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Long-term trends on the effects of the southern North Sea beamtrawl fishery on the bivalve mollusc *Arctica islandica* L. (Mollusca, bivalvia)

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Arctica islandica has been used as an indicator organism for the intensity of bottom trawling in the southern North Sea. That this species is affected by beamtrawl fisheries is illustrated by the high incidence of damage found on shells from heavily fished areas.

Between 80 and 90% of the damage was found at the posterior ventral side of the shell. This can be explained by the orientation of the living animal in the upper sediment layer and the horizontal movement of the tickler chains on the bottom.

Scars on the external shell surface were dated by internal growth lines, revealing that the sampling site had been disturbed at least once a year since 1974.

The observed trends in the occurrence of scars per year show a striking coincidence with the increase in capacity of the Dutch fishing fleet over the period 1972–1991.

Key words: *Arctica islandica*, bottom fisheries, North Sea.

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Introduction

In the southern North Sea the most important fishing gear used is the beamtrawl (de Groot, 1973; Welleman, 1989). This gear consists of two sledges held apart by a beam to which the net is attached. In front of the net a variable number of tickler chains are present in order to increase the catch (de Groot, 1984; Creutzberg *et al.*, 1987; Fonds, 1991). A detailed description of the gear is given by Blom (1990).

Welleman (1989) gives a brief review of research carried out in the 1970s to describe the qualitative effects of trawling on the seabed. Since then, however, the Dutch fishing fleet has changed considerably. For example, engine power, beam width, gear weight, fishing speed, and the number of vessels (>300 HP) have increased (Welleman, 1989). These changes initiated a renewed interest in research on the effects of fishing gear on the seabed and benthos of the North Sea. Most of this present-day research focuses on short-term or direct effects, such as penetration depth of the tickler chains (Bergman and Hup, 1992), survival of by-catch (Bergman *et al.*, 1990; Bergman, 1992; Fonds *et al.*, 1992), or the change in sediment characteristics (Laban and Lindeboom, 1991).

Recent attempts to study long-term effects by comparing the fauna of "unfished" and fished areas are frustrated by the fact that even in these "unfished" areas trawl marks were found (Bergman, 1992). In the present paper preliminary results obtained from using *Arctica islandica* as an indicator of the long-term effects of fishing are presented.

Arctica islandica is a large bivalve mollusc which is widely distributed over the North Sea and northern Atlantic (Nicol, 1953). The animal lives buried in the sediment with its short siphons protruding from the sediment surface. It produces annual internal growth marks (Turekian *et al.*, 1982) which can be made visible and used for age determinations (Ropes, 1985). Some specimens grow very old. Ropes (1985) reported that 100-year-old specimens were frequently found in the population that he studied. Growth is rapid for the first 15 to 20 years, then it slows down markedly (Ropes, 1985; Witbaard and Duineveld, 1990).

Witbaard and Duineveld (1990) discussed the possible use of the annual growth marks of *Arctica* to evaluate the status of the benthic environment. The present study deals with such an application. Because repeated damage was regularly found, the question was raised if *Arctica islandica* could be used as an indicator species

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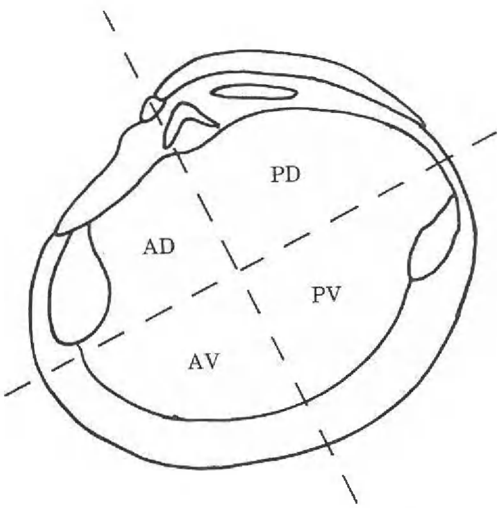


Figure 1. A right-hand valve of *Arctica islandica* subdivided in four equal-sized areas. The siphons are located at the post-ventral margin. This side is oriented upwards at the sediment water interface. PD, posterior dorsal; PV, posterior ventral; AD, anterior dorsal; AV, anterior ventral.

to study the effects of beamtrawling on the benthic environment.

The following aspects were considered:

1. Description of damage and damage patterns in *Arctica* shells, to see if there was any systematic pattern possibly caused by fisheries.
2. Dating of externally visible scars by using growth lines with the aim of estimating the frequency of the bottom disturbance and to try to relate this to any trend in fishing intensity.

Material and methods

Damage patterns

Between March and December 1991 about 1700 empty shells, both single valves and doublets ("doublet" meaning that of each shell at least the hinge part of both valves was present), were collected from 146 stations in the North Sea. These shells were analysed for the presence, degree, and position of damage. The stations were clustered into three areas, north-west North Sea, mid-west North Sea, and the south-east North Sea, to see whether regional differences in damage and damage patterns existed. For this analysis only "doublets" were used. Stations where no doublets were found were excluded from the analyses.

To study the position of the injuries the shell was divided into four areas of equal size: anterior dorsal, anterior ventral, posterior ventral, and posterior dorsal. The posterior ventral side is where the siphons are located (Fig. 1). Damage was assigned to one of the four categories according to the position of the major area of damage. Shells of which more than 50% was missing were treated as a separate group because the location of the damage could not be determined.

The relative size of damage of each shell (in per cent) was estimated to classify it into categories ranging from shells of which more than 50% was missing to undamaged. Scars originating from previous encounters were recorded separately. Main categories distinguished here were repaired cracks and a bulbous greyish thickening of the internal shell layers caused by the enclosure of sediment within the calcium carbonate.

Growth lines

On 4 October 1991 a sample of 52 living *Arctica* was collected from the catch of a commercial beam trawler at location 54°03′N, 06°18′E. After freezing to kill the animals, they were carefully cleaned. A drawing was made of each shell in which the position and size of scars were recorded. Observed scars were arranged into categories according to their position mentioned above. Then, the left-hand valves were embedded in epoxy resin (polypox, THV 500, harder 125) to facilitate further processing, i.e. sawing along mapped scars. The obtained sections were ground, polished, and etched in order to make acetate peels (Kennish *et al.*, 1980). These peels were photographed by means of light microscopy. Recognition and dating of the scars were done by comparing the drawings, photographs, and original shell sections.

Shell strength

The idea that shell strength is size-dependent was tested. The sample used was collected from the south-east

Table 1. Number of undamaged and damaged doublets for the three areas discerned. For each area the position of the outermost stations is given.

Area	No. of stations	Border positions: Longitude (east)	Border positions: Latitude (north)	No. of damaged doublets	No. of undamaged doublets
North-west North Sea	5	1°44′–3°69′	58°41′–59°24′	97	35
Mid-west North Sea	8	1°45′–3°00′	56°06′–57°31′	127	96
South-east North Sea	66	3°16′–6°00′	52°59′–54°59′	429	48

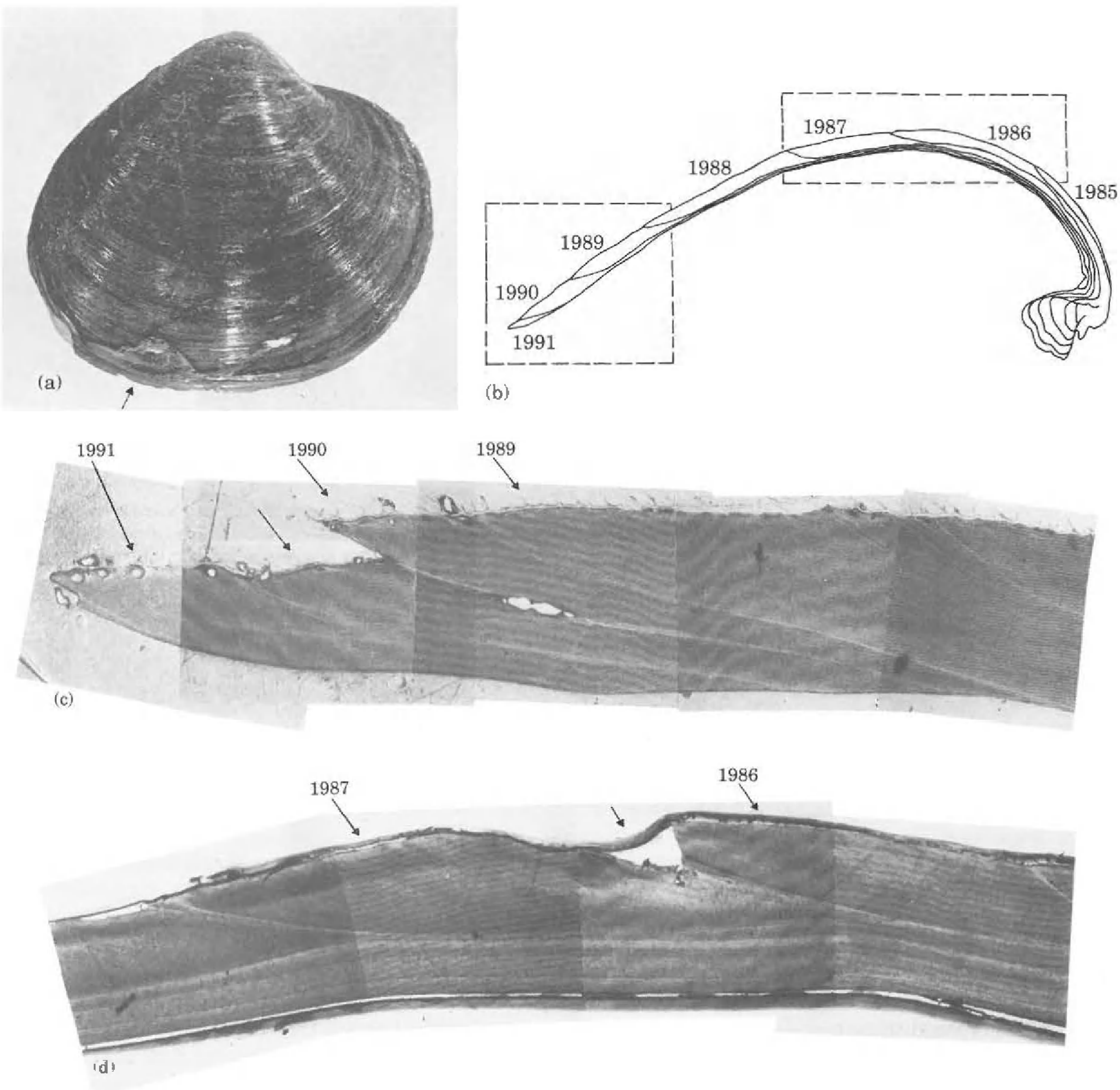


Figure 2. (a) The appearance of a scar on the external post-ventral shell side, together with two examples of the appearance in a cross section (acetate peel). (b) Schematic drawing of a cross section showing the outline of photos (c) and (d). (c) A clear dip in the shell is found, but no definite signs of a broken shell are visible. (d) The former shell margin has been broken (arrow).

North Sea at 53°52′N, 4°59′E. From the sample four groups were formed according to shell height. The shell heights within these groups were approximately 20, 40, 60, and 80 mm. After removal of the soft tissue, the shells were dried at room temperature for 1 week.

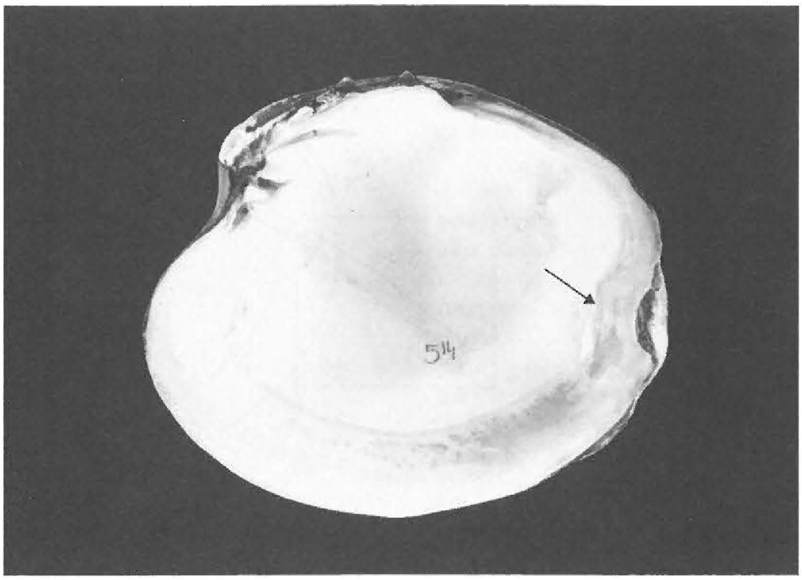
To estimate the shell strength the maximum force needed to crush a shell was recorded with an automated material testing system (Instron Corp. Series IX 1.04). The force was applied on a maximum of 0.8 mm^2 shell surface at the point of maximum valve convexity. The shell was kept in place by a piece of plasticine.

Results

Damage patterns

The ratio of undamaged to damaged doublets is given in Table 1. Only 10% of the empty doublets from the south-east North Sea were undamaged. In samples from the northern North Sea and mid-west North Sea about 40% were undamaged.

A similar trend was found when the amount of damage was expressed as a percentage of the missing shell material. The samples from the mid-west and



(a)

(b)

Figure 3. (a) Between the internal shell layers the greyish thickened ventral shell margin can be seen. Sand is enclosed in the shell. (b) The appearance in a cross section.

northern North Sea showed lower percentages of damage in the categories 5–25%, 25–50%, and >50% missing. The category <5% did not differ between areas studied.

In all geographical areas most damage was situated on the posterior ventral side of the shell. In the northern and mid-west North Sea this accounted for about 50%, while in the south-east North Sea 80% of the damage was found on the posterior ventral side. Other shell parts were less frequently damaged. Within the south-east North Sea only 15% of the damage was found at the anterior ventral side.

In both groups (shells caught empty and alive) about 90% of the scars were found on the posterior shell side.

Growth lines

Of the 52 shells collected, four showed ill-defined growth line patterns and so were excluded from further analyses. The sample consisted of at least three age groups: 11, 12, and 18 years old. Within the sample the number of shells older than 18 years was too small to define any age group. The oldest animal found was 33 years old, hence offering the possibility of back-dating to 1959. There was not a single specimen without scars. One 19-year-old animal had no less than eight scars. Figures 2 and 3 illustrate the appearance of scars in shell sections.

Two types were distinguished:

Type I. The former shell margin does not show any sign of breakage. Only soft tissue has been damaged which causes a depression in the shell surface that delineates pre- and post-damaged growth (Fig. 2c).

Type II. The former shell margin was demolished. Sometimes shell fragments clinging onto the shell were still present. Because the shell margin which supported the mantle was removed, post-damage growth was resumed at a lower level causing a dip in the shell. This dip may be visible over a prolonged growth interval (Fig. 2d).

Both types of injury often occur in combination with the enclosure of sand grains within the shell material (Fig. 3). Sometimes complete aggregations of sand are present. The periostracum may or may not be present over the injury.

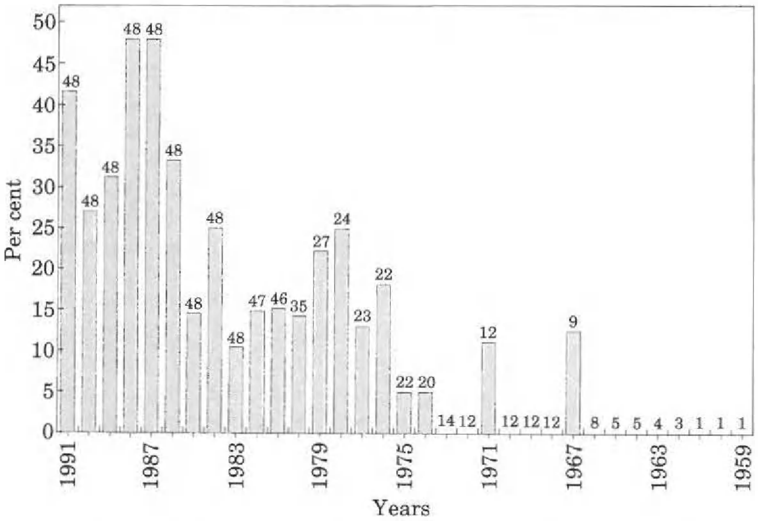


Figure 4. Occurrence of damage in *Arctica* shells for the period 1959–1991. Each bar represents the relative occurrence of scars (damaged increments) per year. The number of shells with a scar in a certain year is given as a percentage of all shells studied for that year. The total number of shells is given above each bar.

Figure 4 illustrates the frequency of scars (damaged increments) present in each year relative to the total number of shells studied for that year. Scars were found for all years between 1974 and 1991. For the period 1959–1973, damage was only found in 1967 and 1971. There was an upward tendency discernible in the occurrence of scars per year over the total time interval.

Abrupt increases can be recognized for the years 1976 and 1986. Mean values were calculated for the periods delimited by those years. For the period 1959–1975, 1976–1985, and 1986–1991, the means were 2.0% ($\pm$4.1), 17.3% ($\pm$5.1), and 38.2% ($\pm$8.9), respectively. All differences observed were significant (H-test, $p \leq 0.001$).

Shell strength

Figure 5 shows that shell strength increased with size. Mean force to crush shells from the smallest and largest categories was 300 ($\pm$64)N (kg m s^{-2}) and 800 ($\pm$345)N (kg m s^{-2}), respectively. Only the category with the smallest shells (20 mm) differed significantly from the other categories. The other categories did not differ from each other (H-test, $p \leq 0.05$).

Discussion

Direct evidence that *Arctica islandica* was influenced by fisheries came from Fonds (1991), Fonds *et al.* (1992), and our own observations. Fonds (1991) reported that up to 90% of *Arctica* caught by a commercial trawler were severely damaged. His estimate for mortality of these shells ranged from 74 to 90%. He demonstrated that shells are damaged on board as well during the process of fishing. Both the number of damaged shells and the total number of shells caught increases when tickler chains are used. The mean number of damaged shells was 74% with ticklers versus 27% without (Fonds, 1991).

The destructive effect of bottom trawling is also illustrated by the low numbers of undamaged shells found in the heavily fished south-east North Sea. In more northern areas about four times as many undamaged shells were found (Table 1).

Estimates for the penetration depth of the tickler chains vary depending on bottom type (Welleman, 1989). Such estimates have been based on direct experimental evidence (Margetts and Bridger, 1971; Bridger, 1972), as well as on the occurrence of certain infaunal species in the catch. Bergman and Hup (1992) estimated in this way a penetration depth of 6 cm in hard sand. Stones can be dug out by ticker chains (Bridger, 1970; Margetts and Bridger, 1971), so *Arctica* may be dug out in the similar way.

Such observations illustrate the vulnerability of *Arctica* to bottom trawling. Even tickler chains moving only over the sediment surface can explain the damage pattern observed. This is illustrated by the high percentage of posterior ventral damages (siphon side) found in our data.

Caddy (1968) observed that sand was forced into the shell of *Placopecten magelanicus* by the passage of a dredge. The greyish thickening (sand enclosures in the calcium carbonate) found in *Arctica* shells may be explained by a similar process; in this case, possibly caused by the passage of a trawl.

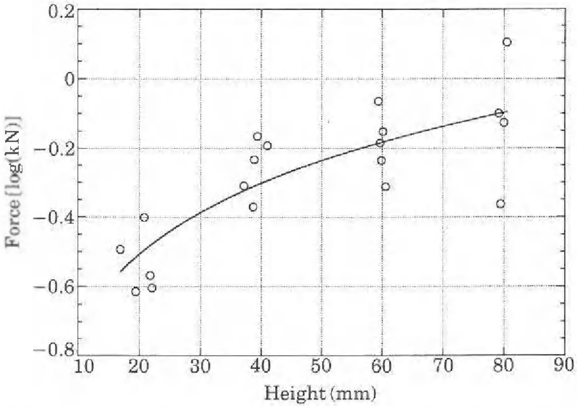


Figure 5. The relation between shell height and the force needed to crush it. Through the points a logarithmic regression is fitted; $y = -1.4 + 0.7 \log(x)$ $r = 0.8$ ($p < 0.05$).

Abrupt physical disturbances, for instance temperature, may cause damage patterns comparable to those caused by fisheries (Ropes *et al.*, 1984). There is, however, very little current reasearch on this topic (Anon., 1992a), and therefore it is difficult to estimate its significance. The physical disturbances mentioned above cause growth interruptions over the whole shell (Kennish, 1980), while damage caused by fisheries can be distinguished by its local character and mainly posterior position.

Predators may also damage *Arctica* shells, but it is unrealistic to assume that damage by, for instance, lobsters can explain the mass occurrence of damaged shells in the south-east North Sea. Despite its near absence in this area a lobster (*Homarus americanus*) could only open about 7-cm-high *Arctica* shells after series of repeated trials (own observation). Arntz and Weber (1970) also demonstrated that cod (from the Baltic) were not able to crush *Arctica* shells larger than 4 cm. Because *Arctica* from the North Sea have thicker shells than those from the Baltic a great impact by cod in the North Sea is not expected.

Bottom-trawl activities may be reflected in the age–frequency distribution of the *Arctica* population. In the south-east North Sea juvenile shells (1–4 cm high) are rarely found, while spat (1–2 mm high) and full-grown shells (6–7 cm high) are more regularly found (our own observations). This odd-size distribution can be explained by the difference in shell strength as presented in Figure 5 which shows that large shells can resist higher forces than small shells. The results found by Rumohr and Krost (1992), however, suggest a contradictory effect of an otter trawl. They found higher percentages of damaged shells with increasing shell size. It is not known whether this has to do with any specific action of the otter trawl. What actually happens in the field is hard to estimate. Factors like sediment type, total shell surface, surface of impact, burrowing depth, and tickler chain penetration into the sediment all play a role.

The observed increase in the occurrence of scars since 1972 may be explained by developments in the fishing fleet initiated by the European policy on fisheries. This policy aimed at the improvement of the economic position of the fisheries. Despite measures that have been taken since the early eighties to limit the overall fishing capacity, the result has been a net increase of this capacity (Anon., 1992b).

This was caused by both structural changes within the fishing fleet and the gear used. In the period 1972–1990 total engine power of the Dutch beamtrawl fleet increased from approximately 250×10^3 to 600×10^3 HP (Anon., 1991), which was mainly caused by the increase of the number of vessels larger than 1500 HP. These structural changes have led to higher fishing speeds, a wider range of action, and qualitative changes of the fishing gear (larger beam width and gear weights). The pattern observed in Figure 4 may be a reflection of these general changes. Whether the increase in occurrence of scars per year is caused by the overall increase of fishing capacity or a redistribution of the fishing fleet in space and time cannot be said. Known estimates for the above-mentioned redistribution concern ICES quadrants (areas of approximately 3400 km^2), while the results presented in Figure 4 concern processes of a local scale.

Rijnsdorp *et al.* (1991) described that within an ICES quadrant the fishing intensity may be heterogeneously distributed. However, time series of the distribution of fishing effort on these local scales are lacking.

Dating scars in *Arctica* may be a possible way to reconstruct such time series. Figure 4 shows, for instance, that the study site has been trawled each year since 1974.

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