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Tree of the sea

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CHAPTER 6[*]

The effects of southern North Sea beam trawl fishery on the bivalve mollusc *Arctica islandica* L. (Mollusca, Bivalvia)

R. Witbaard & R. Klein

This chapter is based on;

Witbaard R. & R. Klein, 1993. A new a approach in studying the long-term effects of bottom trawling. ICES CM 1993/K16: 8pp.; Witbaard, R. & R. Klein, 1994. Long-term trends on the effects of southern North Sea beam trawl fishery on the bivalve mollusc *Arctica islandica* L. (Mollusca, Bivalvia). ICES J. Mar. Sci., 51: 99-105; Klein, R. & R. Witbaard, 1995. Long-term trends in the effects of beam trawl fishery on the shells of *Arctica islandica*. NIOZ rapport 1995-3: 15pp.

ABSTRACT

Arctica islandica has been used as an indicator organism for the intensity of bottom trawl fishery in the southern North Sea. That this species is affected by beam trawl fisheries is illustrated by the high incidence of damage found on shells from heavily fished areas whereas these numbers are lower in less intensively fished areas.

The inventory of damage patterns demonstrated that damage and scars were evenly distributed over both valves.

Between 80 and 90% of the damage and scars were 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.

According to literature the percentage of damaged North Sea shells was above what could be expected on basis of natural scar frequencies. A comparison of the average number of scars per shell was made between samples from the south-eastern North Sea and samples collected off Nova Scotia (Canada). Whereas only 2% of the North Sea shells was without scars about 40% of the Canadian shells was without damage.

Scars on the external shell surface were dated by internal growth lines, revealing that all sampling sites had been disturbed at least once a year since 1970.

Logit regression showed that the observed trends could be the effect of fishing. The average number of scars for all samples show s a striking coincidence with the change in capacity of the Dutch fishing fleet over the last 20 years.

INTRODUCTION

In the southern North Sea the most important fishing gear used is the beam trawl (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 is 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 effects of trawling on the sea bed qualitatively. However, since then 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 focusses on short-term or direct effects, such as penetration depth of the tickler chains (Bergman & Hup, 1992), survival of by-catch (Bergman *et al.*, 1990; Bergman, 1992; Fonds *et al.*, 1992) or the change in sediment characteristics (Laban & 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). It can furthermore be argued that present day benthic communities already are impoverished by the repeated disturbance associated with the fishing activities. These communities will already have reached a new equilibrium state from which the fragile and sensitive species have disappeared. Thus it can be questioned if such approach could reveal the effects of fisheries. Therefore a method was developed (Witbaard & Klein, 1993) in which above-mentioned problems are avoided. The long-term trends of the effects of beam trawling on *Arctica islandica* were assessed by using the internal growth lines. *Arctica islandica* is a large bivalve mollusc which is widely distributed over the North Sea and northern Atlantic (chapter 2). The animal lives buried in the sediment with its short siphons protruding from the sediment surface (figure 6.1).

It produces annual internal growth marks (chapter 2) which can be made visible and used for age determinations (Ropes, 1985). Because the growth of an increment is related to environmental conditions, successive increments can reflect environmental change in time. Witbaard & Duineveld (1990) for instance discussed such application of the annual growth marks of *Arctica* to evaluate the status of the benthic environment in the North Sea.

In the same way repetitive non-lethal shell damage, due to beam trawl fishery, could lead to a scar-record that reflects the distribution of the beam trawl fishery through time and space. The use of *Arctica* in such way is especially interesting since longevity surpasses 100 years and thus may offer possibilities to assess man's impact during the last century. The present study deals with this aspect. It was questioned whether *Arctica islandica* could be used as an indicator species to study the long-term effects of beam trawling on the benthic environment. The following aspects were considered:

- Description of damage and damage patterns in *Arctica* shells, to see if there is any systematic pattern possibly caused by fisheries.
- Dating of externally visible scars by using the internal growth lines with the aim to estimate the frequency of the bottom disturbance.
- Relate the observed trends to any trend in fishing intensity.

Figure 6.1

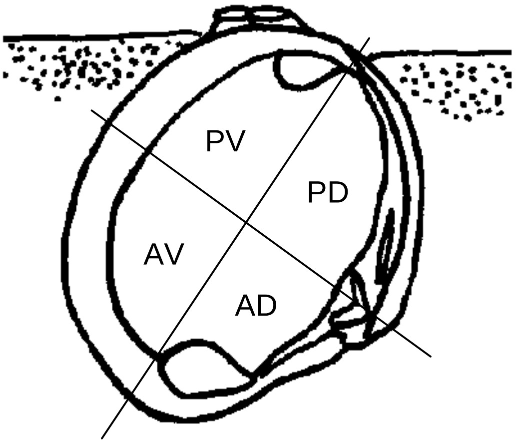

Figure 6.1. Normal orientation of *Arctica* buried in the sediment. Subdivision of a left-hand valve into four equally sized areas indicated by crossing lines. Abbreviations; AD = anterior dorsal, AV = anterior ventral, PV = posterior ventral and PD = posterior dorsal.

MATERIAL AND METHODS

Damage patterns in empty shells

Between March and December 1991 over 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 analyzed 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 (table 6.1), 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 (AD), anterior ventral (AV), posterior ventral (PV) and posterior dorsal (PD). The posterior ventral side is where the siphons are located (figure 6.1). Damage was assigned to one of these 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.

Table 6.1

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

Table 6.1. Number of undamaged and damaged doublets for the three areas described in the text. For each area the position of the outermost stations is given. The last two collumns give the number of recently damaged empty doublets and the number of complete empty doublets. Scars were not seen as recent damage.

The relative size of damage of each shell (in percentage) 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 grayish* thickening of the internal shell layers caused by the enclosure of sediment within the calcium carbonate.

Shell strength

Small *Arctica* are almost lacking in the populations from the south-east North Sea (chapter 2). Such population structure may be related to a size specific difference in sensitivity to bottom trawling. Therefore the size dependence of shell strength was tested. The sample used was collected from the south-east North Sea at 53°52'N, 04°59'E (sample 3, table 6.2). 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 one week.

Shell strength was measured as the maximum force needed to crush a shell and 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.

Scar Trend Determination

Four samples from the North Sea (table 6.2) were used for Scar Trend Determination (STD). In September 1993 sample 1 and 2 were collected during the IMPACT I program (EC FAR MA 2-549) from two different locations in the south-east North Sea. During this cruise the R.V. "Tridens" was equipped with a commercial 12 m beam trawl. Sample 3 was collected with R.V. "Aurelia" in March 1991 by using a fine meshed 5.5 m beam trawl. Sample 4 was collected with a commercial trawler on 4 October 1991. Shell samples were frozen on board.

Of each sample approximately 50 of the smallest specimens were selected for STD since larger *Arctica* are more difficult to analyze. After thawing, soft tissue was carefully removed and the shells were dried at room temperature.

Table 6.2

Area	Sample	No. of stations	No. of shells	Latitude	Longitude
North Sea	1	1	42	54°22'N	04°51'E
North Sea	2	1	42	54°42'N	04°49'E
North Sea	3	4	50	53°52'N	04°59'E
North Sea	4	1	48	54°03'N	06°18'E
Canada	5	1	10	43°29'N	61°44'W
Canada	6	1	12	43°30'N	65°30'W
Canada	7	1	20	43°29'N	65°28'W

Table 6.2. Sampling details of the shells used in STD. Sample 3 is a composite sample of specimens collected at four locations around the position given.

Of each shell a drawing was made in which the position and size of scars was recorded. Observed scars were arranged into categories according to their position (AD, AV, PD, PV) as 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. If the scars were not symmetrically distributed over both valves the right-hand valve was also included in the analyses. This procedure resulted in the preparation of several sections per shell.

Each section was ground, polished and etched in order to make acetate peels (Kennish *et al.*, 1980). These peels were photographed by means of light microscopy. Recognition of the scars was done by comparing the drawings, photos and original shell sections. Because the shell grows by annual accretion of an increment, it was possible to assign a year to each increment. Each damaged increment was subsequently marked with the year in which it was found. In this way a chronology of the occurrence of scars for each shell was obtained. The long-term trend in scar frequency was determined by counting the scars for every year in all shells of the entire sample. For comparison, these frequencies were expressed as percentage of the total number of shells that accounted for that year.

In addition to these four North Sea samples, three samples collected from Nova Scotia at the Canadian east coast (sample 5-7; table 6.2) were analyzed on the presence of externally visible scars. Scars were not dated as described above. These samples served as a reference to estimate natural scar frequencies, since there is, except for some scalloping, no commercial fishing in the area from where they were collected (D. Gordon, pers. communication).

Statistical analyses

The scar frequencies are obtained by summing scar/year occurrences of all individuals in each sample. In these summations different aged animals are equally judged. If the occurrence of a scar is exclusively related to bottom fisheries and not to the size of the animal, the observed long-term trend in the occurrence of scars in a sample would be a direct reflection of the fishing effort. In this context one can speak of a *year* related effect. If there is a size or age dependent difference in survival or repair of the damage, the observed time trends can be influenced by the age composition of the samples. Such effects are referred to as an *age* related effect. It neither can be excluded that an interaction between such *age* and *year* related effect exists.

Logit regression (Jongman *et al.*, 1987; Crawley, 1993) was used to decide which of above factors most likely caused the observed long-term trend in scar frequencies. In logit regression a response model is fitted which describes the probability of occurrence of, in this case, a scar being dependent on *age*, *year* or both factors. The model fits are made according to the maximum likelihood principle in which the residual deviance is used to evaluate the model fit. It is tried to minimize this deviance. For the application here, four models have been fitted. The null model describes a common probability of all observations and is based on one parameter. The other models include either the effects of *year*, *age* or both. The difference in deviance between the null model and any of the other models is used to test its significance, *i.e.*

to determine which of the variables (*age*, *year* or both) resulted in a better fit, expressed as a decrease in deviance.

RESULTS

Damage patterns in empty shells

The regional differences in the ratio of undamaged to damaged doublets is given in table 6.1. 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 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.

Comparison of the left and right hand valves showed that damage was equally divided over both valves. In all three 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 82% of the damage was found on the posterior ventral side (figure 6.2). Other shell parts were less frequently damaged. Within the south-east North Sea only 13% of the damage was found at the anterior ventral side. Similarly is in both groups of shells (caught empty and living) about 90% of the scars positioned on the posterior shell side.

Figure 6.2

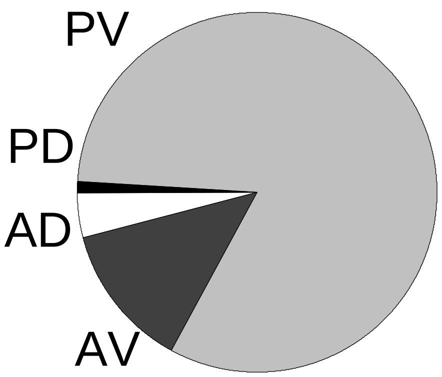

Figure 6.2. Relative proportion of positioned damage in dead shells collected from the south-east North Sea. Abbreviations explained in text and figure 6.1.

Shell strength

Figure 6.3 shows that shell strength increases with size. Mean forces to crush shells from the smallest and largest categories was 300 (±64) N (Kg.m.s^{-2}) and 800 (±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, $p < 0.05$).

Figure 6.3

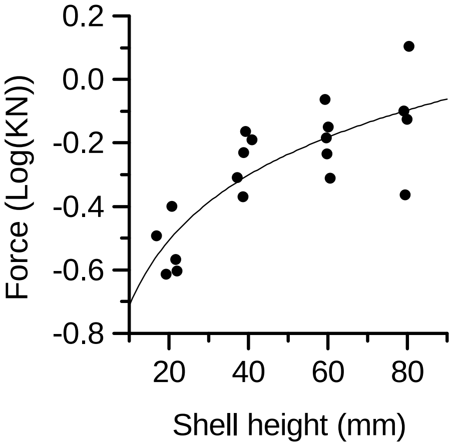

Figure 6.3. The relation between shell height and the force needed to crush it. Through the points a logarithmic regression is fitted; $y=-1.4+0.7\text{Log}(x)$. $r=0.8$ ($p<0.05$). Force in Log(kN) and shell height in mm.

Scar trend determination

A total of 182 shells, almost equally divided over the four samples, was analyzed in STD. Size distribution and number of scars per shell for these samples and the samples from the Canadian east coast is given in figure 6.4. The low number of large shells shows that small shells were preferred in the analyses and does not represent the population size distribution. The figure illustrates that the number of scars/shell does not bear a relation with shell height. The maximum number of scars found on one specimen was 15 (sample 2) and only 3 shells from sample 2 did not have recognizable scars. The average number of scars per shell for the North Sea samples was 4.4 (±0.7). The Canadian shells have a much lower scar frequency of 1.2 (± 0.9). The percentage of shells without scars in the Canadian samples is about 42% whereas only 2% of the North Sea shells were without scars.

The oldest animal used for STD originated from sample 3 and had an age of 80 years, hence offering the possibility to backdate to 1912. Specimens in the other samples were much younger, not extending any further than 1960 or 1950.

Figure 6.4

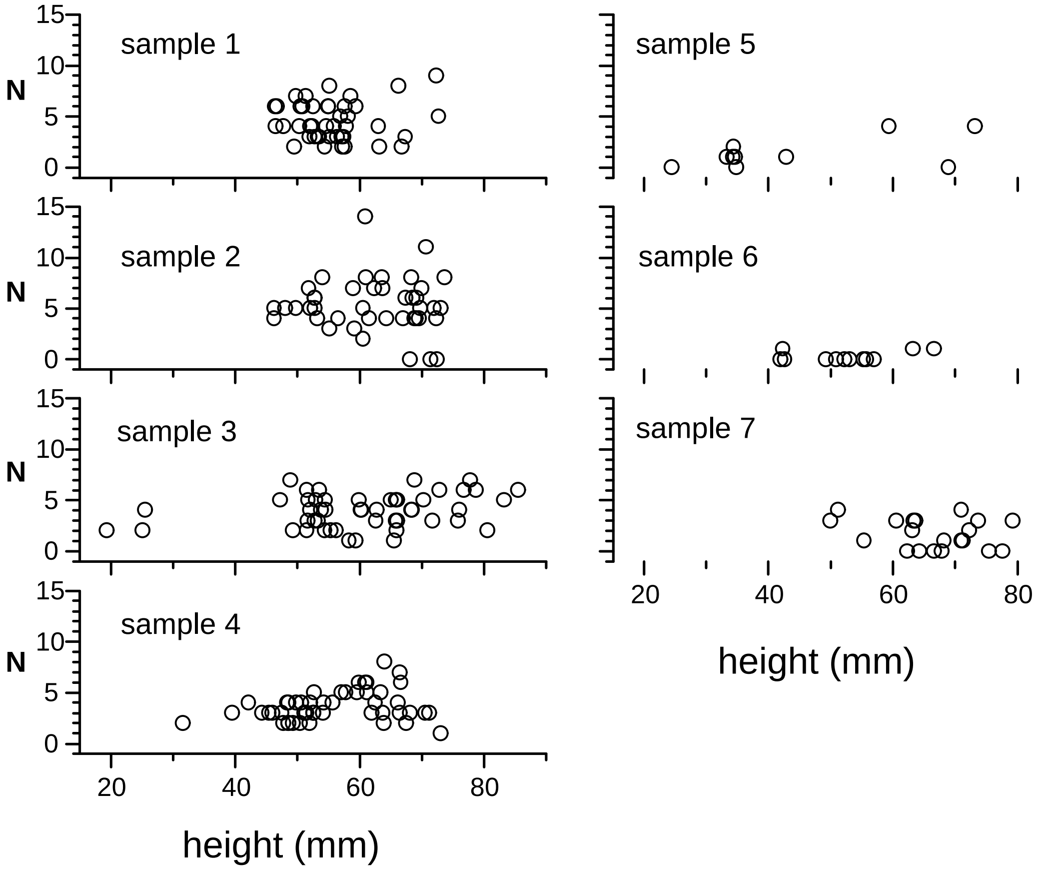

Figure 6.4. Number of scars per shell. For each shell of a certain size (horizontal axis) the total number of scars (N) is given on the vertical axis. Samples 1 to 4 were used in STD and originated from the North Sea. Samples 5, 6 and 7 originated from the east Canadian coast.

Growth lines

Figures 6.5 and 6.6 illustrate the appearance of damage in shell cross 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-damage growth (figure 6.5c).
- 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 is resumed at a lower level causing a dip in the shell. This dip may be visible over a prolonged growth interval (figure 6.5d).

Both types of injury often occur in combination with the enclosure of sand grains within the shell material (figure 6.6). Sometimes complete aggregations of sand are present. The periostracum may or may not be present over the injury.

Figure 6.5

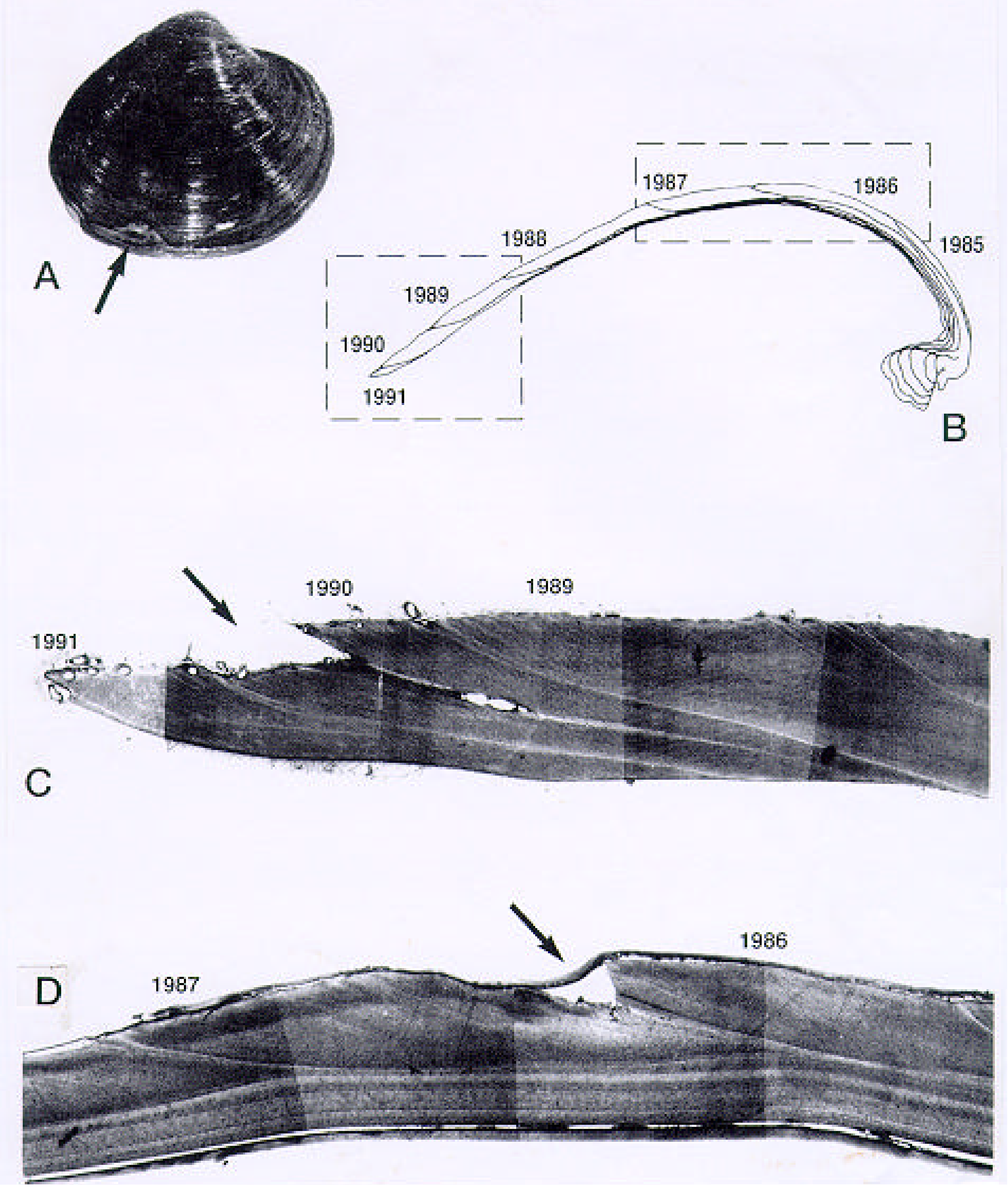

Figure 6.5. The appearance of scars on the external shell surface and in cross-section. (A), The arrow indicates an old, but repaired injury. (B), Schematic drawing of a cross section showing the outline of photos C and D. (C), A clear dip in the shell is found, but no definite signs of a broken margin are visible. (D), A clear dip in the shell surface is visible.

Figure 6.6

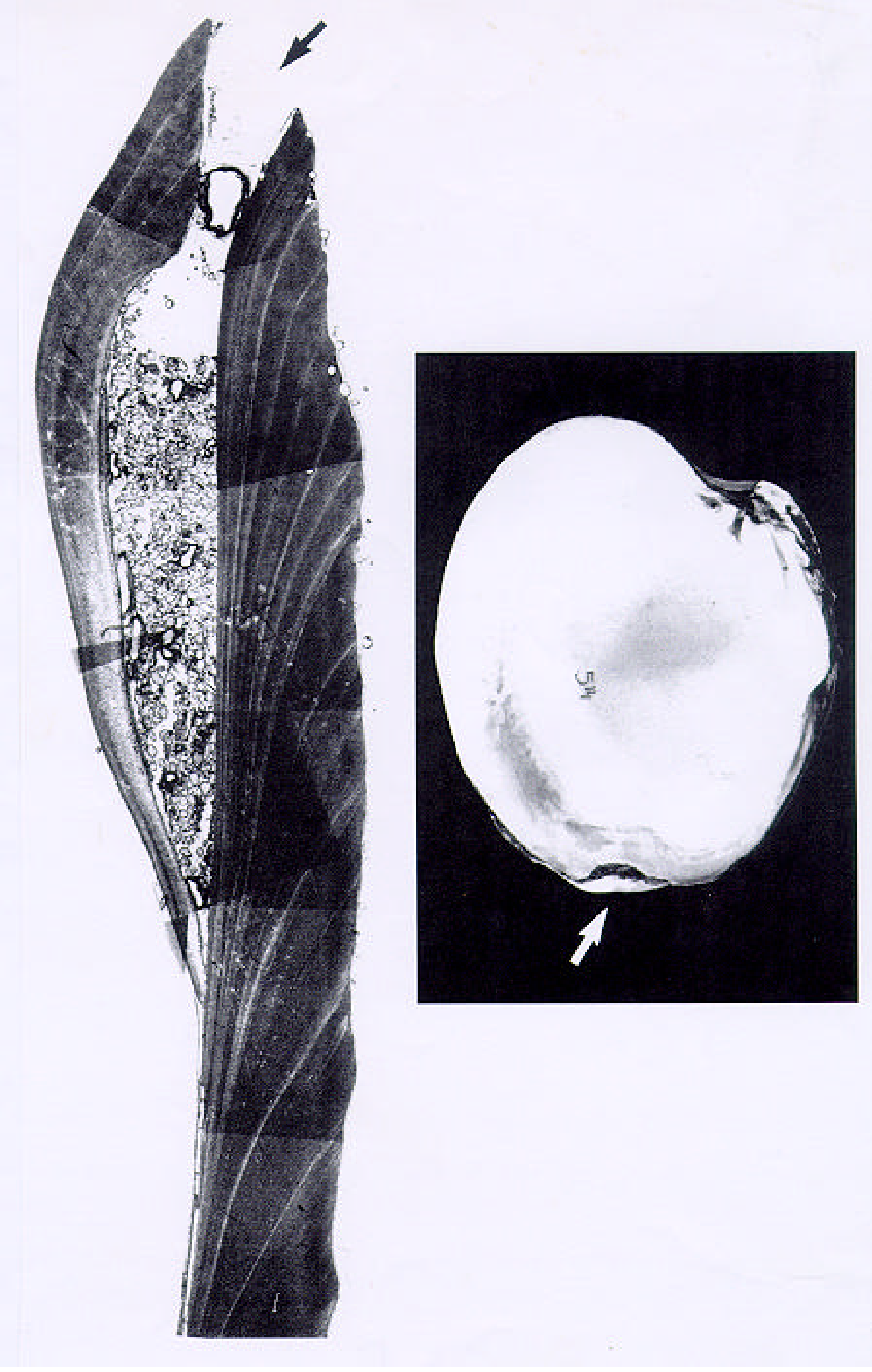

Figure 6.6. Inside view of a right hand valve with cross-section of the posterior part. The greyish thickening of the post ventral margin is caused by the enclosure of sand grains within the calcium carbonate. This is clearly illustrated in the cross-section.

Figure 6.7

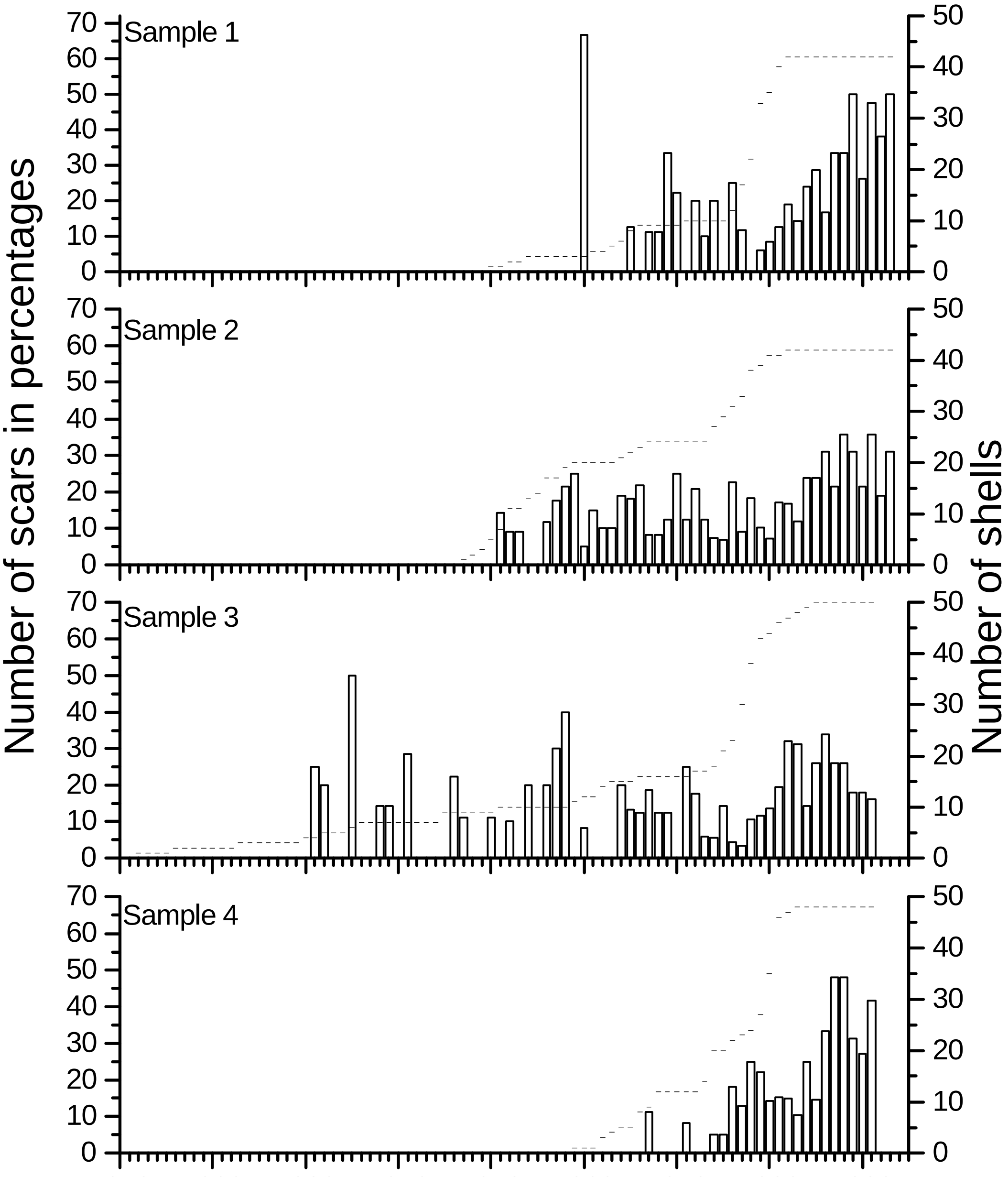

Figure 6.7. Frequency of scars on *Arctica* shells from the samples from the North Sea (Sample 1-4). Each bar represents the relative occurrence of scars (damaged and repaired increments) per year. The number of shells with a scar in a certain year is given as a percentage of all shells studies. The total number of shells studied for every year is illustrated by the horizontal dashed line.

Figure 6.7 illustrates for the four North Sea samples the frequency of scars (damaged increments) present in each year relative to the total number of shells studied for that year. It is obvious that scars are present throughout the time series back to 1931. In all samples at least one scar in every year was found since the late 1970s. Maximum scar/shell ratios in the most recent period for samples 1, 2, 3 and 4 are 0.50, 0.36, 0.34 and 0.48 respectively. Except for sample 2 do all collections suggest more frequent damage since the mid 1970s. Before that period certain years were without scars. All samples show roughly the same trend of a rapid increase in damage in the 1980s with a slight decrease in most recent years. The similarity of the observed trends in each of the samples has been compared in table 6.3 for the period since 1977. Except for sample 3 are all other combinations positively correlated with each other.

Table 6.3

	Sample 1	Sample 2	Sample 3	Sample 4	Engine power
Sample 1	16	16	14	14	15
Sample 2	* 0.757	16	14	14	15
Sample 3	0.190	0.297	14	14	14
Sample 4	* 0.592	** 0.692	0.084	14	14
Engine power	**0.763	** 0.712	* 0.612	* 0.515	15

Table 6.3. Correlation of the average scar-trends in the four samples since 1977 (≥ 20 shells/year). For each correlated pair the number of overlapping years and the correlation coefficients are given. In the last row the correlation coefficients between the annual average number of scars and the capacity of the fishing fleet (in HP) is made. * indicates significant at p<0.05; ** indicates significant at p<0.01.

In sample 4 a more or less abrupt increase in the percentage damaged shells 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% (± 4.1), 17.3% (± 5.1) and 38.2% (± 8.9) respectively. All differences observed were significant (H-test, P≤ 0.001).

The statistical analyses to decide upon the most likely cause (*age*, *year* or both) of the observed trends is summarized in table 6.4. For each of the samples a comparison is made between the *age*-, *year*- and the combined model with the null model. All three models appeared to have a good fit and led to a significant reduction of the scaled deviance when compared to the null model. For samples 2, 3 and 4, the reduction in deviance for the *age* model is slightly larger than for the *year* model. Only in sample 1 this trend is opposite. The combination model (*age* + *year*) gives in all cases the greatest reduction in deviance. Presented results suggest that both *age* and *year* effectively explain the observed trends. The slightly larger *age* effect in three of the samples may indicate a size dependent effect on either survival, repair or recognition of the scars. The observation that the combined model gives the highest reduction in scaled deviance may illustrate that both the age of the animal at the moment the scars were formed as well as the year in which the scars were formed could have had its effect on the observed frequencies.

Table 6.4

Sample	Number (n)	Model type	Scaled Deviance(sD)	Degrees freedom	$^{**}G^2$ (sDa-sDb)	v (dfa-dfb)	p
1	42	null model	876.0	797	-	-	-
		age model	770.2	754	105.8	43.0	<0.001
		year model	754.2	754	121.8	43.0	<0.001
		combined	685.6	711	190.4	86.0	<0.001
2	42	null model	1166.1	1233	-	-	-
		age model	1052.7	1187	113.4	46.0	<0.001
		year model	1092.3	1187	73.8	46.0	<0.01
		combined	973.6	1141	192.5	92.0	<0.001
3	50	null model	1096.0	1269	-	-	-
		age model	913.1	1190	182.9	79.0	<0.001
		year model	956.4	1190	139.6	79.0	<0.001
		combined	794.8	1111	301.2	158.0	«0.01*
4	48	null model	837.0	787	-	-	-
		age model	727.3	755	109.8	32.0	<0.001
		year model	736.7	755	100.3	32.0	<0.001
		combined	665.9	723	171.1	64.0	<0.001

Table 6.4. Summary of the results of the logit regression. For each sample the number of shells, the tested models, the scaled deviance of the tested model and its difference to the deviance of the null model is given. The significance of the decrease in deviance by the addition of a *year, age* or *year + age* effect is summarized in the last column (p).

DISCUSSION

There are several observations which suggest that *Arctica* is negatively affected by bottom trawling. A comparison of relative densities during the seventies compared to such estimates made between 1990 and 1993 suggest a decrease in abundance (chapter 2). The mortality rate in the south-east North Sea (Oyster Ground) also seems to be higher than that in the northern North Sea or western Atlantic (chapter 2). 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 whereas in more northern areas about four times as many undamaged shells are found (table 6.1). Direct evidence that *Arctica islandica* is indeed 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 as 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).

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 & Bridger, 1971; Bridger, 1972) as well as on the occurrence of certain infaunal species in the catch. Bergman & 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, 1971), so *Arctica* may be dug out in a similar way.

Such observations illustrate the vulnerability of *Arctica* to bottom trawling. Even ticklers only moving over the sediment surface can explain the damage pattern of a high percentage of posterior ventral damage (siphon side). The cumulative long-term effect of damage on that shell side might explain the relative shorter shell length to shell height in the shells from the Oyster Ground as reported in chapter 2.

Caddy (1968) observed that sand was forced into the shell of *Placopecten magelanicus* by the passage of a dredge. The grayish thickening (figure 6.6), caused by sand enclosures within the calcium carbonate, found in *Arctica* shells may be explained by similar process; in this case, possibly caused by the passage of a trawl.

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 research on this topic (Anon., 1992a), and therefore it is difficult to estimate its significance. It is furthermore unlikely that such abrupt events occur in the subtidal environment sampled. 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 the question is raised which predator in the south-east North Sea utilizes full grown *Arctica* shells. 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 a 7 cm-high *Arctica* shell after series of repeated trials (own observation). If the lobster succeeded the fractures made were differently positioned and shaped, compared to those found in dead shells from the Oyster Ground. Arntz & Weber (1970) also demonstrated that cod (from the Baltic) was 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.

The average number of scars in the Canadian shells compare well with the literature value for natural scar frequencies of 1.6. A maximum of 4 scars per individual is considered to be high and the number of damaged shells scarcely exceed 50% (Miller, 1983; Vermeij *et al*., 1981; Vermeij, 1983; Schmidt, 1988; Vale & Rex, 1988). The average frequency of scars in North Sea shells is much higher compared to these figures or to the Canadian samples, underlining that the North Sea specimens have a higher damage frequency than can be expected on basis of natural causes.

The age-frequency distribution of the *Arctica* population may be a reflection of a size dependent effect of bottom trawling. In the south-east North Sea juvenile shells (1-3 cm high) are rarely found, while spat (zero age group; 1-7.5 mm high) and full-grown shells (>5 cm high) are more regularly found (chapter 2). This odd size distribution can be explained by the difference in shell strength as presented in figure 6.3. The figure shows that large shells can resist higher forces than small shells; thus fishing mortality for juvenile shells is probably higher. The results found by Rumohr & Krost (1992), however, suggest a contradictory effect of an otter trawl. They found higher percentages of damaged shells with increasing shell size. It is unknown 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.

Link with fisheries

The observed increase in the occurrence of scars can be explained by developments in the fishing fleet which were 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 1980s 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 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 changes have led to higher fishing speeds, a wider range of action and qualitative changes of the fishing gear. The resulting change in temporal and spatial distribution of the Dutch beam trawl fleet is however poorly documented, *i.e.* in variable units, irregularly and until recently for whole ICES rectangles only. Because the results of this study represent disturbance on a much smaller scale, it is difficult to relate the observed long-term trends in scar occurrence exactly to changes of fishing intensity at sea.

The composition of the Dutch fleet in terms of engine power is, however, well documented (Anon., 1992b) and this measure was therefore used in a preliminary comparison with the results presented here. It is likely that the fishing intensity at any site somehow reflects the developments in the total capacity of the fleet. Increased engine power which resulted in heavier gears, wider beams and higher fishing speeds will have led to a greater destructive action and an increased bottom surface being fished. Thus even at a constant number of trawlers in a certain area this will result in a net increase in fishing intensity.

Figure 6.8

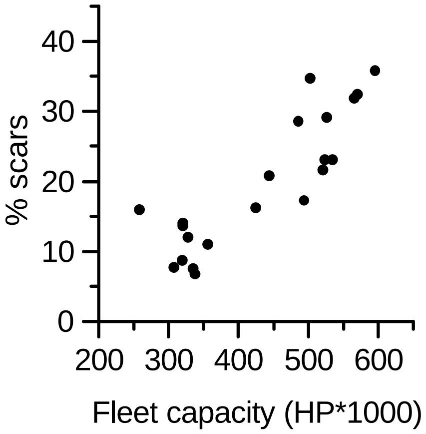

Figure 6.8. Graphical display of the correlation between the average scar incidence (all four samples) and the developments in the Dutch beam trawl fleet expressed as engine power.

The statistical analyses demonstrated that the STD patterns (figure 6.6) indeed may be the result of a *year* c.q. fishery related effect and the scar trends for all four stations were significantly correlated with the overall increase of fishing capacity (table 6.3). Figure 6.8 illustrates this relationship and suggests that the average number of scars is a reflection of the fishing effort. Whether the observed patterns in STD are a reflection of the change in qualitative characteristics 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 6.3 concern processes at a local scale.

Not until recently, knowledge about fishing intensity on such local scales was lacking. However, in 1991 Rijnsdorp *et al*. demonstrated that within an ICES quadrant the distribution of the fishing fleet may be very heterogeneous. Such detailed information is lacking for the period in which greatest changes within the Dutch fishing fleet took place. Dating the scars in the shells of *Arctica islandica* may however, give insight in small-scaled spatial distribution of the fishing fleet in the past.

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