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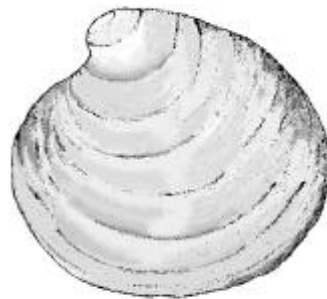
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Then, a growth spurt takes place.

In ten years of time the specimens may attain a size of approximately 4.5 cm height. The periostracum has a yellow to brown colour. Among the superficial striations of the periostracum, annual growth lines which are recognisable as a shallow groove, can be discerned.

CHAPTER 2

Notes on the biology and ecology of the bivalve *Arctica islandica* L. from the North Sea



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Notes on the biology and ecology of the bivalve *Arctica islandica* L. from the North Sea

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ABSTRACT

The present paper summarises new observations on the distribution, density, population structure and other topics of the ecology of the bivalve *Arctica islandica* in the North Sea. Where possible, a comparison with results reported in the literature is made.

Arctica is found over almost the entire North Sea north of 53°30'N. Here, its distribution seems to be limited to depths below that of the 30 meter depth contour. A comparison of density estimates made between 1970s and the early 1990s, suggest a decrease in abundance. In most areas of the North Sea the populations are dominated by full grown specimens exceeding 50 mm shell height. Smaller animals are rarely found. As a consequence the population P/B is low (0.03). Instantaneous mortality rates for full grown *Arctica* vary between 0.05 and 0.07. These values are much higher than reported for the western Atlantic. Mortality in the south-eastern North Sea is higher than in the northern North Sea.

About 31.5 % of the animals appeared to be infected by the commensal nemertean worm *Malacobdella grossa* but no significant effect of infection on the condition of the host was observed. Variation in shell morphology of different populations within the North Sea is discussed.

INTRODUCTION

Arctica islandica is the only living species of a bivalve genus which had its origin in the early Cretaceous (Nicol, 1951). *Arctica* is known under various common names such as "Iceland Cyprina", "Ocean Quahog" and "Mahogany Clam". The latter is derived from the golden brown colour of the periostracum present on the shells of young specimens. The periostracum becomes black when the animal grows older because of the deposition of iron complexes (Brey *et al.*, 1990).

Arctica has been studied for its anatomy (Salleudin, 1964; Palmer, 1979), behaviour (Taylor, 1976) and physiology (Bayne, 1971). Since the 1980s, ecological aspects of *Arctica* have become the subject of study because the species became commercially

important along the American east coast (Kennish *et al.*, 1994). To arrive at acceptable levels of exploitation, information on distribution, population size and growth was urgently needed.

A significant result of these studies was the knowledge about growth rates and longevity. By counting the annually (chapter 3) deposited internal growth lines, Ropes (1985) estimated longevity to surpass 200 years, which has made *Arctica* the longest lived bivalve known (Heller, 1990).

Knowledge on growth production and population ecology in European waters remained scarce. At the Netherlands Institute for Sea Research (NIOZ) a project was initiated to fill this gap. Part of this study focussed on the use of the internal growth lines to assess long-term variations in the benthic environment retrospectively. During this project, living *Arctica* were collected from all over the North Sea. This yielded new information about its distribution and ecology in the North Sea which is dealt with in the present paper.

DISTRIBUTION

Arctica is found in the shelf seas of the North European continent ranging from the Bay of Biscay in the south (Nicol, 1951) to the White Sea in the north (Zatsepin & Filatova, 1961). *Arctica* has been recorded from the North Sea in faunal studies throughout this century (Petersen, 1915, 1918; Davis, 1923, 1925; Holme, 1956; Hunt, 1925) but distributional maps reveal little detail (Seaward, 1990).

A map with higher spatial resolution (Witbaard *et al.*, 1994, chapter 3) was obtained in 1986, from the ICES Benthic Survey (IBS) (Duineveld *et al.*, 1991; Künitzer, 1990). However, this map was limited to the southern and central North Sea and was based on boxcore samples. While adult *Arctica* were found only sporadically, spat (zero age group) was quite abundant in these samples. Therefore, the map merely reflects the distribution and density of spat fall rather than the distribution of adults (Witbaard *et al.*, 1994). By plotting records collected since 1972 from commercial trawlers and from surveys with research vessels, a map has been constructed which more accurately reflects the distribution of adults (figure 2.1).

Arctica has been found over the entire North Sea north of 53°30'N. It is obvious that its southern limit of distribution closely follows the 30 meter depth contour up to the Danish coast where only a few specimens were found at shallower depths (56°00'N 08°02'E). Despite intensive sampling programs, *Arctica* has never been reported for the Dutch coastal waters or the Southern Bight (Noort *et al.*, 1979-1986; Holtmann & Groenewold, 1992; 1994; Duineveld *et al.*, 1991).

Figure 2.1

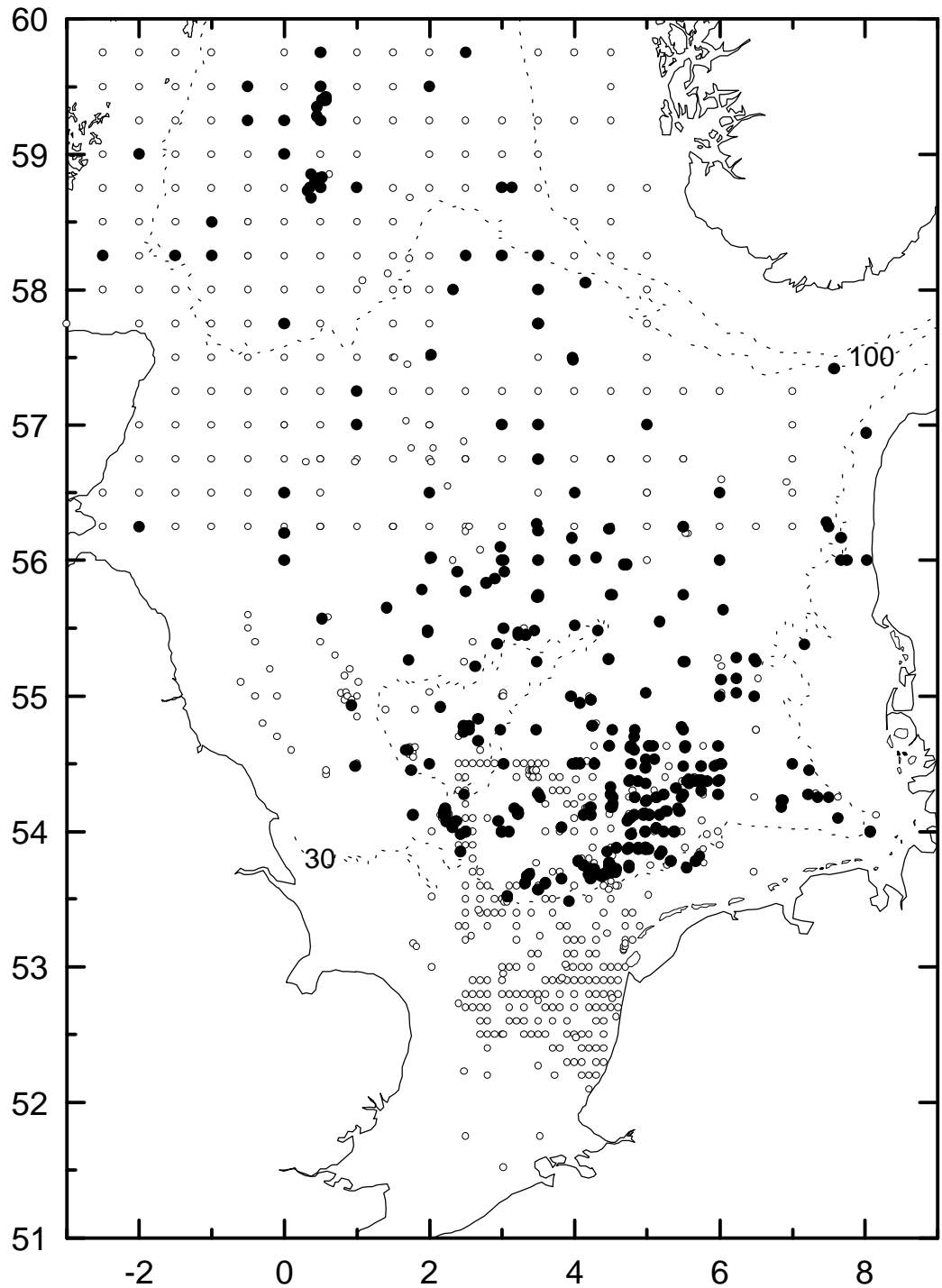


Figure 2.1. Distribution of *Arctica islandica* in the North Sea. Solid circles denote the occurrence of living *Arctica* while hollow circles indicate absence in the sample. Only the occurrence of full grown (non spat) animals is given. The map is composed of data collected between 1990 and 1995 by cruises with research vessels and commercial trawlers as well as data presented by Duineveld *et al.*, (1991); Künitzer (1990); Eleftheriou & Basford, (1989); Basford *et al.*, (1989); Heyman (unpublished); van Moorsel, (1993) and van Noort *et al.*, (1979-1986).

The 30 meter depth contour roughly follows the tidally mixed waters in the south and the deeper, summer stratified waters in the north. Across this boundary the sediment composition changes from coarse sand (median grain size 250-300 μm) in the south to mud (median grain size $<125 \mu\text{m}$) in the north (Creutzberg & Postma, 1985). Nevertheless a prominent role of sediment composition as distribution determining factor for adults seems unlikely. Although *Arctica* is most often found in fine grained sediments (Rowell & Chaisson, 1983; Thórarinsdóttir & Einarsson, 1994; Bearnse, 1976) it has been recorded from coarse sand or gravel as well (Thórarinsdóttir & Einarsson, 1994; Zatsepin & Filatova, 1961). Locations within the North Sea where it occurs on relatively coarse sediments are the Monkey Bank, Cleaver Bank and the south-western part of Dogger Bank (see table 5.2).

It is possible that the southern limit of its distribution, coinciding with the 30 m depth contour, could be set by the maximum bottom water temperature of 16°C (Tomczak & Goedecke, 1964) which also approximately follows the 30 m depth contour. A similar temperature controlled limit has been observed along the American east coast. Here the distribution is confined to a body of cold bottom water in which the 16°C isotherm limits its inshore distribution (Mann, 1982). While mature *Arctica* can withstand temperatures up to 20°C (Loosanoff, 1953), such temperatures are detrimental to larvae since Lutz *et al.* (1989) observed optimum growth rates between 13 and 15°C . At higher temperatures larval growth decreases and ultimately stops. High tidal currents in the shallow waters are another possible reason for its absence. Sediment instability *i.e.* resuspension or sediment scour might inhibit larval settling or impair their survival.

DENSITY

In most areas of the North Sea, densities of *Arctica* are so low that they are rarely found in grab samples. It is only in the Fladen Ground that almost every boxcore yields one or more living specimens (Wilde *et al.*, 1986). Here, the estimated densities ranged from 10 to 16 individuals/ m^2 (chapter 7). In the intensively sampled Oyster Ground area *Arctica* is rarely found in grab samples which suggests very low densities. Like for most other areas within the North Sea density estimates in de Oyster Ground are still semi-quantitative because they are based on beam trawl surveys. Experiments (Groot & Lindeboom, 1994) have shown that such trawl surveys give a poor quantitative estimate of the abundance of infaunal species. A twelve-fold fishing of the same area showed that the first trawl only contains 1 to 5% of the total number of *Arctica* caught (Fonds, 1994; Witbaard, 1995). Numbers of *Arctica* in the catch did not decrease until the 9th trawl passage and after the 12th passage it was estimated

that about 100 % was caught. This repeated fishing of the same bottom area in the Oyster Ground (~54°32'N 05°05'E) yielded a density of 57 individuals/ha (0.006/m²). Using a deep digging dredge, Bergman & van Santbrink (1994) estimated the density of *Arctica* at 1800 quahogs/ha at 53°45'N 04°30'E. But even at such "high" (0.2 ind/m²) densities, elaborate boxcore sampling is needed to verify the actual density. Despite the above mentioned difficulties to assess densities, a comparison has been made between abundance estimates made during the 1970s (Noort *et al.*, 1979-1986) and those made since 1990. In both periods an almost identical 5.5 m wide, fine meshed beam trawl was used. Only the number of tickler chains was higher during the surveys in the most recent period. The results are graphically displayed in figure 2.2.

Figure 2.2

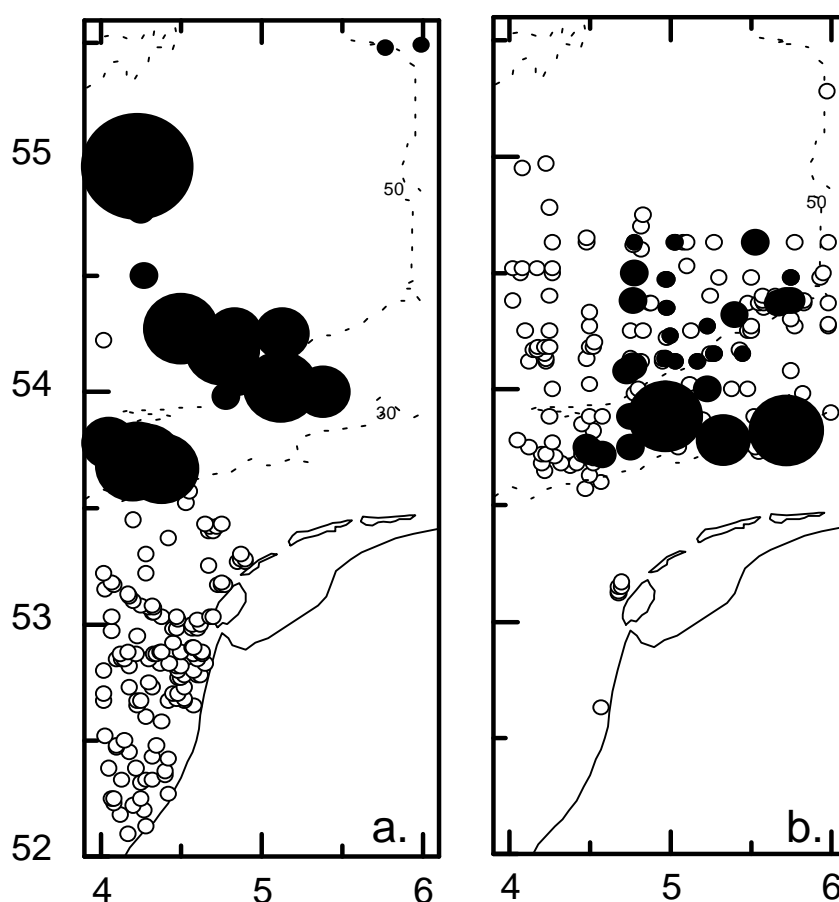


Figure 2.2. The comparison of relative densities of *Arctica islandica* in the south-eastern North Sea. The size of the circles corresponds to the relative abundance. Hollow circles indicate the absence despite sampling. (a), Abundance as estimated by Noort *et al.* (1979-1986) between 1972 and 1980. (b), Densities determined from cruises with RV "Aurelia" and RV "Pelagia" between 1990 and 1994.

The size of the circles indicates the relative abundance, with larger circles corresponding to higher densities. Noort *et al.* (1979-1986) did not sample very often

in the Oyster Ground but they found *Arctica* at almost all of the stations they visited. At most stations the abundance was relatively high, while quahogs were either lacking or had a lower density in the most recent period. This difference is even more striking considering the higher sampling effort (denser sampling grid and the use of more tickler chains) in the most recent period.

Figure 2.3.

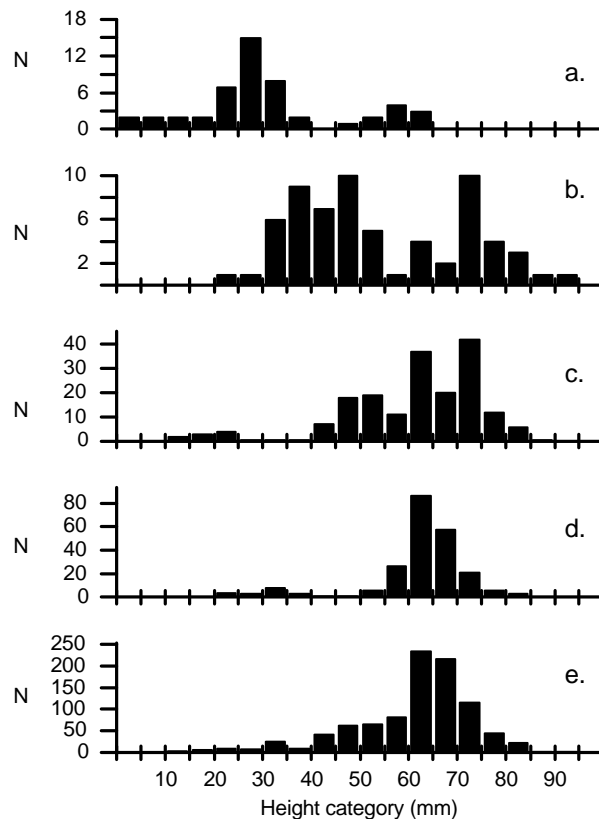


Figure 2.3. Size frequency distribution of four *Arctica islandica* populations within the North Sea. N= the number of *Arctica*. (a), Fladen Ground population (58°40'-59°20'N, 00°20'E) as sampled in 1983 by Wilde *et al.* (1986). (b), Population from the Silverpit (~54°08'N, 02°12' E) sampled in 1993. (c), Central Oyster Ground (Oyst I ~54°22'N, 05°40'E) sampled in 1991. (d), Southern Oyster Ground (Oyst II ~53°52'N, 04°59'E) sampled in 1991. (e), All animals collected from the Oyster Ground between 53°-55°N and 3°-6°E in the period 1990-1994.

For the North Sea, the estimated densities are low when compared to densities of full grown *Arctica* as reported for north-west Iceland, Nova Scotia or the White Sea, where up to 100 individuals/m² can be found (Rowell & Chaisson, 1983; Zatspein & Filatova, 1961; Thórarinsdóttir & Einarsson, 1994).

POPULATION STRUCTURE

In the North Sea, a few sites have been sampled intensely by boxcorers or have been trawled frequently with fine meshed nets (mesh size 2*2 cm). Size frequency distributions of the *Arctica* collected at these sites are depicted in figure 2.3.

In the samples from both the Fladen Ground (2.3a) and Silverpit (2.3b) a bimodal distribution was found. Such bimodality is less clear or even absent in all Oyster Ground samples (2.3c-2.3d). The latter are dominated by larger specimens with heights between 60 and 70 mm. A low abundance of small animals as compared to the abundance of large *Arctica* has also been observed for the populations along the American coast (Murawski & Serchuk, 1979a; Murawski *et al.*, 1982) and north-west Iceland (Thórarinsdóttir & Einarsson, 1994). Murawski *et al.* (1982) suggested that this skewed size frequency distributions may have resulted from either irregular recruitment or low survival of recruits. Evidence for a low survival of recruits is supported by the disappearance of spat which was present in the spring of 1986 (Duineveld *et al.*, 1991; see figure 3.1). This spatfall was never retraced as juvenile specimens in later years.

GROWTH & PRODUCTION

For the determination of a size weight relationship living animals were used which were collected between 1990 and 1994. First the shell height, shell length and shell width of each specimen were measured. Soft-tissue was subsequently removed, drained on paper and weighed, yielding the shell-free wet weight (sfww). Tissue was dried at 60°C until constant weight, yielding the shell-free dry weight (sfdw). For the determination of the ash contents the dried tissue was incinerated in a furnace at 540°C for three hours. The difference between sfdw and ash was taken as ash-free dry weight (afdww).

The ash-free dry weight was 13% of the shell-free wet weight and 80% of the shell-free dry weight. These results are very similar to those reported by Rumohr *et al.* (1987). The resulting relationship between height and afdww is depicted in figure 2.4.

When the size-weight relationship is combined with age-size regressions (chapter 5) and the age-frequency distributions (figure 2.3), an estimate for the population P/B ratio is obtained. When a growth season of one year without mortality or recruitment is assumed, the sum of weight increase of all animals corresponds to a minimal estimate of secondary production. These results are summarised in table 2.1 together with average shell size and average age of the animals in the population.

The average P/B for the Oyster Ground has the lowest value although the animals have growth rates which are 2 to 3 times higher than those from the Fladen Ground (Witbaard & Duineveld, 1990). As this discrepancy is caused by the different age

structures of both populations, the P/B ratios were recalculated for separate age groups as well (table 2.2). This demonstrates a rapid decline in P/B with age. The youngest specimens have P/B ratios which exceed 1, but in animals older than 5 years the P/B ratio rapidly decreases to 0.02.

Figure 2.4

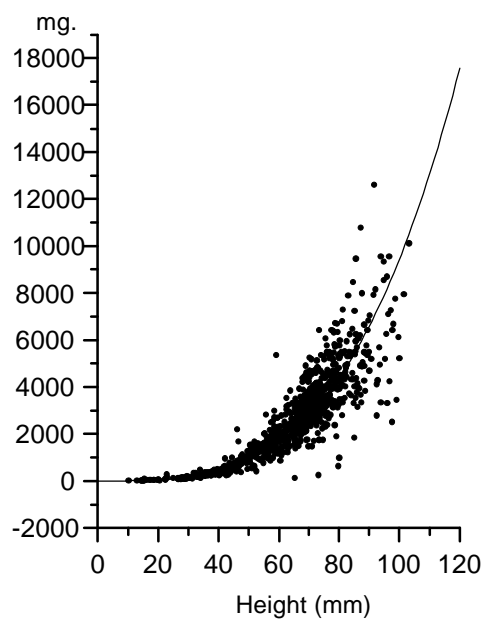


Figure 2.4. Relationship between shell height (mm) and ash-free dry weight (mg) for animals collected in the North Sea between 1990 and 1994. The equation for the best fitting regression line is $Weight=0.0014*Height^{3.14}$

Table 2.1

Area	Oyster Ground	Silver pit	Fladen Ground	Kiel Bay
Height	66.6	58.9	35.9	25
Avg. age	40.5	28.7	32.0	3-5
P/B pop.	0.02	0.04	0.03	0.34

Table 2.1. A comparison of P/B ratios of some *Arctica islandica* populations. Average P/B ratio together with average shell height and average age for specimens from populations in the Oyster Ground (~53°52'N, 04°59'E), Silverpit (~54°08'N, 02°12'E), Fladen Ground (58°40'-59°20'N, 00°20'E) and Kiel Bay (Brey *et al.*, 1990).

The population P/B for the North Sea is low compared to the Kiel Bay (Baltic Sea) population which is 0.34 (Brey *et al.*, 1990). This difference is mainly due to

dominance of younger age classes in Kiel Bay. If similar age groups are considered, the average ratios compare well.

Table 2.2

Age (yr.)	Oyster Ground	Silver pit	Fladen Ground	Average
1-5	1.0		1.34	1.17
6-11	0.15	0.28	0.39	0.27
11-20	0.08	0.13	0.10	0.10
21-30	0.05	0.06	0.06	0.05
>30	0.02	0.02	0.01	0.02

Table 2.2. P/B ratios for different age groups in three areas of the North Sea. The last column gives the average P/B ratio for all areas. Geographical positions are as given in table 2.1.

MORTALITY

Among the predators which prey on *Arctica* are eider ducks (*Sommateria mollissima*), common scoter (*Melanitta nigra*) (Meissner & Brager, 1990), gulls (Zatsepin & Filatova, 1961), fishes (Schäfer, 1972; Arntz & Weber, 1970; Cramer & Daan, 1986), *Asterias rubens* (Anger, 1977; Hunt, 1925), *Natica* spp (Christensen, 1970) and *Buccinum undatum* (Nielsen, 1975). Spat are especially prone to predation by *Astropecten irregularis* (Christensen, 1970). In the south-eastern North Sea and in the Baltic Sea, bottom trawling is another significant source of mortality (Witbaard & Klein, 1994; Rumohr & Krost, 1990; Arntz & Weber, 1970).

From the size-frequency data (figure 2.3), instantaneous mortality rates were estimated by applying the method described by Brey *et al.* (1990). This was done for the populations from the Fladen Ground and the Oyster Ground. A comparison of both populations suggests higher mortality rates in the Oyster Ground. The instantaneous mortality rate for the Fladen Ground population is 0.32 during the first 10 years of life but decreases rapidly in older animals to less than 0.05. In the Oyster Ground mortality for *Arctica* exceeding 60 mm (>20 years) is estimated at 0.07.

The mortality rate for the North Sea populations is somewhat higher than those calculated for the American or Canadian east coast. Murawski & Serchuk (1979b) reported a value between 0.027 and 0.02 and Rowell *et al.* (1990) gave estimates which varied between 0.015 and 0.05. Brey *et al.* (1990) found a size dependence for the population in Kiel Bay (Baltic Sea). The mortality rate for *Arctica* less than 38 mm was 0.46, 0.06 for specimens with shells between 38 and 52 mm and finally 0.92 for animals larger than 52 mm. They ascribed this trend to the combined effects of size

specific predation and bottom trawling (Brey *et al.*, 1990). The higher mortality rates in the Oyster Ground (south-eastern North Sea) compared to the Fladen Ground points to a relation with the intense bottom trawling in the south-eastern North Sea as outlined in chapter 6. Therefore the decrease in abundance over the past two decades (figure 2.2) seems to be due to the effects of bottom trawling.

COMMENSALISM

Arctica islandica belongs to that group of bivalves which is used as a host by the nemertean worm *Malacobdella grossa* (Gibson, 1967, 1968). This worm is usually found between the mantel epithelium and the gills of its host. Sometimes two worms per *Arctica* are found and large shells are usually occupied by larger worms (Gibson, 1968; Gering 1911). The grade of infection differs among populations. Along the American east coast infected clams are rarely found (0-0.05%; Jones, 1979) while on average, 27 to 58% of the clams in Kiel Bay are infected (Gering, 1911; Arntz, 1972). The analyses of 974 *Arctica* specimens from the North Sea, revealed an average infection percentage of 31.5. Larger *Arctica* were infected more frequently than smaller specimens (table 2.3b) which is consistent with the results of Gering (1911) and Arntz (1972). However, the differences in percentage of infection between different areas in the North Sea are small (table 2.3a).

Table 2.3a

Area	% infected	N.
North Sea (whole)	31.4	974
Oyster Ground	34.5	620
Fladen Ground	20.4	54
Central North Sea	26.0	68
German Bight	31.7	82
Western North Sea	25.7	105

Table 2.3b

Size class (mm)	% infected	N
<35	14.2	134
36-55	26.7	157
56-70	32.7	324
71-85	39.6	316
>85	34.6	81

Table 2.3. Percentage of *Arctica* infected with *Malacobdella grossa*. (a), Percentage of infection split per area in the North Sea. (b), Percentage of infection split per size group in the North Sea. N= the number of *Arctica* analysed.

Because commensals are thought to have either a positive or no effect on their host, the condition index (afd_w/height³) of infected and non infected *Arctica* (N=265) was compared. All clams used for this comparison were collected from one site in the Oyster Ground (54°22' N 05°40'E) within one week. The infected animals tended to have a slightly better condition index but the difference was insignificant. Still, Arntz (1972) observed a significant better condition of infected *Arctica*. This effect is

thought to be the result of a stimulation of the filtering activity caused by the presence of the worm (Gibson, 1968).

PHENOTYPIC VARIATION

The maximum observed shell heights for the North Sea populations varied between 96.8 and 99.1 mm. Only for specimens from the Fladen Ground the maximum shell height was lower. It did not exceed 73.5 mm. The shape of the shell, *i.e.* the relationships between height, length, width and weight however appeared to differ. The shell shape of 7 North Sea populations was analysed in more detail, using measurements of height, length, width (chapter 1) and the weight of the right hand valve.

Figure 2.5

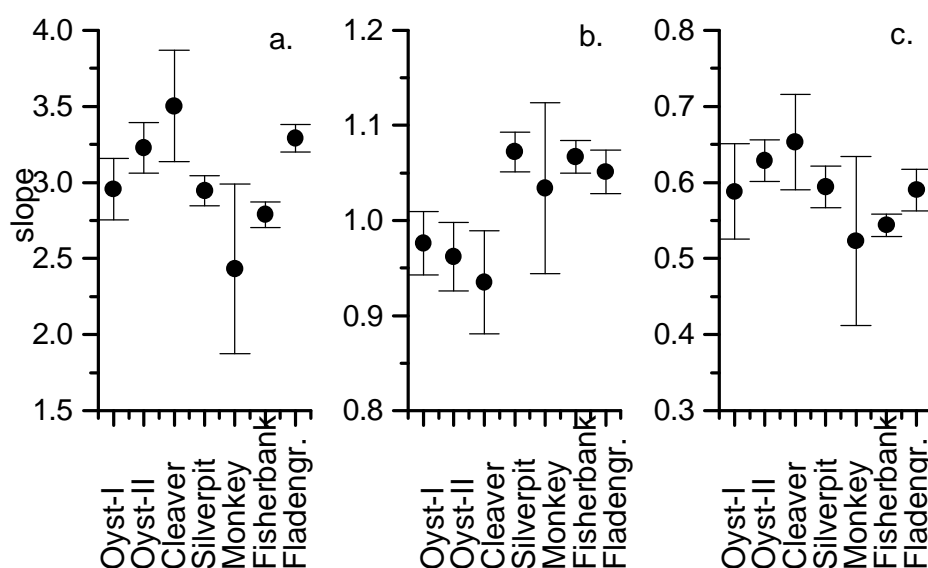


Figure 2.5. Morphological differences of 7 *Arctica* populations collected from the North Sea. Each graph gives the regression coefficient with the calculated comparison interval around it. If two intervals do not overlap, the coefficients differ significantly at $p < 0.05$. (a), Regression coefficients between Log(shell height) and Log (shell weight). (b), Regression coefficients between shell height and shell length. (c), Regression coefficients between shell height and doublet width. Oyst-I ($\sim 54^{\circ}22'$ N, $05^{\circ}40'E$), Oyst-II ($\sim 53^{\circ}52'N$, $04^{\circ}59'E$), Cleaver Bank ($\sim 54^{\circ}10'N$, $02-03'E$), Silverpit ($\sim 54^{\circ}08'N$, $02^{\circ}12' E$), Monkey Bank ($56^{\circ}30'N$, $06^{\circ}00'E$), Fisher Bank $\sim 57^{\circ}00'N$, $03^{\circ}30'E$), Fladen Ground from between $58^{\circ}40'-59^{\circ}20'N$, $00^{\circ}20'E$.

For each population these measurements were used for the establishment of a relationship between height & length, height & width and Log(height) & Log (weight). This relationship was determined by calculating the least square regression line and the difference between the regression coefficients was subsequently tested for significance by the calculation of T-comparison intervals around them (Gabriel's approximate method; Sokal & Rohlf, 1982). In this way the steepness of the slope,

describing the relationship between any of the measurements was tested. The coefficients are significantly different ($p < 0.05$) if, when presented in a graphical display, the intervals do not overlap.

The results are depicted in figure 2.5. The populations collected from the southern North Sea (Oyster-I, Oyster-II, Cleaver) separate from those from the central and northern North Sea (Monkey Bank, Fisher Bank and Fladen Ground), while *Arctica* from the Silverpit have an intermediate position. The separation between northern and southern North Sea is less clear when the relations between Log(height) and Log(weight) are compared (figure 2.5a), *i.e.* the regression coefficient derived for the Fladen Ground specimens differs significantly from the other populations of the northern North Sea but not from those of the Oyster Ground. The relatively smaller length compared to shell height for the Oyster Ground population (figure 2.5b) may have resulted from frequent damage of the post-ventral shell margin by passing bottom trawls (see chapter 6). Frequent damage of this area may have resulted in a truncation of that shell side and thus explain the different regression coefficients.

However, it is unlikely that all differences are due to the effects of fisheries. Signs of truncation or other deformations are rarely found within the populations from Fladen Ground, Fisher Bank, Monkey Bank or Silverpit while these populations differ significantly in respect to their relation of shell weight and height. Whether these differences are phenotypic or genetically determined remains unknown. This surely needs attention because it could imply reproductive isolation of *Arctica* populations even within the North Sea.

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