \mu\text{m}$ is addressed to identify if important information on the community is being missed. Abundance (N), differences (Table 3.4) and deviations of individual species (Table B.4) were calculated. The difference varies between 2.86% minimum (S11 September 2010) and 40% maximum (S40 March 2011). However, highest differences ($>10\%$) are found among the stations with poor abundances (S11, S15, S40) where already small deviations have larger impact. *Elphidium excavatum* is a species always present in the 125 μm interval and is also the species accounting for the most for the deviations (see Table B.4). There are no species exclusively populating the 125 μm sieve interval and hence all of them present have to be considered juvenile.

In addition, Wilcoxon's signed rank test was calculated in PAST 2.11 (Table 3.5). The H_0 hypothesis for Wilcoxon's test is: no median shift (no difference) between the two compared datasets. Significance limit α was chosen to be 5%. In three cores the null hypothesis has to be rejected which means a statistical significant difference between them: S7 September 2010, S15 September 2010 and S28 September 2010. These are the cores with the highest δN values (see table below).

Table 3.4: Diversity and abundance of the 125 μm size fraction

	$N_{>150 \mu\text{m}}$	$N_{>125 \mu\text{m}}$	δN	$\% \delta N$	$S_{>150 \mu\text{m}}$	$S_{>125 \mu\text{m}}$
S7 Sep10	850	901	61	6.00	18	18
S7 Mar11	218	233	15	6.88	12	12
S11 Sep10	35	36	1	2.86	8	8
S11 Mar11	16	19	3	18.75	6	6
S15 Sep10	559	597	38	6.80	7	7
S15 Mar11	95	106	11	11.58	4	4
S28 Sep10	714	782	64	9.52	14	14
S28 Mar11	236	257	21	8.90	9	9
S40 Sep10	102	116	14	13.73	7	7
S40 Mar11	10	14	4	40.00	1	1

Table 3.5: Wilcoxon signed rank test $>150 \mu\text{m}$ vs. $>125 \mu\text{m}$

	W	z	p(same)	$\alpha = 0.05$
S7Sep10	28	2.375	0.017552	reject H_0
S7Mar11	10	1.841	0.0656	no difference
S11Sep10	1	1	0.31731	no difference
S11Mar11	3	1.414	0.1573	no difference
S15Sep10	15	2.041	0.041227	reject H_0
S15Mar11	1	1	0.31731	no difference
S28Sep10	45	2.716	0.0066061	reject H_0
S28Mar11	10	1.841	0.0656	no difference
S40Sep10	1	1	0.31731	no difference
S40Mar11	1	1	0.31731	no difference

Chapter 4

Discussion and perspectives

The most dominant species in the Seine Estuary and Eastern Bay of Seine, *Elphidium excavatum* and *Ammonia beccarii* are typical of temperate estuarine environments, including European regions (Murray and Alve 2000, Murray 2006). Both species have already been reported from adjacent French coasts and estuarine tidal flats (Debenay and Guillou 2002, Debenay 2009, Goubert 1997). According to Debenay (2009) their distribution in paralic environments is related to the prevailing sea-to-freshwater gradient with *Ammonia beccarii* occupying coarse sand substrates and *Elphidium excavatum* muddy sand areas. Both are often considered as very tolerant to most kinds of contaminants. They are motile species changing from epifaunal to infaunal habitats and highly adaptable to changes in food availability and/or changing environmental conditions (Linke and Lutze 1993). Debenay et al. (2001) point out that *E. excavatum* and *A. beccarii* are tolerant pioneer taxa in the open ocean harbor in Port Joinville, France, capable of recolonizing barren sediments quickly. Sharifi et al. (1991) established that *E. excavatum* is the most tolerant species to heavy metal pollution, followed by *H. germanica* and *A. beccarii* in that given order. *A. beccarii* is the more tolerant species to low oxygen concentrations, tenuous pH levels, most diluted salinities and severest pollutions (Murray 2006).

Despite these enormous tolerances of *A. beccarii*, the environmental pressure was never severe enough that *A. beccarii* could outnumber *E. excavatum*, which would make a strong case for anthropogenic pollution (Yanko et al. 1994, Samir and El-Din 2001). As no heavy metal analysis results of the sediment body are available, it is impossible to attribute the dominance of *E. excavatum* to high heavy metal concentrations as reported by Sharifi et al. (1991). One explanation for the often occurring dominance of *A. beccarii* and *E. excavatum* might be the high mobility of sand banks in the Seine Estuary (Lesourd et al. 2001). One can assume that erosional activities occur in many places and occasionally due to the Estuarine Turbidity Maximum (ETM) at the most riverine influenced station (estuary mouth, S40). Owing to their high ability to recolonize stripped bare sediment bodies (Debenay et al. 2001), *E. excavatum* and *A. beccarii* could proliferate favorably.

Porcelaneous tests (most notably the infaunal *Quinqueloculina seminula*) are rare in the study area, except in the peripheral region of the tidal inlet where they might take up to 15% of the standing crop (S7 September 2010). However, *Q. seminula* has been reported to be among the opportunistic pioneer species recolonizing barren substrates after volcanic ashfall (Hess and Kuhnt 1996) or resuspension events (Duros et al. 2011) in the deep sea. This might be in accordance with the highly turbulent and erosive behavior of the estuary hydrodynamics although ETM does not reach that far to Station 7. Apart from this, Debenay and Guillou (2002) describe *Q. seminula* as a dominant species in paralic environments in the vicinity of

seaweeds.

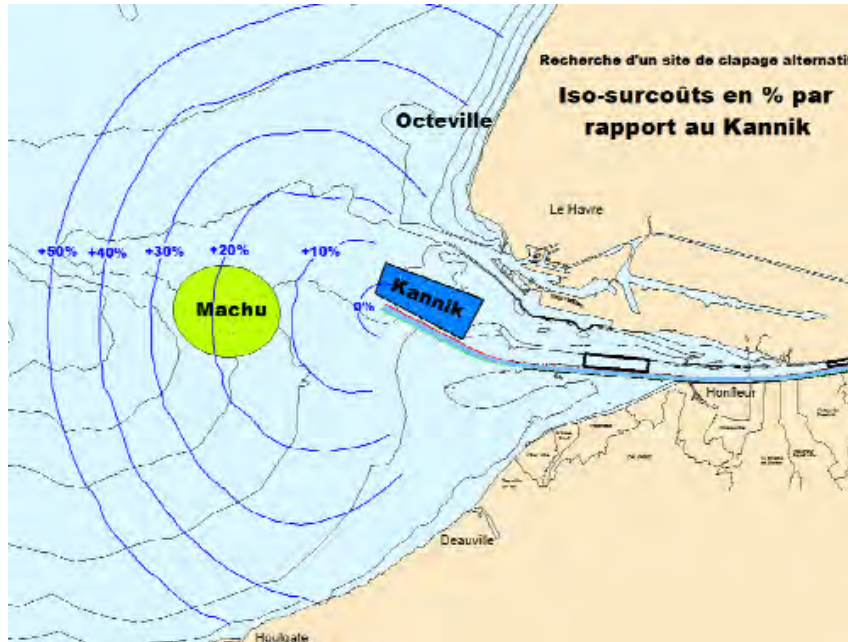
Living **agglutinated** species were patchily distributed. *Psammosphaera* and *Hemisphaerammina* very often grow as accessory species that nevertheless are well represented. Noticeable spikes occurred in the most marine Station 11 in September 2008 and 2009 when *E. excavatum* and *A. beccari* are highly underrepresented. In the following year (September 2010) they do not flourish in Station 11. An explanation through freshwater input seems implausible as substantially elevated values were not measured in the 2010 summer months. In the literature they are not described to be pioneer species being especially pollutant tolerating.

Overall, abundances of standing stock are temporary fairly poor. In natural communities standing stock is not a constant as some species have pronounced reproduction periods. Despite the fact that sampling times were planned to pick up seasons of estimated increased reproduction (especially for the separately collected macrofauna), abundances vary strongly in interannual comparison. Low abundances should not be confused with degradation, as reproduction cycles and standing stock peaks of many species are proven not to be steered by seasons like studies in England (Murray and Alve 2000) and France (Debenay et al. 2006, Debenay 2009) showed. Hence, it is vital to provide sufficient covarying environmental parameters.

Station 7 in the northern periphery is remarkably close to the disposal zone of Octeville (ca. 1.7 km). Large amounts (lately $>2 \cdot 10^6 \text{ m}^3$) of dredged material are annually discharged there (see statistics in GIPSeine-Aval 2009). The latter stems from the navigation channels where large freighters unloading at the GPMR and GPMH pass through. Augmented concentrations of organic matter PCB, PAH and heavy metals might affect communities. Bacteria thriving in these conditions might be a reason for the generally elevated foram densities in samples from station 7. According to a dossier of GPMR 2011 several concentrations of hazardous materials are tested but are conform to French environmental laws. Effects of erosional currents are uncertain entraining the dumped and potentially contaminated material. Thus, it is difficult to appoint influences of resedimented dredging material for possible perturbations at Station 7.

For future samplings it has to be considered that plans for a creation of the Kannik disposal site is advanced and is likely to impact benthic communities. In the vicinity of Station 11 (Rade de la Carosse, see Figure 2.3) the GPMR is scheduling a large new disposal site Machu (see Figure 4.1; GPMR 2011). If presently carried out biological and sedimentological experiments succeed, GPMR's main site "Kannick" will phase-out by 2014 and disposal will change position. Further impacts will have to be evaluated by then or could even be studied in the course of the running experiments on benthic macrofauna and fish.

Figure 4.1: Localities of the GPMR's disposal sites: Kannik and the planned site Machu (in experimentation phase). from GPMR (2011)



In the Seine Estuary, great inter- and intra-annual differences in species richness have been recorded. The temporal variation in species richness results from rareness and probably patchiness of rare species that occur only exceptionally at a given station. As no replication method was used, these species were collected randomly at each sampling period, leading to irregular species richness. As diversity tends to increase with distance to the freshwater source (i.e. hydrographic limit) and the turbiditic maximum, it can be concluded that the agglutinated species and especially *Q. seminula* need marine influence similar like Debenay et al. (2006) point out in their findings at the Vie Estuary. So as to compare the present findings of this study with results of four studies from other French locations, the pollution tolerant found species are summarized and given in Table 4.1 below. These studies are addressed in the following.

A recent study conducted in the polluted North Sea harbor and estuary of Boulogne-sur-Mer by Armynot du Châtelet et al. (2011) found a positive correlation of *Haynesina germanica* and *Bolivina pseudoplicata* to contaminants like heavy metals. In the outer (marine influenced) parts of the harbor basins *Elphidium excavatum* and *Elphidium magellanicum* replace the heavy-metal tolerant taxa. These four taxa were found to serve as excellent key taxa that correlate with anthropogenic impacts

and consequently reflect the influence of the pollutants introduced from industrial activity in the Boulogne-sur-Mer harbor basins.

Numerous studies have been conducted in French estuaries discharging to the Atlantic Ocean and also the English Channel (Debenay et al. 2006, Debenay 2009, Armynot du Châtelet and Debenay 2010) but many of them took place in different microhabitat settings and hence diversities and abundances are not directly comparable to this study's results in numbers. Debenay (2009) compared samples from intertidal sites of the anthropogenically contaminated Seine estuary and as reference the less polluted Authie Estuary. The evidence favored an evidently high impact of chronic pollution to foraminiferal assemblages on Seine sand banks. The main differences between the two estuaries were a higher percentage of *Ammonia tepida* in the Seine Estuary while it was quite rare in the Authie Estuary, and a lower density and species richness in the living and dead assemblages of the Seine Estuary. Influences of salinity, granulometrical composition and elevation influences could be excluded. According to Debenay, both the lower density and higher proportion of *A. tepida* in the Seine Estuary were more than likely related to pollution.

Observations made by Armynot du Châtelet et al. (2004) on five harbors located in moderately polluted estuaries on the coast of Vendée indicate pollution impact. Possible sources in harbor basins are motor-fuel, paint and remnants of the Erika oil spill in 1999. Foraminiferal species richness and density showed to be higher within lower polluted areas. Key taxon indicating pollution stress was determined to be *Haynesina germanica*. Though, results were not clear enough to separate pollution influences from low salinities caused by riverine runoff.

Foraminifera stocks at Port Joinville Harbor on Yeu Island has been documented by Debenay et al. (2001). The difference to estuarine settings is the constricted influence of freshwater. Local harbor pollution mainly originates from boats, including detergents, paint, motor-fuel and oil. *Elphidium excavatum* and *Haynesina germanica* were indicative taxa in places with reduced densities. Main impacting factors were found to be grain-size, heavy metals and hydrocarbons.

The dominance of *E. excavatum* in all stations of this study concurs with the estuarine setting of the Liane River at Boulogne-sur-Mer (Armynot du Châtelet et al. 2011): Strong tidal effects, low salinity, skirting ships and effluents from highly contaminated harbor basins. Moreover, *E. excavatum* is indicator species in the Port Joinville which lacks the freshwater influence (Debenay et al. 2001). Pollution sources were in both cases hydrocarbons and heavy metals caused by skirting boats, maintenance and unloading activities. Yet, in the case of the Seine Estuary, it is uncertain if this key taxon can be traced back to such perturbations.

Many of the reported taxa in this study are reported by Yanko et al. (1999) to be pollution tolerant and show an opportunistic behavior to proliferate under harsh conditions when less tolerant taxa perish. Matching taxa are *Eggerelloides scaber*, *Ammonia beccarii*, *Buliminella elegantissima*, *Elphidium excavatum*, *E. excavatum clavatum*, *Miliolinella subrotunda* and *Quinqueloculina seminula*.

This contrasts to reports on average coastal environments (i.e. more or less undisturbed) like the North European Wadden Sea, where the genus *Ammonia*, *Elphidium* and *Haynesina* make up 99% of the total fauna Langer et al. (1989). A study on a 180 years spanning core in the Dutch Wadden Sea by de Nooijer (2007) showed a high dominance of *Elphidium excavatum* during times of the industrial onset in 1830. Furthermore, *Ammonia tepida* and *Elphidium excavatum williamsoni* are common species with niches in Northern Europe. Pivotal changes have altered the community to become dominated by *Haynesina germanica* through the construction of a dam. Pollution effects were first detected from 1960 on.

This particular ambivalent circumstance makes it difficult to pinpoint in the Seine Estuary a specific key taxon like the ubiquitous *E. excavatum* might favor. Direct correlation with contaminating substances could clear things up.

Table 4.1: Pollutant resistant foraminifera species published French locations and in this study

	Published localities					This study				
	Boulogne-sur-Mer – Liane River (Armynot du Châtelet et al. 2011)	Boulogne-sur-Mer – harbor (Armynot du Châtelet et al. 2011)	Seine Estuary tidal flats (Debenay 2009)	Port Joinvill Harbor (Debenay et al. 2001)	Vendée Estuaries and Harbors (Armynot du Châtelet et al. 2004)	S7	S11	S15	S28	S40
<i>Ammonia tepida</i>			✕							
<i>A. beccarii</i>							✕	✕	✕	
<i>Bolivina pseudoplicata</i>		✕								
<i>Criboelphidium williamsoni</i>										
<i>Elphidium excavatum</i>	✕			✕		✕	✕	✕	✕	✕
<i>E. magellanicum</i>	✕									
<i>Haynesina germanica</i>		✕		✕	✕					
<i>Quinqueloculina seminula</i>						✕	✕			

Chapter 5

Conclusions

The data provided by the 3-year survey of foraminiferal assemblages in 5 selected stations of the Seine estuary eastern Bay of Seine, lead to a series of conclusions about the spatiotemporal dynamics of living assemblages and their relationships with estuarine dynamics.

The dominant species living in the Seine Estuary are typical paralic species dominated by *Elphidium excavatum*, *Ammonia beccarii*, and to a lesser extent the agglutinated group around *Psammospaera*. In areas with highest pressure of water currents, low salinities and large proportions of the sand fraction in the estuary axis (S40, S15, S11) diversities are lowest throughout all seasons. These conditions exclusively favor the presence of *E. excavatum* and *A. beccarii*. The stations in the north and south of the outlet (S7 & S28) show elevated abundances but also high diversities. During seasonal changes these characteristics overlap. These patterns pass on downcore whereas poor surface abundances might be attributed to the high erosional function of the Estuarine Turbidity Maximum or tidal currents. Abundance of living foraminifera could not be directly correlated with seasonal runoff changes. Possibly, foraminiferal reactions to runoff are not immediate enough and superimposed by physico-chemical parameters not incorporated in this study. Debenay et al. (2006) speculates a delayed reaction to altered parameters of less than one month is likely. Hence, attribution to environmental influence is difficult.

Outlook

This ecological study of foraminifera was part of a bigger program so that choices of sampling pattern, number of samples, replicates, etc. were restricted. Regarding the uncertainties of the interpretation of the species appearance and abundance in this time-series study it becomes clear that more information is needed. Riverine freshwater input as proxy for salinity might only be one factor among many covarying factors. A more immediate record of contaminants but also influences of marine and riverine water masses is worthwhile. This could be for example a widened and improved measurement of physico-chemical parameters e.g. metals, organic carbon, Phosphor, Nitrogen, Sulfur, organic pollutants, salinity, temperature, pH, stream velocity and microflora (food availability). Also a laborious taking of replicates should be considered in order to evaluate variability and appearance of rare species and hopefully the group of agglutinated foraminifera like *Psammospaera* and others. Future study designs should incorporate a continuous granulometry and a definitive core division and length pattern for a improved comparability of the infaunal depth stratification. This could help to identify more accurately the acting forces but also the triggers for reproduction patterns, which is a topic still poorly understood in

foraminiferal communities.

Debenay (2009) tried to evaluate the pollution impact by comparison with the less populated Authie estuary nearby. This seems to be a reasonable approach but was placed on intertidal banks where communities experience different natural pressures. Repeating aerial exposure and high salinities of pore water lead to reduced diversity in the living stock in Debenay's study. To help this discrepancy the adaption of the hydro-sedimentary and ecological environment should be tried. Otherwise, a baseline study (deep core) of fossil foraminifera embracing the pristine and preindustrial (>200 years ago) communities of the estuary could be useful. Empiric proof could be given what species lived in what quantity when human contaminants have not been present. Difficulties of this approach is the uncertainty of the thanatocenosis. Several transport agents could have operated on fossil foraminifera such as it is known from fossilized sea shell detritus.

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Appendix A

Plates

Plate 1

1 - 8 *Ammonia beccarii* (Linnaeus, 1758)

- 1 umbilical side (SEM)
- 2 spiral side (SEM)
- 3 umbilical side (SEM)
- 4 spiral side (SEM)
- 5 detail of umbilicus (SEM)
- 6 umbilical side (optical microscope)
- 7 spiral side (optical microscope)
- 8 umbilical side (optical microscope)

9 - 12 *Bulimina elongata* d'Orbigny, 1826

- 9 side view (SEM)
- 10 side view (SEM)
- 11 side view (optical microscope)
- 12 side view (optical microscope)

All scale bars 100 μm .

Plate 1

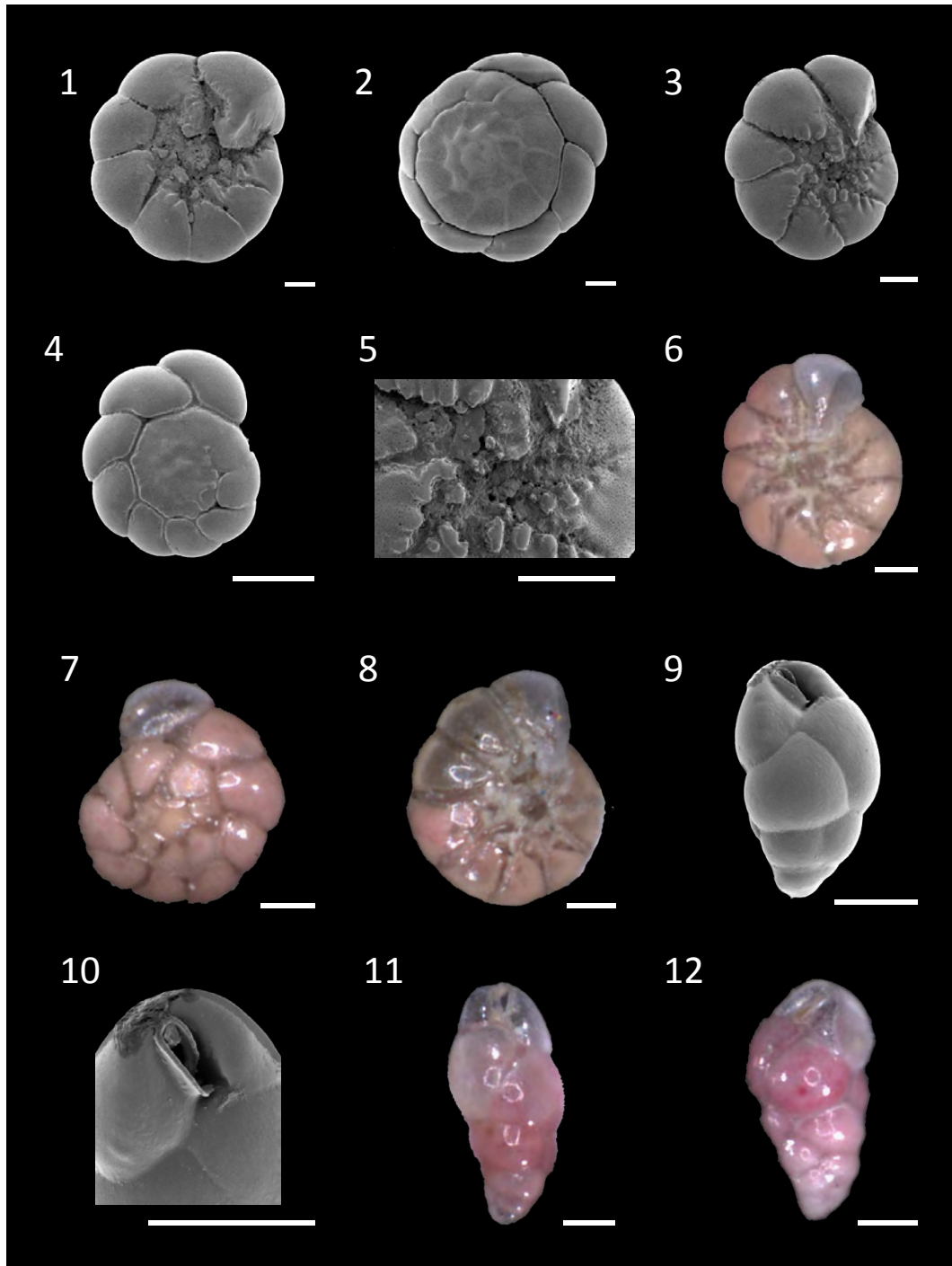


Plate 2

1 - 3 *Buliminella elegantissima* (d'Orbigny, 1839)

- 1 side view (SEM)
- 2 side view (optical microscope)
- 3 side view (optical microscope)

4 - 8 *Criboelphidium magellanicum* Heron-Allen & Earland, 1932

- 4-5 side views (SEM)
- 6 detail of chamber wall (SEM)
- 7-8 side views (optical microscope)

9 - 12 *Elphidium excavatum* (Terquem, 1875)

- 9-12 side views (SEM)

Elphidium excavatum continues on next plate.

All scale bars 100 μm .

Plate 2

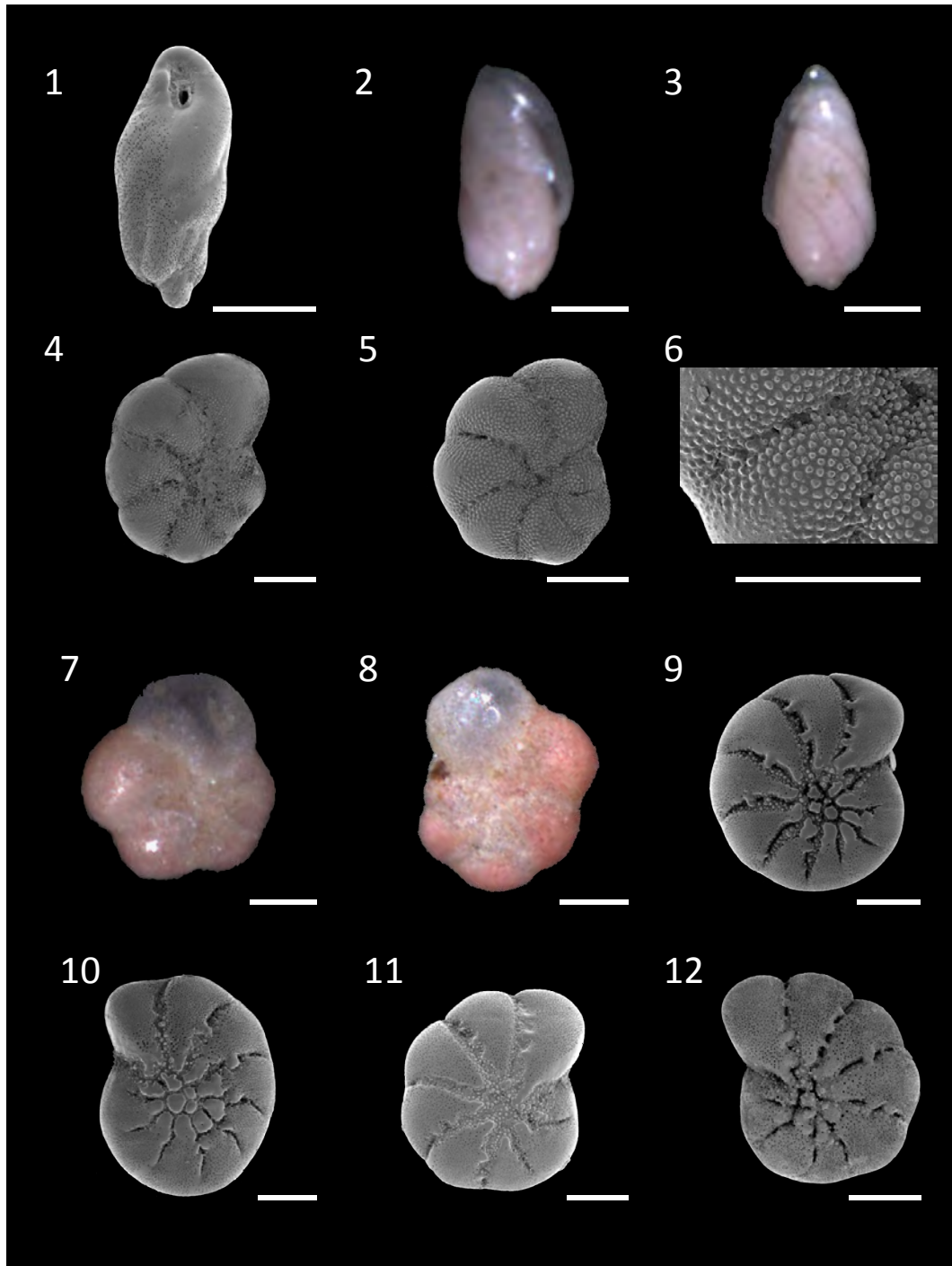


Plate 3

1 - 6 *Elphidium excavatum* (Terquem, 1875)

- 1 side view (SEM)
- 2 detail of umbilicus (SEM)
- 3-6 side views (optical microscope)

7 - 12 *Elphidium excavatum clavatum* Cushman, 1930

- 7-9 side views (SEM)
- 10 detail of umbilicus and warts in suturs
- 11-12 side views (optical microscope)

All scale bars 100 μm .

Plate 3

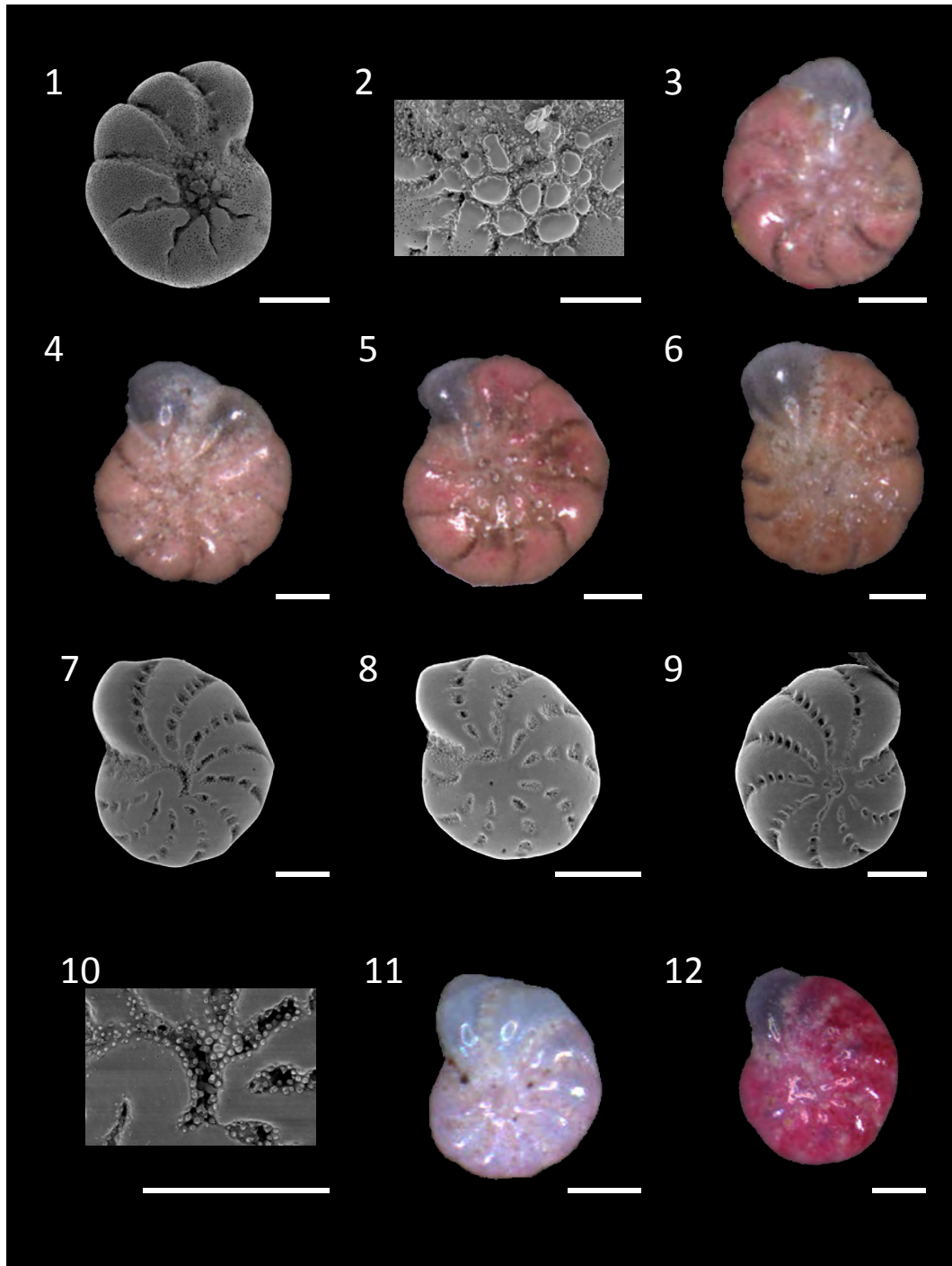


Plate 4

1 *Fissurina* sp.

1 side view (optical microscope)

2 *Globulina gibba* (d'Orbigny, 1826)

2 side view, note the aperture pointing up (optical microscope)

3 *Nonion subturgidum* (Cushman, 1924)

3 side view (optical microscope)

4-6 *Nonionella bradii* (Chapman, 1917)

4-5 side view (SEM)

6 side view (optical microscope)

7 *Nonionoides turgida* (Williamson, 1858)

7 side view (optical microscope)

8 - 9 *Rosalina globularis* d'Orbigny, 1826

8 spiral side (optical microscope)

9 umbilical side (optical microscope)

All scale bars 100 μm .

Plate 4

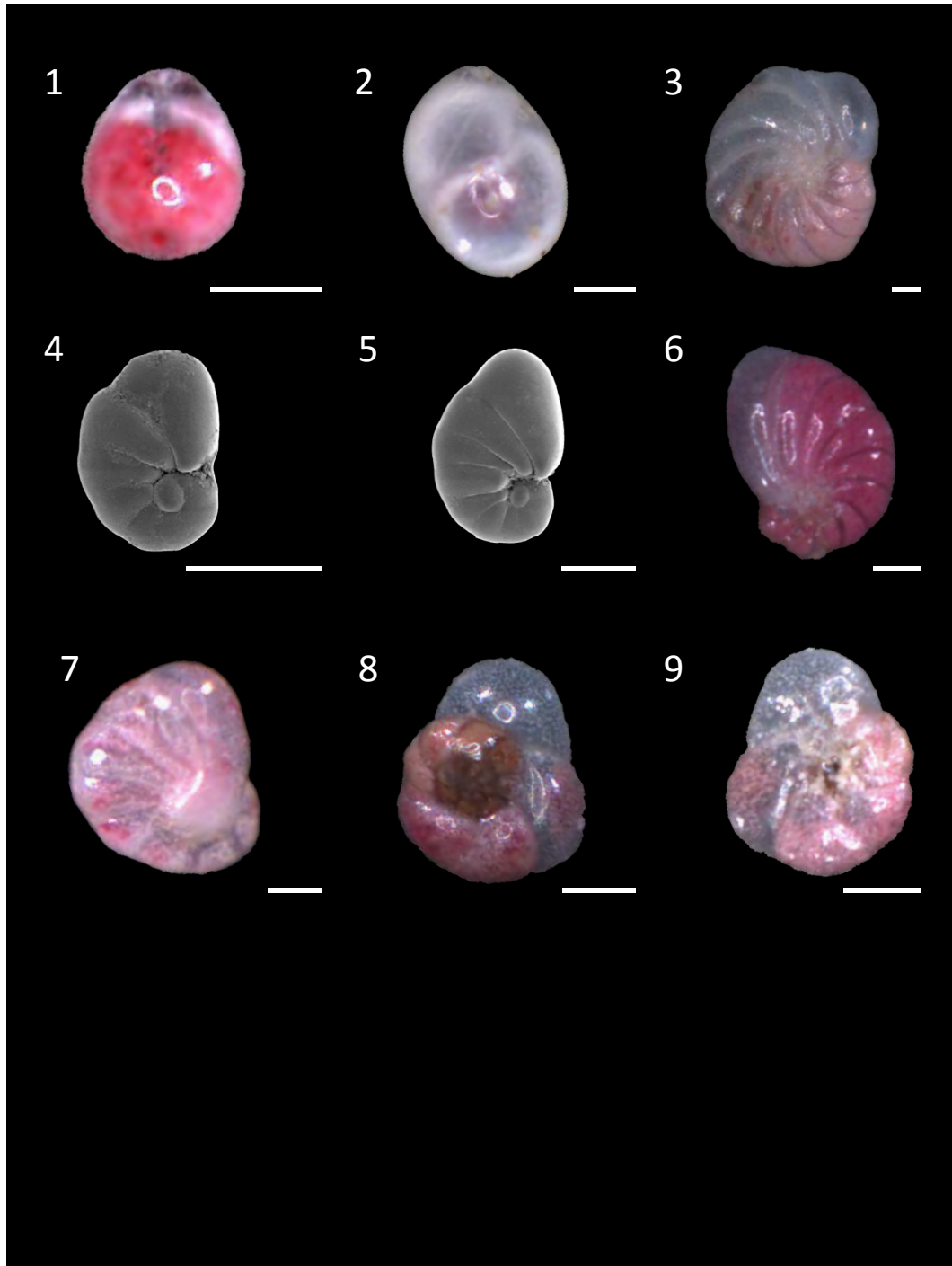


Plate 5

1 - 2 *Adelosina costata*

- 1 side view (optical microscope)
- 2 oblique view (optical microscope)

3 - 5 *Miliolinella* sp.

- 3-5 side views (optical microscope)

6 *Quinqueloculina aspera* group

- 6 side view (optical microscope)

7-9 *Quinqueloculina seminula* (Linnaeus, 1758)

- 7-8 side views (optical microscope)
- 9 side view (SEM)

10 - 11 *Triloculina longirostra* (d'Orbigny, 1826)

- 10-11 side views (optical microscope)

All scale bars 100 μm .

Plate 5

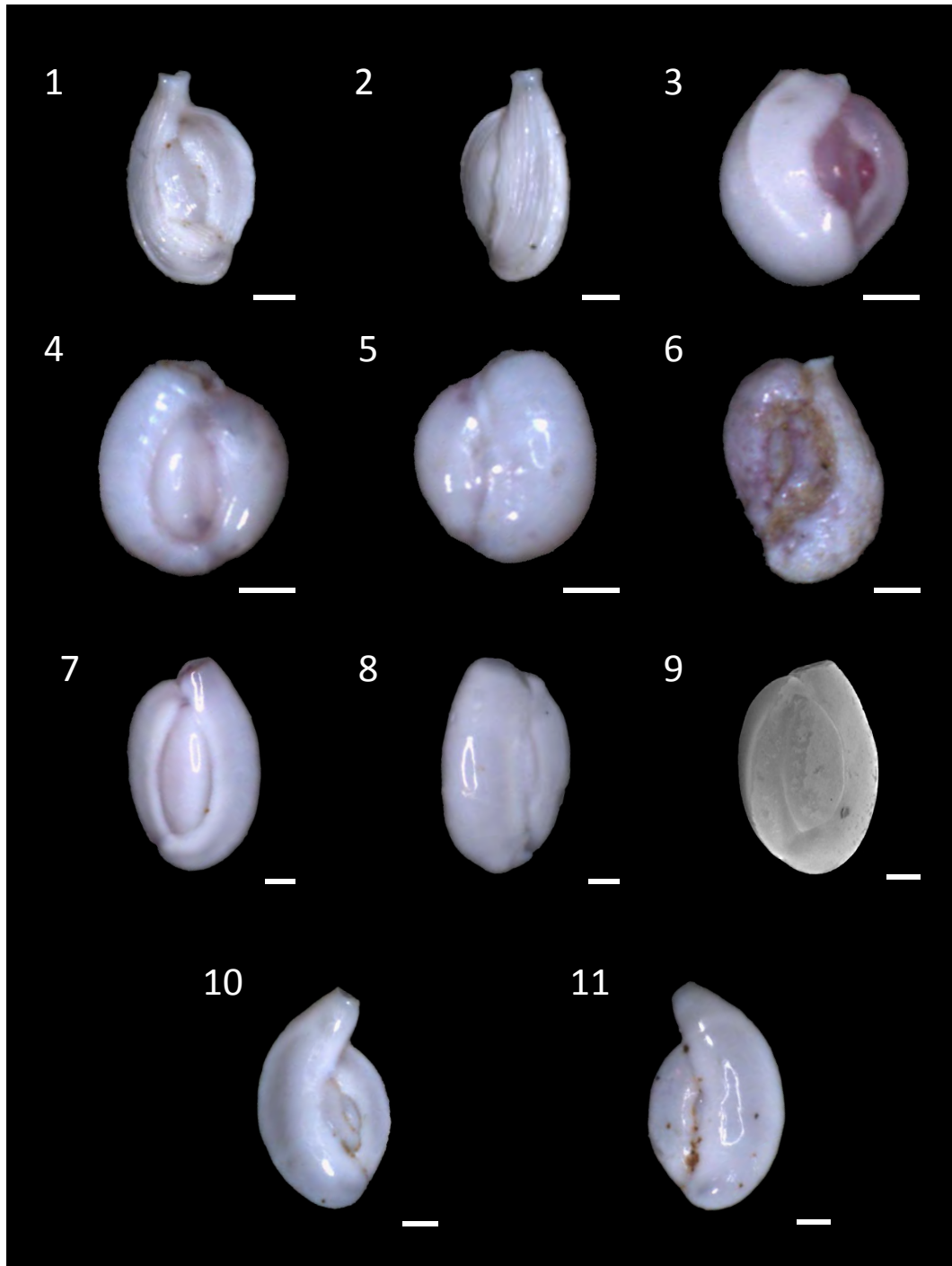


Plate 6

1 Agglutinated sp.

1 side view (optical microscope)

2-6 *Eggerelloides scaber* (Williamson, 1858)

2-3 apertural view (SEM)

4-6 side view (optical microscope)

7 - 12 *Hemisphaerammina* sp.

7-8 dorsal view (SEM)

9 oblique view (SEM)

10 side view (SEM)

11-12 dorsal view (optical microscope)

All scale bars 100 μm .

Plate 6

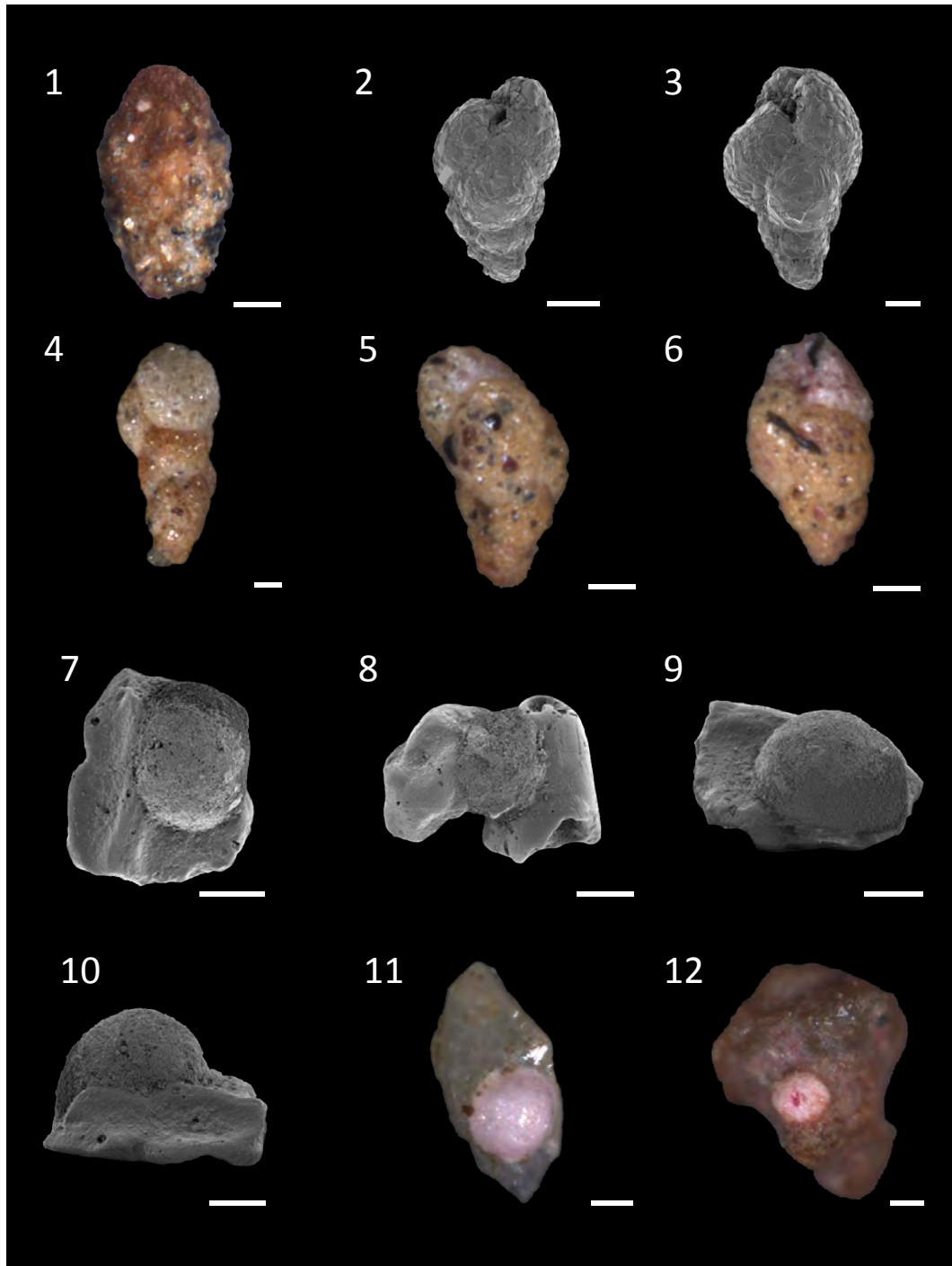


Plate 7

1 - 5 *Psammospaera bowmanni* Heron-Allen & Earland, 1912

1-2 side views (SEM)

3-5 side views (optical microscope)

6 - 12 *Psammospaera fusca* Schulze, 1875

6-9 peripheral views (SEM)

10-12 dorsal peripheral views (optical microscope)

All scale bars 100 μm .

Plate 7

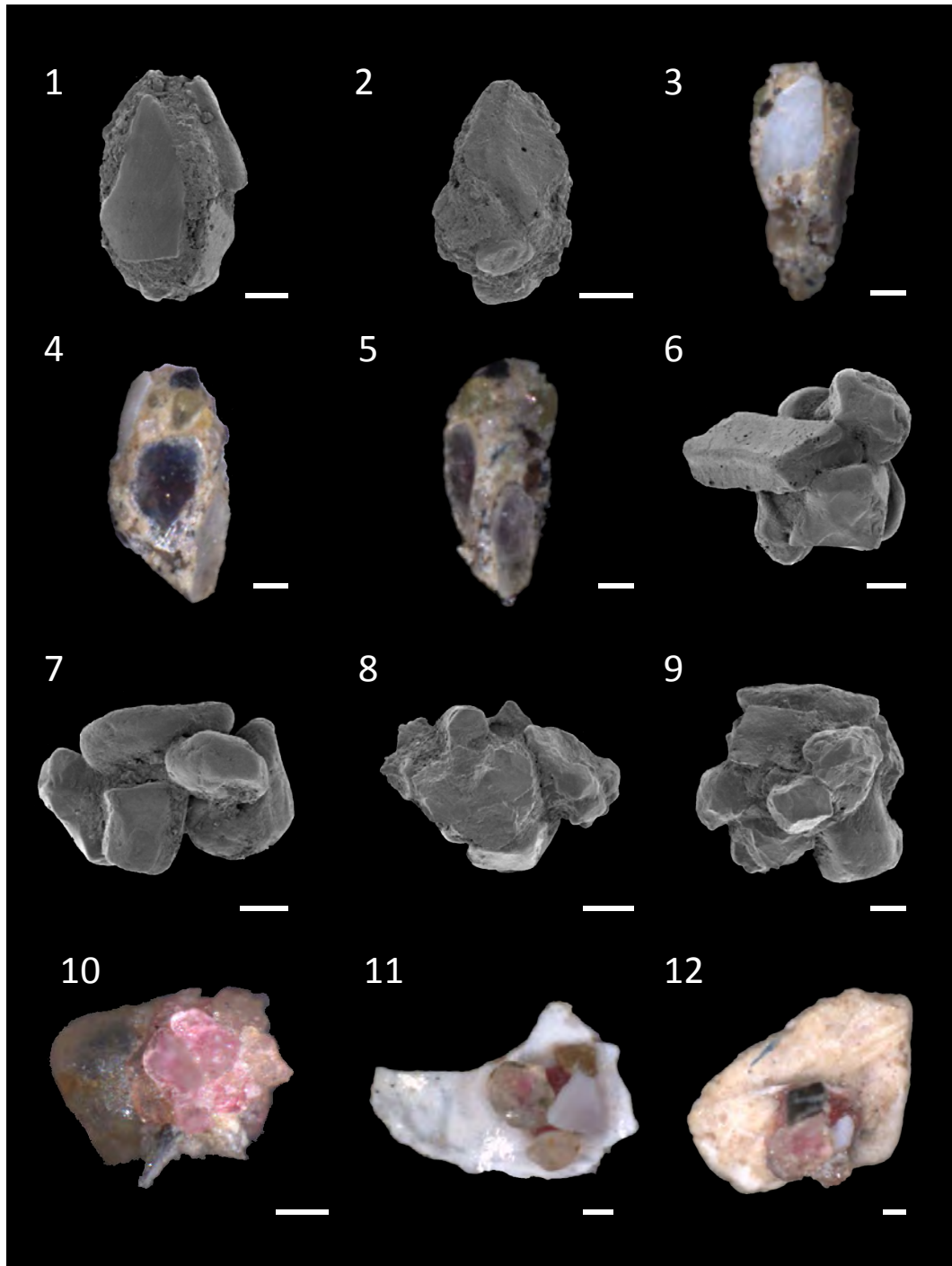


Plate 8

1 - 3 *Psammosphaera* sp.

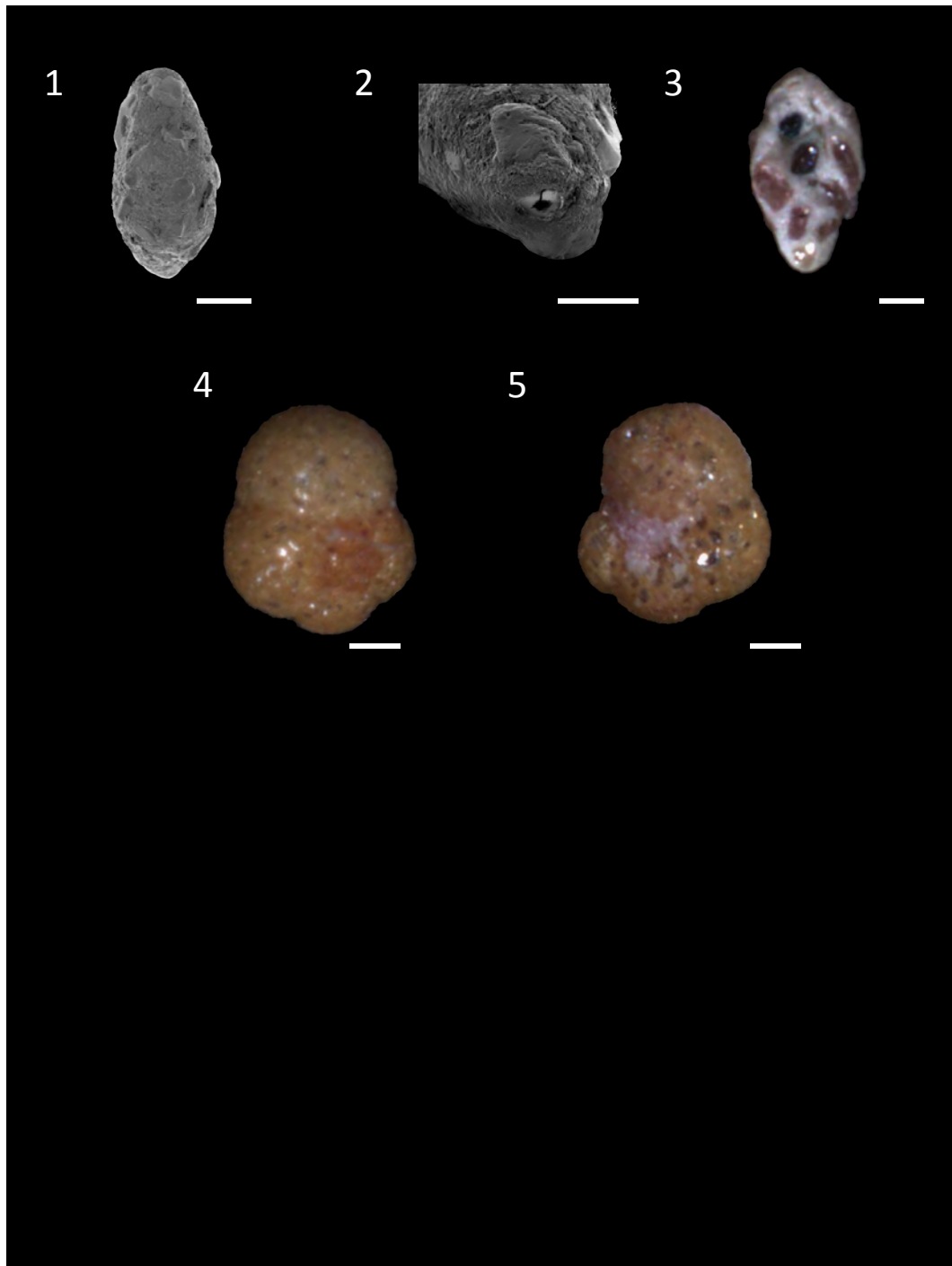
- 1 side view (SEM)
- 2 apertural view (SEM)
- 3 side view (optical microscope)

4 - 5 *Trochammia* sp.

- 4 spiral side (optical microscope)
- 5 umbilical side (optical microscope)

All scale bars 100 μm .

Plate 8



Appendix B

Additional diagrams and tables

Table B.1: Granulometry data of the September 2008 sampling campaign

	S7		S11		S15		S28		S40	
fraction	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
> 5 mm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 mm	4.07	0.71	0.47	0.07	0.15	0.04	4.28	0.87	0.05	0.00
2 mm	4.32	0.75	3.48	0.53	1.18	0.31	9.20	1.87	0.46	0.05
1.6 mm	1.78	0.31	1.78	0.27	1.00	0.27	4.82	0.98	0.26	0.03
1.25 mm	2.01	0.35	1.90	0.29	1.24	0.33	5.35	1.09	0.25	0.02
1 mm	2.53	0.44	2.27	0.35	1.36	0.36	6.22	1.26	0.52	0.05
0.8 mm	2.70	0.47	2.10	0.32	1.52	0.40	5.82	1.18	0.63	0.06
0.63 mm	3.38	0.59	1.98	0.30	2.02	0.54	6.15	1.25	0.99	0.10
0.5 mm	3.25	0.57	1.59	0.24	1.62	0.43	4.41	0.89	1.40	0.14
0.4 mm	5.86	1.02	3.68	0.56	2.14	0.57	5.39	1.09	3.96	0.39
0.315 mm	10.19	1.77	15.68	2.39	3.99	1.06	6.28	1.27	18.66	1.84
0.25 mm	11.24	1.95	38.59	5.87	8.57	2.28	8.37	1.70	78.04	7.69
0.2 mm	20.92	3.64	441.65	67.24	107.28	28.55	66.06	13.41	455.95	44.96
0.16 mm	48.55	8.44	109.90	16.73	159.33	42.40	212.00	43.02	203.56	20.07
0.125 mm	162.00	28.17	22.80	3.47	51.16	13.62	65.66	13.32	148.51	14.64
0.1 mm	62.81	10.92	2.41	0.37	6.94	1.85	14.36	2.91	40.09	3.95
0.08 mm	36.69	6.38	0.71	0.11	2.95	0.79	4.81	0.98	24.89	2.45
0.063 mm	19.12	3.33	0.58	0.09	3.59	0.96	4.16	0.84	16.47	1.62
0.05 mm	7.26	1.26	0.23	0.04	1.86	0.49	2.20	0.45	6.36	0.63
< 0.05 mm	166.30	28.92	5.07	0.77	17.86	4.75	57.25	11.62	13.13	1.29
total	574.98	100.00	656.87	100.00	375.76	100.00	492.79	100.00	1014.18	100.00

Table B.2: List of detailed core subsampling

Station	7	11	15	28	40
description	North	Estuary channel distal	Estuary channel medial	South	Estuary channel proximal
Latitude	49°31,840'N	49°28,151'N	49°26,175'N	49°20,066'N	49°25,902'N
Longitude	0°01,103'E	0°03,932'W	0°00,266'E	0°06,025'W	0°03,838'E
depth [m]	18.2	10.4	7.5	12.5	3.5
September 2008	0 - 0.5 cm	0 - 0.5 cm	0 - 0.5 cm	0 - 0.5 cm	0 - 0.5 cm
	0.5 - 1 cm	0.5 - 1 cm	0.5 - 1 cm	0.5 - 1 cm	0.5 - 1 cm
	1 - 1.5 cm	1 - 1.5 cm	1 - 1.5 cm	1 - 1.5 cm	1 - 1.5 cm
	1.5 - 2 cm	1.5 - 2 cm	1.5 - 2 cm	1.5 - 2 cm	1.5 - 2 cm
September 2009	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm
	1 - 3 cm	1 - 3 cm	1 - 3 cm	1 - 3 cm	1 - 3 cm
	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm
December 2009	No data	No data	0 - 1 cm	0 - 1 cm	0 - 1 cm
			1 - 3 cm	1 - 3 cm	1 - 3 cm
			3 - 5 cm		
April 2010	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm
	1 - 2 cm	1 - 2 cm	1 - 2 cm	1 - 2 cm	1 - 2 cm
	2 - 3 cm	2 - 3 cm	2 - 3 cm	2 - 3 cm	2 - 3 cm
	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm
September 2010	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm
	1 - 3 cm	1 - 3 cm	1 - 3 cm	1 - 3 cm	1 - 3 cm
	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm
March 2011	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm	0 - 1 cm
	1 - 3 cm	1 - 3 cm	1 - 3 cm	1 - 3 cm	1 - 3 cm
	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm	3 - 5 cm

Table B.4: Percentual difference of the >150 μm vs. the >125 μm fraction per species.

	S7Sep10	S7Mar11	S11Sep10	S11Mar11	S15Sep10	S15Mar11	S28Sep10	S28Mar11	S40Sep10	S40Mar11	Mean
	% δ per taxon										
<i>Ammonia beccarii</i>	3.5	0.46			0.18		0.14	0.85			
<i>Ammonia parkinsoniana</i>											
<i>Bulimina elongata</i>		0.92						0.42			
<i>Buliminella elegantissima</i>	0.12										
<i>Criboelphidium magellanicum</i>							0.28				
<i>Elphidium excavatum</i>	4.0	5.05	2.86	12.5	5.9	11.58	6.16	6.78	13.73	40.00	
<i>Elphidium excavatum clavatum</i>	0.35				0.72		0.14				
<i>Nonionella bradii</i>	0.24	0.46					0.14				
<i>Nonionella labradorica</i>											
<i>Nonionoides turgida</i>							0.14				
<i>Miliolinella</i> sp.	0.12										
<i>Quinqueloculina seminula</i>							0.14	0.85			
<i>Eggerelloides scaber</i>							0.14				
<i>Hemisphaerammina</i> sp.				6.25							
<i>Psammosphaera fusca</i>							2.24				
% δ all specimens	6.00	6.88	2.86	18.75	6.80	11.58	9.52	8.90	13.73	40.00	12.50

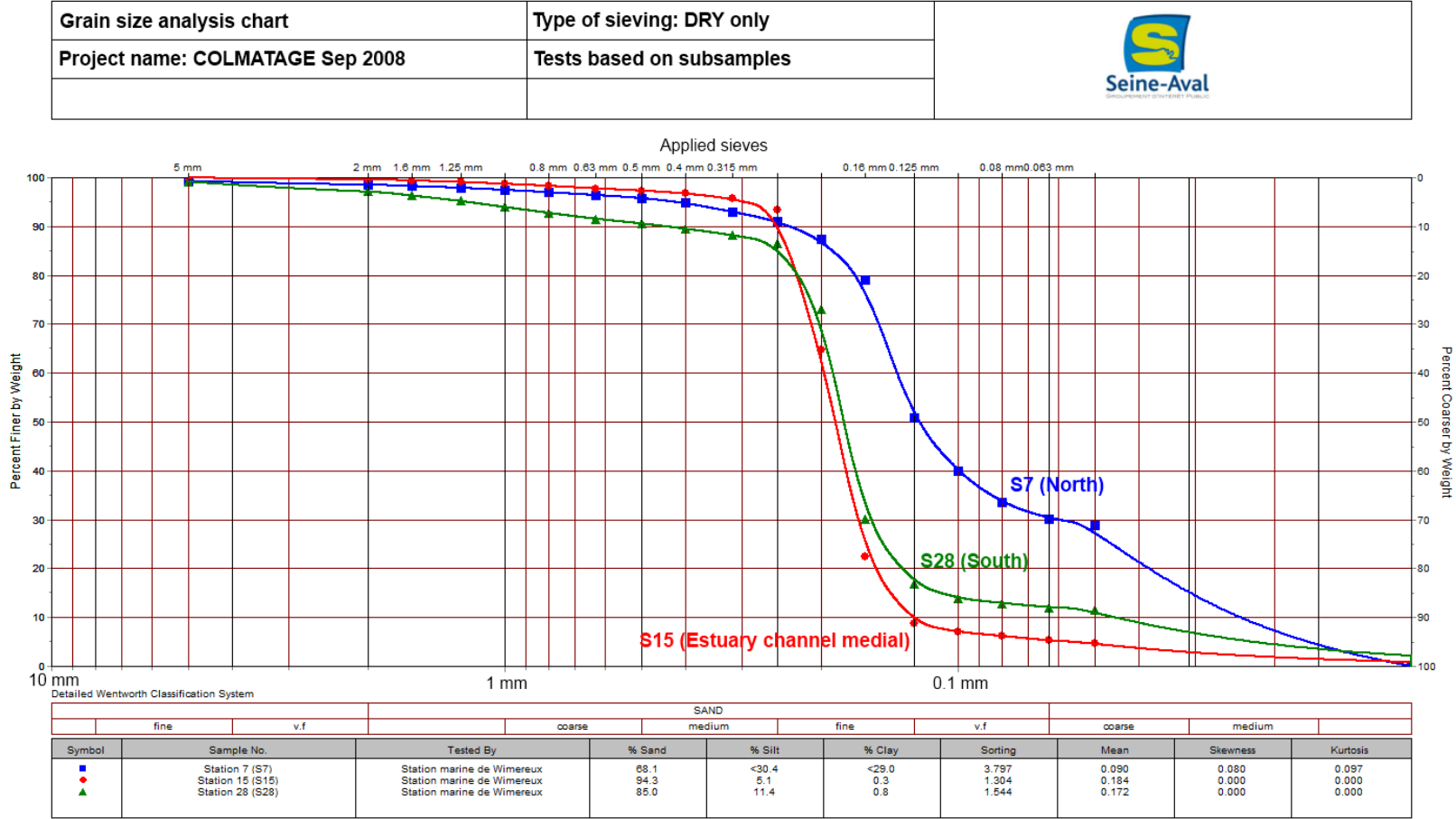



Figure B.1: Cumulative plot of the September 2008 grain size analysis (North/South transect, Station 7, 15, 28)

Grain size analysis chart	Type of sieving: DRY only	
Project name: COLMATAGE Sep 2008	Tests based on subsamples	

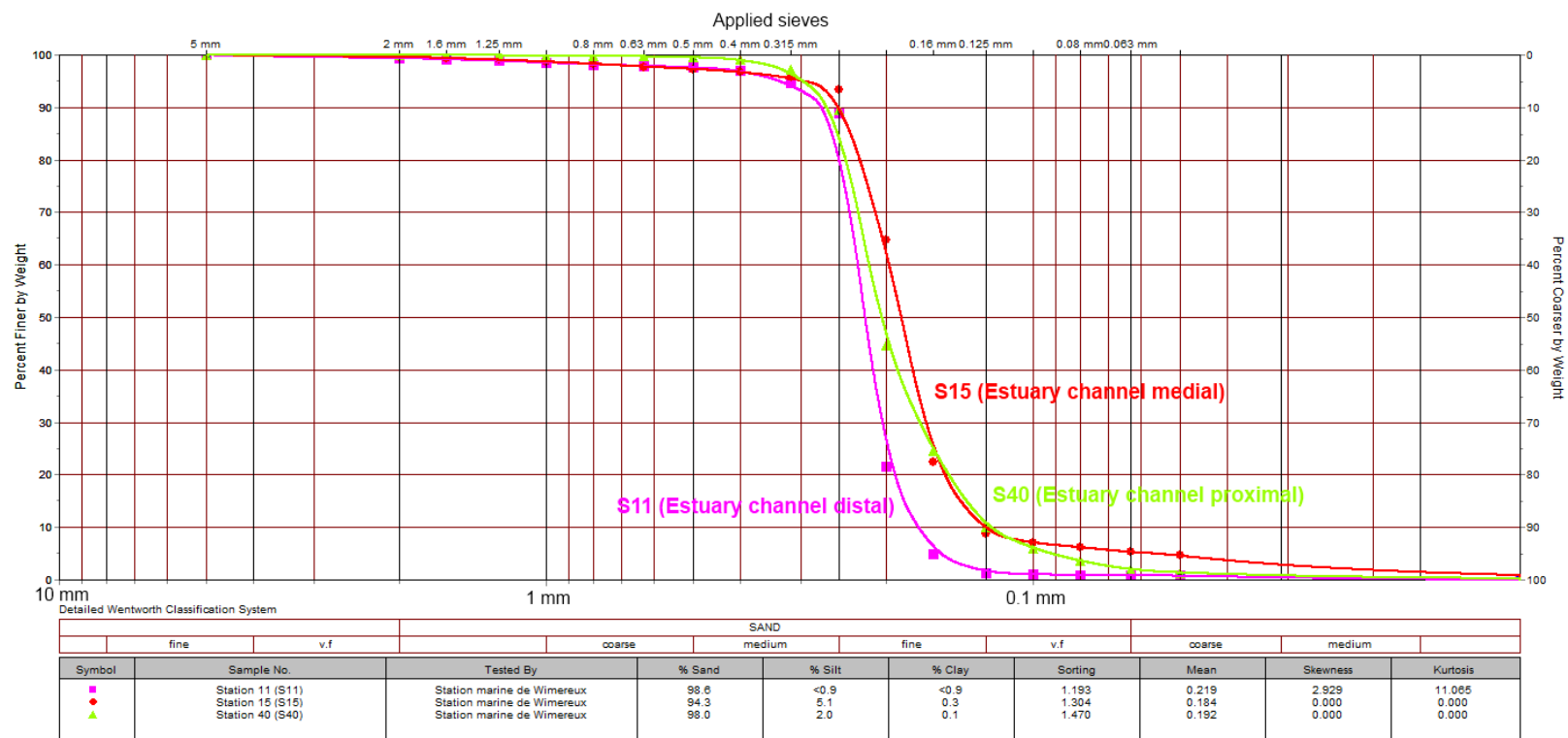


Figure B.2: Cumulative plot of the September 2008 grain size analysis (West/East transect, Station 11, 15, 40)

Figure B.3: Surface layer faunal analysis: 0-1 cm, >150 μm . Comparison of abundance, species richness, A-E index, Shannon H and freshwater influx

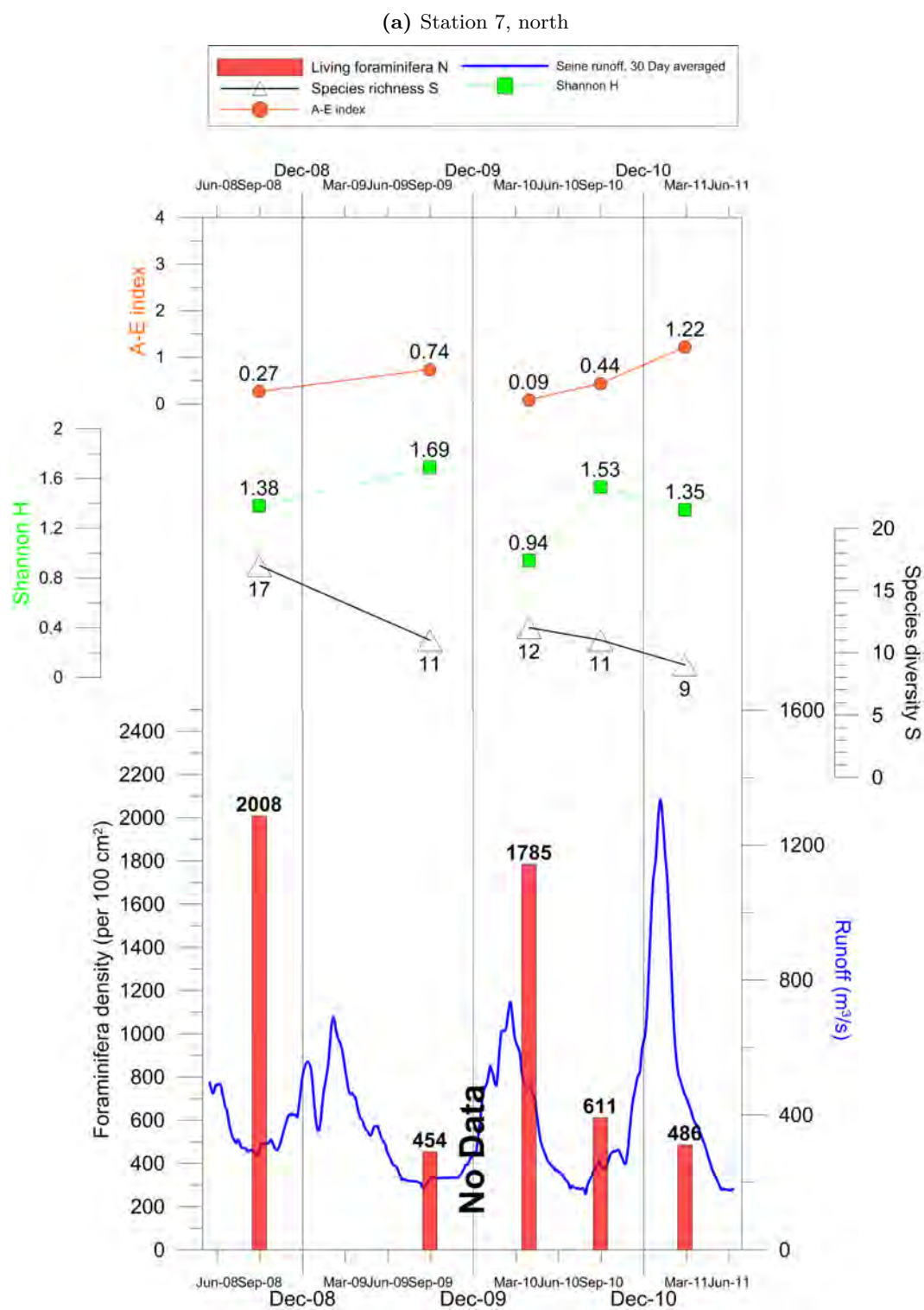


Figure B.3: continued

(b) Station 11, estuary channel distal

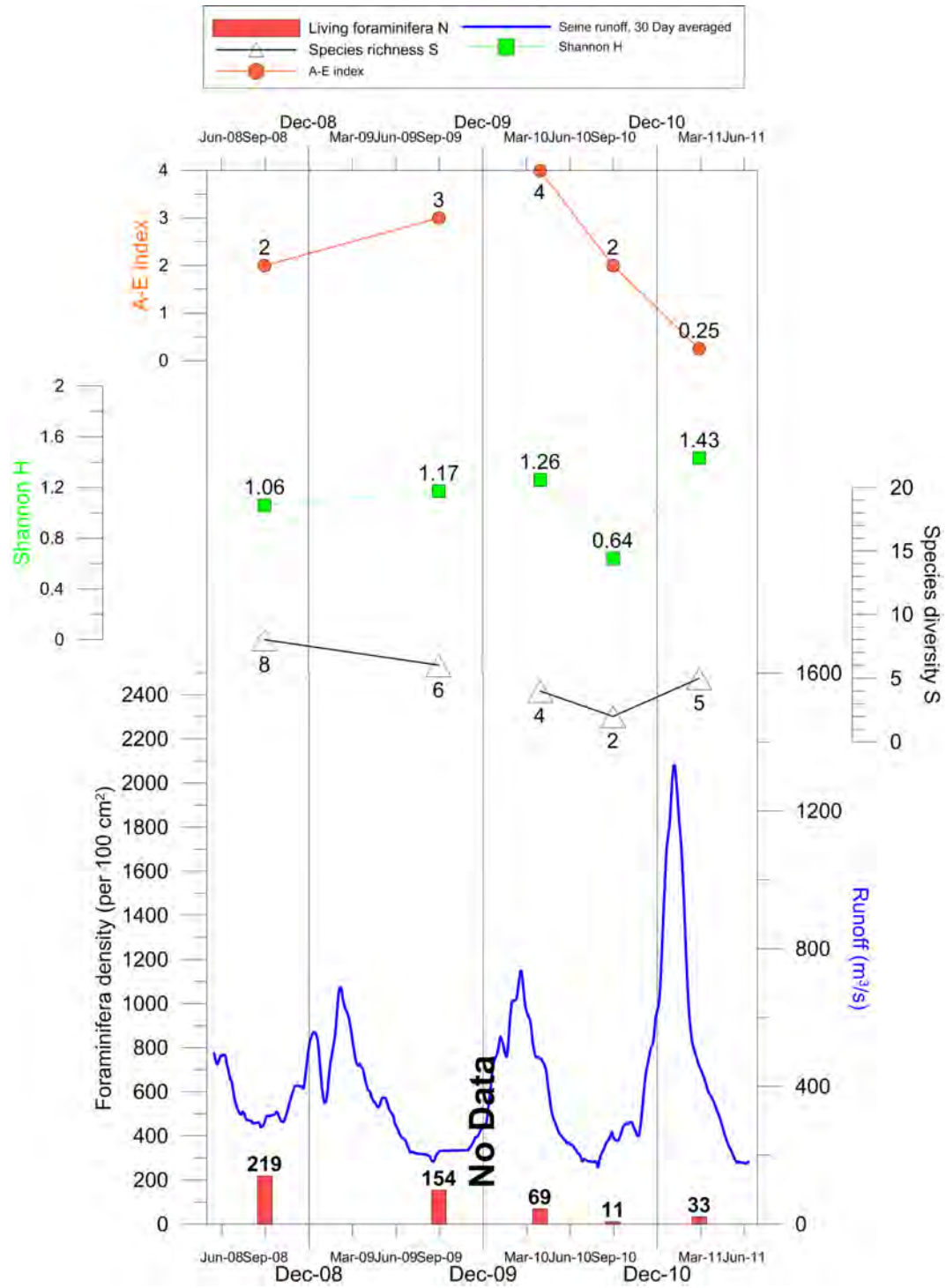


Figure B.3: continued

(c) Station 15, estuary channel medial

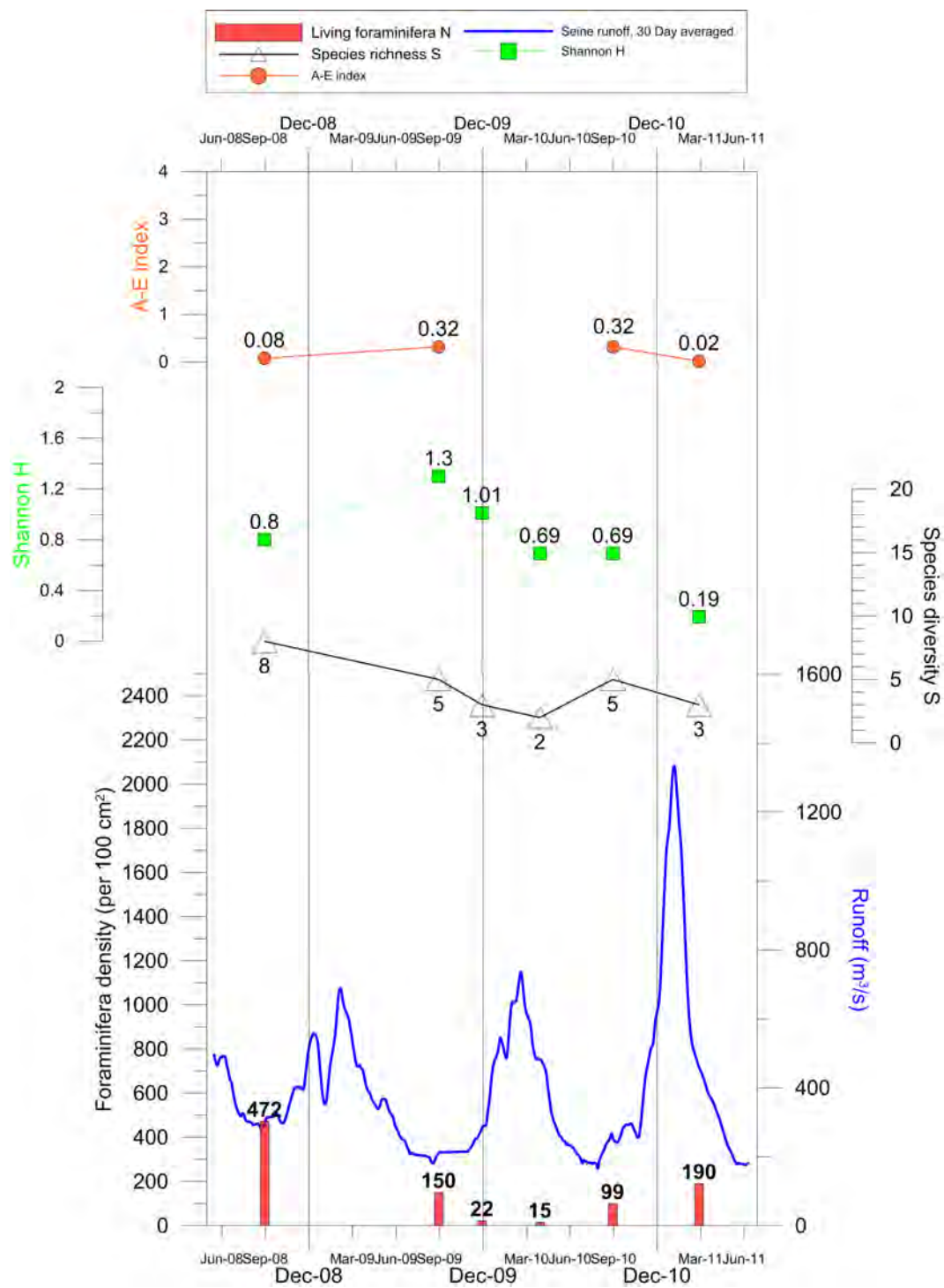


Figure B.3: continued

(d) Station 28, south

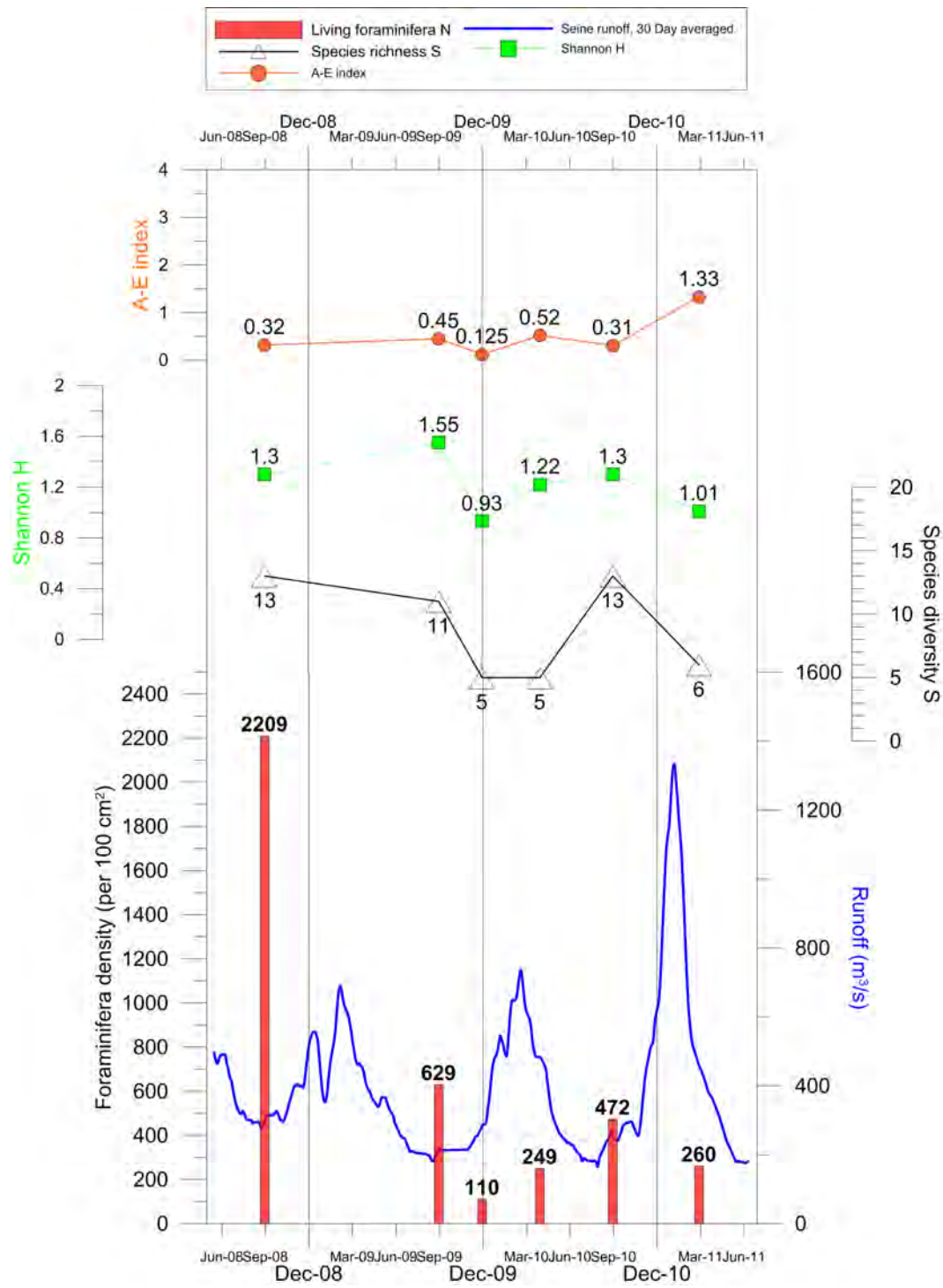


Figure B.3: continued

(e) Station 40, estuary channel proximal

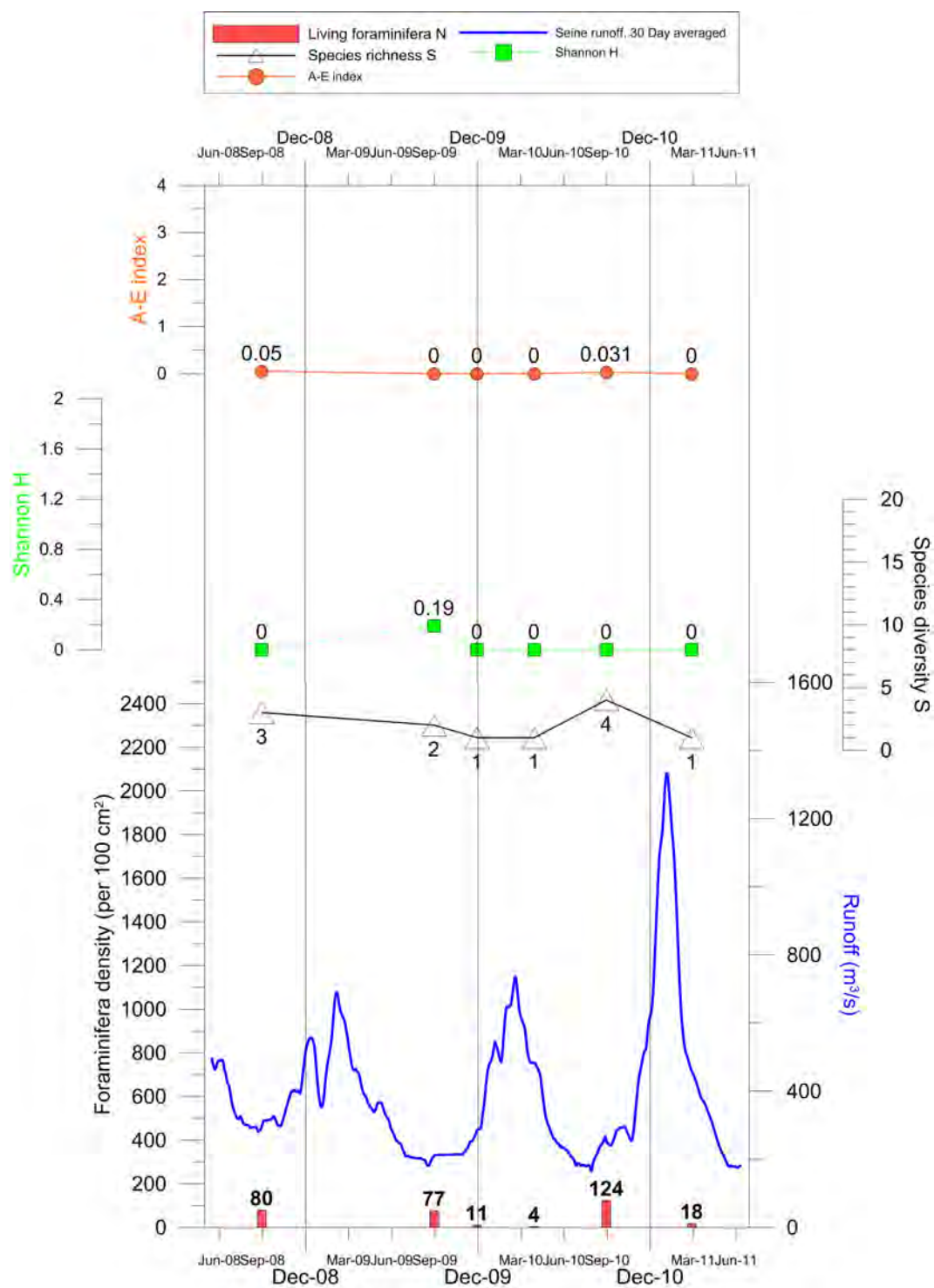
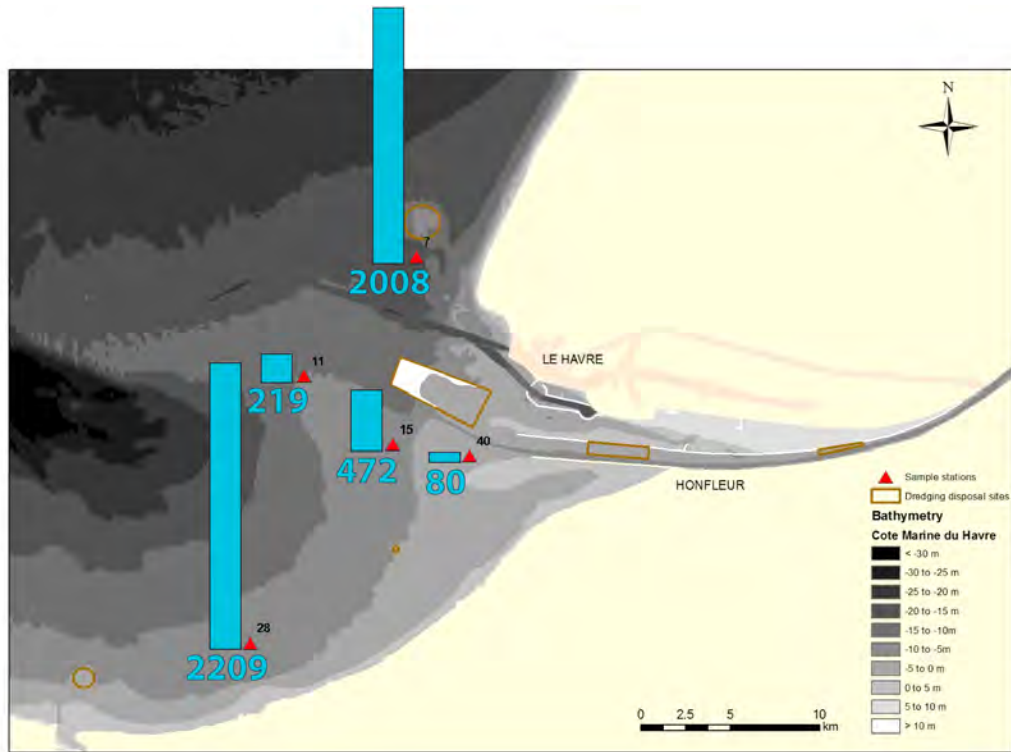


Figure B.4: Surface layer faunal analysis: 0-1 cm, >150 mm. Comparison of abundance per 100 cm²

(a) September 2008



(b) September 2009

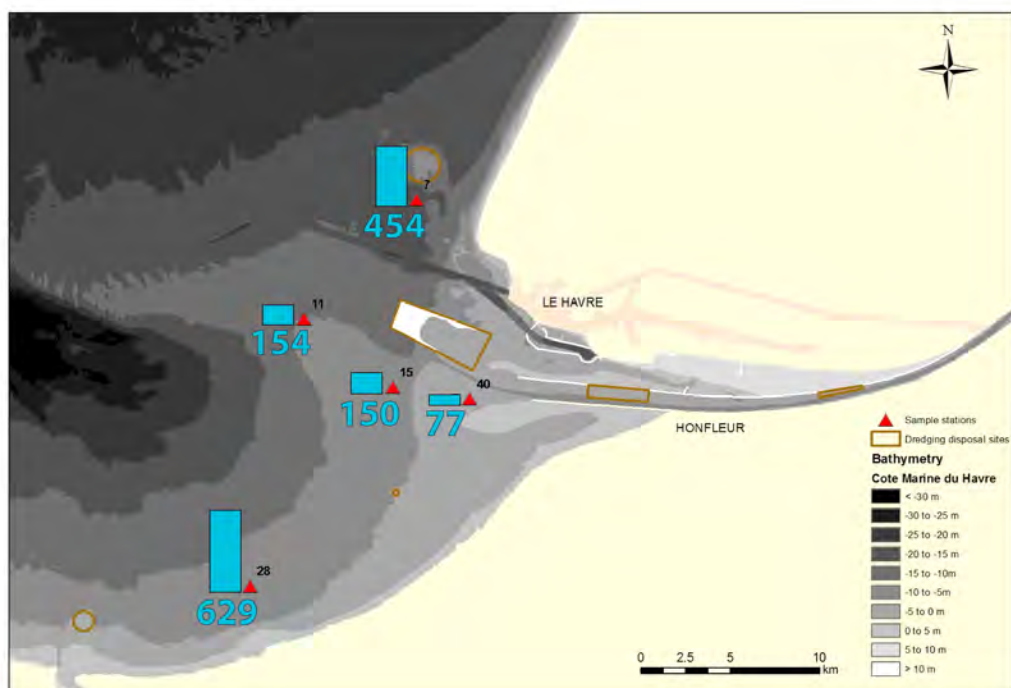
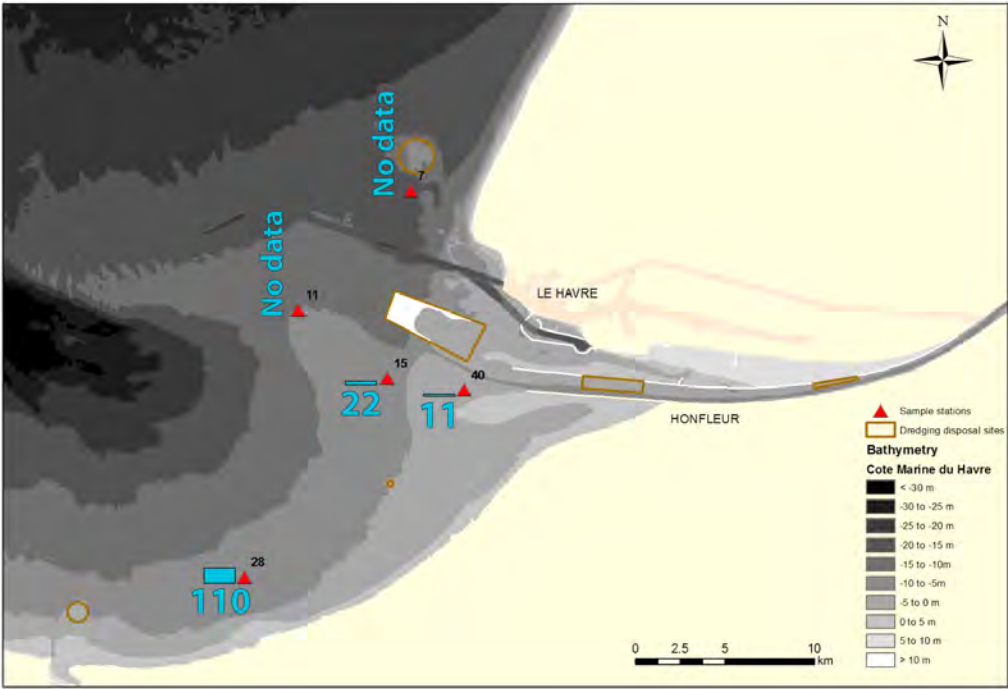


Figure B.4: continued

(c) December 2009



(d) April 2010

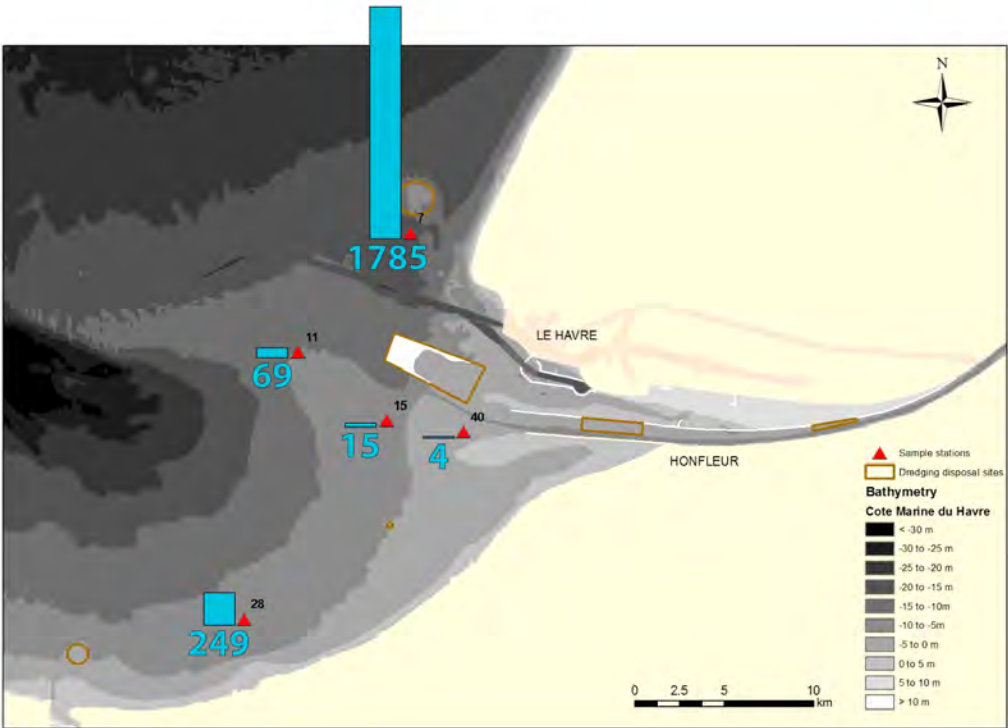
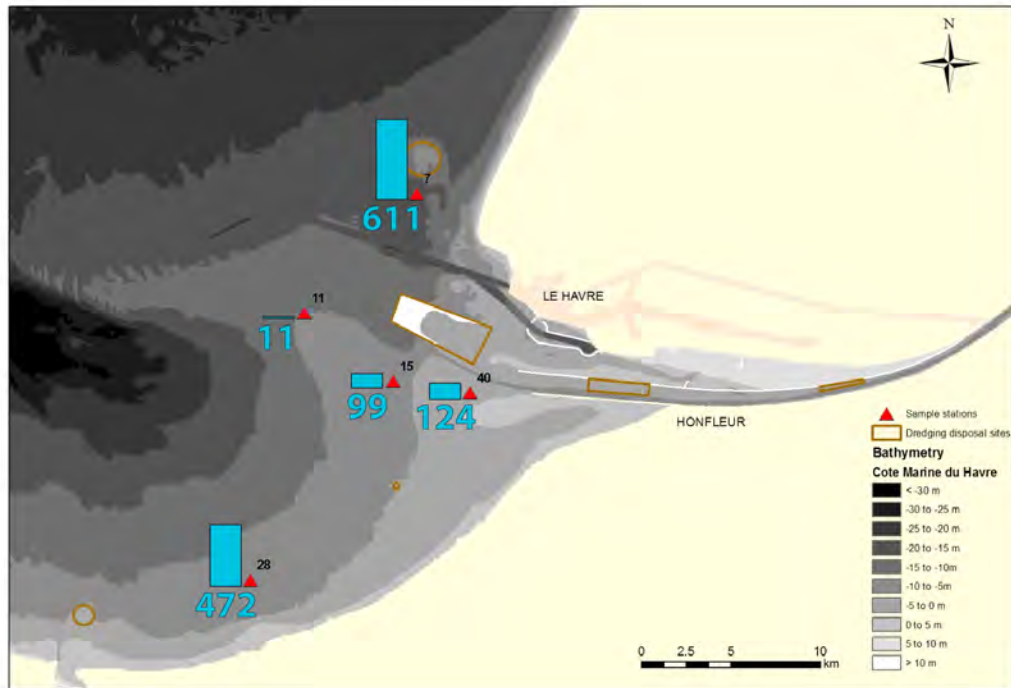


Figure B.4: continued

(e) September 2010



(f) March 2011

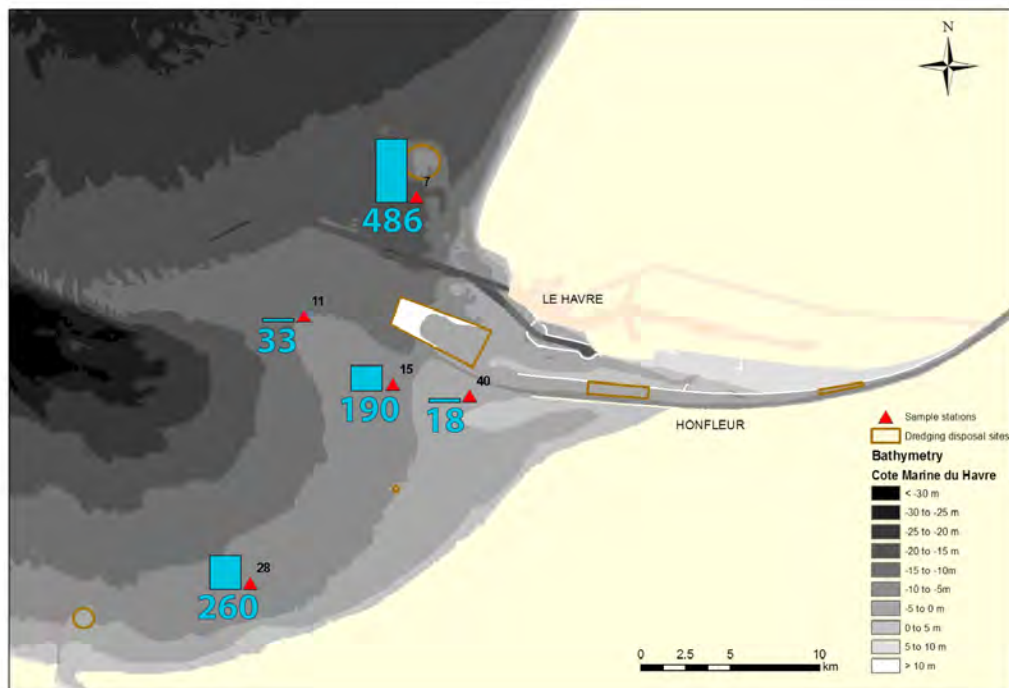
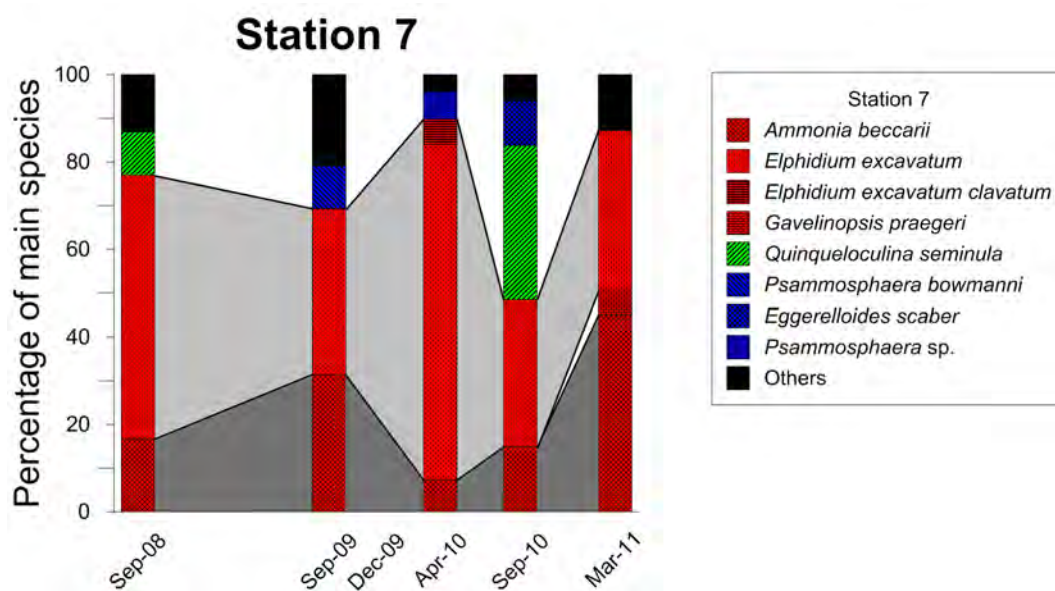


Figure B.5: Foraminiferal abundance in the 0-1 cm surface layer. Species <5% are assigned to the group “Others”. Dark grey marks the *Ammonia* genus and light grey *Elphidium* and its taxa.

(a) Station 7, north



(b) Station 11, estuary channel distal

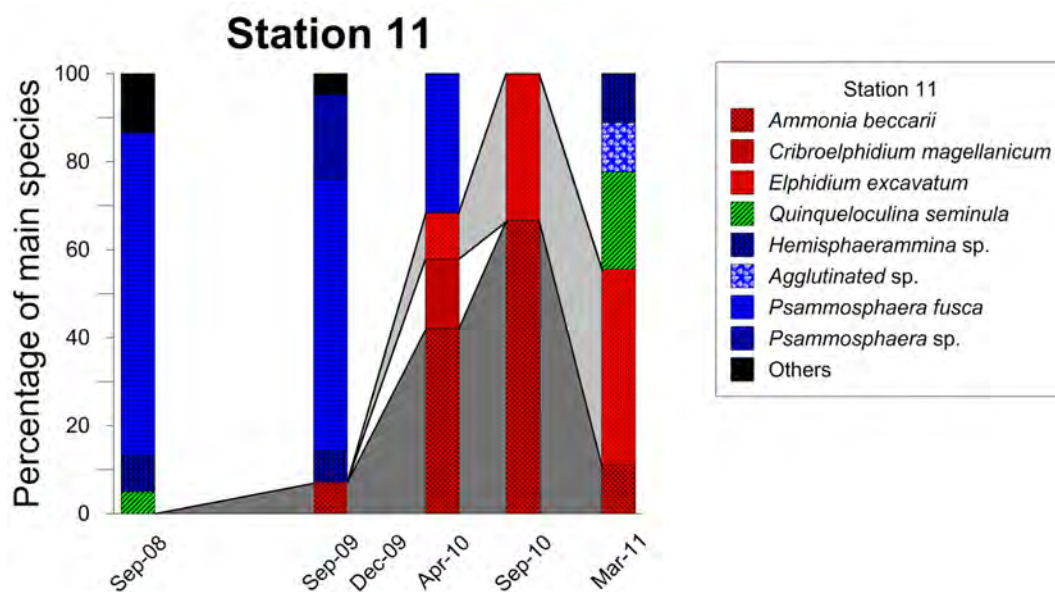
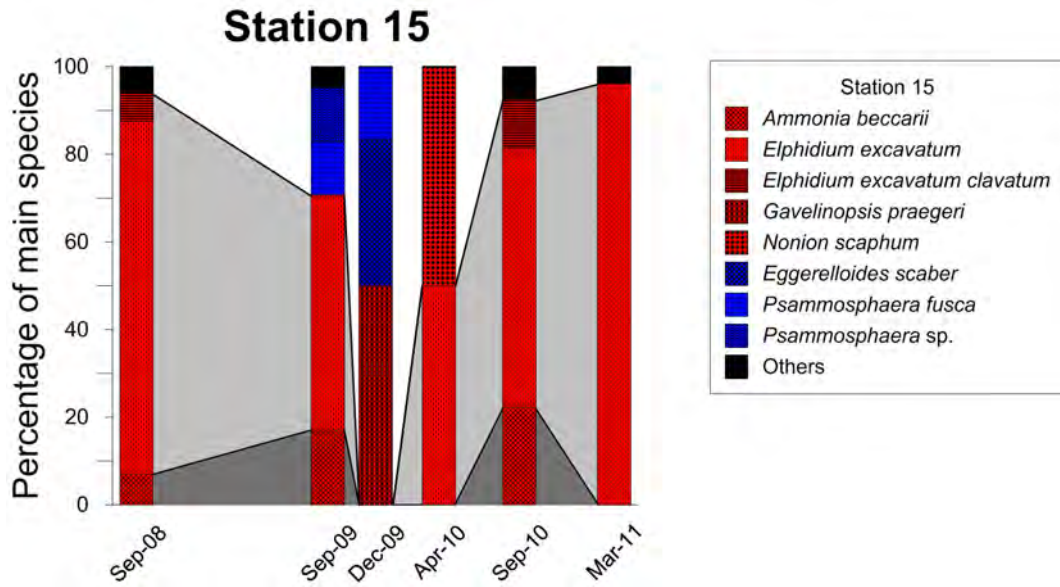


Figure B.5: continued

(c) Station 15, estuary channel medial



(d) Station 28, south

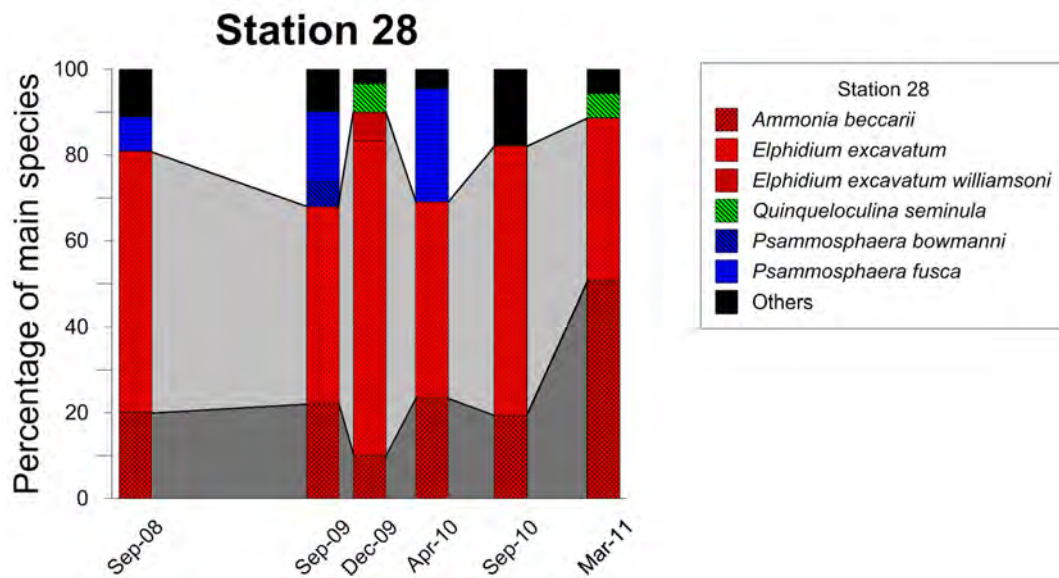
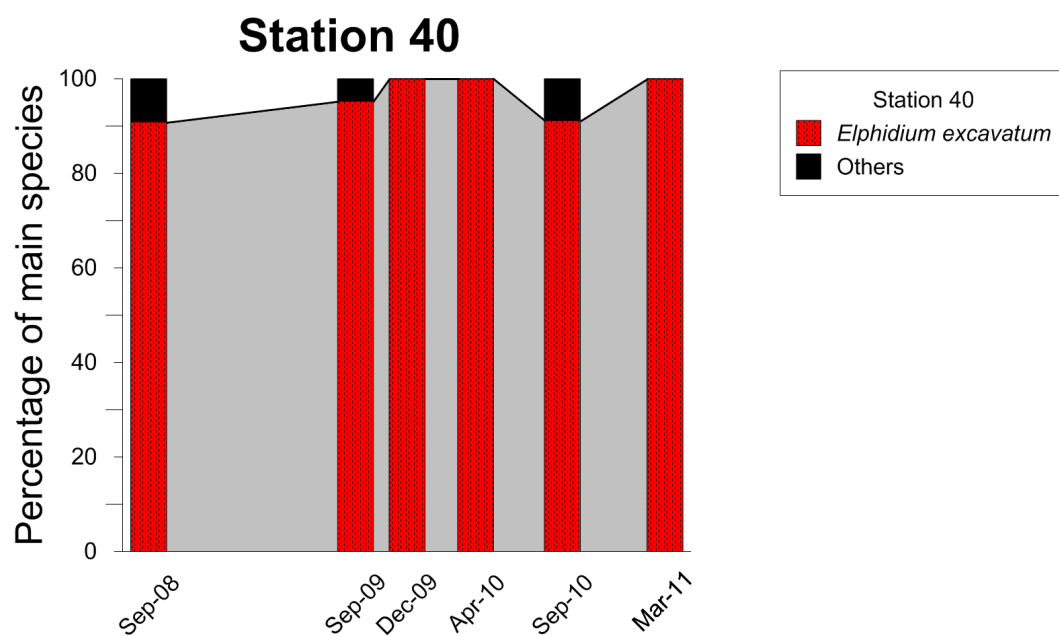


Figure B.5: continued

(e) Station 40, estuary channel proximal



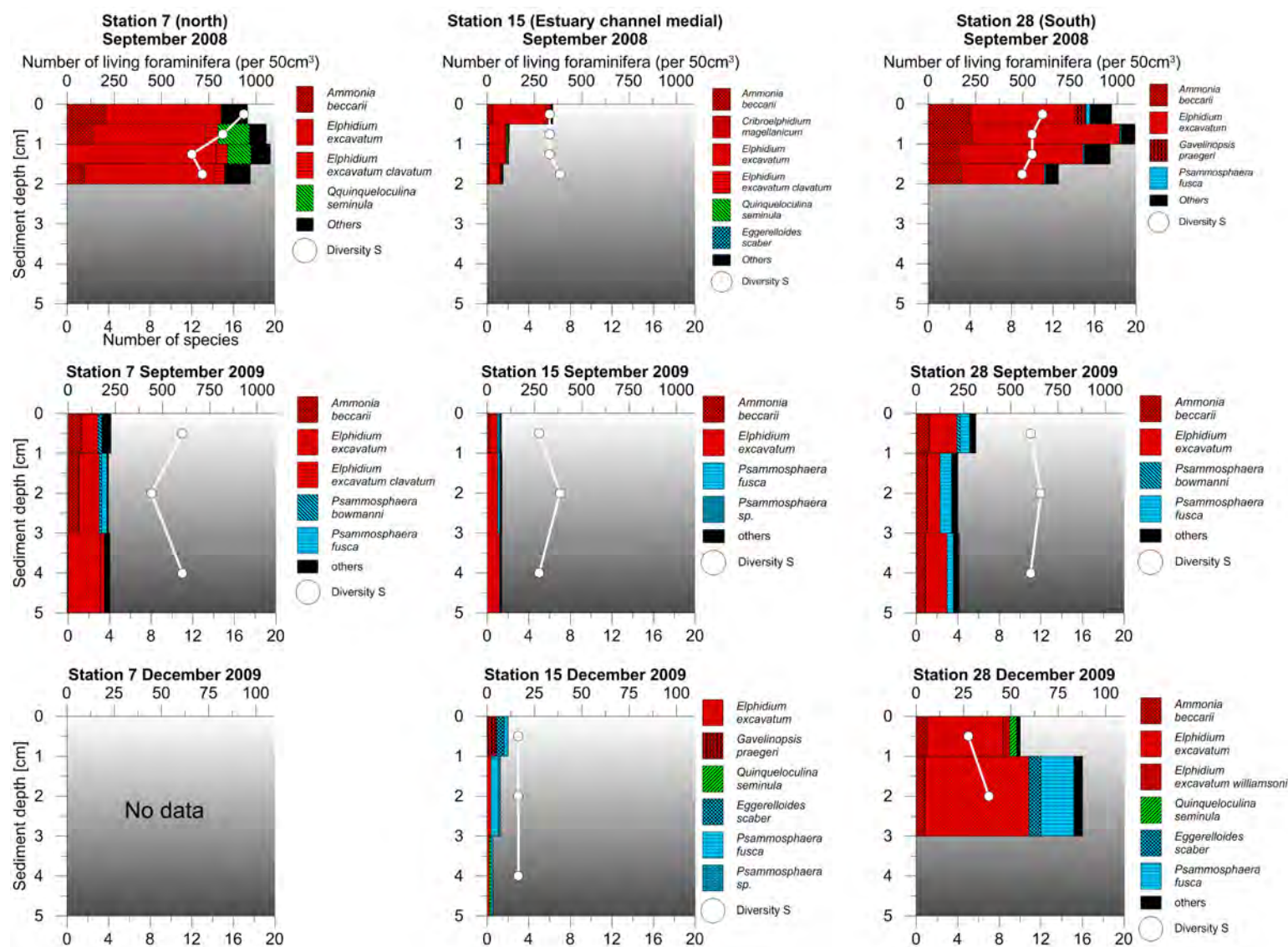


Figure B.6: Foraminiferal abundance and diversity downcore along the north-south transect. Species <5% are allocated to “others”.

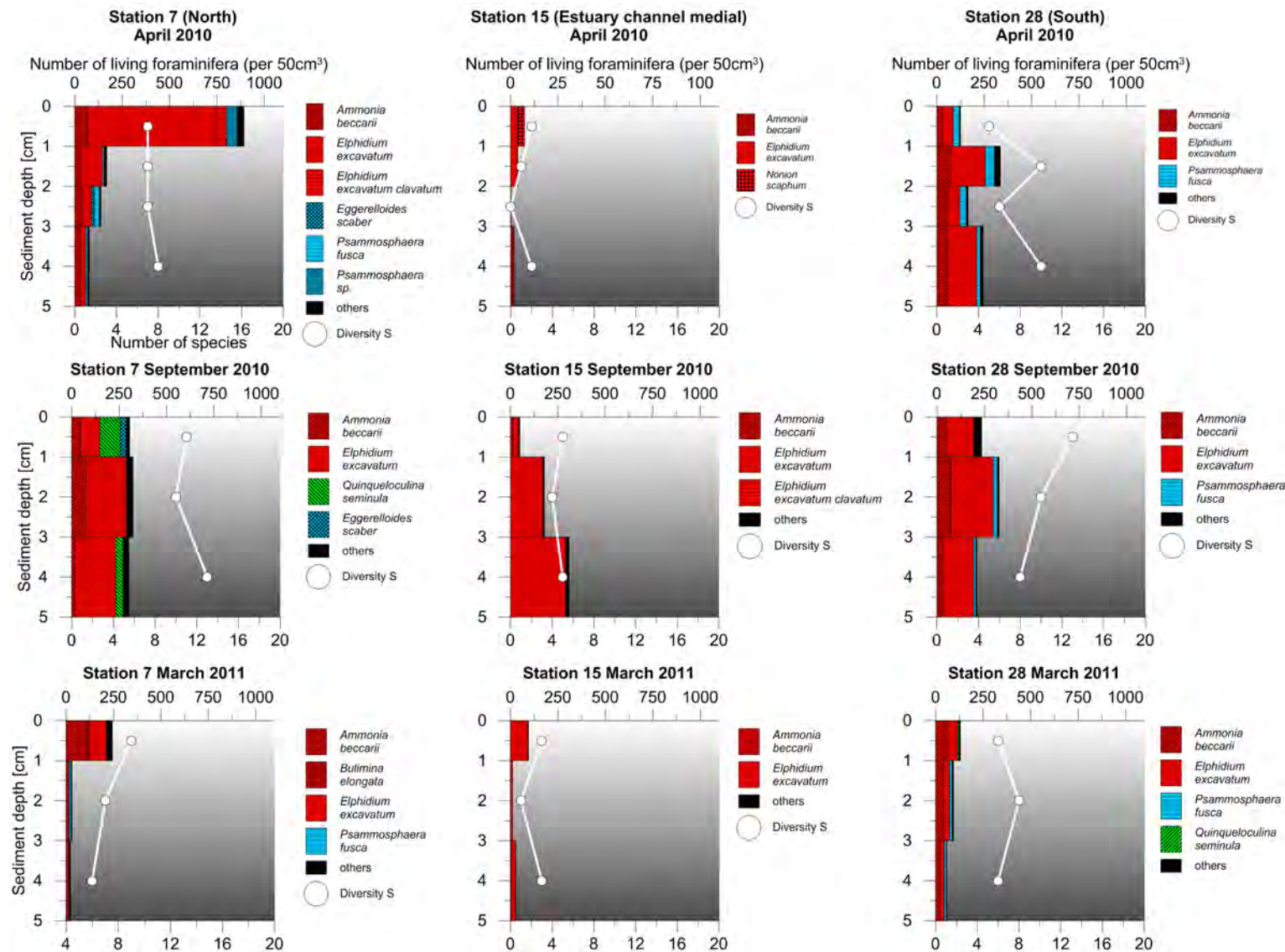


Figure B.6: continued

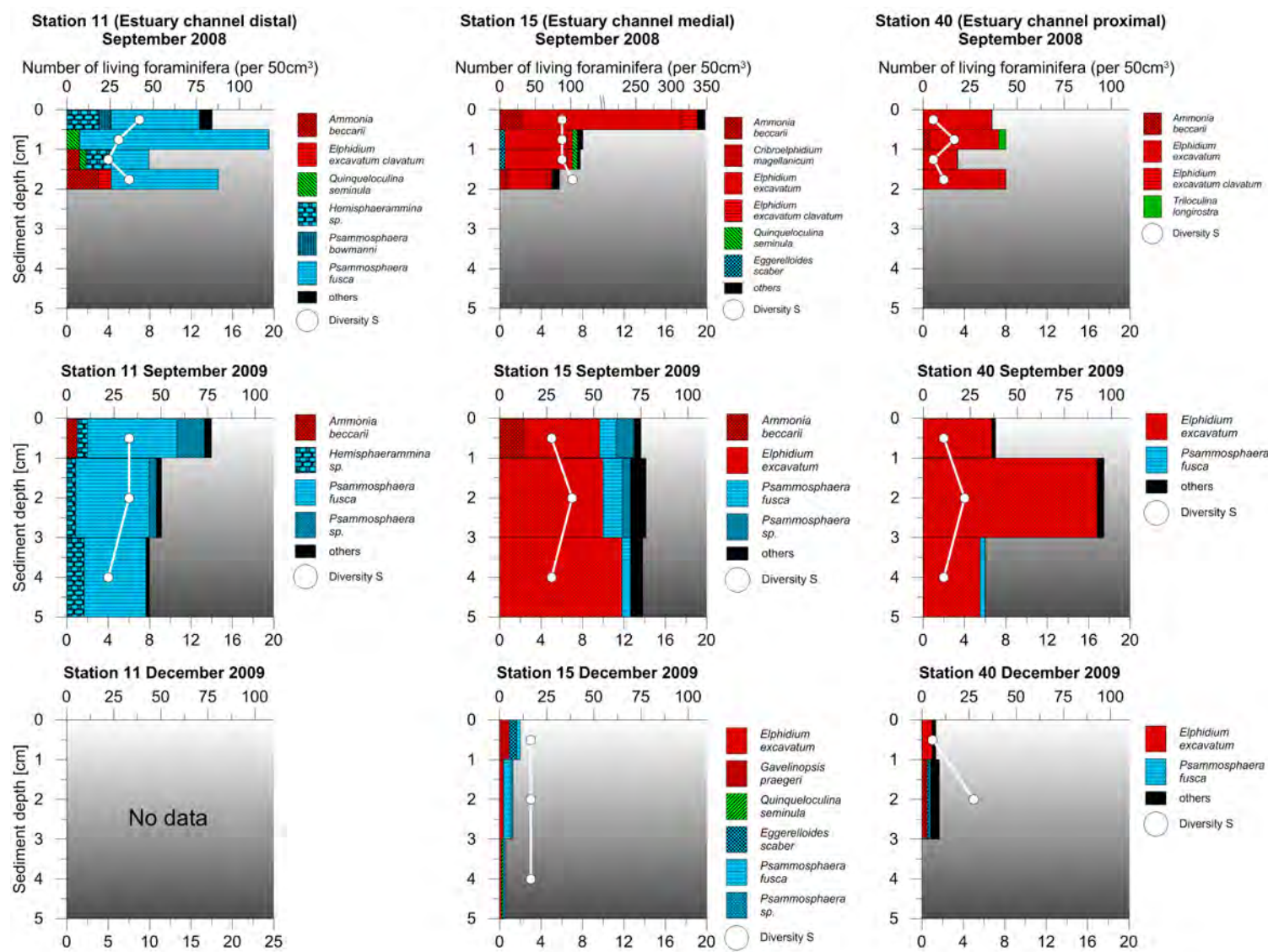


Figure B.7: Foraminiferal abundance and diversity downcore along the west-east transect. Species <5% are allocated to “others”.

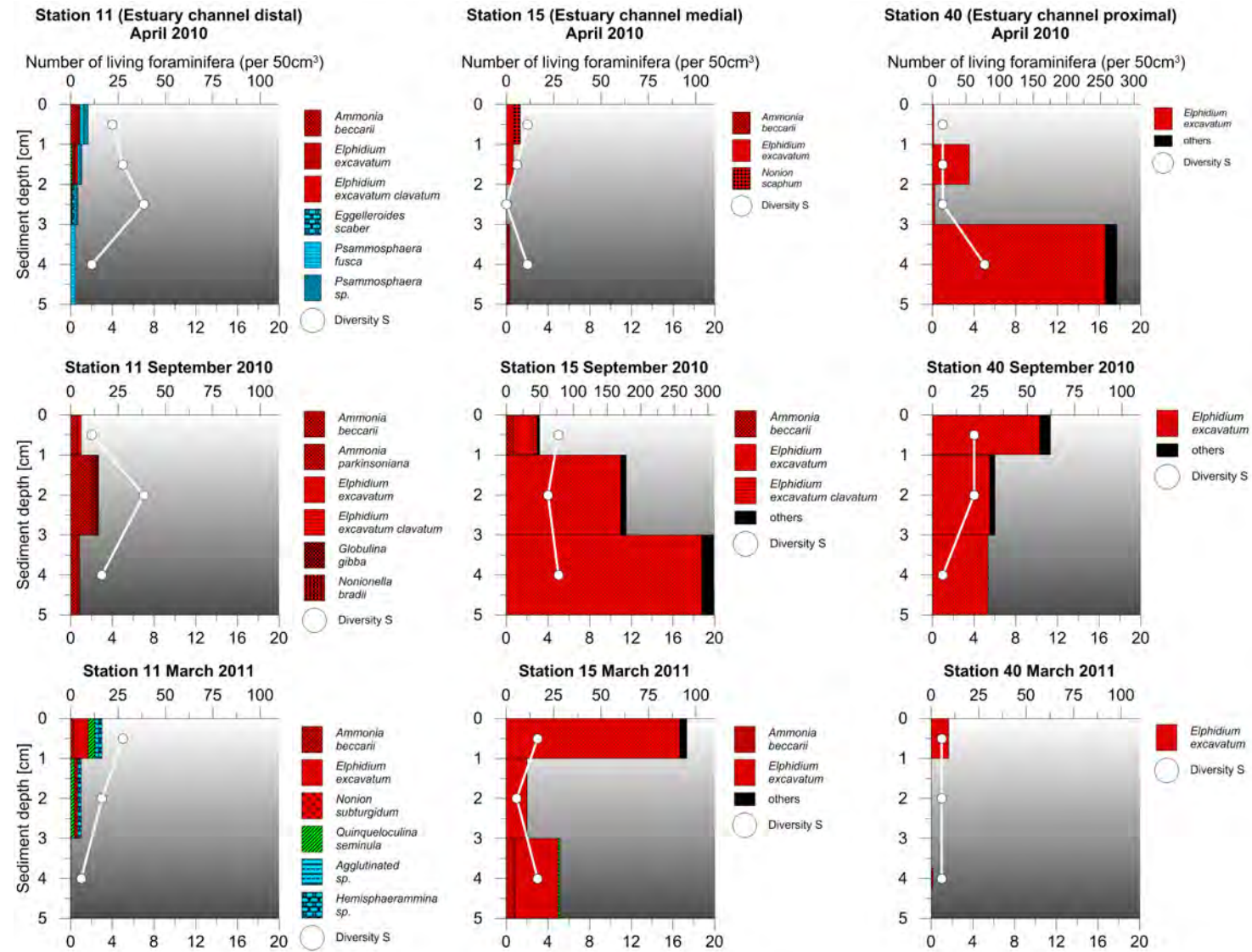
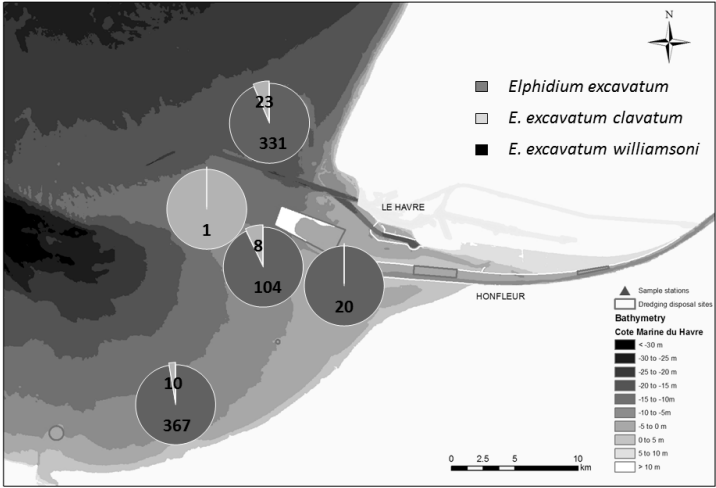


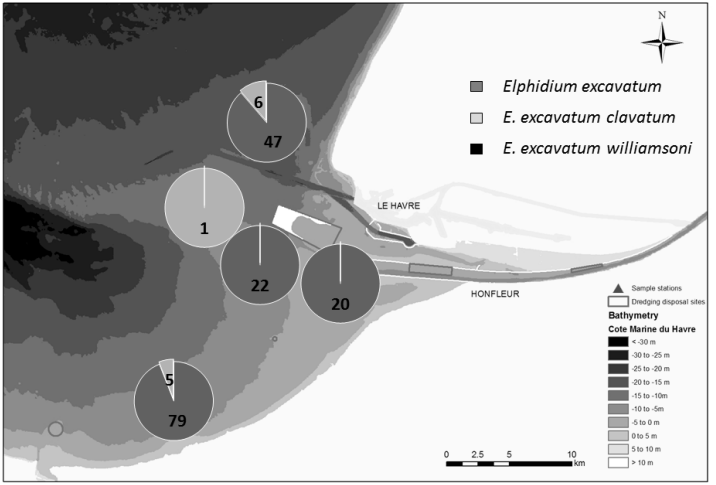
Figure B.7: continued

Figure B.8: Distribution of *Elphidium excavatum* morphospecies. 0-1 cm, >150 µm

(a) September 2008



(b) September 2009



(c) December 2009

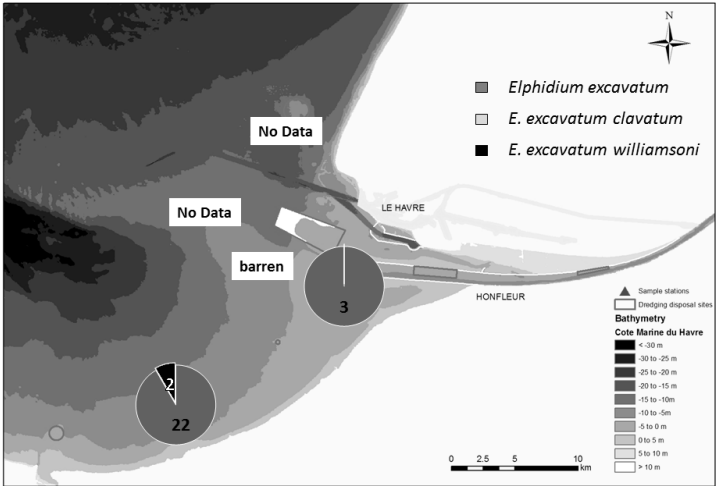
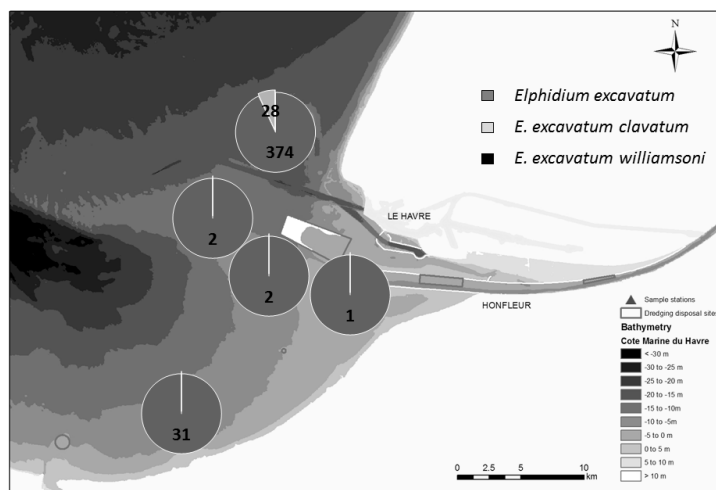
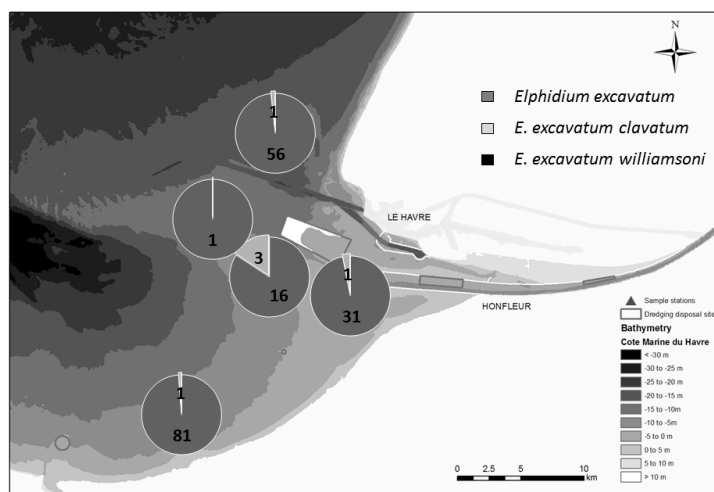


Figure B.8: continued

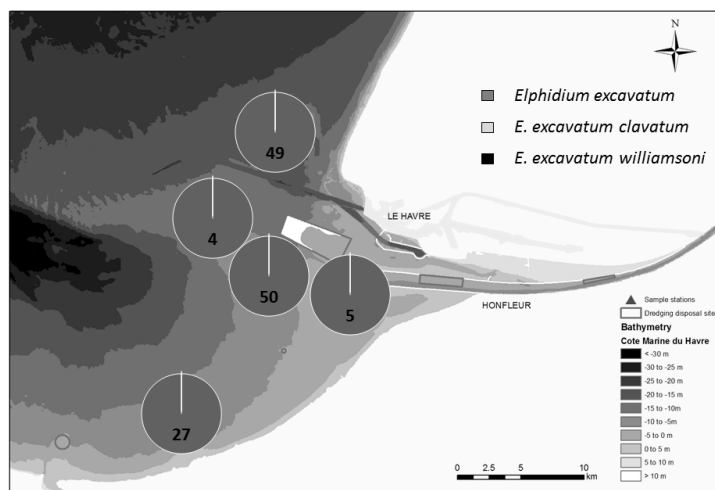
(d) April 2010



(e) September 2010



(f) March 2011



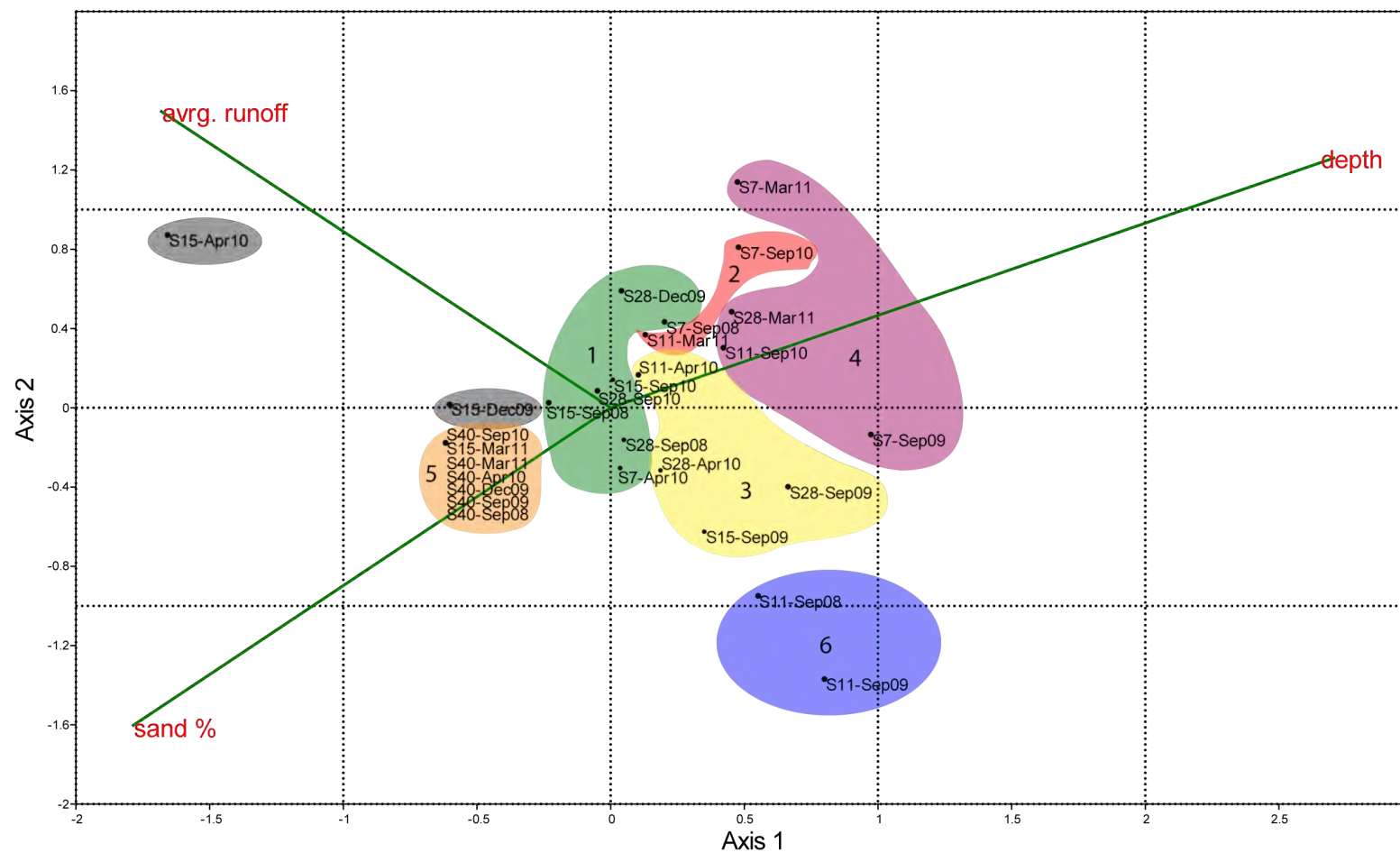


Figure B.9: Ordination diagram of the Canonical correspondence analysis for **station** positioning. 0-1 cm, >150 μ m, species >5%, arcsin transformation

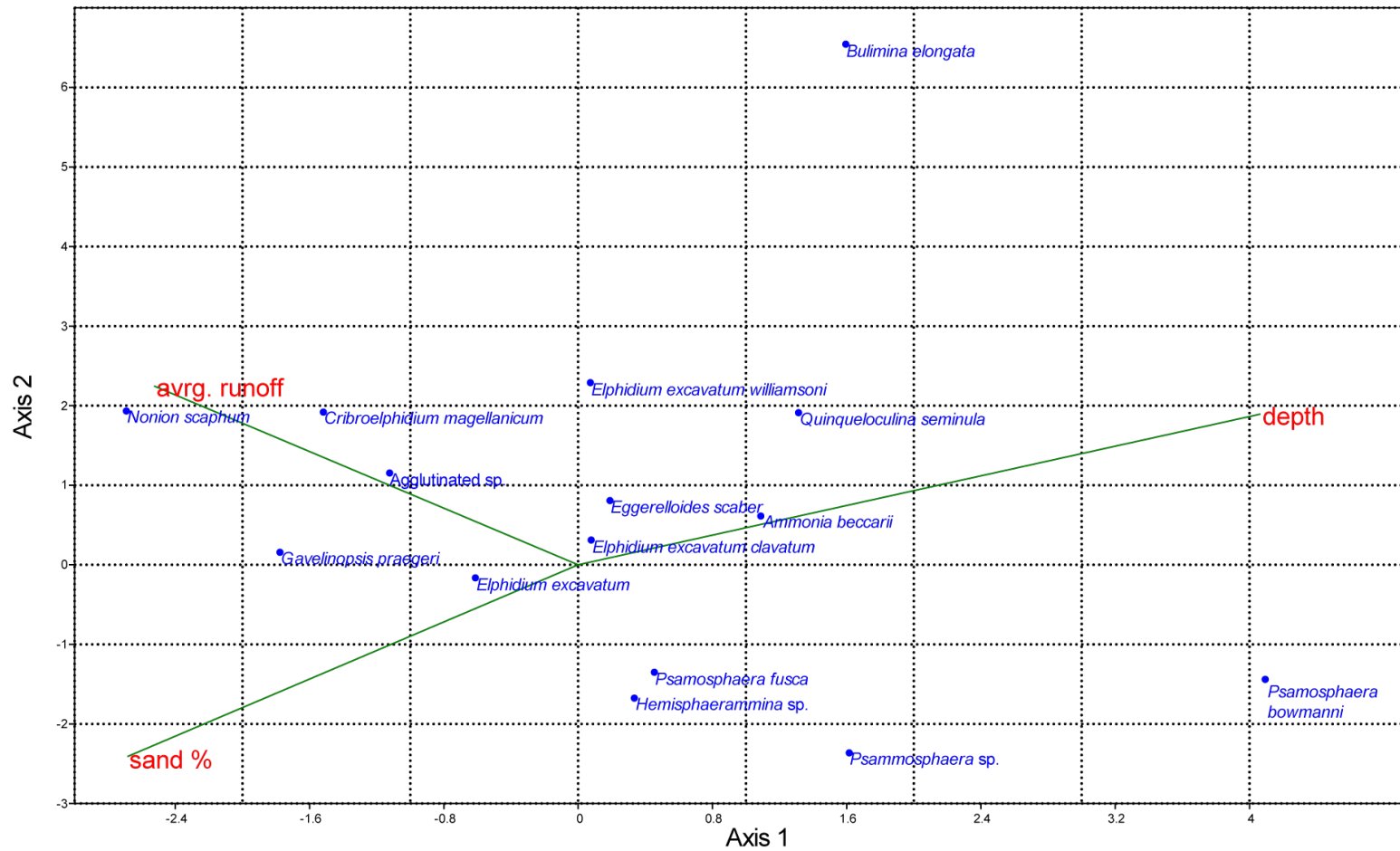


Figure B.10: Ordination diagram of the Canonical correspondance analysis for **species** positioning. Data: 0-1 cm, >150 μ m, species >5%, arcsin transformation

Appendix C

Census

Table C.1: Station 7

date	September 2008				September 2009			Dec. 2009
depth [cm]	0–0.5	0.5–1	1–1.5	1.5–2	0–1	1–3	3–5	-
grain size [µm]	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	No Data
<i>Ammonia beccarii</i>	55	37	20	25	39	64	100	
<i>Ammonia parkinsoniana</i>	1	2	5				5	
<i>Bulimina elongata</i>	6		1	3	3		3	
<i>Buliminella elegantissima</i>		2						
<i>Criboelphidium magellanicum</i>	1	4	1	4	1		1	
<i>Elphidium excavatum</i>	168	163	216	188	47	115	188	
<i>E. excavatum clavatum</i>	5	18	16	15	6	20	22	
<i>E. excavatum williamsoni</i>								
<i>Fissurina</i> sp.								
<i>Gavelinopsis praegeri</i>	1	1						
<i>Globulina gibba</i>								
<i>Nonion scaphum</i>	1	1		2				
<i>Nonion suburgidum</i>								
<i>Nonionella bradii</i>								
<i>Nonionella labradorica</i>	1	1						
<i>Nonionoides turgida</i>								
<i>Rosalina globularis</i>								
<i>Adelosina costata</i>								
<i>Adelosina laevigata</i>				1				
<i>Miliolinella</i> sp.								
<i>Quinqueloculina aspera</i> group								
<i>Quinqueloculina seminula</i>	80	46	34	13	6	3	2	
<i>Triloculina longirostra</i>			1					
<i>Triloculina trigonula</i>								
Agglutinated sp.								
<i>Eggerelloides scaber</i>		2	3	3	2	10	20	
<i>Hemisphaerammina</i> sp.	1				2			
<i>Jadammina macrescens</i>								
<i>Reophax dentaliniformis</i>								
<i>Psammosphaera bowmanni</i>	3	2	5	3	12	14	12	
<i>Psammosphaera fusca</i>	9	6	6	5	20	32	20	
<i>Psammosphaera</i> sp.		2	4	2	4	2	3	
<i>Trochammina</i> sp.								

Table C.1: Station 7 continued

date	April 2010										September 2010										March 2011													
depth [cm]	0-1		1-2		2-3		3-5		0-1		1-3		3-5		0-1		1-3		3-5															
grain size [µm]	150 - 500	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150												
<i>Ammonia beccarii</i>	36	2	15	1	7	14		7	24			34	2	6	76	1	4	14		26	43		2	16		8	9	1	125 - 150					
<i>Ammonia parkinsoniana</i>																																		
<i>Bulimina elongata</i>	3				1		2		1			1	5		3	1		1	1		7	2						2						
<i>Buliminella elegantissima</i>																					2	1												
<i>Criboelphidium magellanicum</i>	1											2											1											
<i>Elphidium excavatum</i>	374	9	54	7		27	3		33			56	14	2	240	5	1	271	24	4	63	6		11		1	16	1	125 - 150					
<i>E. excavatum clavatum</i>	28												1		1	10			14	3	1													
<i>E. excavatum williamsoni</i>																																		
<i>Fissurina</i> sp.																																		
<i>Gavelinopsis praegeri</i>																																		
<i>Globulina gibba</i>																																		
<i>Nonion scaphum</i>	2																																	
<i>Nonion suburgidum</i>											1																							
<i>Nonionella bradii</i>	2											1						1		1	1													
<i>Nonionella labradorica</i>																																		
<i>Nonionoides turgida</i>	6											2						1		2	1													
<i>Rosalina globularis</i>																																		
<i>Adelosina costata</i>																1	1																	
<i>Adelosina laevigata</i>																																		
<i>Miliolinella</i> sp.	1										2					1					5					1								
<i>Quinqueloculina aspera</i> group											1																							
<i>Quinqueloculina seminula</i>	2											31	37	19	20		37	5	1	1	1		1	1	1									
<i>Triloculina longirostra</i>											1																							
<i>Triloculina trigonula</i>																																		
<i>Agglutinated</i> sp.																1																		
<i>Eggerelloides scaber</i>		1	2			2	6		3			17	12					5					1	5	2									
<i>Hemisphaerammina</i> sp.																																		
<i>Jadammina macrescens</i>																																		
<i>Reophax dentaliniformis</i>																																		
<i>Psammosphaera bowmanni</i>	1	2										2																						
<i>Psammosphaera fusca</i>	2	5	11					4		7	2	1					5						1	3	9					1		1	1	
<i>Psammosphaera</i> sp.	31	1					1					3												2										
<i>Trochammina</i> sp.											1					1	1												3					

Table C.2: Station 11

date	September 2008				September 2009			Dec. 2009
depth [cm]	0–0.5	0.5–1	1–1.5	1.5–2	0–1	1–3	3–5	-
grain size [µm]	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	No Data
<i>Ammonia beccarii</i>	1	1	2	5	3		1	
<i>Ammonia parkinsoniana</i>								
<i>Bulimina elongata</i>								
<i>Buliminella elegantissima</i>								
<i>Criboelphidium magellanicum</i>	1	1			1	1		
<i>Elphidium excavatum</i>						1		
<i>E. excavatum clavatum</i>	1			2	1	1		
<i>E. excavatum williamsoni</i>								
<i>Fissurina</i> sp.								
<i>Gavelinopsis praegeri</i>		1		1				
<i>Globulina gibba</i>								
<i>Nonion scaphum</i>								
<i>Nonion suburgidum</i>								
<i>Nonionella bradii</i>								
<i>Nonionella labradorica</i>								
<i>Nonionoides turgida</i>								
<i>Rosalina globularis</i>								
<i>Adelosina costata</i>								
<i>Adelosina laevigata</i>								
<i>Miliolinella</i> sp.								
<i>Quinqueloculina aspera</i> group								
<i>Quinqueloculina seminula</i>	1	2	1					
<i>Triloculina longirostra</i>								
<i>Triloculina trigonula</i>								
Agglutinated sp.								
<i>Eggerelloides scaber</i>								
<i>Hemisphaerammina</i> sp.	5		4	1	3	5	10	
<i>Jadammina macrescens</i>								
<i>Reophax dentaliniformis</i>								
<i>Psammosphaera bowmanni</i>	2							
<i>Psammosphaera fusca</i>	14	30	6	17	26	43	36	
<i>Psammosphaera</i> sp.				1	8	4	1	
<i>Trochammina</i> sp.								

Table C.2: Station 11 continued

date	April 2010								September 2010				March 2011			
depth [cm]	0-1		1-2		2-3		3-5		0-1	1-3		3-5	0-1	1-3		3-5
grain size [µm]	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500
<i>Ammonia beccarii</i>	4	4		5			1			2	3	9	3	1		
<i>Ammonia parkinsoniana</i>										1						
<i>Bulimina elongata</i>																
<i>Buliminella elegantissima</i>																
<i>Criboelphidium magellanicum</i>		3	1		1											
<i>Elphidium excavatum</i>	1	1	2		4	2		1	1		1			4	1	
<i>E. excavatum clavatum</i>							1				1					
<i>E. excavatum williamsoni</i>																
<i>Fissurina</i> sp.																
<i>Gavelinopsis praegeri</i>																
<i>Globulina gibba</i>											1					
<i>Nonion scaphum</i>																
<i>Nonion suburgidum</i>														1		
<i>Nonionella bradii</i>											1		1			
<i>Nonionella labradorica</i>																
<i>Nonionoides turgida</i>																
<i>Rosalina globularis</i>																
<i>Adelosina costata</i>																
<i>Adelosina laevigata</i>																
<i>Miliolinella</i> sp.																
<i>Quinqueloculina aspera</i> group																
<i>Quinqueloculina seminula</i>			1	1			1		1					2		2
<i>Triloculina longirostra</i>																
<i>Triloculina trigonula</i>																
Agglutinated sp.														1		
<i>Eggerelloides scaber</i>																
<i>Hemisphaerammina</i> sp.							1				1			1		1
<i>Jadammina macrescens</i>																
<i>Reophax dentaliniformis</i>																
<i>Psammosphaera bowmanni</i>																
<i>Psammosphaera fusca</i>	6		3			1		7			3		6	1		
<i>Psammosphaera</i> sp.						2										
<i>Trochammina</i> sp.																

Table C.3: Station 15

date	September 2008				September 2009			December 2009		
depth [cm]	0–0.5	0.5–1	1–1.5	1.5–2	0–1	1–3	3–5	0–1	1–3	3–5
grain size [µm]	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500
<i>Ammonia beccarii</i>	8	1		3	7	3	1			
<i>Ammonia parkinsoniana</i>										
<i>Bulimina elongata</i>										
<i>Buliminella elegantissima</i>										
<i>Criboelphidium magellanicum</i>		1	3	2						
<i>Elphidium excavatum</i>	78	26	26	15	22	60	71	2	1	
<i>E. excavatum clavatum</i>	6	2	2	2		1	2			
<i>E. excavatum williamsoni</i>										
<i>Fissurina</i> sp.										
<i>Gavelinopsis praegeri</i>	1							3		
<i>Globulina gibba</i>										
<i>Nonion scaphum</i>										
<i>Nonion suburgidum</i>										
<i>Nonionella bradii</i>										
<i>Nonionella labradorica</i>				1						
<i>Nonionoides turgida</i>										
<i>Rosalina globularis</i>										
<i>Adelosina costata</i>	1									
<i>Adelosina laevigata</i>										
<i>Miliolinella</i> sp.										
<i>Quinqueloculina aspera</i> group										
<i>Quinqueloculina seminula</i>	1	2	2						1	
<i>Triloculina longirostra</i>										
<i>Triloculina trigonula</i>										
Agglutinated sp.										
<i>Eggerelloides scaber</i>		2	2	1				2		
<i>Hemisphaerammina</i> sp.						2				
<i>Jadammina macrescens</i>										
<i>Reophax dentaliniformis</i>										
<i>Psammosphaera bowmanni</i>					2	3				
<i>Psammosphaera fusca</i>					5	11	5	1	4	1
<i>Psammosphaera</i> sp.			1	1	5	5	4		1	
<i>Trochammina</i> sp.										

Table C.3: Station 15 continued

date	April 2010						September 2010						March 2011					
depth [cm]	0–1	1–2	2–3	3–5			0–1	1–3		3–5			0–1	1–3		3–5		
grain size [μm]	150 - 500	150 - 500	150 - 500	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150
<i>Ammonia beccarii</i>				1			1	5		3			3	1		1		5
<i>Ammonia parkinsoniana</i>																		
<i>Bulimina elongata</i>					1													
<i>Buliminella elegantissima</i>												1						
<i>Criboelphidium magellanicum</i>									2									
<i>Elphidium excavatum</i>	2	2		1	47	6	16	3	186	12	3	315	18	50	6	12	4	25
<i>E. excavatum clavatum</i>							3	1	5	2		14	1					
<i>E. excavatum williamsoni</i>																		
<i>Fissurina</i> sp.					1													
<i>Gavelinopsis praegeri</i>																		
<i>Globulina gibba</i>																		
<i>Nonion scaphum</i>	2																	
<i>Nonion suburgidum</i>																		
<i>Nonionella bradii</i>													1					
<i>Nonionella labradorica</i>																		
<i>Nonionoides turgida</i>																		
<i>Rosalina globularis</i>																		
<i>Adelosina costata</i>																		
<i>Adelosina laevigata</i>																		
<i>Miliolinella</i> sp.																		
<i>Quinqueloculina aspera</i> group																		
<i>Quinqueloculina seminula</i>						1												
<i>Triloculina longirostra</i>																		
<i>Triloculina trigonula</i>																		
Agglutinated sp.											1							
<i>Eggerelloides scaber</i>							1		1								1	
<i>Hemisphaerammina</i> sp.																		
<i>Jadammina macrescens</i>																		
<i>Reophax dentaliniformis</i>																		
<i>Psammosphaera bowmanni</i>																		
<i>Psammosphaera fusca</i>											1							
<i>Psammosphaera</i> sp.																		
<i>Trochammina</i> sp.																		

Table C.4: Station 28

date	September 2008				September 2009			December 2009	
depth [cm]	0–0.5	0.5–1	1–1.5	1–2	0–1	1–3	3–5	0–1	1–3
grain size [µm]	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500
<i>Ammonia beccarii</i>	59	63	44	48	38	62	54	3	5
<i>Ammonia parkinsoniana</i>							1		
<i>Bulimina elongata</i>	5		2	3	3	1	3		
<i>Buliminella elegantissima</i>			1						
<i>Criboelphidium magellanicum</i>		2	8	3	1	1	2		
<i>Elphidium excavatum</i>	153	214	180	120	79	75	124	22	60
<i>E. excavatum clavatum</i>	3	7	14	6	5	11	12		1
<i>E. excavatum williamsoni</i>								2	
<i>Fissurina</i> sp.	1								
<i>Gavelinopsis praegeri</i>	16	2						1	
<i>Globulina gibba</i>									
<i>Nonion scaphum</i>									
<i>Nonion suburgidum</i>									
<i>Nonionella bradii</i>									
<i>Nonionella labradorica</i>	7	2				1			
<i>Nonionoides turgida</i>									
<i>Rosalina globularis</i>					1	1			
<i>Adelosina costata</i>	2								
<i>Adelosina laevigata</i>									
<i>Miliolinella</i> sp.									
<i>Quinqueloculina aspera</i> group		2							
<i>Quinqueloculina seminula</i>					1	5		2	3
<i>Triloculina longirostra</i>									
<i>Triloculina trigonula</i>			1	1			1		
Agglutinated sp.									1
<i>Eggerelloides scaber</i>	7	1	9			2	3		7
<i>Hemisphaerammina</i> sp.									
<i>Jadammina macrescens</i>					1				
<i>Reophax dentaliniformis</i>									
<i>Psammosphaera bowmanni</i>				2	10	9	7		
<i>Psammosphaera fusca</i>	26	22	20	13	28	67	36		19
<i>Psammosphaera</i> sp.	6	4	2	3	5	5	4		
<i>Trochammina</i> sp.									

Table C.4: Station 28 continued

date	April 2010						September 2010						March 2011											
depth [cm]	0–1	1–2	2–3	3–5			0–1	1–3		3–5			0–1	1–3		3–5								
grain size [µm]	150 - 500	150 - 500	150 - 500	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150						
<i>Ammonia beccarii</i>	16	38	32	10	50	1	7	18	1	18	62	10	26	9	27	1	11	34	1	6	18			
<i>Ammonia parkinsoniana</i>																								
<i>Bulimina elongata</i>		4				3		5		1			1		2	1		2			1			
<i>Buliminella elegantissima</i>						1																		
<i>Criboelphidium magellanicum</i>		1			1			1		1	2		1											
<i>Elphidium excavatum</i>	31	102	35		170	26	1	80	16	7	237	22	3	173	6	1	26	11	1	34	3	1	24	2
<i>E. excavatum clavatum</i>		3	1					1	1		2													
<i>E. excavatum williamsoni</i>																								
<i>Fissurina</i> sp.																								
<i>Gavelinopsis praegeri</i>																								
<i>Globulina gibba</i>																								
<i>Nonion scaphum</i>																								
<i>Nonion suburgidum</i>																								
<i>Nonionella bradii</i>								1	1				1											
<i>Nonionella labradorica</i>																								
<i>Nonionoides turgida</i>								1			1													
<i>Rosalina globularis</i>																			1					
<i>Adelosina costata</i>																								
<i>Adelosina laevigata</i>																								
<i>Miliolinella</i> sp.					1			1											1					
<i>Quinqueloculina aspera</i> group					1													1	1					
<i>Quinqueloculina seminula</i>	1	5	2		7	1	1		1		1		1	1		4	1							1
<i>Triloculina longirostra</i>																								
<i>Triloculina trigonula</i>																								
Agglutinated sp.										1														
<i>Eggerelloides scaber</i>		2	2		3			5	1		2		1		1		3			1				
<i>Hemisphaerammina</i> sp.							3	1																
<i>Jadammina macrescens</i>																								
<i>Reophax dentaliniformis</i>		1																						
<i>Psammosphaera bowmanni</i>																								
<i>Psammosphaera fusca</i>	18	26	18	19	2		1		21	4		11	1	16		1		14			8	3		
<i>Psammosphaera</i> sp.	2	1			1			2		2								2				1		
<i>Trochammina</i> sp.					1					1														

Table C.5: Station 40

date	September 2008				September 2009			December 2009	
depth [cm]	0–0.5	0.5–1	1–1.5	1.5–2	0–1	1–3	3–5	0–1	1–3
grain size [μm]	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500	150 - 500
<i>Ammonia beccarii</i>	1				2			2	
<i>Ammonia parkinsoniana</i>									
<i>Bulimina elongata</i>									
<i>Buliminella elegantissima</i>									
<i>Criboelphidium magellanicum</i>								1	
<i>Elphidium excavatum</i>	10	10	5	11	20	101	33	3	1
<i>E. excavatum clavatum</i>	1				1				
<i>E. excavatum williamsoni</i>									
<i>Fissurina</i> sp.									
<i>Gavelinopsis praegeri</i>									
<i>Globulina gibba</i>									
<i>Nonion scaphum</i>									
<i>Nonion suburgidum</i>									
<i>Nonionella bradii</i>									
<i>Nonionella labradorica</i>									
<i>Nonionoides turgida</i>									
<i>Rosalina globularis</i>									
<i>Adelosina costata</i>									
<i>Adelosina laevigata</i>									
<i>Miliolinella</i> sp.									
<i>Quinqueloculina aspera</i> group									
<i>Quinqueloculina seminula</i>					1				
<i>Triloculina longirostra</i>	1								
<i>Triloculina trigonula</i>									
Agglutinated sp.									
<i>Eggerelloides scaber</i>								1	
<i>Hemisphaerammina</i> sp.									
<i>Jadammina macrescens</i>									
<i>Reophax dentaliniformis</i>									
<i>Psammosphaera bowmanni</i>									
<i>Psammosphaera fusca</i>					1 3			1	
<i>Psammosphaera</i> sp.									
<i>Trochammina</i> sp.									

Table C.5: Station 40 continued

date	April 2010						September 2010						March 2011								
depth [cm]	0-1	1-2	2-3	3-5			0-1	1-3			3-5			0-1	1-3			3-5			
grain size [µm]	150 - 500	150 - 500	150 - 500	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150	315 - 500	150 - 315	125 - 150
<i>Ammonia beccarii</i>	3						1														
<i>Ammonia parkinsoniana</i>																					
<i>Bulimina elongata</i>							1														
<i>Buliminella elegantissima</i>																					
<i>Criboelphidium magellanicum</i>	6 2						1														
<i>Elphidium excavatum</i>	1	30	2	281 30			31	7	1	32	3	1	31	4	5	4 3			1	1	
<i>E. excavatum clavatum</i>	3						1														
<i>E. excavatum williamsoni</i>																					
<i>Fissurina</i> sp.																					
<i>Gavelinopsis praegeri</i>																					
<i>Globulina gibba</i>																					
<i>Nonion scaphum</i>																					
<i>Nonion suburgidum</i>																					
<i>Nonionella bradii</i>																					
<i>Nonionella labradorica</i>																					
<i>Nonionoides turgida</i>																					
<i>Rosalina globularis</i>																					
<i>Adelosina costata</i>																					
<i>Adelosina laevigata</i>																					
<i>Miliolinella</i> sp.																					
<i>Quinqueloculina aspera</i> group																					
<i>Quinqueloculina seminula</i>							1														
<i>Triloculina longirostra</i>																					
<i>Triloculina trigonula</i>																					
Agglutinated sp.																					
<i>Eggerelloides scaber</i>																					
<i>Hemisphaerammina</i> sp.																					
<i>Jadammina macrescens</i>																					
<i>Reophax dentaliniformis</i>																					
<i>Psammosphaera bowmanni</i>																					
<i>Psammosphaera fusca</i>	5 2						1														
<i>Psammosphaera</i> sp.																					
<i>Trochammina</i> sp.																					

Appendix D

Alphabetical species list

Adelosina costata; pl. 5, figs. 1-2

Adelosina laevigata d'Orbigny, 1826 in Colom, 1974, figs. 52a-52j and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=492867> on 2011-10-11

Agglutinated sp.; pl. 6; fig. 1

Ammonia beccarii (Cushman, 1926); pl. 1, figs. 1-8 in Jorissen, 1988, pls. 5-6 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=112849> on 2011-10-11

Ammonia parkinsoniana (d'Orbigny, 1839) in Jorissen 1988, pl 7-10 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=418095> on 2011-10-11

Bulimina elongata d'Orbigny, 1826; pl. 1, figs. 9-12 in Jones, 1994, pl. 50, figs. 3-4 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113037> on 2011-10-11

Buliminella elegantissima (d'Orbigny, 1839); pl. 2, figs. 1-3 in van Voorthuysen, 1973, pl. 3, figs. 3a-3b and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113747> on 2011-10-11

Criboelphidium magellanicum Heron-Allen & Earland, 1932; pl. 2, figs. 4-8 in Herron-Allen and Earland, 1932, p. 440, pl. 16, figs. 1-4 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113242> on 2011-10-11

Eggerelloides scaber (Williamson, 1858) pl. 6, figs. 2-6 in Jones, 1994, pl. 47, figs. 15-17 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113938> on 2011-10-11

Elphidium excavatum (Terquem, 1875); pl. 2, figs. 9-12; pl. 3, figs. 1-6 in Feyling-Hanssen, 1972, pl. 3-6 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113267> on 2011-10-11

Elphidium excavatum clavatum **Cushman, 1930; pl. 3 figs. 7-12** in Feyling-Hanssen, 1972, pl. 1, figs. 1-2 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=466569> on 2011-10-11

Elphidium excavatum williamsoni **Haynes, 1973** in Haynes, 1873, p.207, pl. 24, fig. 7., pl. 25, figs. 6, 9, pl. 27, figs. 1-3 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=466572> on 2011-10-11

Fissurina sp.; pl. 1, fig. 1

Gavelinopsi praegeeri (**Heron-Allen & Earland, 1913**) in Schiebel, 1992, pl. 4, fig. 6. and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113159> on 2011-10-11

Globulina gibba (**d'Orbigny, 1826**); pl. 4, fig. 1 in Cushman & Ozawa, 1930, pl. 16, figs. 1-4 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113656> on 2011-10-11

Hemisphaerammina sp.; pl. 6, figs. 7-12

Jadammina macrescens (**Brady, 1870**) in Brady & Robertson, 1870, pl. 11, figs. 5a-c and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=114305> on 2011-10-11

Miliolinella sp.; pl. 5, figs. 3-5

Nonion scaphum (**Fichtel and Moll, 1978**) in Jones, 1994, pl. 109, fig. 12

Nonion subturgidum (**Cushman, 1924**); pl. 4, fig. 3 in Cushman 1939, pl. 6, fig 29 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=527089> on 2011-10-11

Nonionella bradii (**Chapman, 1917**); pl. 4, figs. 4-6 in Williamson, 1858, pl. 4, figs. 95-97 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=397142> on 2011-10-11

- Nonionella labradorica* (Dawson, 1860) in Patterson & Kumar, 2002, pl. 2 fig. 20 in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=293026> on 2011-10-11
- Nonionoides turgida* (Williamson, 1858); pl. 4, fig. 7 in Murray, 2003, figs. 9.4–9.5 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=466471> on 2011-10-11
- Psammosphaera bowmanni* Heron-Allen & Earland, 1912; pl. 7, figs. 1-5 in Gooday et al., 2010, pl. 1, A-B and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=114181> on 2011-10-11
- Psammosphaera fusca* Schulze, 1875; pl. 7, figs. 6-12 in Schultze, 1875, pl. 2, fig. 8a–f and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=114184> on 2011-10-11
- Psammosphaera* sp.; pl. 8, figs. 1-3
- Quinqueloculina aspera* group; pl. 5, fig. 6
- Quinqueloculina seminula* (Linnaeus, 1758); pl. 5, figs. 7-9 in Jones, 1994, pl. 5, fig. 6 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=112674> on 2011-10-11
- Reophax dentaliniformis* Brady 1881 in Hermelin, 1983, pl. 1 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=114000> on 2011-10-11
- Rosalina globularis* d'Orbigny, 1826; pl. 4, figs. 8-9 in Hansen and Revets, 1992, pl. 6, figs. 7-8 and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at <http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=113171> on 2011-10-11
- Triloculina longirostra* (d'Orbigny, 1826); pl. 5, figs. 10-11 in Jorissen, 1988, pl. 2, fig. 14
- Triloculina trigonula* (Lamarck, 1804) in Colom, 1974, figs. 56j–l and in Hayward, B.W., Cedhagen, T., Kaminski, M., Gross, O. (2011) World Modern Foraminifera Database at

<http://www.marinespecies.org/foraminifera/aphia.php?p=taxdetails&id=112772> on 2011-10-11

Trochammina sp.; pl. 8, figs. 4-5

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