Seasonal changes in the macro-zoobenthos of Roebuck Bay: a 10 year study

Report on *MONROEB*-2,

*MON*itoring *ROE*buck Bay *B*enthos, 1996-2005

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ABSTRACT

Roebuck Bay in the Kimberley region of northwest Australia is especially famous for the tens of thousands of shorebirds that spent the tropical winter here. Shorebirds are attracted to the richness of benthic invertebrates living in and on the intertidal flats.

To research the changes in the benthic fauna of these intertidal flats throughout the year, and from year to year, a benthic monitoring programme was started in 1996. The aim of MONROEB (MONitoring ROEbuck Bay Benthos), which is still running, is to find out if there are changes over time in the composition and density of the benthic fauna and to study growth and recruitment patterns on a tropical intertidal flat. To the best of our knowledge this is the first long-term study of the seasonal dynamics of intertidal benthos in the tropics.

From March 1996 onwards, two sites in the bay were sampled almost monthly. One site is a sandy place off 'Fall Point', the other is a very muddy place off 'One Tree', at the eastern end of Crab Creek Road. At these two sites the benthic invertebrates were monitored at two stations, respectively 150 m and 250 m offshore. The sampling was carried out by the Broome Bird Observatory wardens assisted by volunteers. At each of the four stations (two sites with two stations each), four samples each consisting of six cores of 83 cm^2 to a depth of 20 cm were taken. Each sample was sieved over a 1-mm mesh, which thus yielded the 'macrozoobenthic animals'. The sieved samples were directly sorted in trays with salt water. All animals were conserved in formalin, stored in ethanol and sent to the Royal Netherlands Institute for Sea Research (NIOZ) for identification. The sampling programme is still continuing, but the analysis includes samples up to October 2005. The first results on the years 1996 to 2001 are published in NIOZ-report 2003-4. In the present report the data for 1996 to 2005 are presented. We refer to the years 1996 to 2001 as the first period and 2001 to 2005 as the second period.

In the laboratory, all molluscs and crabs (to species level), the polychaete tubeworms Oweniidae and Chaetopteridae (to family level), the ostracods (three taxa), the brachiopods (one species *Lingula*), the echinoderms, the pygnogonids (sea spiders), anemones, tunicates and fish were distinguished, counted and, if possible, their lengths measured to the nearest mm. The remaining polychaetes were not analysed yet.

In the process almost 29,500 macrozoobenthic animals were sorted and assigned names. At least 144 different taxa were encountered, including 45 different species of bivalve, 30 gastropods, 3 scaphopods, 7 echinoderms and 17 crab species. The total number of species was much higher in the sands off Fall Point than in the soft mud off One Tree. There were hardly any differences between the relatively nearshore and offshore stations.

At Fall Point the most common species were the bivalves *Anodontia omissa, Divaricella ornata* and *Tellina piratica*, the gastropods *Vexillum radix* and Eulimidae spec., the scaphopod *Laevidentalium* cf. *lubricatum*, the crab taxon *Macrophthalmus* spec., the 'spidercrab' *Halicarcinus* cf. *australis*, the crabs *Hexapus* spec. and *Myrodes eudactylus*, the polychaete tubeworms *Chaetopteridae* and Oweniidae, an ostracod, hermit crabs, the brachiopod *Lingula* spec., brittlestar *Amphiura tenuis* and starfish *Astropecten granulatus*. At One Tree the most common species were the bivalves *Tellina* cf. *exotica* and *Siliqua pulchella*, the gastropods *Tornatina* spec., *Salinator* cf. *burmana* and the small *Nassarius* spec., the scaphopod *Dentalium* cf. *bartonae*, hermit crabs and mudskippers Periophthalmidae.

Of the 15 numerically dominant taxa, most of which were bivalves, the seasonal changes are given. In contrast to the clear and regular annual rhythmicity in the numbers of most species on temperate intertidal flats, the species in Roebuck Bay show a great variety of density changes, with little evidence for clear circannual cycles. Bloody cockles *Anadara granosa* had the highest densities from early to mid 1997 with lower numbers since. The lucinid bivalve *Anodontia omissa* reached peak densities in late 1997 and again in late 1999. Another lucinid bivalve, *Divaricella* irpex, showed peaked numbers every two years up to 2000 but from that time numbers stayed low. The razorclam-like *Siliqua pulchella* peaked in mid 1997, with a gradual decline in numbers until 2002 when there was a peak again. The *tellinid Tellina capsoides* peaked in late 1996-1997 and declined to zero for almost three years but recovered a litlle. In contrast, *Tellina piratica* peaked five times over the ten year of study. *Tellina 'exotica'* declined until 2001, but seems to have recovered since. The Ingrid-eating snail *Nassarius dorsatus* showed repeated peak numbers after the cold (dry) seasons but from 2000 until 2005 numbers are very low. *Laevidentalium* cf. *lubricatum* had peaks in 1996 and 1997 but was only found in low numbers since. *Dentalium* cf. *bartonae* had its peak from 1997 until the beginning of 2001 but decreased to very low numbers. The tubeworms Chaetopteridae and Oweniidae showed no sign of regular circannual changes in numbers either. After a huge peak in 1997 Chaetopteridae was only present in very low numbers. Oweniidae showed peaks in 1997, 1998 and 2000 but declined too. Of the two most common crabs, *Halicarcinus* cf. *australis* peaked seven times in the middle of the year, whereas *Macropthalmus* spec. peaked six times in the middle of the year. The brittlestar *Amphiura tenuis* showed an increase in the first five years, declined a little but was back in 2004 and 2005 again.

For the seven most abundant bivalves and one gastropod, aspects of settlement of new cohorts and the possibility of movements of animals over the intertidal flats were examined by looking at the size-frequency distributions. Unlike in a temperate area, there is no single time period of settlement. Settlement of the different species in the Bay took place at different times of the year. *Anadara granosa* settled in the course of the wet seasons (January-March). Both lucinids, *Anodontia omissa* and *Divaricella irpex* settled early in the wet, *Siliqua pulchella* probably settled late in the wet. The tellinids settled in the middle of the wet (*Tellina capsoides*), after the wet (*Tellina piratica*) or at the beginning and the end of the wet season (*Tellina 'exotica'*). For one bivalve species, *Siliqua pulchella*, there were clear indications that these animals make movements over the intertidal flats after settlement.

At the end of the first MONROEB-period in May 2001 most of the species that were abundant in 1996 and 1997 had declined dramatically. It seems that some of the species are recovering in the years 2001 to 2005.

1. INTRODUCTION

Roebuck Bay is a tropical marine embayment with extensive intertidal mudflats (Fig. 1 and see front cover). The intertidal mudflats regularly support over 100,000 birds, which makes it one of the most important intertidal areas for shorebirds in the world. Roebuck Bay is designated as a Ramsar-site (Watkins 1993). That Roebuck Bay can host hundreds of thousands of shorebirds, but also large populations of fish, sharks, rays and turtles means it must contain a rich food-source for those animals (see Pepping *et al*. 1999).

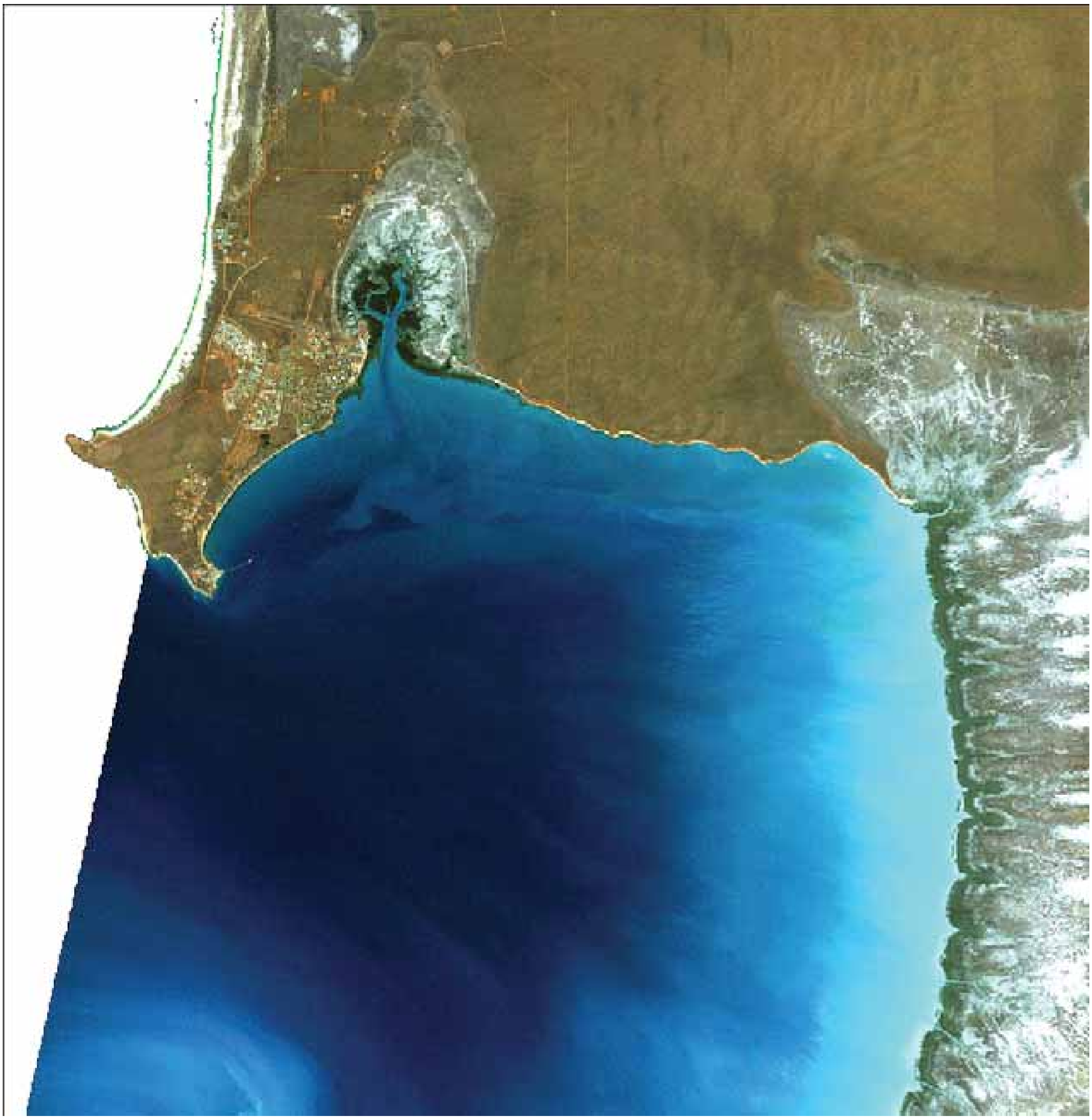
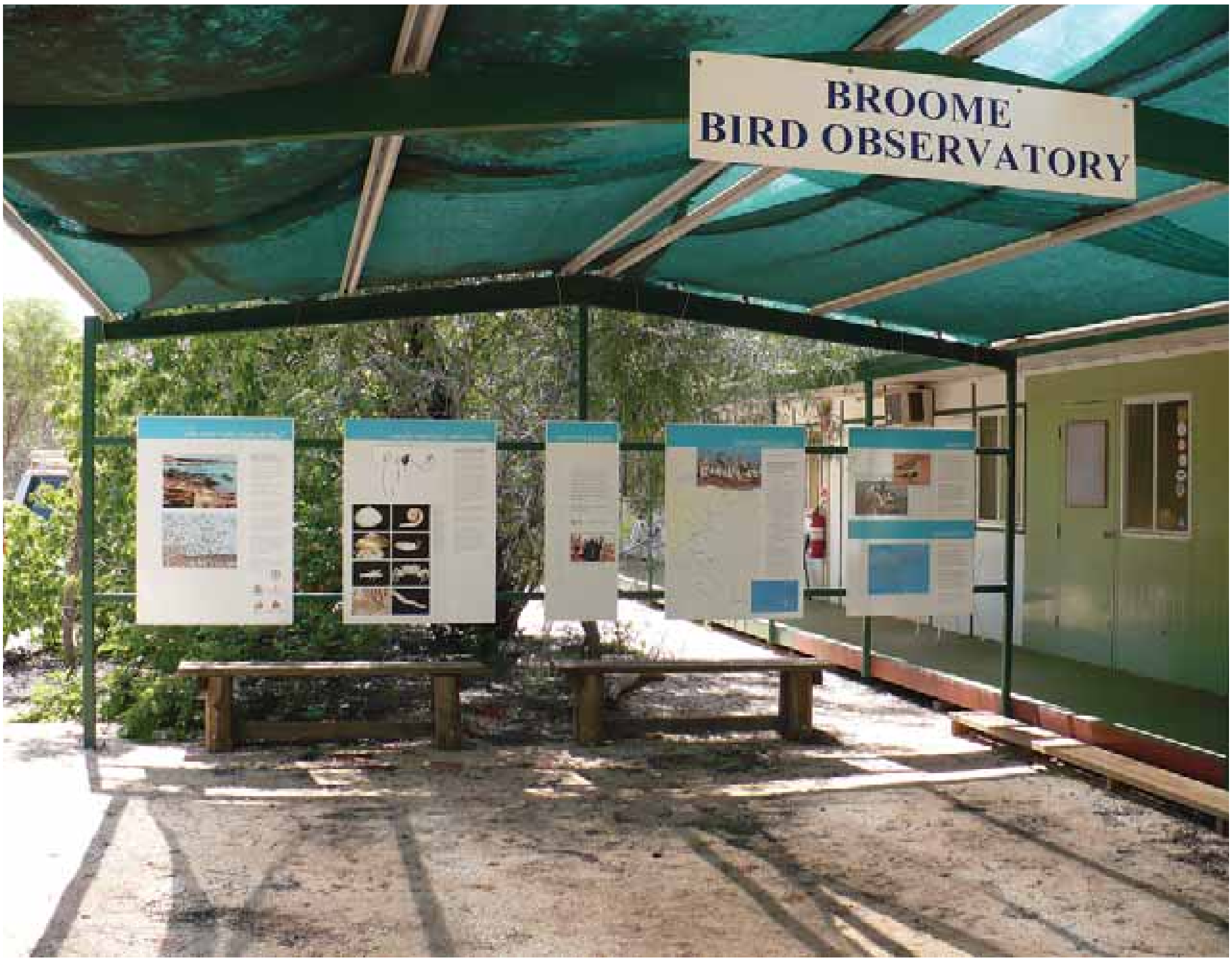


Figure 1. Roebuck Bay at high tide, with the town of Broome and Dampier Creek in the north. From left to right: Cable Beach, Gantheaume Point, Broome, Dampier Creek, the northern shore, Crab Creek and then the huge mangrove fringe that continues to the south.

There are many threats to the bay connected with the expansion of Broome, like the increase in nutrients and pollution. To be able to follow changes in the intertidal ecosystem it is necessary to have baseline studies on different trophic levels of the ecosystem. Thanks to the presence of the Broome Bird Observatory (BBO) the shorebirds are monitored monthly since the 1980's. In March 1996 a monitoring scheme of macrobenthic animals (those living on and in the mud and retained on a 1 mm sieve) of the intertidal flats of Roebuck Bay was initiated by Grant Pearson from the Department of Conservation and Land Management of Western Australia (CALM) and Theunis Piersma from the Netherlands Institute for Sea Research (NIOZ). This was the start of the first long-term study, MONROEB (Monitoring Roebuck Bay Benthos), on seasonality of macrozoobenthos on tropical mudflats. In 2003 the first report on MONROEB was published covering the results of the sampling effort from March 1996 to May 2001 (de Goeij et al. 2003). With the help of many volunteers it has been possible to continue this unique programme and at the moment (July 2008) it is still running. The present report represents an unique and indispensable data-series to address the general question about benthic variability and seasonality in tropical intertidal ecosystems, and more particularly the changes taking place in Roebuck Bay.

Broome Bird Observatory (BBO) and its wardens have played a major role in continuing this sampling programme, together with the immense effort of many (volunteer) participants over 10 years now.



Picture 1. The reception of Broome Bird Observatory

In 1996, 2000, 2002 and 2006 four big projects have taken place in which the benthic fauna of whole Roebuck Bay was mapped (ROEBIM, Trackin'2000, SROEBIM02, ROEBIM06). These projects showed the extreme biodiversity of the Bay and the patchiness of many different species (Pepping *et al*. 1999, Rogers *et al.* 2000, Piersma *et al*. 2002, Piersma *et al*. 2006).

The analyses of the samples collected during the first five years (de Goeij *et al.*, 2003) showed dramatic declines in numbers for almost all species. The present report, MONROEB-2, will tell us whether the benthic fauna in the Bay has recovered over the succeeding five years.

2. STUDY SITES AND METHODS

2.1 STUDY SITES

In March 1996 two sites were selected: 'Fall Point', that represents a rather sandy type of substrate at a corner of Roebuck Bay where the intertidal flat is narrowest and 'One Tree' that represents the deep blue mud typical of the northeastern mangrove-bordered edge of Roebuck Bay (see Pepping *et al.* 1999).

Figure 2. The study area with the two sites (FP= Fall Point and OT= One Tree) and the four sampling stations (A and B at each site) in the northeastern corner of Roebuck Bay. BBO= Broome Bird Observatory.

At each of these sites, two sampling stations were positioned approximately 150 m and 250 m offshore (perpendicular to the beach, more or less directed to the south), named A and B (Fig. 2). Co-ordinates for Fall Point-A: 17°59.030' S, 122° 20.173' E, Fall Point-B 17°59.116' S, 122° 20.167' E, One Tree-A: 17°59.253' S, 122° 21.789' E. The One Tree site is slightly longer exposed per tidal cycle than the Fall Point site, especially during neap tides.

Picture 2. A sandy area (photo Petra de Goeij)

Picture 3. A 'blue' muddy area (photo Jan van de Kam)

2.2 METHODS

The two sites (=four stations) were sampled almost every month in the period March 1996 to October 2005. At each station 4 samples were taken, each consisting of 6 standard cores with a diameter of 10.3 cm and a surface of 1/120 m^2 (=0.083 m^2 =83 cm^2), taken to a depth of 20 cm. Each sample was sieved on location over a sieve with a mesh-size of 1 mm. Each sample thus represented a mudsurface of 6*1/120 = 1/20m^2, and each station represented a sampled surface of 4*1/20 = 1/5 m^2. To obtain a density per m^2, the number of animals per station was multiplied by 5. To obtain over-all densities per sampling date, averages of the station-specific densities were calculated. Due to weather conditions or personnel shortage it was not possible to sample every month and sometimes not all samples were taken. In Appendix I the sampling schedule and sampling effort are given.The density data used in the Figures 5-34 have been calculated from the actual sampled surface (see Appendix I).

The sieved samples were transferred to the Broome Bird Observatory where they were sorted in trays with salt water, on most occasions on the same day of the sampling. All animals (most still alive) were picked out and fixed with 4% formaldehyde. After a few days the formaldehyde was removed and replaced by 70% ethanol. The samples were sent to the Royal Netherlands Institute of Sea Research (NIOZ) for detailed analysis. Before the samples were packed and sent, the ethanol was removed and replaced by ethanol saturated paper tissue, to prevent both leakage and dehydra-tion of specimens. After arrival in The Netherlands the vials were filled again with 70% ethanol.

In the laboratory we have identified (and counted) so far all molluscs and crabs (to species level), other crustacean groups to order level but sometimes to species level, of the polychaetes only the tubeworms Oweniidae and Chaetopteridae (to family level), the ostracods (three taxa), the brachiopods (one species of Lingula), the echinoderms, pygnogonids (sea spiders), anemones, tunicates and fish. This leaves the many families of polychaete worms and an assortment of small crustacean forms for a future analysis. All material has been stored on ethanol at NIOZ for further research and examination.

All specimens were counted and their length was measured with callipers to the nearest 0.5 mm. The length of bivalves is defined as the length of the anterior-posterior axis, the length of the gastropods as the distance between the apex and the tip of the anterior (siphonal) canal (when present) or to the farthest edge of the aperture, and the length of the scaphopods as the length of the straight line between both tips of the shell. The size of the crabs was defined as their carapace width. The length of all other specimens is given by the longest body length.
Identifications were made with the help of a stereo-microscope, using among other sources Edgar (1997), Faucauld (1977), Janssen (1995), Jones & Morgan (1994), Lamprell & Whitehead (1992), Lamprell & Healy (1998), Shepherd & Thomas (1989) and Wilson (1993, 1994).

Although it was possible to assign to some species a proper scientific name (mainly the bivalves), for many specimens a field name was given for preliminary use (see Table 1). Note that these fieldnames are not intended to be used in the nomenclature within the meaning of International Committee of Zoological Nomenclature (ICZN). In the process we have so far sorted and assigned names to 29,500 macrozoobenthic animals of at least 144 species. Given the taxonomic gaps, true diversity is likely to be much higher.

3. RESULTS AND DISCUSSION

3.1 Weather Patterns

The weather-pattern was very even throughout the ten years (Fig. 3). Rainfall peaked in the period January to March, with four of the ten years showing a clear second peak in May or June. The peak of over 900 mm in February 1997 occurred only once. Although monthly average maximum temperatures varied with 7.9˚C only from 27.8 to 35.7˚C, there were brief excursions to the lowest part of the temperature range during the middle of each year, with broader bands of higher temperatures from October through April. The monthly average minimum air temperatures varied twice as much, with lows down to 10.5˚C in June and highs up to 27.5˚C in December and January. The patterns of rainfall, maximum and minimum temperature did not change over the years.

During these ten years Roebuck Bay was visited by a cyclone two times. In late January 1998 a cyclone category 1 had some striking effects on some of the outlets off Crab Creek, whereas in April 2000 the cyclone 'Rosita' passed 40 km south of Broome, the latter cyclone is thought to be responsible for the disappearance of most of the seagrass cover on the northern shore of Roebuck Bay (D.I. Rogers pers. comm.).

Picture 4. The road to Crab Creek in the Wet (photo Petra de Goeij)

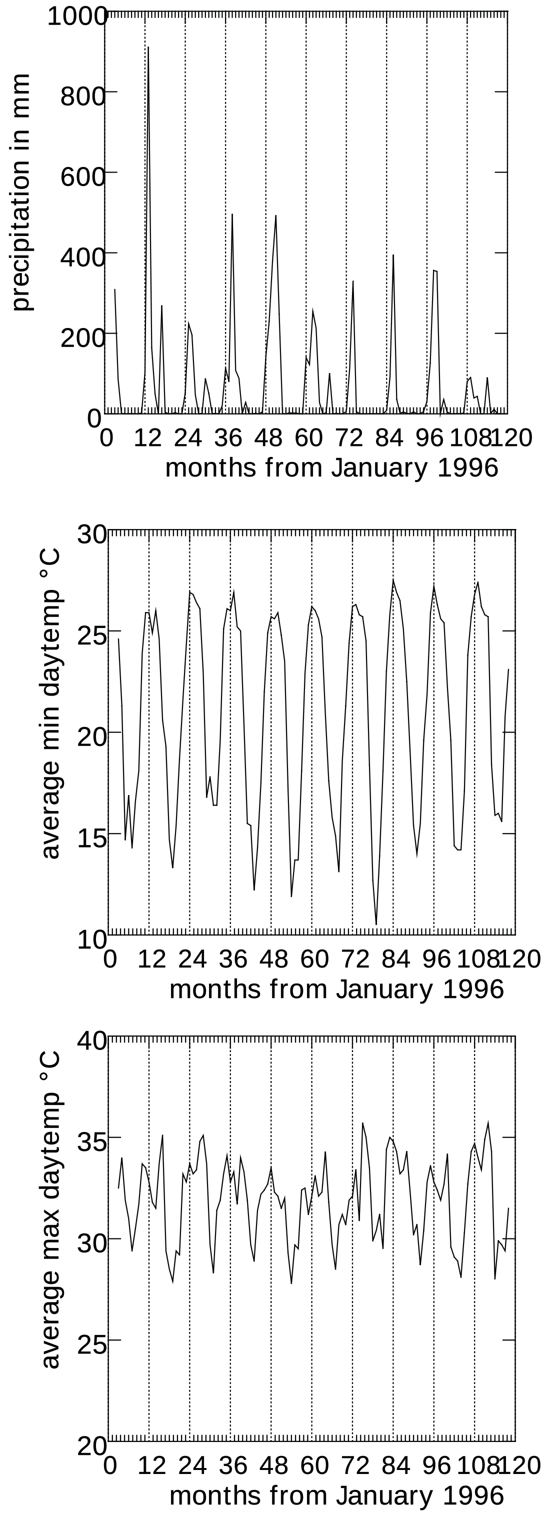


Figure 3. Seasonal patterns of rainfall, average maximum and average minimum temperature at Broome over the entire period of study 1996-2005. The data are presented as monthly sums (mm precipitation) or averages (˚C temperature).

3.2 Overall biodiversity

Table 1. For all different macrozoobenthic taxa that we identified during MONROEB (1996-2005) the numbers are given per station (FP-A, FP-B, OT-A, OT-B) and over all 4 stations (Total sum). FP-A= Fall Point A, FP-B= Fall Point B, OT-A= One Tree A, OT-B= One Tree B. The taxa that could not be identified yet are given in Appendix 1.

Species name	Group	FP-A	FP-B	OT-A	OT-B	Total sum
Nucula cf. *astricta*	Nuculidae	38	18	2		58
Ledella spec.	Nuculanidae	4	1	3		8
Solemya cf. *terraereginae*	Solemyidae	21	42			63
Anadara granosa	Arcidae	1	1	52	58	112
Modiolus micropterus	Mytilidae	3	2			5
Atrina spec.	Pinnidae	1	1			2
Anodontia omissa	Lucinidae	187	453	1		641
Divaricella irpex	Lucinidae	317	233	3	4	557
Ctena "rough"	Lucinidae	161	168			329
Ctena "smooth"	Lucinidae	1	10			11
Montacuta spec.	Galeommatidae	1	3			4
Mysella "curva"	Galeommatidae	21	22		2	45
Pseudophytina macrophthalmensis	?Lasaeidae	55	64	15	35	169
Scintilla spec.	Galeommatidae	42	165	3	1	211
Galeomma spec.	Galeommatidae	19				27
Heterocardia gibbosula	Mactridae		5	44	29	78
Mactra spec. 1	Mactridae	1	1	1		3
Mactra spec ?	Mactridae	1	8	10	10	29
Mactra grandis	Mactridae	3	2	1	2	8
Mactra "brown"	Mactridae			1		1
Mactra "sandattractor"	Mactridae		1	22	26	49
Raeta spec.	Mactridae	3	3			6
Cultellus cultellus	Cultellidae	16	3			19
Siliqua pulchella	Cultellidae	30	19	195	210	454
Tellina capsoides	Tellinidae	1	1	167	153	322
Tellina piratica	Tellinidae	267	221	5	8	501
Tellina inflata	Tellinidae	4	3			7
Tellina amboynensis	Tellinidae	25	11	1	2	39
Tellina "oval"	Tellinidae			2		2
Tellina "pointed"	Tellinidae		1	9	2	12
Tellina cf. *remies*	Tellinidae				2	2
Mud *Tellina*	Tellinidae			1	10	11
Tellina "mysia"	Tellinidae			1	12	13
Tellina "exotica"	Tellinidae	48	59	144	145	396
Tellina "exotica rose"	Tellinidae	11	5			16
Macoma "Roebuck"	Tellinidae				1	1
Gari lessoni	Psammobiidae	5	6		1	12
Solen spec.	Solenidae	1	3		1	5
Anomalocardia squamosa	Veneridae	4	2	1		7
Veneridae spec.	Veneridae	1	2			3
Placamen gravescens	Veneridae		2	2	3	7
Tapes spec.	Veneridae		1			1
Tapes "dirty"	Veneridae	3	1			4
Laternula creccina	Laternulidae	6				6
Stenothyra spec.	Stenothyridae			19	10	29
Vitrinellidae spec.	Vitrinellidae	1				1
Littorina spec.	Littorinidae				1	1
Nerita spec.	Neritidae	2	3		1	6
Epitoniidae spec.	Epitoniidae		3	2	8	13
Cerithidea cingulata	Potamidae	4		1	8	13
Eulimidae spec.	Eulimidae	20	42			62

Species name	Group	FP-A	FP-B	OT-A	OT-B	Total sum
Niso spec.	Eulimidae	1	1			2
Polinices conicus	Naticidae	32	21	3	6	62
Natica "dull colored"	Naticidae	4	8	1		13
Natica "with brown band"	Naticidae				4	4
Columbellidae spec.	Columbellidae	8	6		1	15
Columbellidae "brown"	Columbellidae	2	1		1	4
Nitidella essingtonensis	Columbellidae	3	6	7	2	18
Nassarius dorsatus	Nassariidae	41	36	423	356	856
Nassarius "small Ingrid"	Nassariidae		1	49	32	82
Vexillium radix	Mitridae	35	56	2		93
Mitridae spec.	Mitridae		1			1
Turridae spec.	Turridae	3	9			12
Terebridae spec.	Terebridae	1	5			6
Haminoae "green"	Haminoeidae		7			7
Acteon spec.	Acteonidae	3				3
Retusa spec.	Retusidae	5	1	79	54	139
Salinator cf. *burmana*	Amphibolidae	10		68	52	130
Pyramidellidae spec.	Pyramidellidae	2	1			3
Leucotina spec.	Pyramidellidae		2		3	5
Chrysallida spec.	Chrysallida			6	5	11
Syrnola spec.	Pyramidellidae	8	2	16	7	33
Odostomia spec.	Pyramidellidae	4		1	1	6
Tiberia spec.	Pyramidellidae		1			1
Dentalium spec.	Dentaliidae	25	34	69	39	167
Laevidentalium cf. *lubricatum*	Dentaliidae	78	103	21	30	232
Dentalium cf. *bartonae*	Dentaliidae	2		127	141	270
Cadulus spec.	Dentaliidae		1			1
Chaetopteridae spec.	Chaetopteridae	2455	2550			5005
Oweniidae spec.	Oweniidae	3658	886	16	26	4586
Ostracoda "oval, smooth"	Ostracoda	828	809	14	10	1661
Ostracoda "square, sculptured"	Ostracoda	33	62	1		96
Ostracoda "denticulated"	Ostracoda	71	76	10	5	162
Gammariidae spec.	Amphipoda	32	62	4	1	99
not Gammarus	Amphipoda	19	23			42
Corophium spec.	Amphipoda		50			50
Anthura spec.	Isopoda	23	59		1	83
Tanaidacea spec.	Tanaidacea	299	128			427
Cumacea spec.	Cumacea	34	14		3	51
Mantis Shrimp (Squillidae)	Stomatopoda	11	12	4	4	31
Caridae (shrimp)	Caridea	37	41	22	42	142
shrimp "large"	Caridea		4	1		5
Gourretia coolibas	Caridea	2	1		2	5
Callianassa spec.	Caridea	2	2			4
hermit crab	Anomura	296	213	14	20	543
Dorippe cf. *australiensis*	Dorippidae	5	5			10
Raninidae spec.	Raninidae	1				1
Matuta planipes	Callapidae	15	5			20
cf. *Myrodes eudactylus*	Leucosiidae	9	14	7	2	32
Nursia abbreviata	Leucosiidae	10	4	2	1	17
Ebalia spec.	Leucosiidae	4	1			5
Leucosia spec. D	Leucosiidae	2	6			8
Portunidae spec.	Portunidae	6	5			11
Halicarcinus cf. *australis*	Hymenosomatidae	308	386	2	1	697
Mictyris longicarpus	Mictyridae	5	6	1		12
Pinnotheres cf. *cardii*	Pinnotheridae	3	3	1	3	10
Pilumnidae spec.	Pilumnidae		4	3	2	9
Hairy crab	Pilumnidae	2	3	1		6

Species name	Group	FP-A	FP-B	OT-A	OT-B	Total sum
Hexapus spec.	Goneplacidae	12	17	1	4	34
Macrophthalmus spec.	Macrophthalmidae	259	305	687	640	1891
Uca spec.	Ocypodidae				1	1
Crustacea spec.	Crustacea					128
Edwardsia spec.	Anthozoa	2	6	2	1	11
Shell anemone	Anthozoa			2	1	3
Pycnogonida spec.	Pycnogonida	4	6			10
Lingula spec.	Brachiopoda	113	83	2		198
Amphiura (Ophiopeltis) tenuis	Ophiuroidea	2657	2651	6	8	5322
Astropecten granulatus	Asteroidea	113	10			123
Peronella tuberculata	Echinoidea	1	1			2
Holothuroidea spec.	Holothuroidea	2	3			5
Leptopentacta grisea	Holothuroidea	1	5			6
Holothuria A	Holothuroidea	5	15	1	1	22
Stolus buccalis	Holothuroidea	2				2
Rooted Tunicate	Tunicata		46			46
Sandy Colonial Tunicate	Tunicata	52	751			803
Mudskipper (Periophthalmidae)	Pisces	14	9	114	133	270
Fish (Gobiidae)	Pisces	4	28	25	69	132

Table 2. For all different macrozoobenthic taxa that we identified during MONROEB the numbers are given per station. FP-1 = Fall Point-A+B in period 1 (1996-2001), FP-2 = Fall Point- A+B in period 2 (2001-2005), OT-1 = One Tree A+B in period 1, OT-2 = One Tree A+B in period 2. The taxa that could not be identified yet are given in Appendix II.

Species name	Group	FP-1	FP-2	OT-1	OT-2	Total Sum
Nucula cf. *astricta*	Nuculidae	54	2	2		58
Ledella spec.	Nuculanidae	5		3		8
Solemya cf. *terraereginae*	Solemyidae	38	25			63
Anadara granosa	Arcidae	1	1	86	24	112
Modiolus micropterus	Mytilidae	3	2			5
Atrina spec.	Pinnidae	1	1			2
Anodontia omissa	Lucinidae	577	63	1		641
Divaricella irpex	Lucinidae	478	72	5	2	557
Ctena "rough"	Lucinidae	106	223			329
Ctena "smooth"	Lucinidae	1	10			11
Montacuta spec.	Galeommatidae	3	1			4
Mysella "curva"	Galeommatidae	4	39		2	45
Pseudophytina macrophthalmensis	?Lasaeidae	12	107	10	40	169
Scintilla spec.	Galeommatidae	24	183	2	2	211
Galeomma spec.	Galeommatidae	27				27
Heterocardia gibbosula	Mactridae	3	2	35	38	78
Mactra spec. 1	Mactridae	1	1		1	3
Mactra spec ?	Mactridae	5	4	11	9	29
Mactra grandis	Mactridae	4	1	1	2	8
Mactra "brown"	Mactridae				1	1
Mactra "sandattractor"	Mactridae		1		48	49
Raeta spec.	Mactridae	6				6
Cultellus cultellus	Cultellidae	17	2			19
Siliqua pulchella	Cultellidae	26	23	270	135	454
Tellina capsoides	Tellinidae		2	277	43	322
Tellina piratica	Tellinidae	420	68	12	1	501
Tellina inflate	Tellinidae	5	2			7
Tellina amboynensis	Tellinidae	20	16	3		39
Tellina oval	Tellinidae			1	1	2
Tellina pointed	Tellinidae		1	7	4	12
Tellina cf. *remies*	Tellinidae			1	1	2
Mud *Tellina*	Tellinidae			10	1	11
Tellina "mysia"	Tellinidae			13		13
Tellina "exotica"	Tellinidae	85	22	224	65	396
Tellina "exotica rose"	Tellinidae	16				16
Macoma "Roebuck"	Tellinidae				1	1
Gari lessoni	Psammobiidae	5	6	1		12
Solen spec.	Solenidae	3	1	1		5
Anomalocardia squamosa	Veneridae	6		1		7
Veneridae spec.	Veneridae	3				3
Placamen gravescens	Veneridae	2			5	7
Tapes spec.	Veneridae	1				1
Tapes "dirty"	Veneridae	4				4
Laternula creccina	Laternulidae	6				6
Stenothyra spec.	Stenothyridae			7	22	29
Vitrinellidae spec.	Vitrinellidae	1				1
Littorina spec.	Littorinidae				1	1
Nerita spec.	Neritidae	4	1		1	6
Epitoniidae spec.	Epitoniidae	3		10		13
Cerithidea cingulata	Potamidae	1	3	8	1	13
Eulimidae spec.	Eulimidae	59	3			62
Niso spec.	Eulimidae		2			2

Species name	Group	FP-1	FP-2	OT-1	OT-2	Total Sum
Polinices conicus	Naticidae	31	22	9		62
Natica “dull colored”	Naticidae	4	8		1	13
Natica “with brown band”	Naticidae			4		4
Columbellidae spec.	Columbellidae		14	1		15
Columbellidae “brown”	Columbellidae		3		1	4
Nitidella essingtonensis	Columbellidae	3	6	9		18
Nassarius dorsatus	Nassariidae	35	42	685	94	856
Nassarius “small Ingrid”	Nassariidae	1		40	41	82
Vexillium radix	Mitridae	87	4		2	93
Mitridae spec.	Mitridae		1			1
Turridae spec.	Turridae	6	6			12
Terebridae spec.	Terebridae	2	4			6
Haminoae “green”	Haminoeidae	7				7
Acteon spec.	Acteonidae	1	2			3
Retusa spec.	Retusidae	5	1	80	53	139
Salinator cf. *burmana*	Amphibolidae	1	9	56	64	130
Pyramidellidae spec.	Pyramidellidae	3				3
Leucotina spec.	Pyramidellidae	1	1	3		5
Chrysallida spec.	Chrysallida			11		11
Syrnola spec.	Pyramidellidae	5	5		23	33
Odostomia spec.	Pyramidellidae	1	3		2	6
Tiberia spec.	Pyramidellidae	1				1
Dentalium spec.	Dentaliidae	59		106		165
Laevidentalium cf. *lubricatum*	Dentaliidae	133	48	36	15	232
Dentalium cf. *bartonae*	Dentaliidae	2		253	15	270
Cadulus spec.	Dentaliidae		1			1
Chaetopteridae spec.	Chaetopteridae	4874	131			5005
Oweniidae spec.	Oweniidae	4129	415	42		4586
Ostracoda “oval, smooth”	Ostracoda	1052	585	17	7	1661
Ostracoda “square, sculptured”	Ostracoda	87	8		1	96
Ostracoda “denticulated”	Ostracoda	122	25	3	12	162
Gammariidae spec.	Amphipoda	52	42	4	1	99
not Gammarus	Amphipoda		42			42
Corophium spec.	Amphipoda		50			50
Anthura spec.	Isopoda	16	66		1	83
Tanaidacea spec.	Tanaidacea	56	371			427
Cumacea spec.	Cumacea	1	47	2	1	51
Mantis Shrimp (Squillidae)	Stomatopoda	14	9	4	4	31
Caridae (shrimp)	Caridea	34	44	48	16	142
shrimp “large”	Caridea		4		1	5
Gourretia coolibas	Caridea	3		2		5
Callianassa spec.	Caridea	2	2			4
hermit crab	Anomura	151	358	30	4	543
Dorippe cf. *australiensis*	Dorippidae	8	2			10
Raninidae spec.	Raninidae	1				1
Matuta planipes	Callapidae	13	7			20
cf. *Myrodes eudactylus*	Leucosiidae	17	6	5	4	32
Nursia abbreviata	Leucosiidae	10	4	3		17
Ebalia spec.	Leucosiidae	3	2			5
Leucosia spec. D	Leucosiidae	2	6			8
Portunidae spec.	Portunidae	9	2			11
Halicarcinus cf. *australis*	Hymenosomatidae	562	132	3		697
Mictyris longicarpus	Mictyridae	10	1	1		12
Pinnotheres cf. *cardii*	Pinnotheridae	5	1	4		10
Pilumnidae spec.	Pilumnidae		4	2	3	9
Hairy crab	Pilumnidae	5		1		6
Hexapus spec.	Goneplacidae	24	5	5		34

Species name	Group	FP-1	FP-2	OT-1	OT-2	Total Sum
Macrophthalmus spec.	Macrophthalmidae	384	180	479	848	1891
Uca spec.	Ocypodidae			1		1
Crustacea spec.	Crustacea		128			128
Edwardsia spec.	Anthozoa	6	2	3		11
Shell anemone	Anthozoa			3		3
Pycnogonida spec.	Pycnogonida	10				10
Lingula spec.	Brachiopoda	185	11	1	1	198
Amphiura (Ophiopeltis) tenuis	Ophiuroidea	3514	1794	12	2	5322
Astropecten granulatus	Asteroidea	90	33			123
Peronella tuberculata	Echinoidea	2				2
Holothuroidea spec.	Holothuroidea	2	3			5
Leptopentacta grisea	Holothuroidea	6				
Holothuria A	Holothuroidea	7	13	2		22
Stolus buccalis	Holothuroidea	2				2
Rooted Tunicate	Tunicata	46				46
Sandy Colonial Tunicate	Tunicata	803				803
Mudskipper (Periophthalmidae)	Pisces	17	6	115	132	270
Fish (Gobiidae)	Pisces	32	6	70	24	132

Not many new taxa were found in the samples of the second period from June 2001 to October 2005 compared to the first period, March 1996 to May 2001. We found lower numbers of most species in the second period. A few 'new' species were found and a few species increased. A total of 139 different taxa were encountered in the first period, against 144 in the second. In the first period 23,000 animals were retrieved from the core-samples taken at the One Tree and Fall Point stations and 29,529 in the second period (Table 2). The taxon list included 40 and 45 different bivalves, 26 and 30gastropods, 2 and 3 scaphopods in the first respectively second period and 7 echinoderms, and 17 crabs in both periods. The distribution over the stations was the same as in the first period: the total number of macro-zoobenthic species was much higher in the sands off Fall Point than in the blue muds off One Tree (Fig. 4), and this was true also for the diversity of bivalves, gastropods and crabs. It is also clear that there are hardly any differences between the relatively nearshore station and the one further off, at both sites the station offshore accumulated a few more species (Fig. 4)

In both periods the most common bivalve species at the Fall Point stations were *Anodontia omissa*, *Divaricella irpex*, *Ctena* "rough" and *Tellina piratica* (Table 1 and 2). And in both periods the most common bivalves at the One Tree stations were *Siliqua pulchella*, *Tellina capsoides* and *Tellina* "*exotica*". A few bivalves that were not abundant at all in the first period were found in relatively high numbers in the second period. *Pseudophytina macrophthalmensis*, a tiny bivalve that lives on the legs of the sentinel crab *Macrophthalmus* spec., increased from 12 to 107 at Fall Point and from 10 to 40 at One Tree. *Macrophthalmus* spec. is the only species that was common in the first period and increased in numbers in the second period (from 873 to 1891). However the high increase in numbers of the crab was at One Tree, while the highest numbers of the bivalve were found at Fall Point. *Scintilla* spec., another tiny bivalve increased spectacular from 24 to 183 at Fall Point. *Mactra* "sandattractor", a new species for the second period, was almost only found at One Tree.

The most common gastropod in both periods was the scavenger *Nassarius dorsatus*. However *Nassarius* was found in much lower numbers in the second period. The tiny gastropod *Stenothyra* spec. that under the microscope resembles a tiny elephant (according to some identifiers) increased threefold at One Tree. A small Collumbellidae increased at Fall Point. *Salinator* cf. *burmana*, the mangrove moonsnail, increased at both sites and *Syrnola* spec. increased at One Tree (from 0 to 23). From all other taxa, at Fall Point two Amphipoda appeared in the second period, Tanaidacea spec. increased 6-fold, Cumacea spec. 50 fold and hermit crabs twofold. High numbers of the "spider crab" *Halicarcinus* cf. *australis* were found at Fall Point in the first period but much lower numbers in the second. As mentioned before *Macrophthalmus* spec. at One Tree increased. Mudskippers increased a little at One Tree, but almost disappeared from Fall Point.

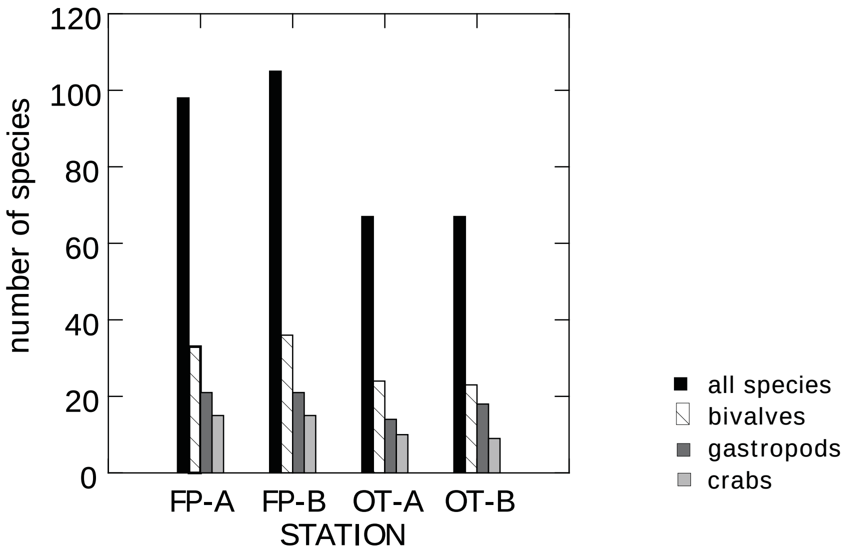


Figure 4.
Total number of taxa (here called all species) encountered during the MONROEB sampling and sorting efforts between 1996 and 2005, with separate columns for respectively bivalves, gastropods and crabs.

3.3 Seasonal changes in abundance

In the next series of figures (Fig. 5 to 19) we present the seasonal changes in the average densities (per m^2) over all four stations of 15 numerically dominant taxa, most of which are bivalves. Densities are plotted as date-specific averages over time, through which a line (excel-moving-average, period 2) was fitted to lead the eye in our search for evidence for seasonal cyclicity. We corrected for the sampling effort and missing samples as described in the methods and Appendix I.

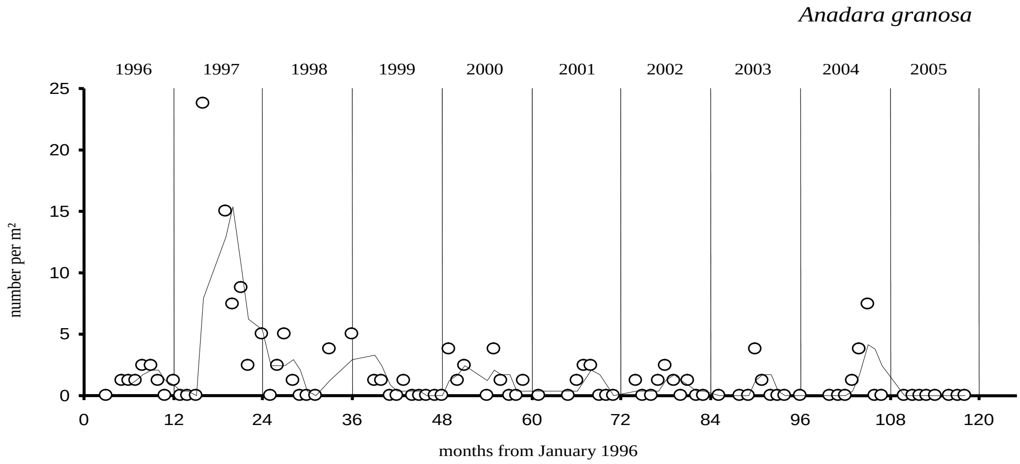


Figure 5. Changes in average density of *Anadara granosa* from March 1996 to Nov 2005.

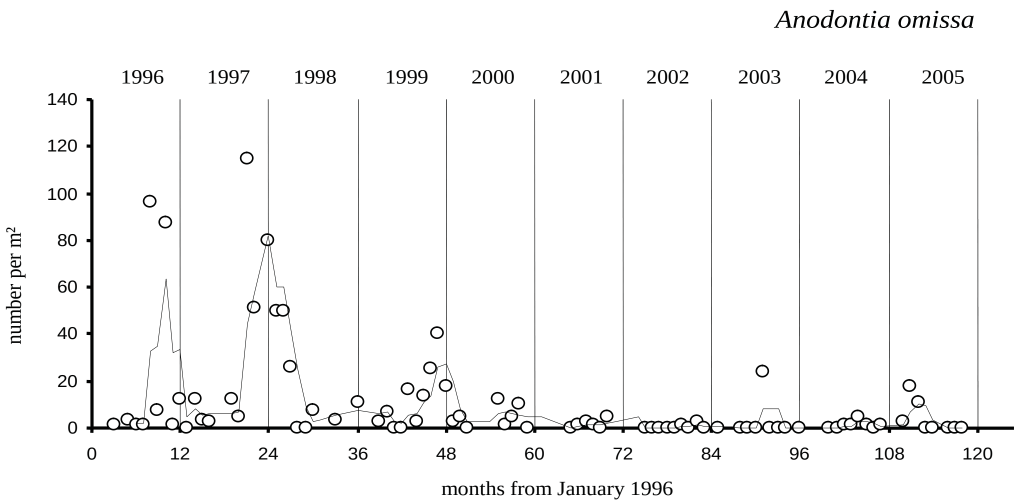


Figure 6. Changes in average density of *Anodontia omissa* from March 1996 to Nov 2005.

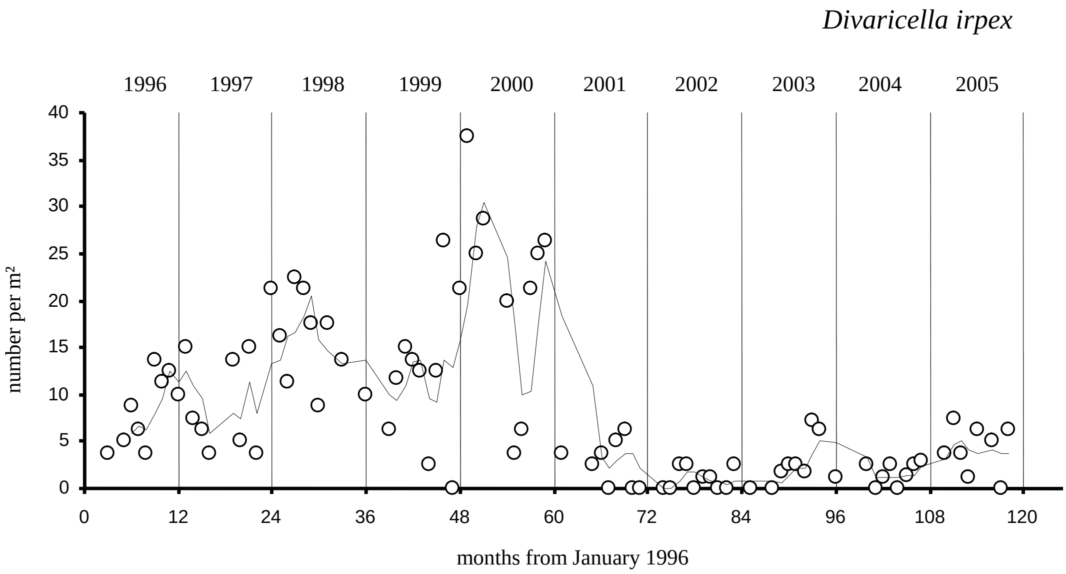


Figure 7. Changes in average density of *Divaricella irpex* from March 1996 to Nov 2005.

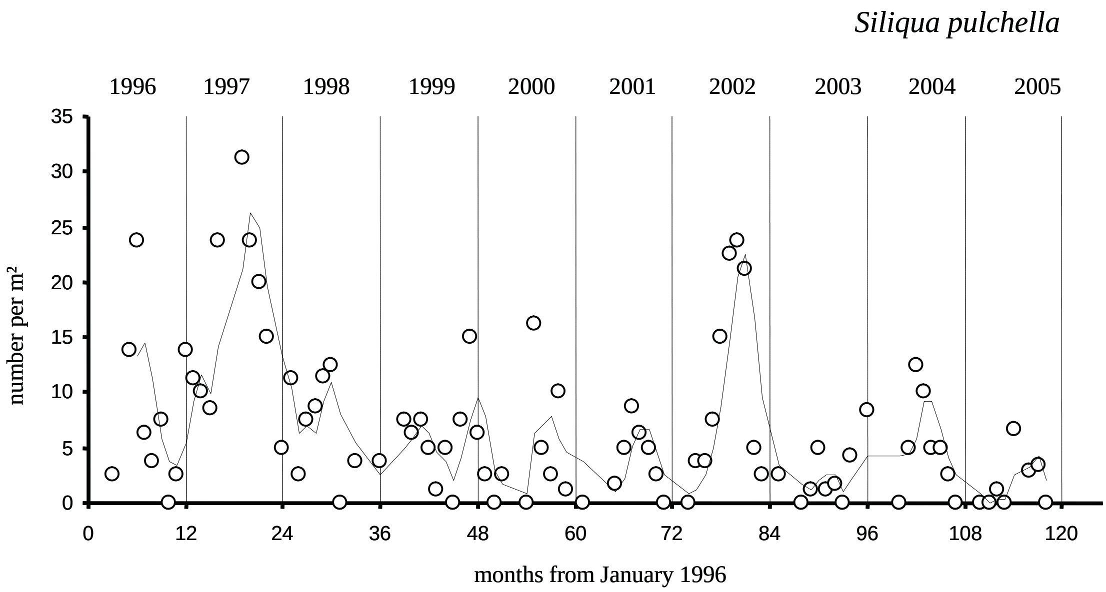


Figure 8. Changes in average density of *Siliqua pulchella* from March 1996 to Nov 2005.

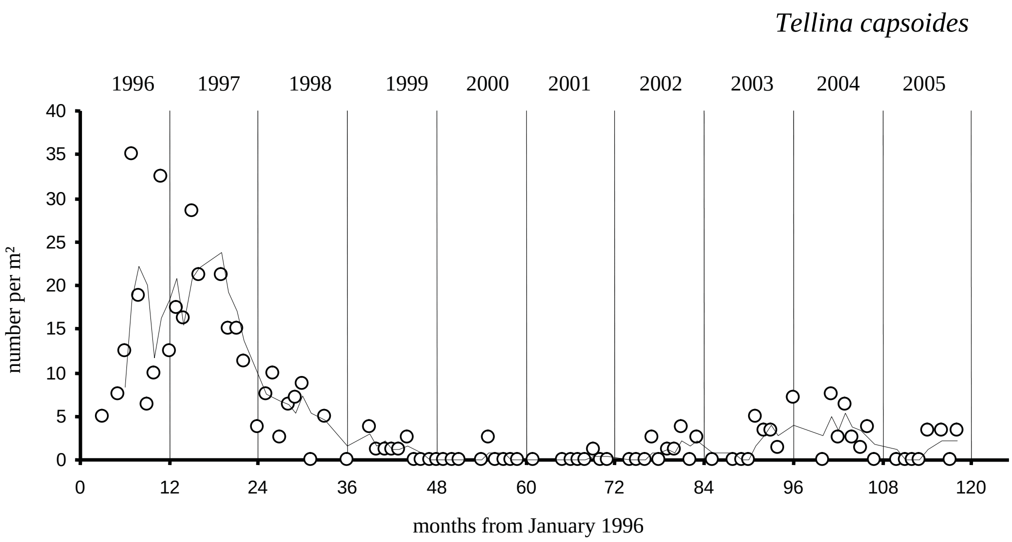


Figure 9. Changes in average density of *Tellina capsoides* from March 1996 to Nov 2005.

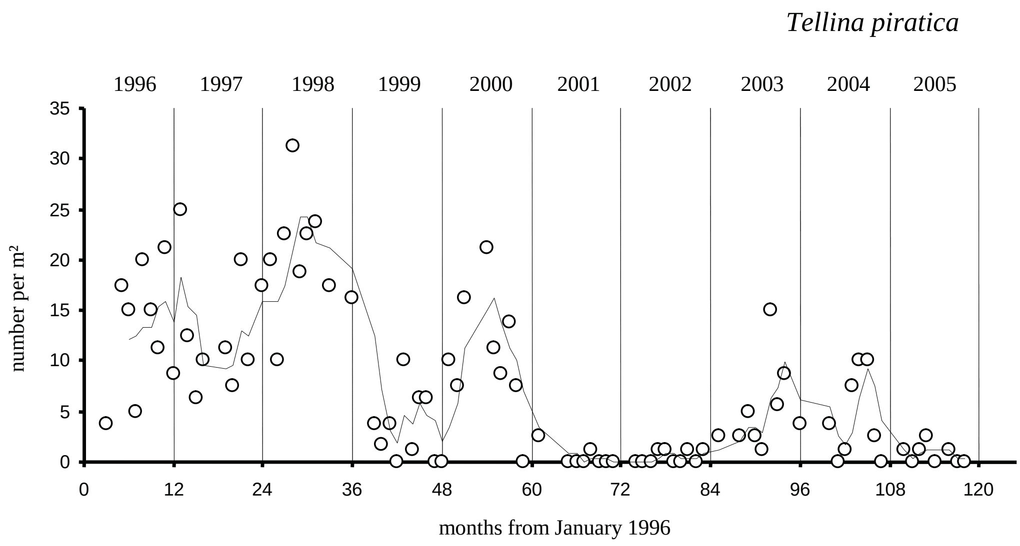


Figure 10. Changes in average density of *Tellina piratica* from March 1996 to Nov 2005.

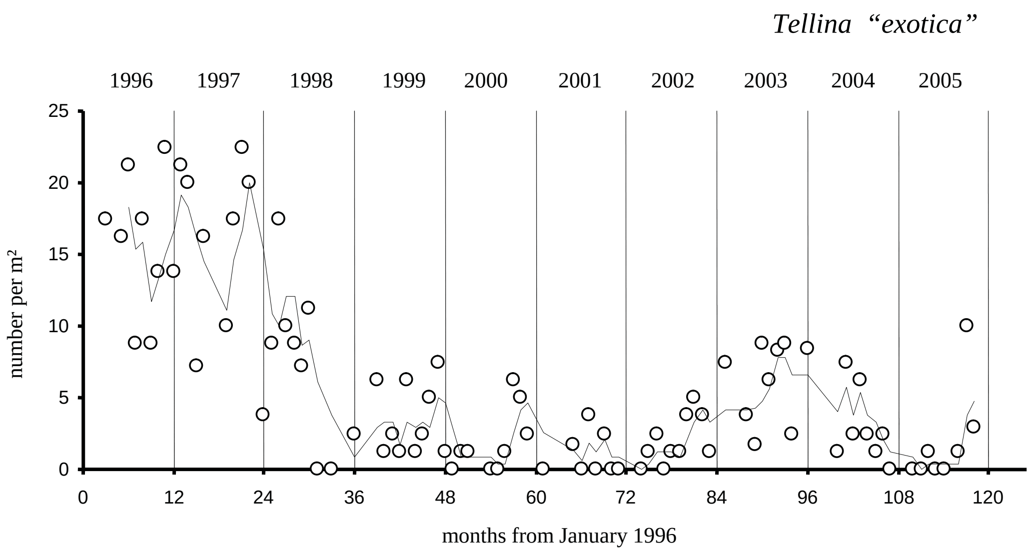


Figure 11. Changes in average density of *Tellina "exotica"* from March 1996 to Nov 2005.

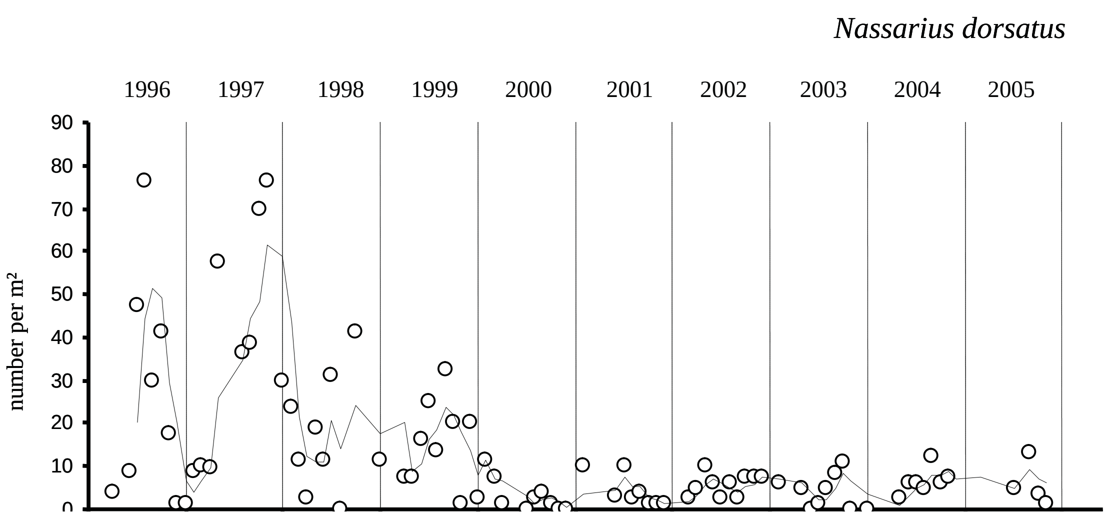


Figure 12. Changes in average density of *Nassarius dorsatus* from March 1996 to Nov 2005.

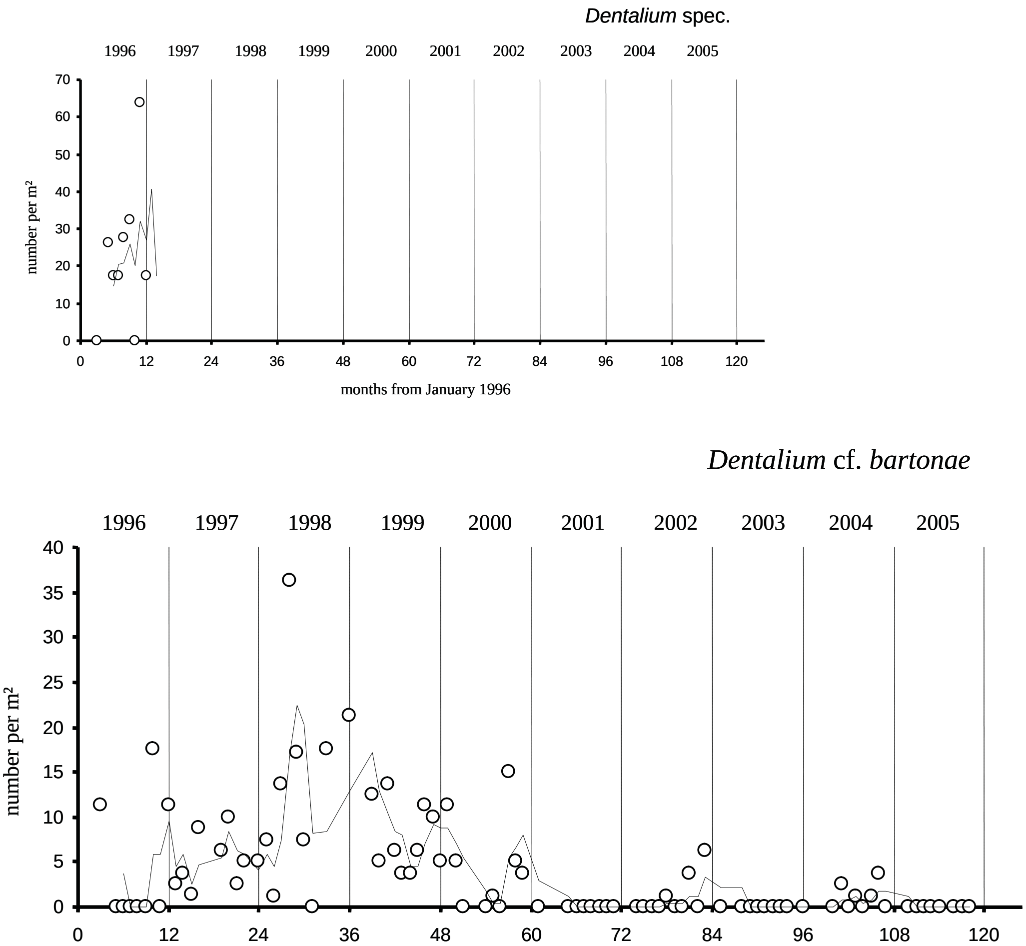


Figure 13. Changes in average density of *Dentalium* spec. and *Dentalium* cf. *bartonae* from March 1996 to Nov 2005. In the first year in some months no distinction was made between *Dentalium* cf. *bartonae* or *Laevidentalium* cf. *lubricatum*: all scaphopods were called *Dentalium* spec.

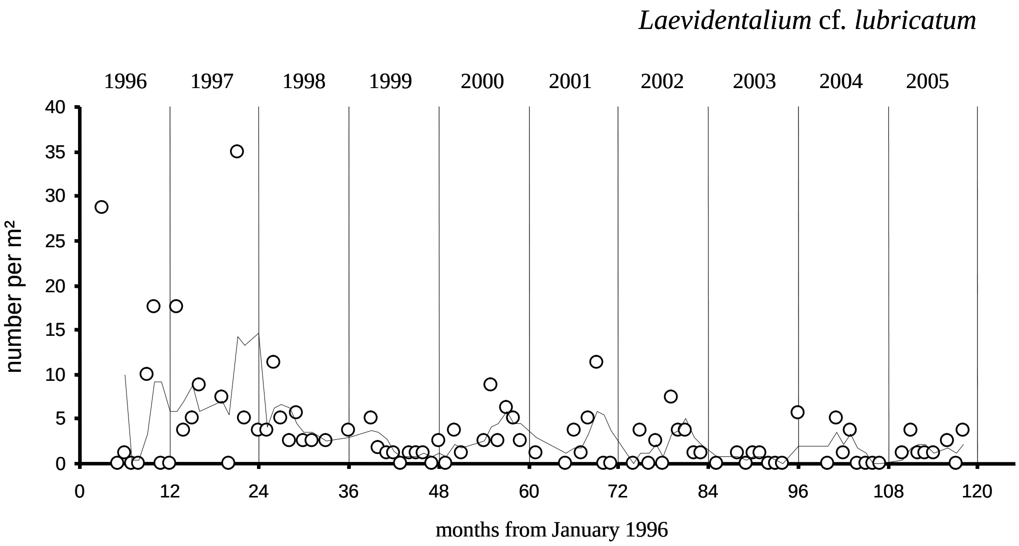


Figure 14. Changes in average density of *Laevidentalium* cf. *lubricatum* from March 1996 to Nov 2005.

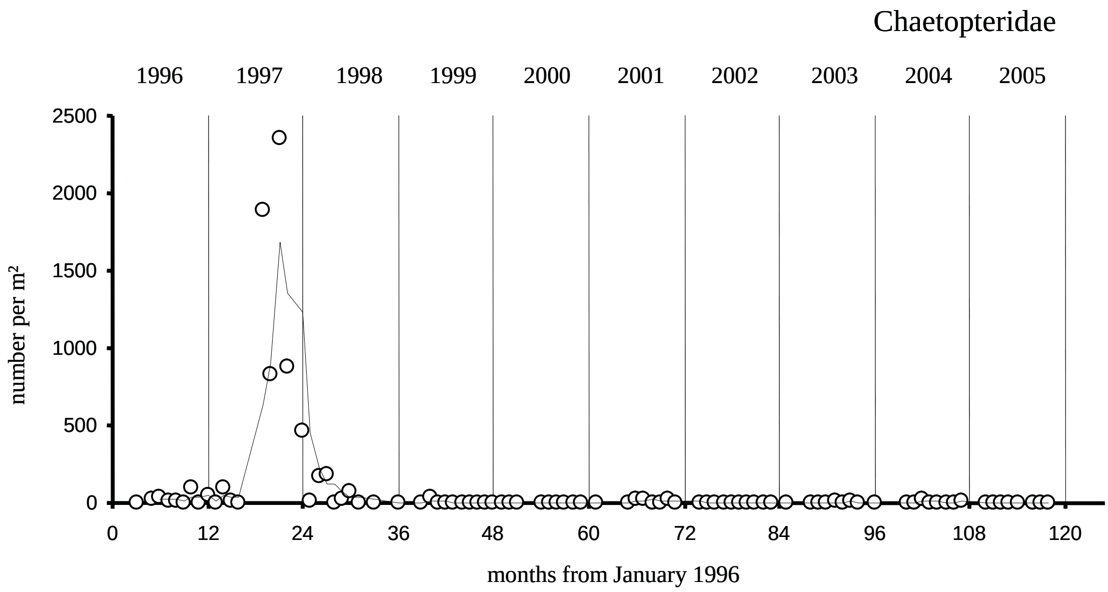


Figure 15a. Changes in average density of Chaetopteridae from March 1996 to Nov 2005.

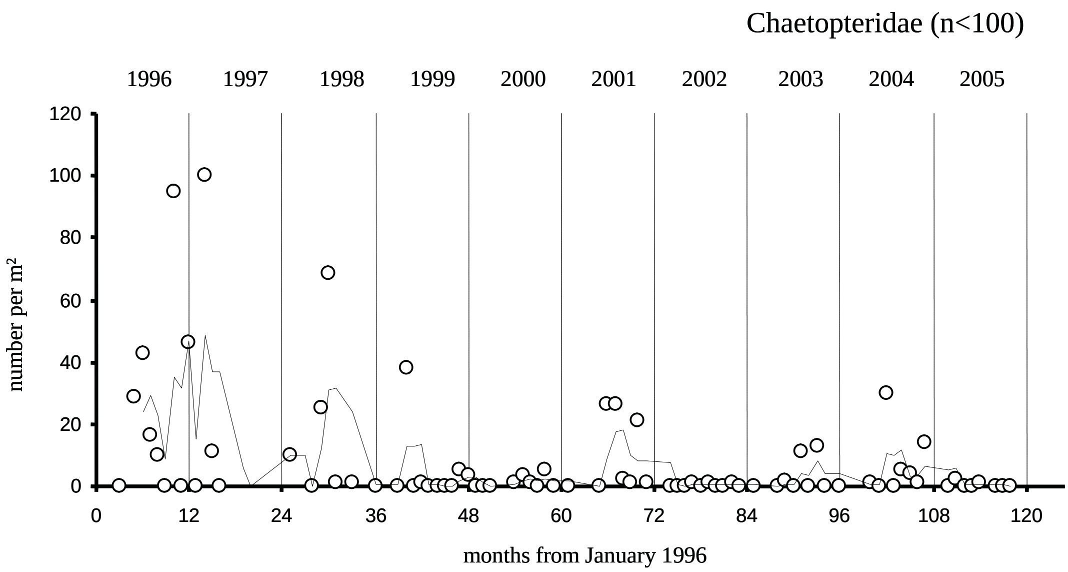


Figure 15b. Changes in average density of Chaetopteridae from March 1996 to Nov 2005, without the densities higher than 100 per m².

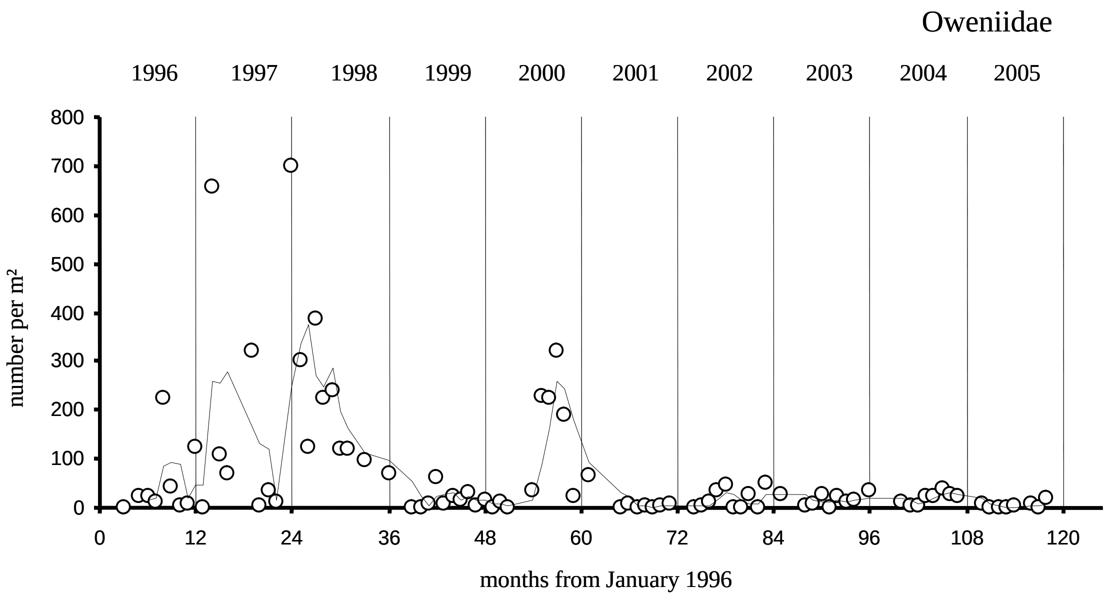


Figure 16a. Changes in average density of Oweniidae from March 1996 to Nov 2005.

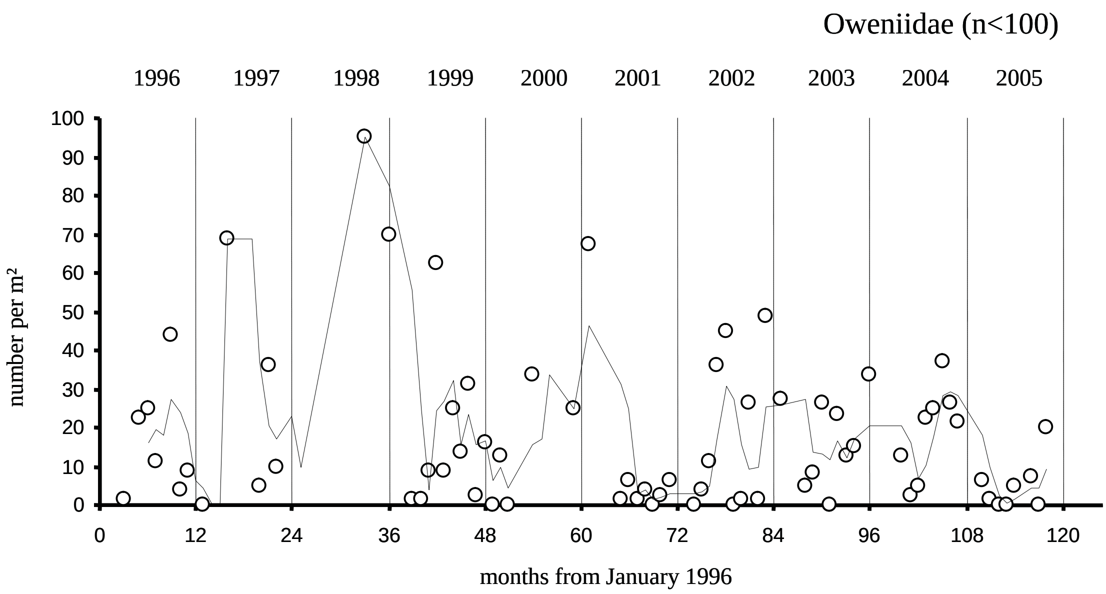


Figure 16b. Changes in average density of Oweniidae from March 1996 to Nov 2005, without the densities higher than 100 per m².

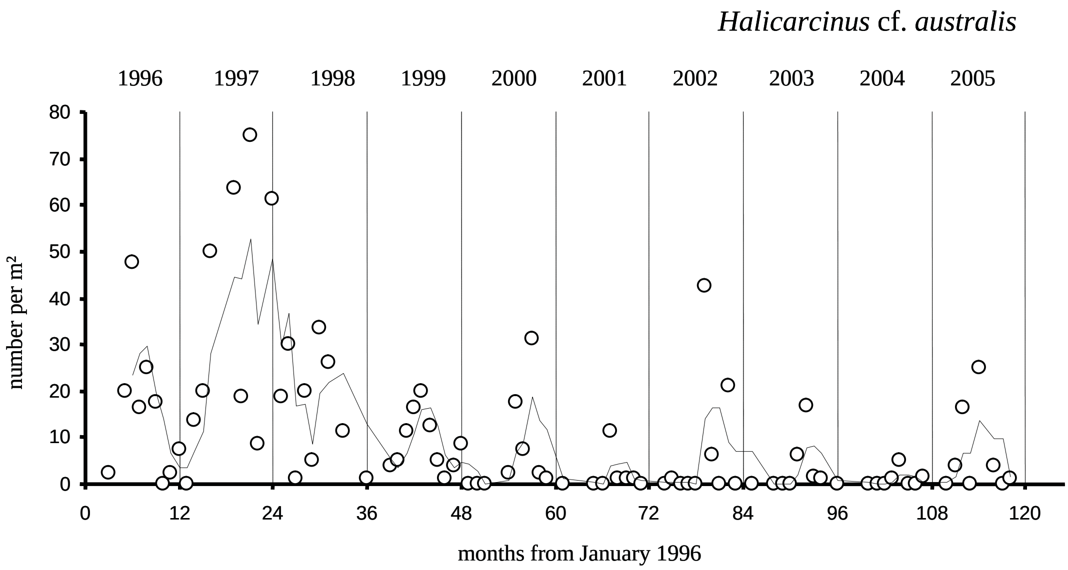


Figure 17. Changes in average density of *Halicarcinus* cf. *australis* from March 1996 to Nov 2005.

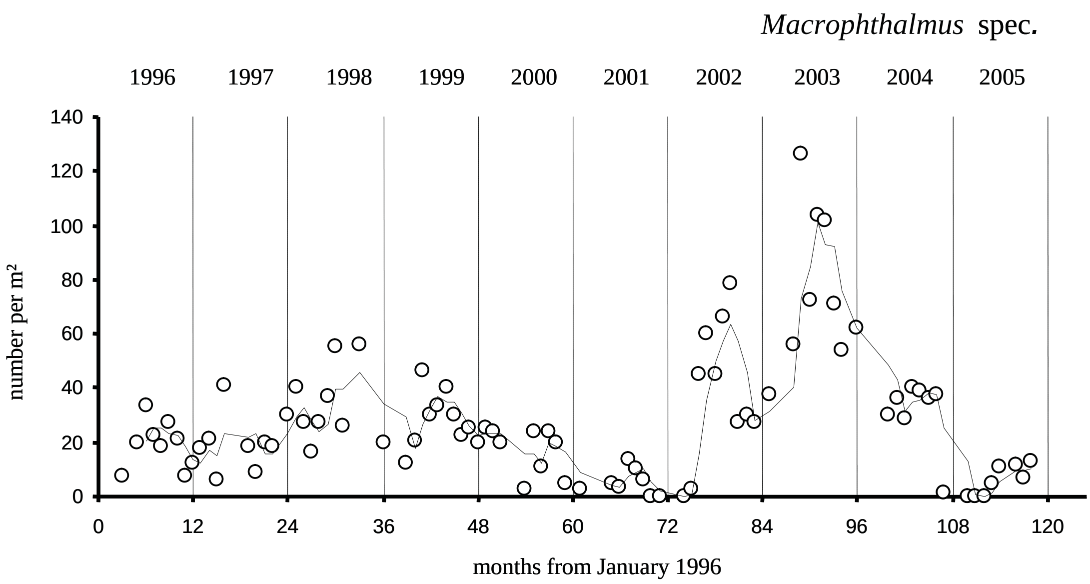


Figure 18. Changes in average density of *Macrophthalmus* spec. from March 1996 - Nov 2005.

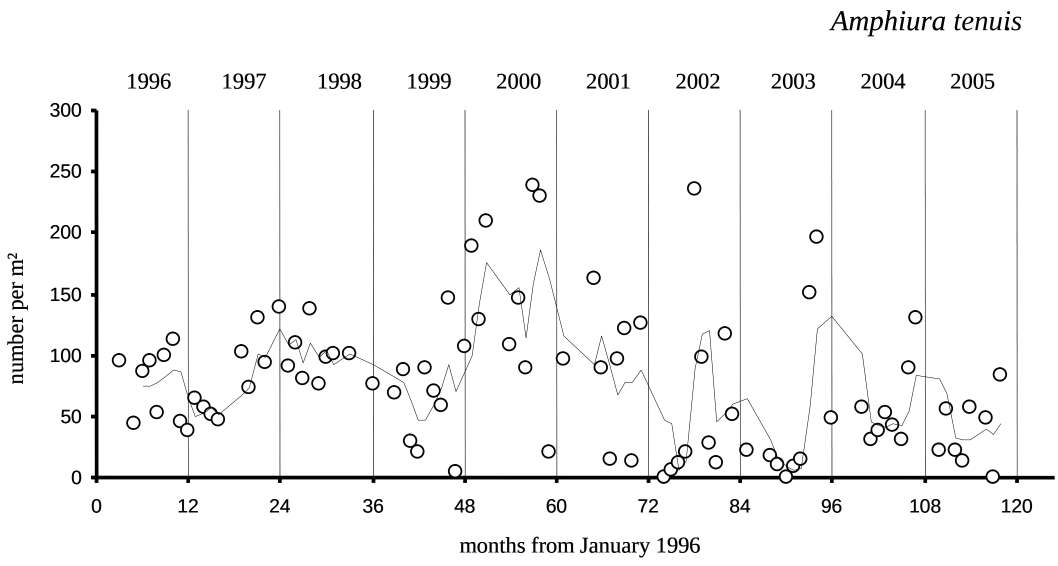


Figure 19. Changes in average density of *Amphiura tenuis* from March 1996 to Nov 2005.

3.4 Size frequencies and recruitment patterns

In Figure 20 to 27 we show the size frequency distributions of 8 species that were present in relative high densities. At a certain value in the size distribution we made a cut off (somewhat arbitrary) to examine if any differences in numerical abundance of the smallest and larger animals in the population exist. These data presented in Figure 28 to 36 might tell us when settlement took place and whether these settlement patterns bear any resemblance to seasonal (climatic) factors.

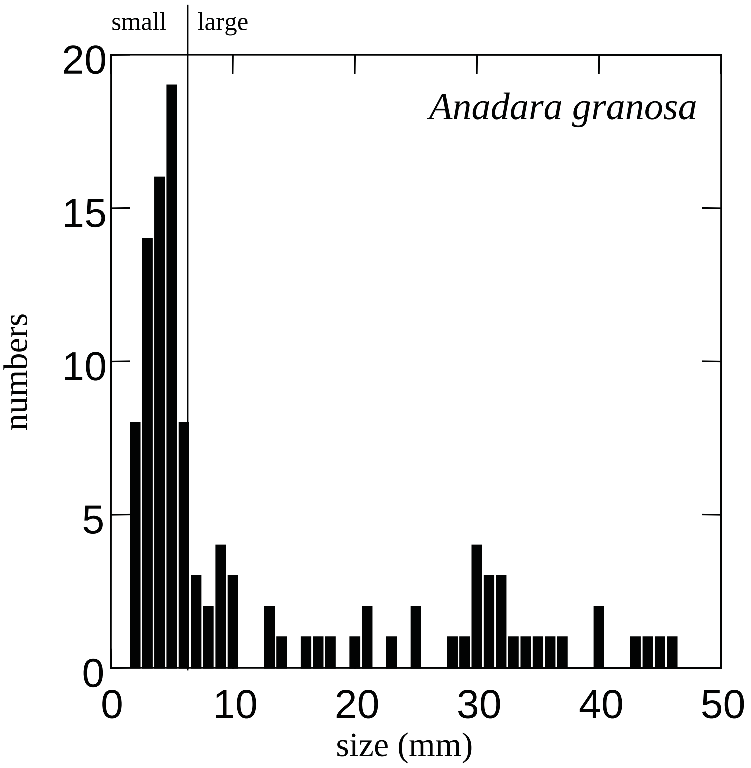


Figure 20. Size-frequency distribution of *Anadara granosa* on the basis of animals found in the monitoring samples between 1996 and 2005.

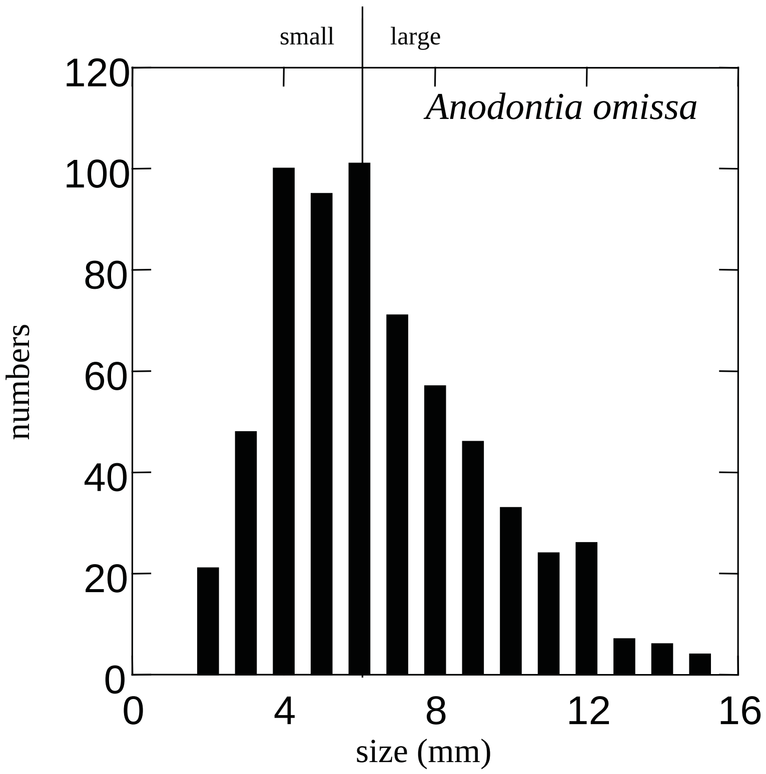


Figure 21. Size-frequency distribution of *Anodontia omissa* on the basis of animals found in the monitoring samples between 1996 and 2005.

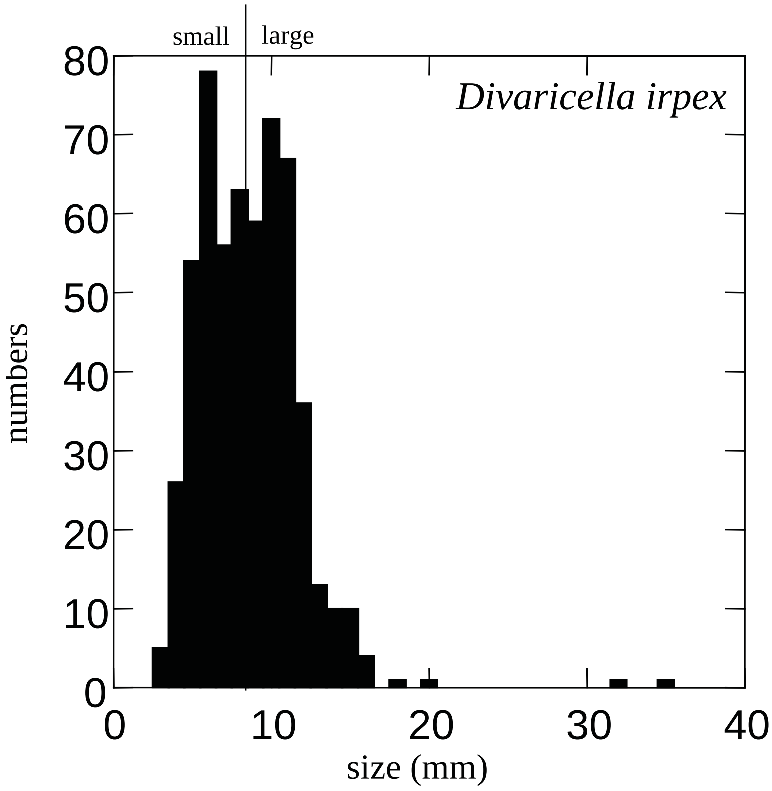


Figure 22. Size-frequency distribution of *Divaricella irpex* on the basis of animals found in the monitoring samples between 1996 and 2005.

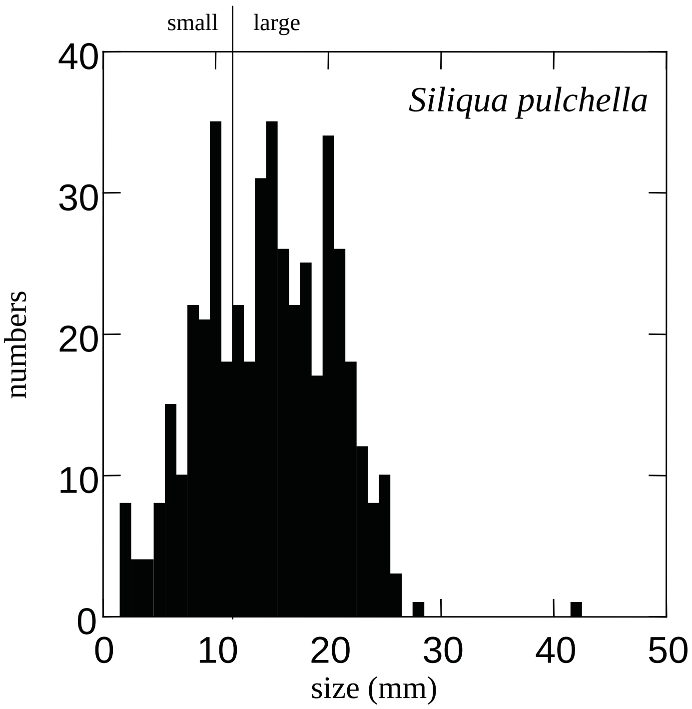


Figure 23. Size-frequency distribution of *Siliqua pulchella* on the basis of animals found in the monitoring samples between 1996 and 2005.

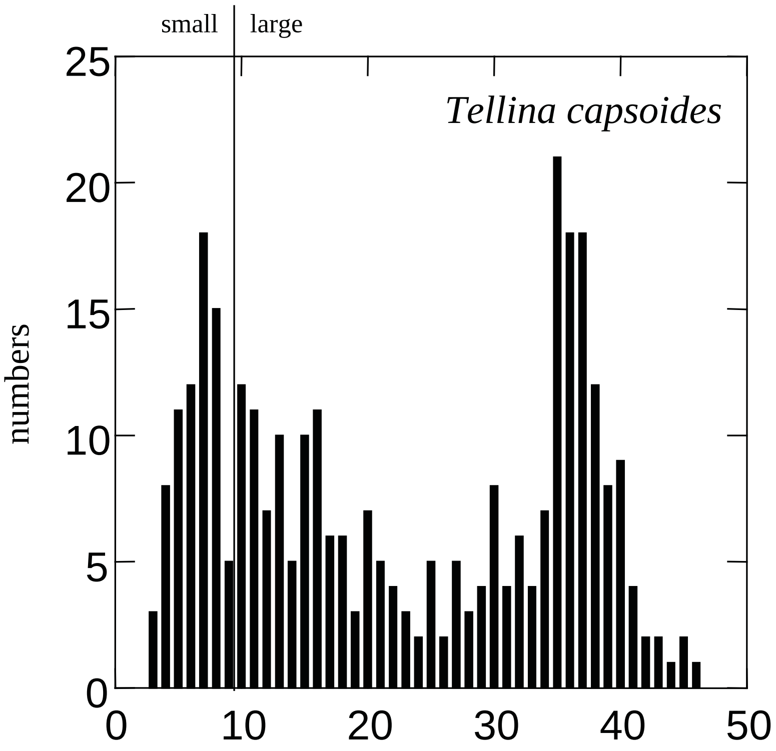


Figure 24. Size-frequency distribution of *Tellina capsoides* on the basis of animals found in the monitoring samples between 1996 and 2005.

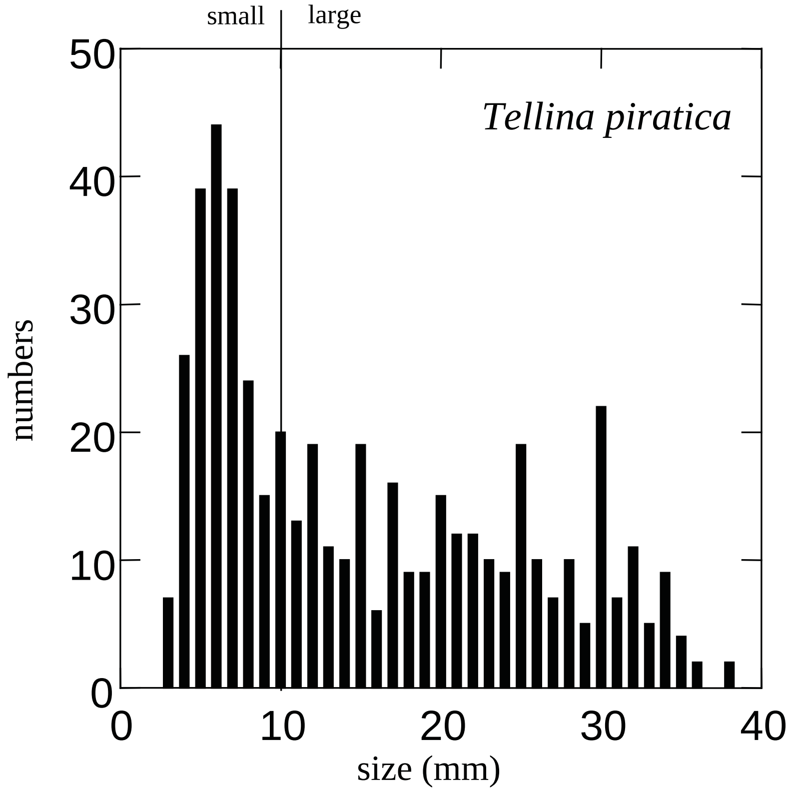


Figure 25. Size-frequency distribution of *Tellina piratica* on the basis of animals found in the monitoring samples between 1996 and 2005.

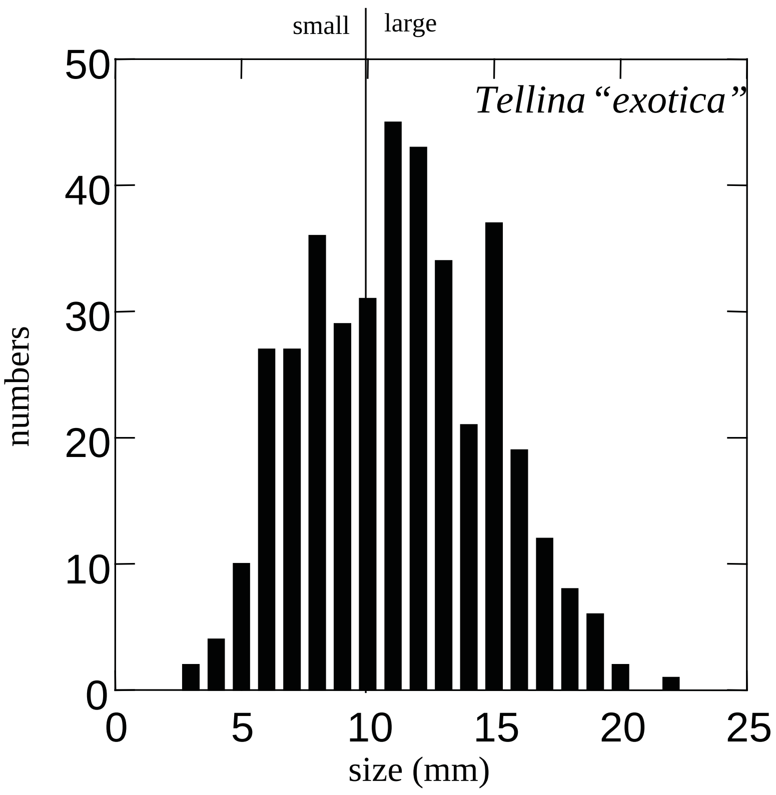


Figure 26. Size-frequency distribution of *Tellina* "exotica" on the basis of animals found in the monitoring samples between 1996 and 2005.

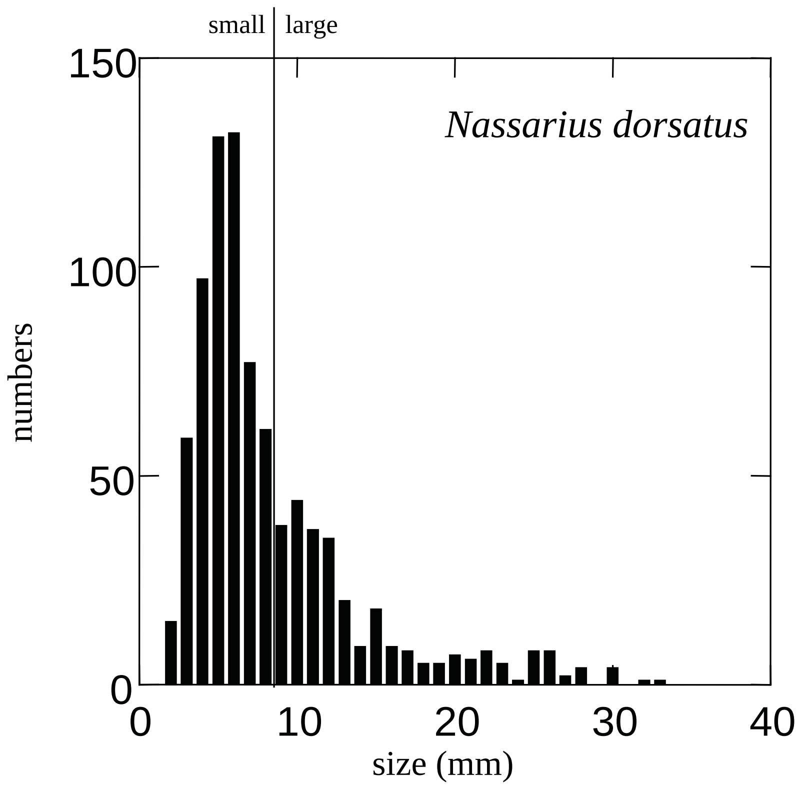


Figure 27. Size-frequency distribution of *Nassarius dorsatus* on the basis of animals found in the monitoring samples between 1996 and 2005.

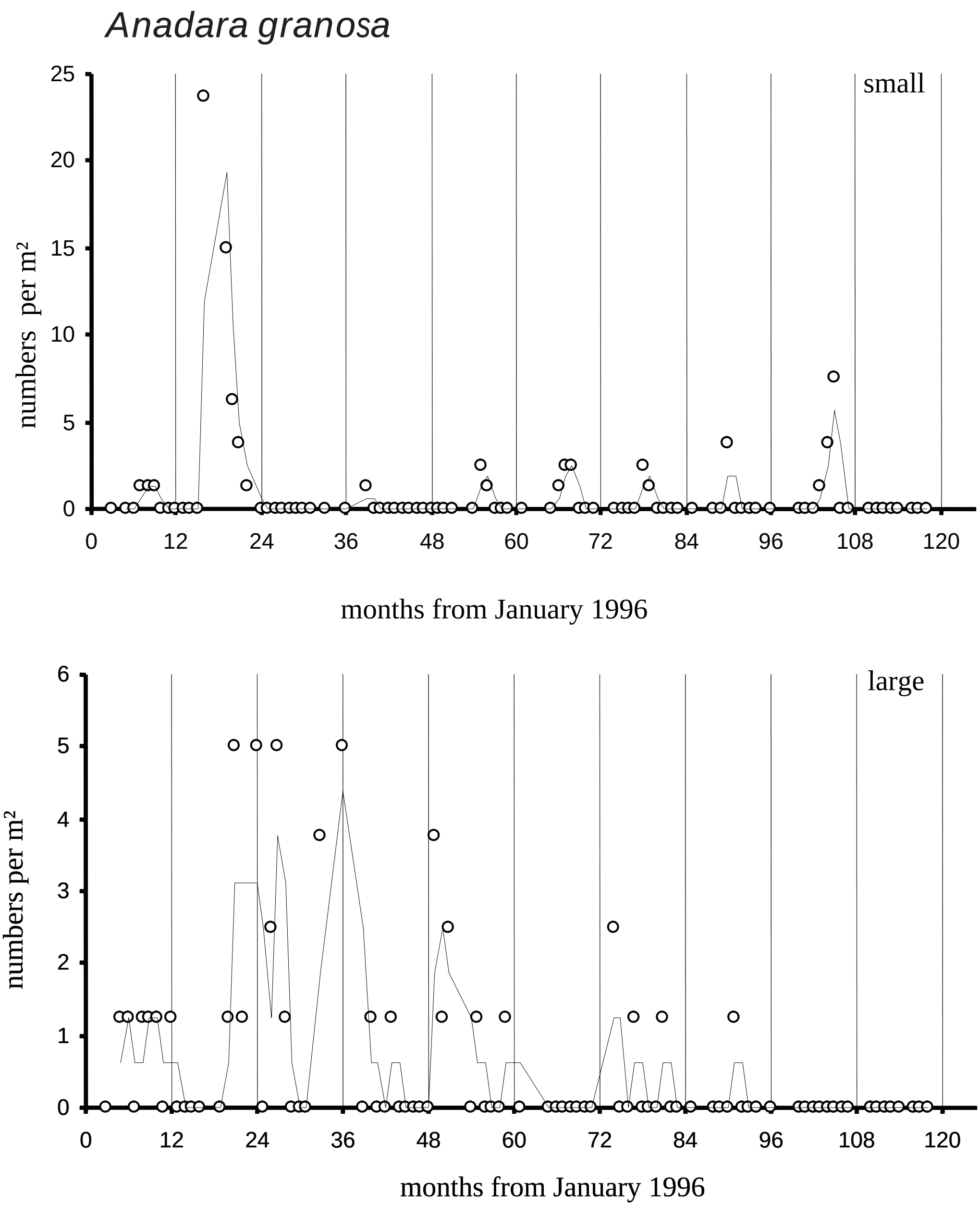


Figure 28. Changes in the densities of small and large *Anadara granosa* (as based on the size-frequency distribution of Fig. 20) from early 1996 to late 2005.

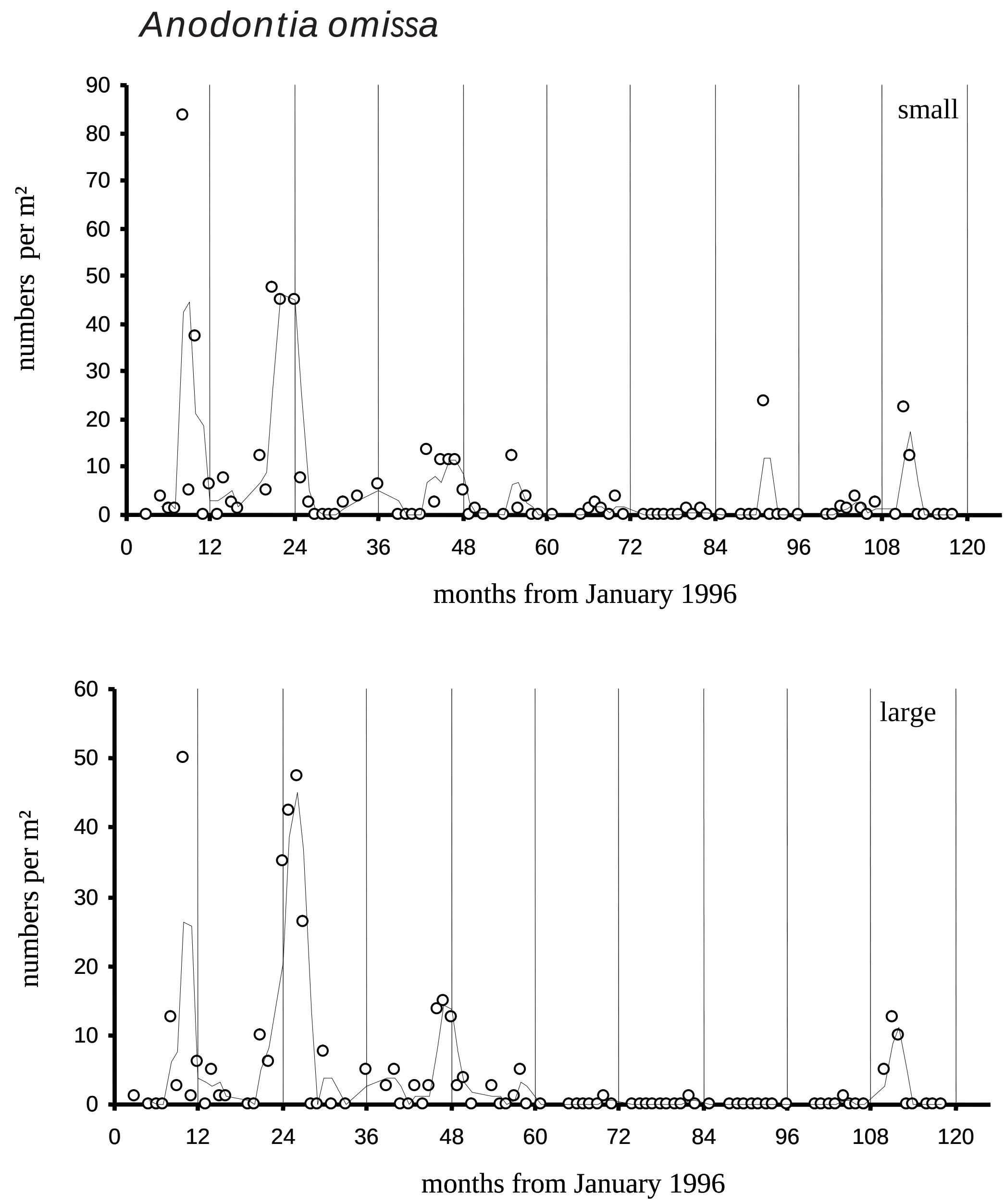


Figure 29. Changes in the densities of small and large *Anodontia omissa* (as based on the size-frequency distribution of Fig. 21) from early 1996 to late 2005.

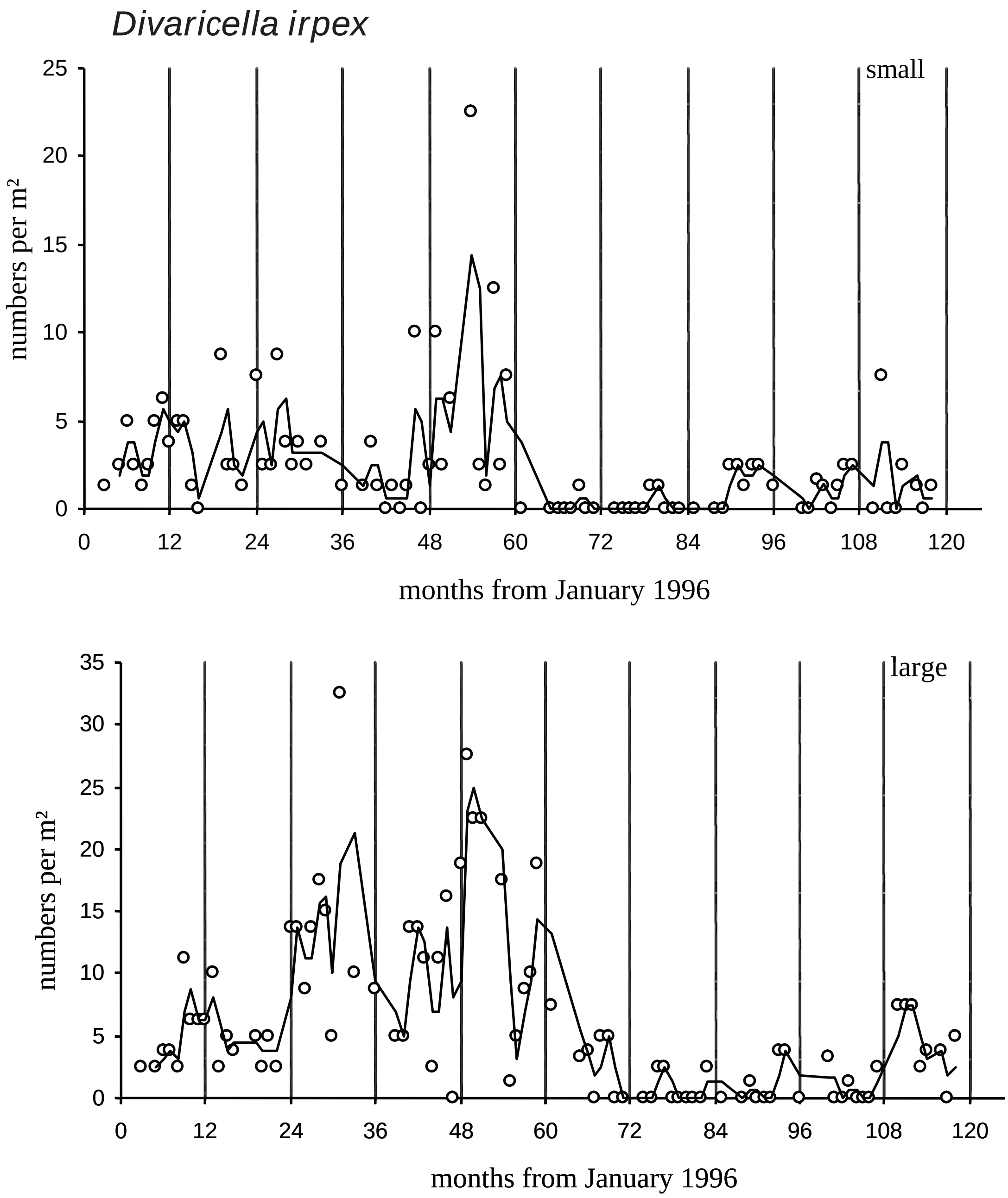
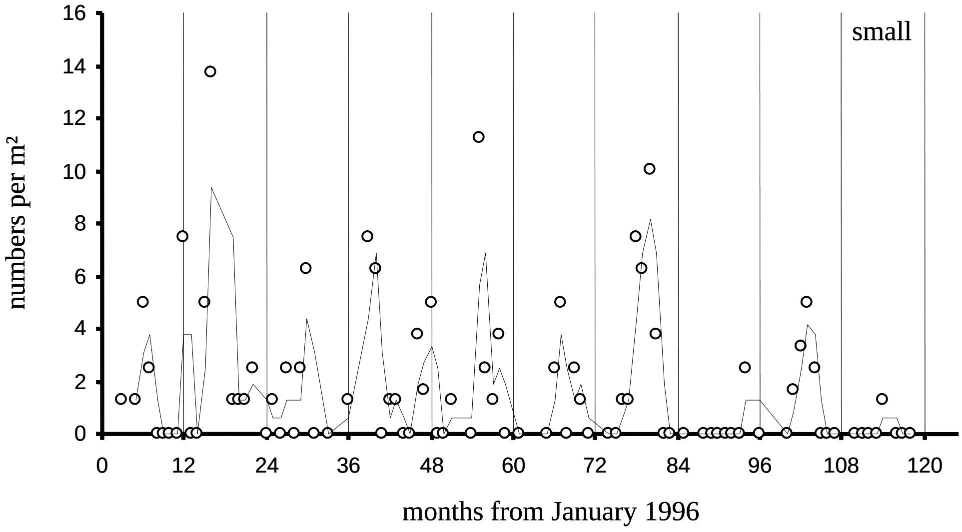


Figure 30. Changes in the densities of small and large *Divaricella irpex* (as based on the size-frequency distribution of Fig. 22) from early 1996 to late 2005.

Siliqua pulchella



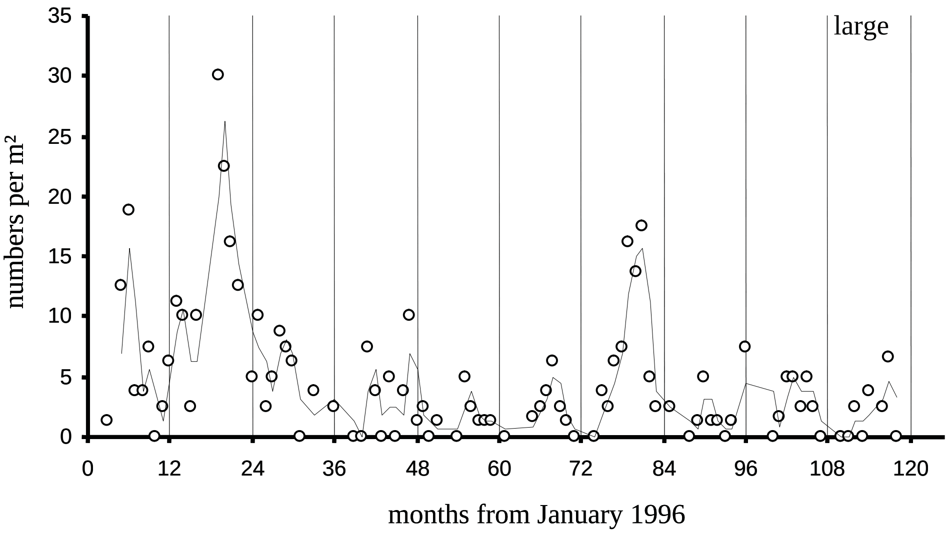


Figure 31. Changes in the densities of small and large *Siliqua pulchella* (as based on the size-frequency distribution of Fig. 23) from early 1996 to late 2005.

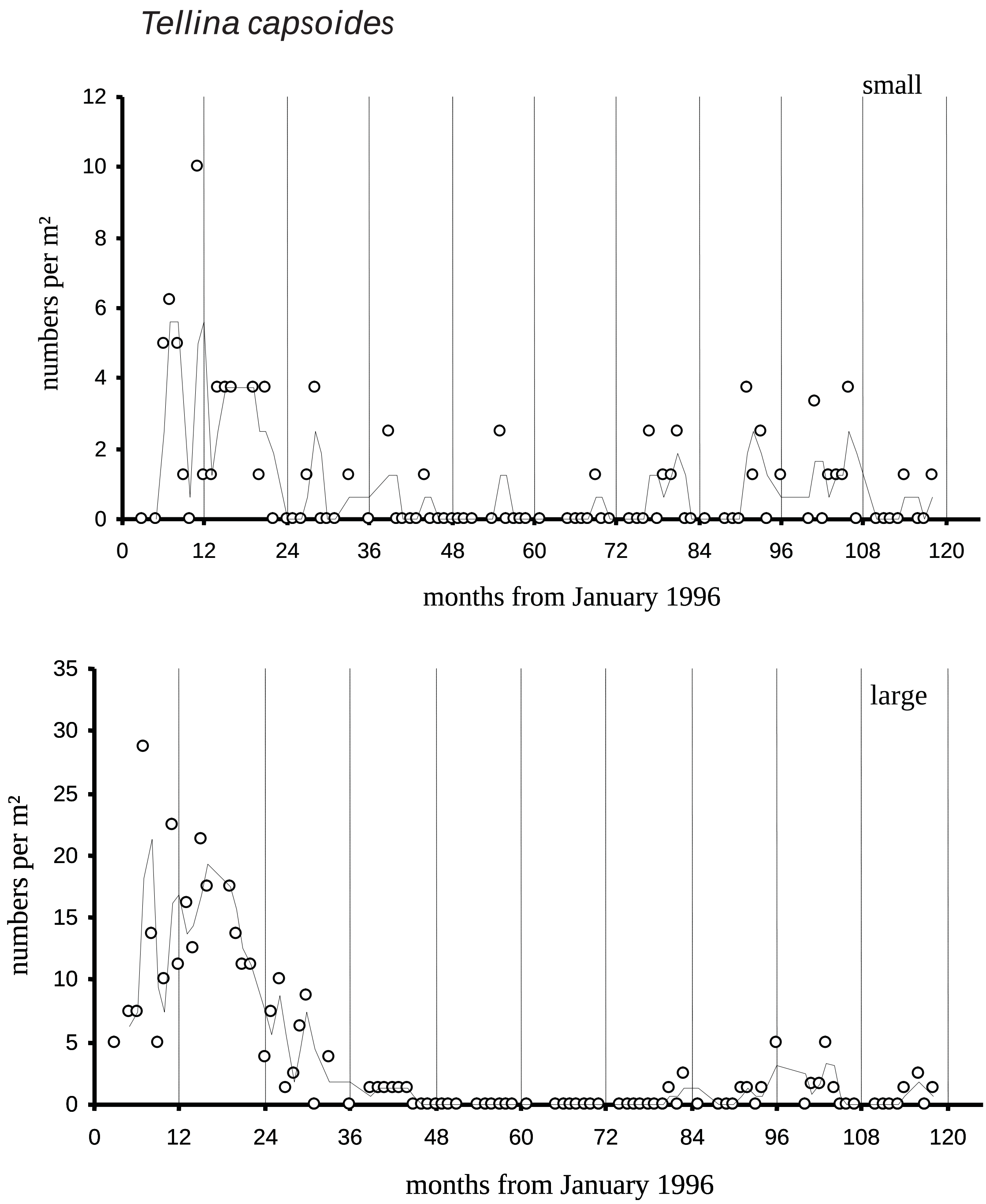
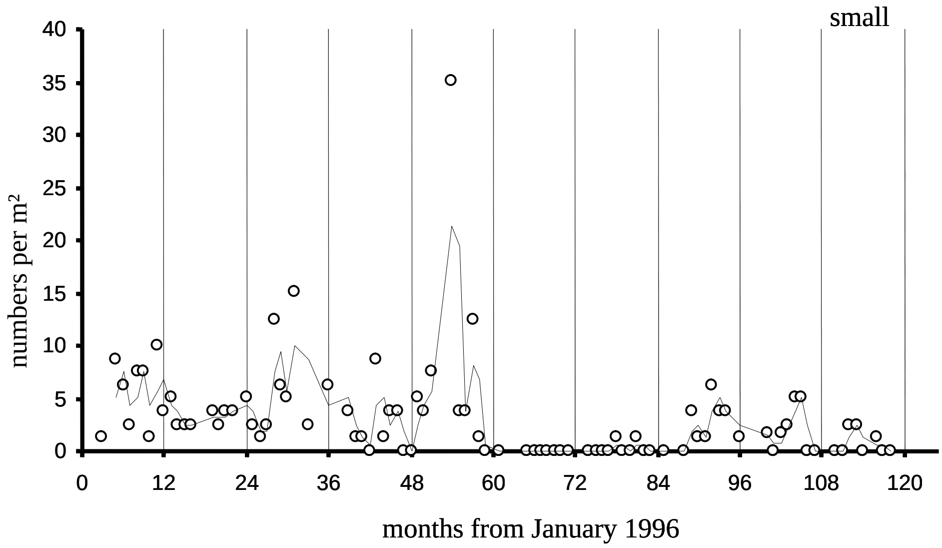


Figure 32. Changes in the densities of small and large *Tellina capsoides* (as based on the size-frequency distribution of Fig. 24) from early 1996 to late 2005.

Tellina piratica



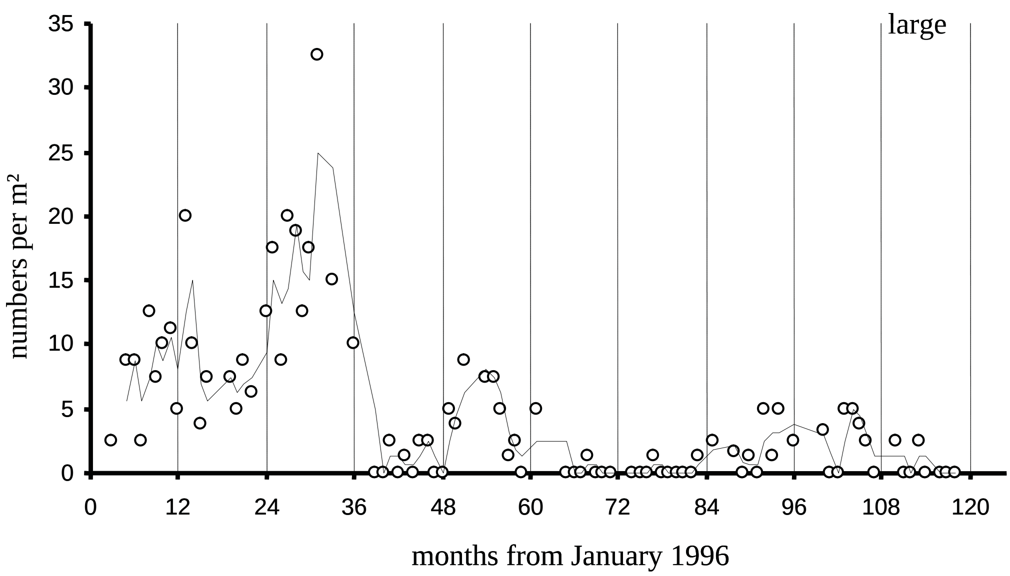


Figure 33. Changes in the densities of small and large *Tellina piratica* (as based on the size-frequency distribution of Fig. 25) from early 1996 to late 2005.

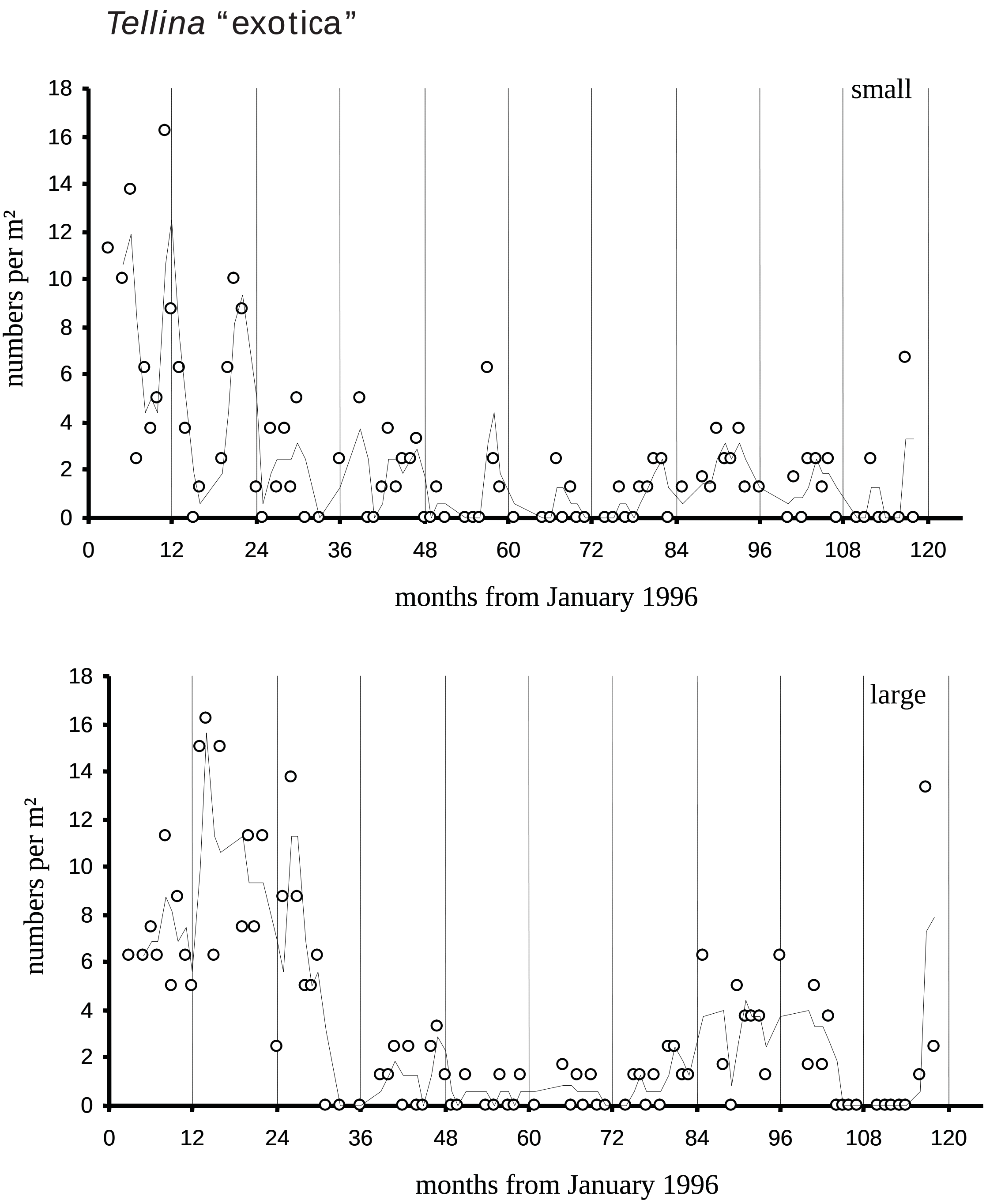
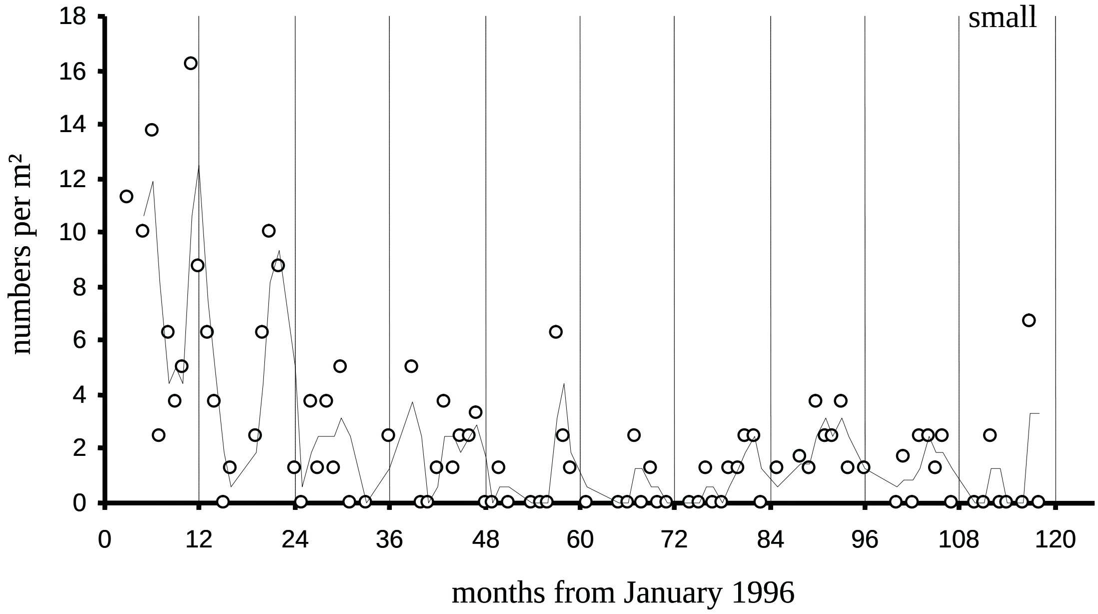


Figure 34. Changes in the densities of small and large *Tellina* "exotica" (as based on the size-frequency distribution of Fig. 26) from early 1996 to late 2005.

Nassarius dorsatus



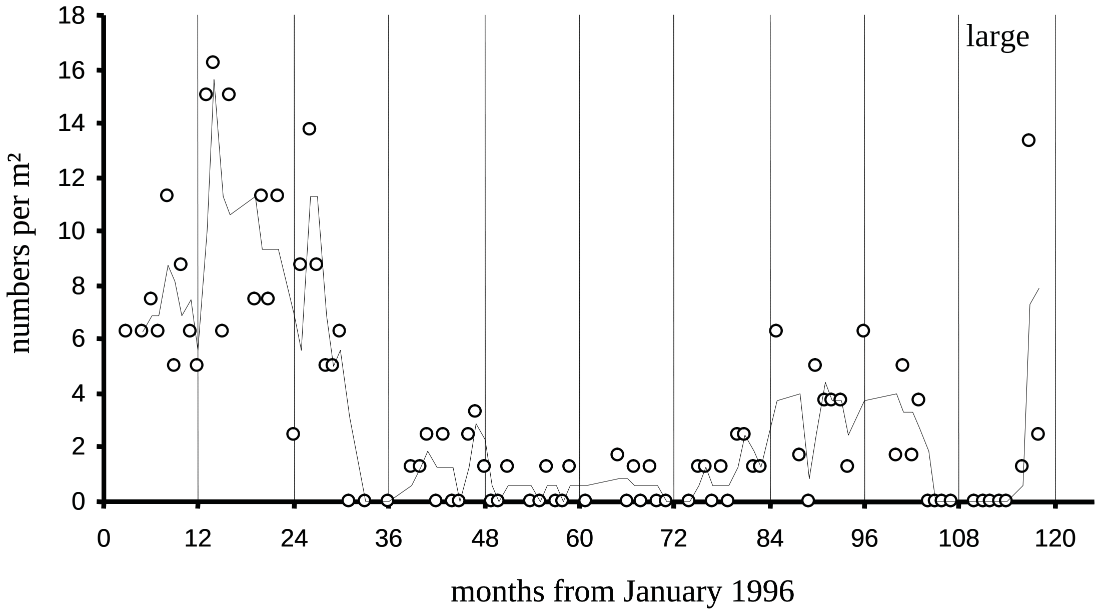


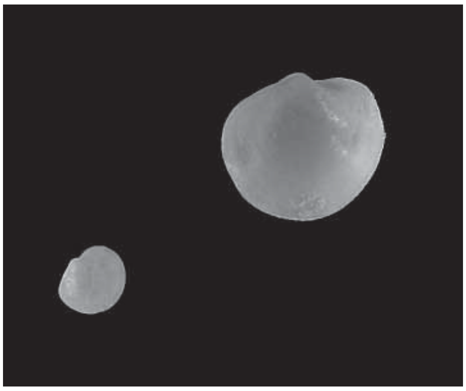
Figure 35. Changes in the densities of small and large *Nassarius dorsatus* (as based on the size-frequency distribution of Fig. 27) from early 1996 to late 2005.

The following description of the results is based on the data in Table 1 and 2, the Figures 5 to 19 (densities), and 20-35 (size-frequencies and recruitment).

Anadara granosa

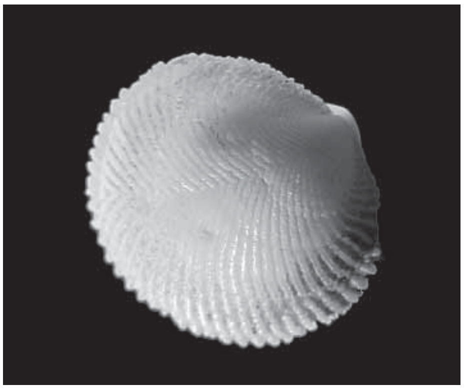
Anadara, also called the 'bloody cockle', is a very thick-shelled bivalve. It used to be staple food for the Aboriginals. Around Roebuck Bay big middens are found where you can encounter large shell-sizes that have never been found in our samples. *Anadara* was exclusively found at One Tree. The highest numbers were found in 1997 and from that time on densities were low. In the last two years not a single adult *Anadara* (>8 mm) was found. In 2004 only a few juveniles were found.

Anodontia omissa



Anodontia, a lucinid with a very fragile shell, was only found at Fall Point. The numbers were highest in 1996 and 1997, after that they declined dramatically. In the years 2001 to 2005 hardly any large *Anodontia* was sampled. In 2005 a small number of adults was there again. In 2003 and 2005 juveniles were found.

Divaricella irpex



Divaricella, another lucinid, but with a very strong shell, was almost only found at Fall Point. The numbers were highest in the years 1998 to 2000. The lowest numbers of both adults and juveniles were reached in 2002 to 2004. In 2005 there was a slight incease.

Siliqua pulchella

Siliqua, the thinnest-shelled species, was mainly found at One Tree, but sometimes also at Fall Point. At One Tree numbers have declined, but not so dramatic as other species have. At Fall Point numbers did not decline. Peak years were 1996, 1997 and 2002. Juveniles were found in almost all years.

Tellina capsoides

T. capsoides, a hard shelled bivalve, was exclusively found at One Tree. High numbers were found in 1996 and 1997. After a real low from 1999 to 2001, they came back in low numbers. However, adults have become rare in the samples.

Tellina piratica

T. piratica, a fine ribbed sandy-coloured shell, was mainly found at Fall Point with highest densities of adults in 1998 and juveniles in 2000. After a low in 2001 and 2002, numbers of both adults and juveniles were increasing again. However, in 2005 there was a decline.

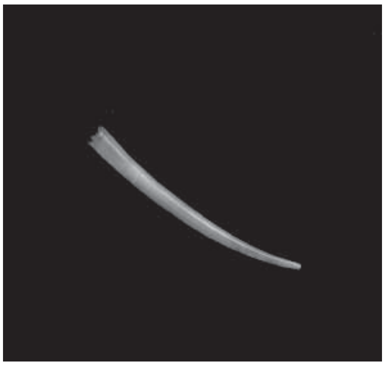
Tellina "exotica"

T. "exotica", a fragile bivalve, was sampled at both sites, with highest numbers at One Tree. At both sites there was a decline, but the bivalve seems to be on its return. In 1996 to 1998 peak numbers were found for both adults and juveniles. Juveniles were present in all years with minimum numbers in 2001 and 2002.

Nassarius dorsatus

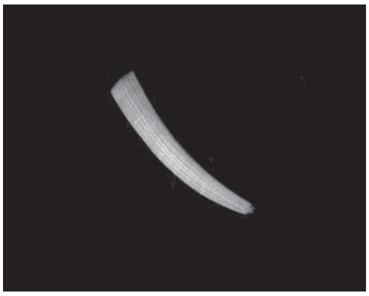
Nassarius was found at both locations but mostly at One Tree. At One Tree numbers declined dramatically. Peak numbers were found in 1996 and 1997. From 2000 onwards numbers, especially for juveniles were low.

Laevidentalium cf. *lubricatum*



Laevidentalium is a smooth tusk-shell. Most *Laevidentalium* were found at Fall Point. The highest numbers were found in 1996 and 1997, since then they seem to be stable at a lower level.

Dentalium cf. *bartonae*



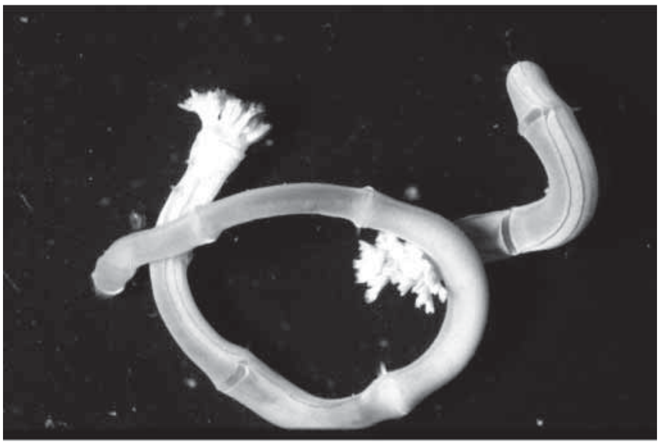
D. cf. *bartonae*, a ribbed tusk-shell, was exclusively found at One Tree. The highest numbers were found in 1998. From 2001 onwards almost none were found.

Dentalium spec.
In the first year of sampling (1996) on a few dates we did not discriminate between *Laevidentalium* and *Dentalium*. We just called all tusk-shells or scaphopods: '*Dentalium* spec.' The numbers were quite high in this first year, so whether they are 'L' or 'D', it means that the decline in 'L' and/or 'D' is even bigger.

Chaetopteridae

Chaetopteridae, ‘plastic tubeworms’, were exclusively found at Fall Point, with huge numbers (>1500) in 1997. Since then the numbers were always low, with some peaks of 20 to 45 per m^2.

Oweniidae

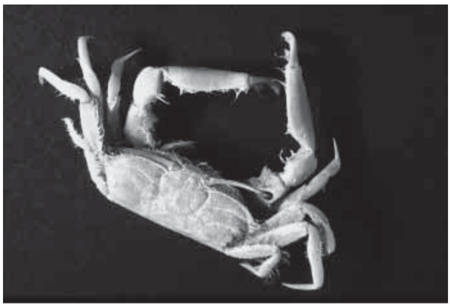


Oweniidae are tubeworms with tubes consisting of fine sandgrains. Most Oweniidae were found at Fall Point. In the first period some were found at One Tree but none in the second period. Huge numbers were found in 1997 and high numbers in 1998 and 2000. After 2000 the numbers went down and up to 40 per m^2.

Halicarcinus cf. *australis*

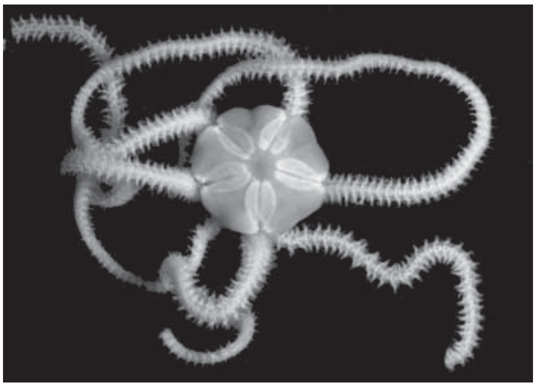
This nice little spider crab was only found at Fall Point where it showed its highest numbers from 1996 to1998. *Halicarcinus* has declined, but throughout the years numbers of 20 to 40 per m^2 were present.

Macrophthalmus spec.



This sentinel crab was found at both Fall Point as One Tree. The numbers declined at Fall Point but increased at One Tree. Peak numbers were found in 2002 and 2003. It is the only species that has increased over the years.

Amphiura tenuis.



Brittlestars were only found at Fall Point. Numbers fluctuate, but over the years they seem to be rather constant.

4. GENERAL DISCUSSION

At both sites, Fall Point and One Tree, more than half of the benthic species declined in the years 1996 to 2005. Around a quarter of the species increased, but with the exception of seven species that we found in numbers higher than 100 over the whole period, the increase is marginal. However at the moment that MONROEB-1 was published, the situation looked more dramatic than it looks at the end of MONROEB-2. Most of the abundant species were in a continuing decline in May 2001. The good news is that most of these species have not declined further and even showed a little increase in the second period.

A reasonable concern shared by several people repeatedly involved in the monthly mudsampling was whether the repeated sampling effort would disturb the local sediments so much that this would have reduced numbers of macrozoobenthic animals in the course of the years. We would expect fragile sedentary species to be most easily affected. That one such species, the brittle star *Amphiura tenuis*, showed a steady increase over time in the first period from 1996 to 2001, and was still abundant in quite high densities at the end of the second sampling period, suggests that the role of disturbance can have been a very minor factor at best. We also like to note that the precision with which the stations were located (counting steps by different team leaders, rather than the consistent use of modern, high precision GPS) was not very high, which would have been a concern in itself was it not for the fantastic congruence in species composition and densities among the two stations at each site. Another fact is that the tide in Roebuck Bay is a 9 metres tide. The sediment is therefore subject to intense natural disturbance on a daily basis especially during spring tides. Thus, we believe that the area over which the monitoring samples were collected was perfectly able to cope with the disturbance inflicted by the human observers.

Another concern is that we only sampled two locations in a huge bay: are these sites really representative? What we can say is that they may not be representative of the state of the whole bay at any time (we would need more monitoring locations for that, e.g. on Town Beach and Dampier Flats), but we do believe they are representative of changes in time. In fact, it is rather gratifying to see that trends apparent from other mudsampling efforts, notably the repeated mapping efforts of the northern shores in June 1996 (Pepping *et al.* 1999), March 2000 (Rogers *et al.* 2000), June 2002 (Pearson *etal.* 2003) and June 2006 (Piersma *etal.* 2006), came up with similar impressions on the abundance of various macrozoobenthic taxa as did MONROEB.

After the fourth benthic mapping of the northern shore, in June 2006, Piersma *et al.* (2006) were able to conclude that despite considerable changes in density (see below) the distribution patterns of almost all species had remained remarkably constant. This means that repeated sampling at single locations should yield good information on changes in time even if that location is not representative of the whole bay. And then, in any case, the great diversity of habitats and benthic communities in Roebuck Bay would make it impossible to find any single location that would fairly represent the Bay's intertidal flats in a spatial way.

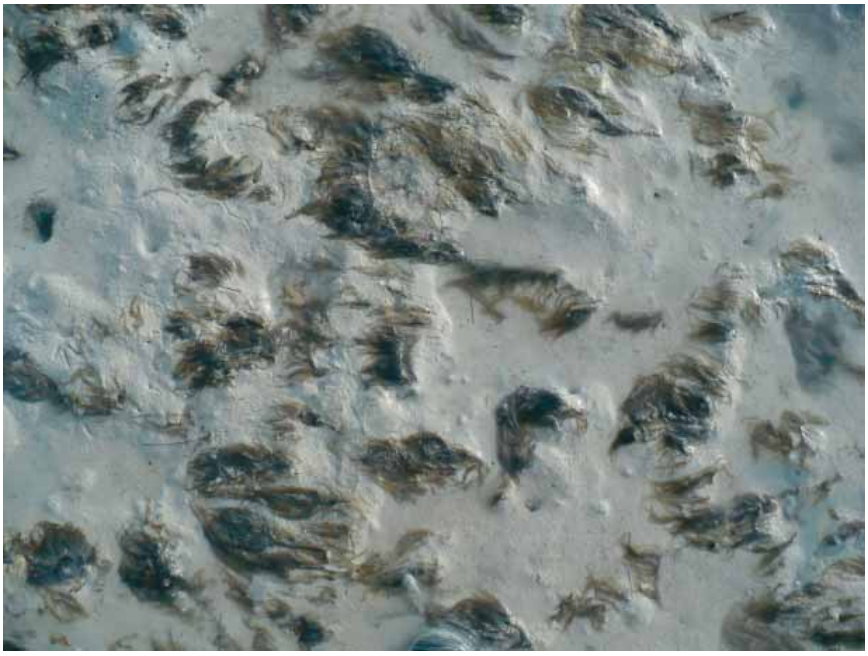
For a start, there is the great abundance of plastic tubeworms Chaetopteridae that made life (sorting samples) so difficult during ROEBIM-97 (Pepping *et al.* 1999); plastic tubeworms were absent during the later efforts, a picture fully consistent with the MONROEB results. Then there is the relative high abundance of *Siliqua pulchella* on the soft muds of Kraken Corner in June 1997 and the near-absence there in both March 2000 and June 2002 (Rogers & Taylor 2002). Again this is consistent with the results of MONROEB. The relative scarcity of Ingrid-eating snails *Nassarius dorsatus* reported during June 2002 was reflected well by the MONROEB results. We conclude that the monitoring has done a fine job in generating interpretable seasonality data for about 15 different taxa.

The decline in numbers in most species can not clearly be explained by consistent changes in the weather conditions. The weather, in fact, has not changed; rainfall, maximum and minimum temperature pattern was very regular throughout the years (see Fig. 3). The only irregularity is the rainfall peak in 1997. The cyclone in 2000 probably has caused disappearence of the seagrass cover on the northern shore, but they have since come back (Piersma *etal.* 2006). In February 2008, during the monthly sampling, PdG and TP noticed that the sediment at One Tree has changed into a much firmer 'easier to walk on' sediment.

Good news is that even though many species declined, juveniles of the most common species still occur in the samples. This means that recruitment is present, although at a very low level. Unfortunately the bivalve that is most 'famous' in the Bay, the bloody cockle, *Anadara granosa*, the staple food of the Aboriginals in the past, is not doing well at all. After 1997 only very low numbers were found, with fortunately in 2004 a small peak of juveniles.
The expansion of Broome, has brought different threats to the natural resources in the Bay. One of the critical examples is the bloom of a toxic blue-green algae, called *Lyngbya*, belonging to the group of Cyanobacteria. This algae is

also referred to as fireweed, because contact with it can result in eye, skin and respiratory irritation for both humans and animals. It is new to Roebuck Bay and has covered large parts of Town Beach and Fall Point already in the last few years. The increase of nutrients from Broome into Roebuck Bay seems to be a dangerous development. Some examples of harmful effects of *Lyngbya* (Moreton Bay Regional Council website 2008) include: Human Health effects of primary contact with *Lyngbya* may include severe contact dermatites, eye irritation, and asthma/ respiratory irritation when *Lyngbya* is in a dry state. Environmental Health effects: seagrass beds can be smothered by *Lyngbya*, reducing food supplies for animals like dugongs and turtels. Economic impacts: commercial fisheries report reduced fish catches and *Lyngbya* being tangled in equipment during *Lyngbya* blooms.

Picture 5. Seagrass on Town Beach with begin of *Lyngbya* growth in February 2008



Picture 6. *Lyngbya* on Town Beach in February 2008

We sampled at ‘only’ two locations, but realising that all the sampling is done by volunteers it is amazing that we managed to get the data-series so far. It is a unique benthic sampling programme in the tropical world. The monthly sampling programme for sure is necessary to continue to ‘keep the watch on’ the health of the Bay. It is also of great importance to sample the whole Bay again as was done in 2002 and partly in 1996 and 2006 to put the MONROEB data on the ‘real’ Roebuck Bay spatial scale. From the different bigger benthic-sampling expeditions we know that Town Beach and Dampier Flats are rich areas. We hope that these areas that are closer to Broome can be included in the monthly sampling effort in the future.

5. ACKNOWLEDGEMENTS

It happened during a tropical downpour in mid March 1996: GBP and TP were crawling on their knees in the mud, amazed at the variety of creeping crawlies and realizing how little we know about what was out there. This was the incentive to start a monitoring scheme of macrobenthic animals of the intertidal flat of Roebuck Bay on 24 March 1996, which was to be run by wardens and volunteers from the Broome Bird Observatory (BBO) with in kind and logistic support from the Western Australian Department of Conservation and Land Management (CALM) and the (now Royal) Netherlands Institute for Sea Research (NIOZ). The monitoring scheme was named MONROEB. BBO and its wardens have played a major role in continuing this sampling programme. Due to the immense effort of many participants over ten years now (1996-2005), a truly unique record of temporal and seasonal changes on a tropical mudflat could now been presented in this report. The data from the first five years (1996-2001) are already presented in the first MONROEB-report (Goeij de *et al.* 2003) published in 2003.

A huge number of people (at least 140) have been involved in this project in one way or another. During the first 18 months, Ali Pentelow from Broome took the lead. From that time on the Broome Bird Observatory (BBO) wardens took the reponsibility for carrying out the programme: thanks a million Becky Hayward and John Fallaw, Janet Sparrow and Chris Hassel, Alistair Dermott and Tracy Stolman, Andre Joubert, Paula and Bill Rutherford, Ricky Coughlan, Joy Tamsey and the assistant wardens in the last five years. Special thanks to Phil Joy for his extraordinary fill-in role between wardens that kept the process rolling.

Special thanks also to the many officers from the West Kimberley Branch of The Department of Conservation and Land Management (now Department of Environmental Conservation (DEC)), especially Allen Grosse, Michael Lapwood (now retired), Jim Lane (Principal Research Scientist), Tim Willing, Kingsley Miller (Acting District Manager) and Jill Green. Thanks also to Holly Smith.

It is important to note that West Kimberley District through the then District Manager, Allen Grosse contributed the initial seed capital that enabled the monitoring to begin.

Environs Kimberley provided ongoing support for the project and assisted from time to time with collections and processing of samples. It was not an easy task to get volunteers in the mud every month, especially not the mud of One Tree. It is peculiar kind of enjoyment to go over your knees in the soft mud! Lots of people tried once. Sorting the samples as soon as they got back from the field was another onerous job which requirement a kind of determination. The following list gives the names of all people who helped in one way or another to get the poor benthic creatures from the mud into the vials. Some names are incomplete, as some helpers were passing through BBO too quickly to get their names properly registered. However, they have to be thanked too!

In chronological order: Ali Pentelow, Becky Hayward, Jon Fallaw, Janet Sparrow, Chris Hassell, Sheila Foster-Nixon, Claas, Tim Willing, Kathryn from CALM, Jenny Noble, Janet Lankester, Helen MacArthur, Rosemary Macarthur, Robert Kirwan, Heather Beswick, John Curran, Phil Joy, Robert Van Leeuwen, David Baker-Gabb, Peter West, Raoul Broughton, Christine McNamara, Shapelle McNee, Ray Lyons, Oliver Vachez, Kathy Fletcher, Mavis Russell, Darlene, Sarah and Tim Cantrill and their children, Shirley Cook, Barbara Lake, Mary Councillor, Ian Snadden, Paul and Jake Botwell, Brenda, Michelle McDonald, Jean, Mike, Dick and Pam Smith, Jeromy, Danny Rogers, Kerry Duff, Sharon, J. Woods, Clare Howard, Magnolia Howard, Wilyarti Howard, Matt Gillis, Jacquie and Nigel Clark, B. Hart, A. Hart, M. Tarry, C. Tarry, A. Dunn, Nicole Grenfell, Sandie McCaig, Macafee, Julie Deleyev, Hunter, Blyth, Shirley Slack-Smith, Pieter Honkoop, eight Australian Wader Study Group members, A. Mayer, Adrian Boyle, Al Dermer, Yus Rusila Noor, H. Rambiak, W. Gebse, Susan, Tracey Stolman, P. Michele, Cass Hutton, S. Hartvigsen, D. Secombe, Jacquie Cochran, Ruth Bonser, Maria Pedersen, Jan Lewis, Astrid and Guido Gomes, Liz Cochran, Persine Ayersberg, André Joubert, M. Slattery, Terry Strong, Jaenet, Peter Tucker, Jun Matsui, Michael Curran, Jane Rusden, John Peterson, Diane Sherman, Sharin Mullaly, Magie Kurcz, Josh van Dijke, Melinda Glace, Andrea Feldpausch, Kelly Millenbah, Max Tishler and still at least 15 more anonymous BBO-guests. In July 2002 we had help from the Police Cadets, they managed to develop the ultimate soft-mud escape trick: ‘the back crawl’.

Rob VanLeeuwen of the Metstation at Broome helped in the mud as well as behind the computer by regularly sending us weather data reports in the first period.

In The Netherlands, especially in the lab, Pieter Honkoop had great input during the first year. Later we received help from Mavis Russell and Danny Rogers during occasional visits to The Netherlands. Kees Camphuijsen provided indispensable help organising the database and carrying out analyses.

The analysis of the data of the first part of this project (MONROEB-1) was funded by the National Heritage Trust through Environs Kimberley.

The analysis of the data of the second part of this project (MONROEB-2) was funded from the DEC Wetland Conservation Project Proposal Nature Conservation Division Grant, Managed by Michael Coote, assisted by Holly Smith.

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APPENDIX I

SAMPLING SCHEME, SAMPLING EFFORT AND CORRECTION FOR MISSING SAMPLES.

SAMPLING SCHEME

The scheme shows the sampled surface (m^2) for all stations per month from March 1996 (= month 3) to Novembre 2005 (=month 118). Sometimes a whole station is missing, sometimes only one corer. This table was used to correct for the densities in Figure 5-35, see the calculation below the table.

	FPA1	FPA2	FPA3	FPA4	FPB1	FPB2	FPB3	FPB4	OTA1	OTA2	OTA3	OTA4	OTB1	OTB2	OTB3	OTB4	sum
3	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
4																	
5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
6	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
7	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
8	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
9	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
11	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
12	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
13	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
14	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
15	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.75
16	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
17																	
18																	
19	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
20	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
21	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.60
22	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
23																	
24	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
25	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
26	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
27	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
28	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80

29	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0.75
30	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
31	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
32																	
33	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
34																	
35																	
36	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
37																	
38																	
39	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
40	0.05	0.05	0.05	0	0.05	0.05	0.05	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.70
41	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
42	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
43	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
44	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
45	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
46	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
47	0.05	0.05	0.05	0.05	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.60
48	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
49	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
51	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
52																	
53																	
54	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
55	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
56	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
57	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
58	0.05	0	0	0.05	0.05	0.05	0	0	0.05	0	0	0.05	0	0	0.05	0.05	0.40
59	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
60																	
61	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
62																	
63																	
64																	
65	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0.05	0.05	0	0.70
66	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80

67	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
68	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
69	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
70	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
71	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
72																	
73																	
74	0	0	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.40
75	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
76	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
77	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
78	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
79	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
80	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
81	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
82	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
83	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
84																	
85	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
86																	
87																	
88	0.05	0.05	0.05	0.05	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.60
89	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.70
90	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
91	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
92	0.05	0.05	0	0.05	0.05	0	0.05	0.05	0	0.05	0	0.05	0.05	0.05	0.05	0.05	0.60
93	0.05	0.05	0	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0	0.05	0.05	0.05	0.05	0.65
94	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0.05	0.05	0.05	0.05	0.75
95																	
96	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0.05	0.05	0.05	0.05	0.75
97																	
98																	
99																	
100	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0.60
101	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0.60
102	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0.60

103	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
104	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
105	0.05	0.05	0.05	0	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.75
106	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.80
107	0.05	0.05	0.05	0	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.35
108																	
109																	
110	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
111	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
112	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
113	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0	0	0	0.40
114	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.70
115																	
116	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.70
117	0	0	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.30
118	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0.70

Sampling effort

The table shows the effort in m^2

	if all samples were taken at both FP and OT	in real 'life'	if all samples were taken at or FP or OT	only FP real	only OT real
Period 1 (1996-2001)	38.4	36.1	19.2	18.5	17.6
Period 2 (2001-2005)	32.8	28.2	16.4	15.5	12.7
Total	71.2	64.3	35.6	34.0	30.3

Correction for missing samples at dates when samples were taken.

To obtain the densities for Figures 5-19 we corrected for the sampling effort per date per station as follows:
((nFPA + nFPB) / (sampled opp FP)) + ((n OTA+ nOTB) / (sampled opp OT))/2.
n=number; FPA = Fall Point A, FPB = Fall Point B, OT = One Tree.

To obtain the densities for Figures 28-35 we used a rougher calculation:
((nFPtot+nOTtot) / (sampled opp FP+OT)).
n=number; FPtot = Fall Point A+B, OTtot = One TreeA+B.

APPENDIX II

The yet unidentified 'taxa' with their numbers for the period 2001-2005.

taxa	FP-A	FP-B	OT-A	**OT-B**	**FP+OT**
bivalve spec.	5	1		3	9
bivalve spec. juv.	3	1	4	5	13
Mactra 'brown tip'				1	1
Tellina inflata		1			1
Tellina spec.		2	2	1	5
Tellina spec. juv.	1			1	2
Macoma spec.	1				1
Placamen spec.		1			1
Gastropoda 'brown'		1			1
Gastropoda spec.1	2				2
Gastropoda spec.2	16	11	4	3	34
Gastropoda spec.3	1				1
Gastropoda x	1				1
Crustacea a.	1				1
Crustacea spec.1	53	72			125
Crustacea spec.2	11	11			22
Leucosia new	1				1
Leucosia spec.	1				1
Crab b.			1		1
Crab spec.1			1		1
Crab spec.2			1	1	2
Crab new	1				1
Crab spec.3		4			4
Crab spec.4			1		1
Tunicate spec.		1			1
Cephalaspidea	2				2