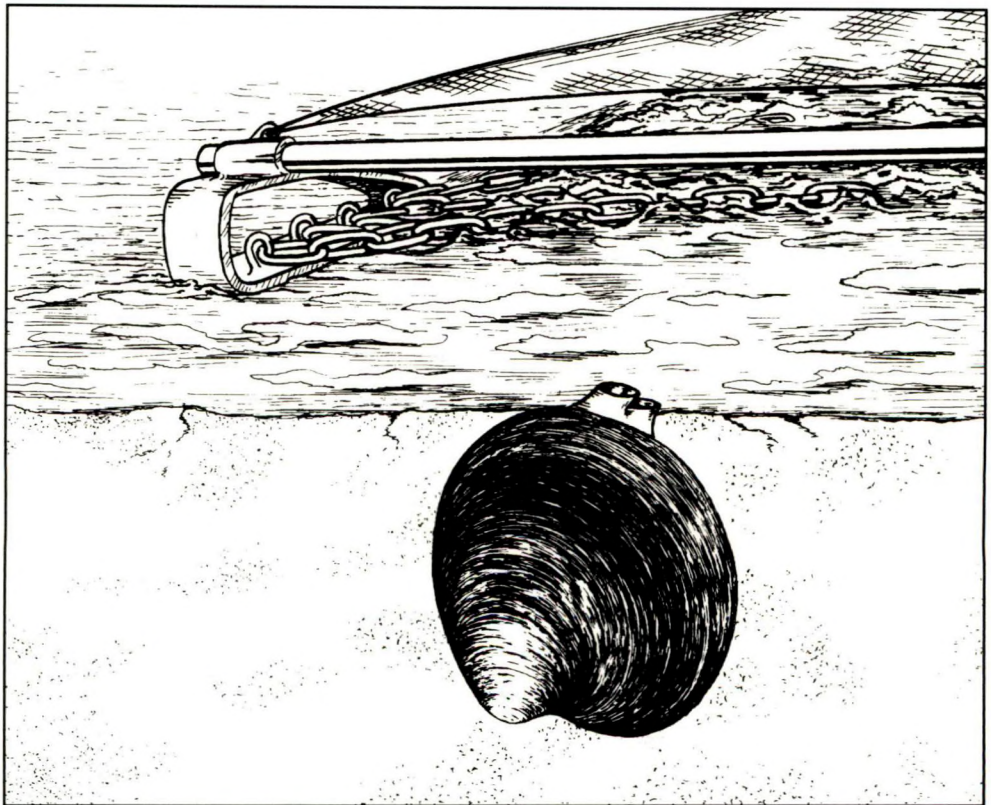


**LONG-TERM TRENDS IN THE EFFECTS OF BEAMTRAWL
FISHERY ON THE SHELLS OF *ARCTICA ISLANDICA***

R. Klein, R. Witbaard



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Beleidsgericht Wetenschappelijk Onderzoek NIOZ (BEWON)

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P.O. Box 59, 1790 AB Den Burg, Texel
The Netherlands

ISSN 0923 - 3210

Cover design: H. Hobbelink

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This study has been carried out with financial assistance from the commission of the European Communities.

NETHERLANDS INSTITUTE FOR SEA RESEARCH

Beleidsgericht Wetenschappelijk Onderzoek NIOZ (BEWON)

ABSTRACT

De lange termijn trends in het optreden van littekens op de schelpen van *Arctica islandica* afkomstig van de zuidoostelijke Noordzee als bevonden in een eerdere pilot-study worden bevestigd door de analyse van schelpen van nabij gelegen gebieden. De schelpen afkomstig van de zuidoostelijke Noordzee vertoonden een veel hogere litteken-frekwentie dan schelpen van onbevestigde gebieden nabij de Canadese oostkust. Uit de combinatie van observaties aan boord en literatuurstudie over het ontstaan van littekens blijkt dat bodemvisserij activiteiten in de zuidoostelijk Noordzee de geobserveerde trends kan verklaren. De analyse van lange termijn trends in het optreden van littekens kan een waardevol instrument zijn om de intensiteit en distributie van bodemvisserij te ontsluiten.

Sleutelwoorden: *Arctica islandica*, Noordzee, Boomkorvisserij, Lange termijn trends, tweekleppig schelpdier.

SAMENVATTING VOOR NIET-SPECIALISTEN

Zowel observaties in het veld als literatuurdata doen vermoeden dat *Arctica islandica* in de zuidoostelijke Noordzee sterk onder de invloed staat van de boomkorvisserij. Tijdens een pilot-study onderzochten WITBAARD & KLEIN (1994) of het voorkomen van littekens op schelpen van *Arctica* een indicatie kon zijn voor bodemvisserij activiteiten.

Het dier onder studie betreft een groot tweekleppig schelpdier welke groeit door middel van jaarlijkse incrementen, die zichtbaar gemaakt kunnen worden (ROPES, 1985). Littekens (beschadigde en herstelde incrementen) op de schelpen van *Arctica* kunnen gedateerd worden door vanaf de schelprand de incrementen te tellen tot aan het increment waarin het litteken is aangetroffen en dit van de vangstdatum af te trekken. Door voor een heel schelpmonster van één positie in elk jaar de litteken-frekwenties op te tellen wordt een lange termijn-serie van litteken-frekwenties op deze positie verkregen.

WITBAARD & KLEIN (1994) schreven de trend die zij vonden in de litteken-frekwenties voor schelpen van de Oestergronden (zuidoostelijke Noordzee) toe aan de bodemvisserij. Omdat het bestudeerde monster afkomstig was van een gebied met een oppervlakte van slechts een paar hectare, was het de vraag of de geobserveerde temporele trend van littekens representatief was voor een groter gebied.

Het huidige onderzoek is uitgevoerd om de gevonden trends te ondersteunen en de toe-

pasbaarheid van de methode zoals in de pilot-study is gebruikt, toe te lichten. Hiervoor werden drie monsters van nabij elkaar gelegen stations geanalyseerd volgens de methode die beschreven wordt in die pilot-study.

Daarnaast werden de litteken-frekwenties bepaald voor drie referentie stations vlakbij de Canadese Oostkust, waar geen commerciële (bodem) visserij plaatsvindt (D. Gordon, persoonlijke communicatie). De litteken-frekwenties voor elk van deze stations werden met die voor schelpen uit de Noordzee vergeleken. De voor de uit de Noordzee afkomstige schelpen afgeleide trends in beschadigings frekwentie werd vergeleken met de beschikbare data over de Nederlandse boomkorvloot.

Het aantal littekens dat in schelpen uit de de referentie gebieden gevonden werd, was vergelijkbaar met literatuur gegevens omtrent littekens die veroorzaakt zijn door bijvoorbeeld niet succesvolle predatie. Het aantal littekens dat bij schelpen afkomstig uit de Oestergronden gevonden werd, was ongeveer drie maal zo hoog.

Boomkorvisserij kan dit surplus aan littekens verklaren (WITBAARD & KLEIN, 1994), omdat de zuid-oostelijke Noordzee zwaar bevestigd wordt met dit type vistuig. Wanneer fluctuaties in the gevonden litteken-frekwenties veroorzaakt zijn door bodem visserij dan zou de trend in deze frekwenties beïnvloed zijn door de jaarlijkse veranderingen die opgetreden zijn binnen de Nederlandse vissersvloot. Deze laatste aanname wordt ondersteund doordat de jaarlijkse fluctuaties in het totale motorvermogen van de Nederlandse boomkorvloot een overeen-

komstige trend vertoond met de littekenfrequenties van het schelp materiaal uit de Oestergronden (Fig. 3C).

CONCLUSIES EN AANBEVELINGEN

Zowel het hoge aantal aan littekens als de gevonden trends in het voorkomen van de littekens op schelpen van *Arctica* uit de zuidoostelijke Noordzee zijn waarschijnlijk veroorzaakt door boomkorvisserij. Vergelijking van de gevonden trends met veranderingen die zijn opgetreden binnen de Nederlandse boomkor

vloot worden echter sterk bemoeilijkt door ontbrekende gegevens over de exacte veranderingen in zowel de verspreiding als de aard van de vissersvloot.

In de toekomst kan *Arctica* wellicht gebruikt worden als indicator van visserij activiteiten. De verschillen in optreden van littekens kan een instrument zijn om de effecten van maatregelen die genomen worden met betrekking tot bodem visserij aan het licht te brengen. Dat wil zeggen dat op deze manier schattingen van visserij-effort op zeer lokale schaal verkregen kan worden.

ABSTRACT

The long-term trends in the occurrence of scars on the shells of *Arctica islandica* from the south-east North Sea as found in a previous pilot study have been confirmed with the analyses of samples from neighbouring sites. The shell samples from the south-east North Sea showed much higher scar frequencies than shell samples collected in unfished areas near the Canadian east coast.

The combination of shipboard observations and literature data on scar inflicting agents suggest that beamtrawl fishery activities in the south-east North Sea could explain the observed scar trends. The analyses of long-term trends in the occurrence of scars might be a valuable tool to expose the intensity and the distribution of bottom fisheries.

Keywords: *Arctica islandica*, North Sea, Beamtrawl fishery, Long-term, Scars, Bivalve, Mollusc.

SUMMARY FOR NONSPECIALISTS

Both field observations and literature data suggest that *Arctica islandica* from the south-east North Sea is strongly affected by beamtrawl fisheries.

During a pilot-study WITBAARD & KLEIN (1994) investigated if the occurrence of scars on shells of *Arctica*, could be indicative for bottom fishery activities. Scars (damaged and repaired increments) on shells of *Arctica* can be dated by counting the annual growth-increments backwards from the shell-edge to the increment in which the scar is found. By summing the scars for each year in samples of approximately 50 shells from one location, a long-term scar frequency record is obtained for this position.

WITBAARD & KLEIN (1994) attributed the trend they found in the scar frequencies of one sample from the Oyster-Grounds (south-east North Sea) to bottom fishery activities. Since the studied sample only represented an area of a few acres it was questionable whether the observed trend of scar occurrence in time was representative for a wider geographical area.

The present study was conducted to seek confirmation of the observed trend and to elucidate the applicability of the method as presented in the pilot-study. Thereto three samples from neighbouring sites were analysed according to the method described in this pilot study. In addition to this, scar frequencies for shell samples from three reference-sites near the Canadian east coast where no commercial bottom fishery occurs, were determined (D. Gordon, personal communications). The scar frequencies for each of these sites were

compared with the obtained scar frequencies for shells from the North Sea. The trends in scar occurrence in *Arctica* from the south-east North Sea have been compared with the available data on Dutch beamtrawl fleet.

The number of scars found for shells from the reference areas was comparable to literature estimates for scar ratios found on molluscs that were caused by for example unsuccessful predation while the number of scars found in shells from the Oyster-Ground was approximately three times higher (Fig. 1).

Beamtrawl fishery however, could explain the surplus of scars found (WITBAARD & KLEIN, 1994), since the south-east North Sea is heavily fished by this type of gear (WELLEMANN, 1989). When the fluctuations in the observed scar frequencies are caused by bottom fisheries, the trend in these scar frequencies would be influenced by annual changes within the Dutch beamtrawl fleet. The latter is supported by corresponding trends in the scar frequencies found for the Oyster-Ground samples (Fig. 2) and temporal fluctuations in the total engine capacity of the Dutch beamtrawl fleet (Fig. 3C).

CONCLUSIONS AND RECOMMENDATIONS

The high number of scars as well as the found trends in occurrence of these scars on shells of *Arctica* from the south-east North Sea is probably caused by beamtrawl fisheries. Comparison of found trends with changes that took place in the Dutch beamtrawl fleet is however obstructed by insufficient detailed data on these changes.

In the future *Arctica* might be used as an indicator for such fishery activities, the differences in scar occurrence per area can be a possible tool to monitor the effects of measures that are taken concerning bottom fisheries. I.e. estimates of fishing effort on very local scales can be obtained by using scar frequencies of *Arctica*.

1. INTRODUCTION

The animal used for this study, *Arctica islandica*, is a large bivalve mollusc which is widely distributed over the North Sea and the Northern Atlantic (NICOL, 1951). This animal grows by means of annual increments. It is possible to differentiate the successive growth layers by making the growth stops between the increments visible. Because the growth of an increment is related to environmental conditions, can successive increments reflect environmental changes in time. Since specimens over a 100 years old are regularly found, long chronicles of environmental changes or other events, recorded in the shell material, can be obtained (see for a full review WITBAARD *et al.*, 1994).

In the same way repetitive non-lethal shell damage due to beamtrawl fishery could lead to a scar-record that reflects the distribution of beamtrawl fishery through time and space. This idea was tested in a pilot study in which the presence and nature of repaired as well as not repaired shell fractures were analysed (WITBAARD & KLEIN, 1994).

It appeared that in samples from the heavily fished Oyster-Ground (south-east North Sea) only 10 % of the shells were undamaged while in samples from the more northerly areas about 4 times as many undamaged shells were found. From one of the Oyster-Ground samples the long-term trend in the occurrence of scars was determined. WITBAARD & KLEIN (1994) attributed this trend to major changes in the Dutch beamtrawl fleet. They argued that observed trend could both be the result of qualitative (catch efficiency and choice of fishing grounds) and quantitative (size and composition of the fleet) changes in the Dutch beamtrawl fleet. Since the studied sample only covered an area of a few acres it was questionable whether the

observed trend represented a general trend for a wider geographical area.

The present study was conducted to elucidate the applicability of the method and to see if the observed trend, obtained in the pilot study, could be confirmed. Hereto three additional shell samples from neighbouring sites were analysed in a comparative way. The scar frequencies for each of these sites have been compared with each other as well as with samples from unfished areas near the Canadian east coast.

2. MATERIAL AND METHODS

2.1. COLLECTION

Three samples of living shells were used for Scar Trend Determination (STD). Sample 1 and 2 have been collected, at two different stations in the south-east North Sea, with RV. Tridens in September 1993 during the IMPACT I program (FAR MA 2-549) (Table 1).

The material was collected with a commercial beamtrawl. In contrast to the other material caught during this cruise the catch from these stations was not dumped on the conveyor-installation. In this way the number of broken shells could be kept to a minimum since such shells can not be used for STD. No suitable third sample could be collected during the IMPACT I program so another sample (sample 3) collected with RV. Aurelia in March 1991 was used. Collection was done with a 5.5 m beamtrawl. The results (sample 4) from the pilot study were re-evaluated.

In addition three samples collected near the Canadian east coast (sample 5-7) were quantitatively analysed on the presence of scars. These samples served as a reference to estimate scar frequencies caused by natural causes, since there is, except for some scalloping, no commercial fishing in the area (D. Gordon, personal communications). Sample 5 was collected in September 1992, sample 6 and 7 in July 1981. These samples were gathered with a hydraulic dredge (commercial gear used for collecting shellfish). The comparison between the Canadian and North Sea samples, despite the difference in the method of collecting, was possible because

recent damage on the shell margin was disregarded and only scars (old fractures away from the shell margin) were studied.

2.2. SCAR ANALYSES

After arrival at the laboratory the soft tissues were removed from the shells which were dried at room temperature. For each sample approximately 50 (if present) of the smallest shells were selected for STD since larger shells are more difficult to analyse. These shells were measured and drawings were made of the outer and inner shell side indicating the proportion and position of the scars. Then the left-hand valve was embedded in epoxy-resin (Polypox THV 500, harder 125) and sawed along mapped scars. If the scars were not symmetrically distributed over both valves the right-hand valve was also used. This resulted in several sections per shell. After grinding, polishing and etching, acetate replicas (KENNISH *et al.*, 1980) were made of the obtained sections. These acetate peels were photographed by means of a light microscope to be able to date and quantify the present scars (see WITBAARD & KLEIN, 1994). Because the animal grows by means of annual increments it is possible to assign a year to each increment. The present scars were dated by counting these increments backwards from the shell edge to the increment in which the scar appeared. In this way a chronology for each shell was obtained where each year in which a scar occurred was marked. The scar frequency was determined by counting all scars in the sample for each year. For comparison the scar frequencies of a certain year were expressed as percentage of the number of shells that accounted for that year. The obtained chronologies were compared and correlated with each other and with the annual fluctuations in the composition of the Dutch beamtrawl fleet.

2.3. STATISTICAL ANALYSIS

The scar frequencies are obtained by summing scar/year occurrences of all individuals in each sample. In this summation different aged animals were equally judged. When the occurrence of scars is related to bottom fisheries and

not to the size of the animal, the observed trends in Fig. 2 would be a direct reflection of the fishing effort at the sampling sites. In this context the effect of bottom fisheries on the occurrence of scars could be referred to as a year related effect and the effect of shell size as an age related effect. The fact whether the observed scar occurrence is related to a certain age, year or both was tested.

For each independent parameter (age, year and age + year) models were assumed with the statistical package GENSTAT 5. These models described the occurrence of scars on a certain moment, depending on a certain age, year or a combination of these. Also a null model is assumed representing a common probability for all observations, this is the simplest model based on just one parameter.

The discrepancy (goodness-of-fit) between the models and the observed scar frequency trend is expressed by their scaled deviance (sD). When the above mentioned null model is assumed to be true, the difference in deviance (G^2) between two models is approximately X_v^2 distributed, where v is the difference in degrees-of-freedom (df). The difference in deviance is used to test which of the models gives the best approximation of the observed. By subtracting the deviance of the model under observation (year, age or year + age model) from the deviance of the null model a relative estimate is obtained for the goodness-of-fit which can occur within the given probability (p). For details see PHILIPPART *et al.* (1992).

2.4 FISHERIES DATA

For the ICES quadrants 36-F4, 36-F5, 37-F4 and 37-F5 the available data (data from RIVO, WELLEMANN, 1989) of beamtrawl effort through time were analysed. The same was done for the total beamtrawl effort of the whole North Sea.

3. RESULTS

3.1. SCAR ANALYSES

Figure 1A shows the size distribution of the shells that were used for STD. The small number of larger shells shows that smaller

sized shells were preferred in the selection procedure. Within these selected samples no definite size classes could be discerned. The number of scars seems not to be related to any specific shell height. The maximum number of scars found on one specimen was 14 and of all shells analysed, three shells carried no scars at all. The average number of scars per shell was 4.4 (± 0.73).

Figure 1B presents a similar plot for samples 5, 6 and 7, the reference samples from the unfished Canadian coast. The average number of scars per shell is 1.2 (± 0.87). Compared to samples 1-4, the overall number of scars is lower and the number of shells without scars is relatively high. About 42% (18/42) of the shells were undamaged while in the samples from the Oyster-Grounds only 2% (3/182) intact shells were found.

Figure 2 illustrates the frequency of scars (damaged and repaired increments) in each year relative to the total number of shells studied for that year. An arbitrary line was drawn through the year 1977, after which each sample consisted of at least 20 shells. Due to the limited number of shells from the older age classes, the data before 1977 is regarded as not representative.

The oldest animal used was 80 years old offering the possibility to back-date to 1912. From 1978 until 1991, in all samples, at least one scar in every year was found. Maximum scar ratios found for samples 1, 2, 3 and 4 are 50, 35.7, 34 and 47.9%, respectively. All samples roughly followed the same trend, they all showed a net increase in damage occurrence from the late seventies until the mid eighties, thereafter a gradual decrease followed. In table 3 correlation coefficients for each possible sample combination is given. Almost all correlation coefficients were high, and only correlation coefficients with sample 3 were not significant ($p < 0.05$).

3.2. STATISTICAL ANALYSIS

Table 2 shows that all assessed models have a good fit ($p < 0.01$), which means that the trends observed in the scar frequencies could be caused by both a separate age- or year effect as well by a combination of these.

Despite the loss in degrees-of-freedom (df) the combined model where both year and age are evaluated has a gain in goodness-of-fit (increased G^2). Meaning that with this model at the same probability level ($p < 0.01$) a better fit is achieved.

Also can be seen that only from sample 1 the year model ($G^2=121.8$) shows a better fit then the age model ($G^2=105.8$), this in contrast to the other samples.

This all implies that as well the age of the animals at the moment the scars were formed as the year in which the scars were formed could have its effect on the observed scar frequencies. When annual fluctuations in fishing effort influence the scar frequency on *Arctica* shells, it is unlikely that this effect would be overshadowed by a possible age effect since the models assumed for all three parameters can contribute to the trends observed.

3.3. FISHERIES DATA

Figure 3A and 3B respectively present the fishing-effort of the Dutch beamtrawl fleet for ICES quadrant 37-F4 and the whole North Sea, expressed in fishdays (days at sea). Between 1984 and 1989 fishing effort data are missing, since they have not been recorded during this period. Also must be noted that from 1962 until 1967 beamtrawl effort was recorded as corrected fishhours. A corrected fishhour is a measure for the time that a vessel is at sea, corrected for its engine power. After this period, until 1983 beamtrawl effort was recorded as uncorrected fishhours for all trawlers with engine powers above 300 hp. Since 1989 beamtrawl effort is recorded as uncorrected fishdays for all trawlers with engine powers above 300 hp. In 1990 one fishday represents 20 hours of fishing for a beamtrawler with a capacity larger then 300 hp, two 12 m beams and a fishing speed of 6 miles/hr (ANONYMOUS, 1990). For comparison reasons all data were transformed into fishdays. Since the gear and capacity of Dutch beamtrawl vessels underwent great changes the transformation to fishdays might not be valid for the whole period. The available data seemed too inconsistent to be used but for the sake of completeness the data of the ICES quadrant 37-F4 and the total

beamtrawl effort are given. Neighbouring ICES 37-F5, 36-F4 and 36-F5 quadrants are not presented.

Figure 3C represents the composition of the Dutch beamtrawl fleet expressed in terms of engine power. Table 3 shows correlation between annual fluctuations in total capacity of the Dutch beamtrawl fleet and the long-term trends in scar frequencies in shell samples from the Oyster-Grounds. It can be seen that for all samples the obtained long term trends are highly significant.

4. DISCUSSION

Bivalves form scars on their shell by repairing shell fractures, caused when part of the shell is broken or chipped away. The mantle tissue will retract to the edge of the fracture and start secreting new shell material until the gap is filled. Such shell repairs often possess a convex surface (SAVAZZI, 1990). Our observations show that only extensive damage seems to cause similar convex shapes on *Arctica* shells.

SAVAZZI (1990) describes that when the mantle tissues are injured the resulting scar on the shell surface has the aspect of a groove. This complies with most scars found on *Arctica*, post damage growth is resumed at a lower level causing a dip in the shell (WITBAARD & KLEIN, 1994) which points to a withdrawal of the mantle epithelium.

WATABE (1983) gives a review of literature about shell regeneration. He concludes that the repair rate of shells seems to be the highest at the shell edge especially in the region of highest linear growth. He reports that for many species the repair rate is often higher than normal growth.

"Damages that occur in the central region of the shell are only slowly repaired. When repair takes place at the shell edge, the structure of repaired shell is essentially the same as normal, if the damage occurs away from the shell edges where the mantle cannot retract, the structure, composition and morphology of the new material often differs from normal."

Own observations show that 90% of the scars found on *Arctica* were positioned on the post ventral shell margin and that the appearance of post damage growth is not essentially different

from pre-damage growth. (WITBAARD & KLEIN, 1994). It is therefore unlikely that the dating procedure is impaired by growth interruptions or malformations of the shell. It is however thinkable that already present scars are broken away by more recent fractures and therefore not recognised in the analyses. Such large scars will only result from extensive damage. Such damage is likely to lead to exposure of the soft tissues making these available for predators for which it forms an easily accessible prey item. It is therefore unlikely that such animals will survive. Because only undamaged specimens which were caught alive, were used in the STD is the effect probably minimal. Preparation of more than one cross-section per valve makes it furthermore possible to check for such "hiding" effects, unless all scars have the same aerial extension and orientation. The overall effects would lead to an underestimation of the scar frequencies and our estimates are therefore conservative.

Shell damage can be inflicted by several factors. For instance unsuccessful predators, abrupt environmental changes or even the burrowing behaviour of the animal itself (CHECA, 1993). Each of these factors cause scars with their own specific character (MILLER, 1983; VERMEIJ, 1983; SAVAZZI, 1990; CHECA, 1993; CADÉE, 1994). Because of this specific character, palaeontologists and biologists are able to reconstruct for example predator/prey relations by means of scar frequencies on molluscs. In the same way scars on *Arctica* shells which are caused by fisheries can be recognised and used (WITBAARD & KLEIN, 1994). Abiotic stress will result in growth interruption present over the whole circumference of the shell while damage caused by unsuccessful predation will result in scars which are often recognisable because of their shape or orientation (KLEIN & WITBAARD, 1993). In most instances predation will lead to dead shells which were omitted from the analyses.

Predation on shellfish can happen in several ways, the shell can for example be crushed with jaws or claws from large predatory fish, lobsters or crabs. They eat all shell size classes their "crushing device" can handle. ARNTZ & WEBER (1970) demonstrated that cod teeth

could not crush *Arctica* shells larger than 4 cm. Also is it unlikely for this type of predators, which crush their prey, to leave high numbers of non mortally damaged shells.

The second type of predation is digestion of the soft tissues without breaking the shell (fishes, Asteroids). From some smaller fish species it is known that they predate on *Arctica*, but only the pre-adult stages are eaten (CARTER, 1968). This type of predation leaves no scars at all. HUNT (1925) makes note of an *Asterias rubens* of 14 cm that predated an *Arctica* of 12 cm.

When a shell is too big to be crushed by the claws of a lobster or crab the third way to get to the soft tissues of a bivalve is applied, i.e. chipping parts of the shell edge until a large enough hole is obtained to eat the interior soft tissues. Some large predatory snails use the same technique (CARTER, 1968; NIELSEN 1975). But NIELSEN (1975) showed with a laboratory test that *Arctica* was able to keep its valves closed for such a long time that the large predatory snail, *Buccinum undatum* lost interest. Unsuccessful predation on *Arctica* by predators that use this "chipping" technique are most likely to leave scars.

The list of potential predators could be endless, but it is not likely that the trends found in the STD are caused by fluctuations of the predator/prey interaction, since to our knowledge large scale fluctuations of this interaction have not been documented. Moreover the number of scars found on *Arctica* from the Oyster-Grounds is much higher than commonly found for predatory damage (MILLER, 1983; VERMEIJ *et al.*, 1981; VERMEIJ, 1983; SCHMIDT, 1988; VALE & REX, 1988). In the Oyster-Ground the average number of scars per shell is 4.4 with a maximum of 14 and almost 100% of the shells per sample is damaged. The reference samples showed an average of 1.2 scars per shell with a maximum of 4 and the percentage of damaged shells per sample is about 25%. These estimates for the reference samples are comparable to literature data on predatory damage where an average of 1.6 scars with a maximum of 4 scars per individual is considered to be high and the percentage of damaged shells per sample scarcely exceed 50% (MILLER, 1983; VERMEIJ *et al.*, 1981;

VERMEIJ, 1983; SCHMIDT, 1988; VALE & REX, 1988). Thus, the scars found on the shells from these unfished areas are probably all caused by unsuccessful predatory attacks.

Although not quantified in the samples from the Oyster-Ground many signs of extensive damage were found (see also WITBAARD & KLEIN 1994), while the shells from the Canadian coast did not have such extensive damage. Thus both the scar frequency and size of these scars in shells from the Oyster-Ground makes it difficult to explain them by predation alone. We therefore assumed on basis of literature and field observations that the surplus of scars found in the Oyster-Ground samples is caused by beamtrawl fisheries since that type of gear is most frequently used in the area.

The role of beamtrawl fishery in causing the observed scars has been outlined by WITBAARD & KLEIN (1994). Most prominent evidence was presented by FONDS (1991) who found that up to 90% of *Arctica* caught by a commercial trawler were severely damaged. He estimated a direct mortality of the catch lying between 74 and 90 %. It is however hard to estimate the mortality rate due to beamtrawl fishing on population level, since reliable density estimates, catch efficiencies and the number of damaged shells left on the sea floor are lacking. Hence, the impact on the population remains unclear.

That beamtrawl fishery with its heavy tickler chains is the most likely for causing the observed scars was already suggested by WITBAARD & KLEIN (1994) on basis of the position of most scars and spatial difference in the ratio between damaged and undamaged shells in different areas of the North Sea.

The role of tickler chains in inflicting the injuries is demonstrated by relation between use of chains and the number damaged shells in the catch (FONDS, 1991). The post ventral position (siphon side) of the scars on the shells could be explained by tickler chains moving over the sediment (WITBAARD & KLEIN, 1994).

When fluctuations in the observed scar frequencies are caused by beamtrawl fishery, the trend in these scar frequencies would be influenced by major changes within the Dutch beamtrawl fleet. The changes that took place in the Dutch beamtrawl fleet comprised engine

power, gears used and fishing speeds. These changes are reflected in the fishing effort (Fig. 3A and 3B) and are as such expected to be recorded in the scar frequencies of *Arctica*.

Although comparative fisheries data are hardly available, Fig. 3 C (ANONYMOUS, 1992) does show that in the in the period 1972-1982 the capacity of the total beamtrawl fleet increased. This was mainly due to a tendency towards ships with higher engine power. After 1988 a decrease followed which was caused by a decline in ships with 300-1500 hp engines. The similar trend was observed in the scar frequencies from the south-east North Sea. Correlation between the scar frequencies (Fig. 2) and the total capacity of the Dutch beamtrawl fleet (Fig. 3C) appeared to be highly significant (Fig 4, Table 3) and thus suggests a relation between both.

When the general trend in all samples is caused by temporal changes, the differences between the samples could be explained by the spatial distribution of the beamtrawl fleet. RIJNSDORP *et al.* (1991; 1994) stated that the distribution of fishing effort is indeed very heterogeneous. Also the interaction between sediment type and gear characteristics will influence the scar frequencies since this is related with for example penetration depth of the gear (BRIDGER, 1972). I.e. gear that digs deeper into the sediment will either cause larger fractures or higher catches of *Arctica* both resulting in a higher number of mortally damaged shells. (WITBAARD & KLEIN, 1994). Temporal changes in the spatial distribution of the fishing fleet might thereby result in small scaled heterogeneity in the amount of shells which are damaged. Hence very local fluctuations of the fishing effort, in both space and time, can be derived from scar frequencies.

Among the trends of each sample some differences can be observed. Sample 3 seems to deviate the most which could be caused by the fact that this is a composite sample out of 4 stations. Mixing stations with low shell numbers could increase noise due to the very local character of the samples. The high correlations between the other samples and the temporal changes in the fishing fleet however suggests a link between both.

Therefore it might be concluded that that the trends found in the scar frequencies of *Arctica islandica* are caused by beamtrawl fisheries and that the animal might be useful for monitoring fishing activity in the past and future.

5. ACKNOWLEDGEMENTS

We would like to thank Dr. T. Rowell for provision of the reference samples. The NIOZ in general and especially departments benthic systems and BEWON are acknowledged for aid and subsistence. Jaap van der Meer from the NIOZ is thanked for the statistical analyses. This study was made possible by the financial support of the Commission of European Communities

6. LITERATURE CITED

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TABLE 1
Sampling details. Position and number of the stations is given.
* Sample 3 is a composite sample.

Sample	Nr° of stations	Latitude north	Longitude east
1	1	54°22'	04°51'
2	1	54°42'	04°49'
3	4	53°53'	04°59'
4	1	54°03'	06°18'
5	1	43°29'	61°44'
6	1	43°30'	65°30'
7	1	43°29'	65°28'

TABLE 2
Results of statistical analysis. For each sample the sample size, the tested models and their subsequent results are given. *Calculated estimate. **G² is the difference between the deviance of the null model and any of the other models.

Sample	Number (n)	Model type	Scaled Deviance (sD)	Degrees freedom(df)	**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 model	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 model	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 model	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 model	665.9	723	171.1	64.0	<0.001

TABLE 3
Correlation between Oyster-Grounds samples and the total capacity of the Dutch fishing fleet. The upper half of the table gives for each correlated pair the number of overlapping years between 1977 and the date of collection, thus the period over which the correlation is calculated. The lower half gives the correlation coefficients, * indicates significant at P<0.05; ** indicates significant at P<0.01.

	Sample 1	Sample 2	Sample 3	Sample 4	Engine powers
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 powers	**0,763	**0,712	*0,612	*0,515	15

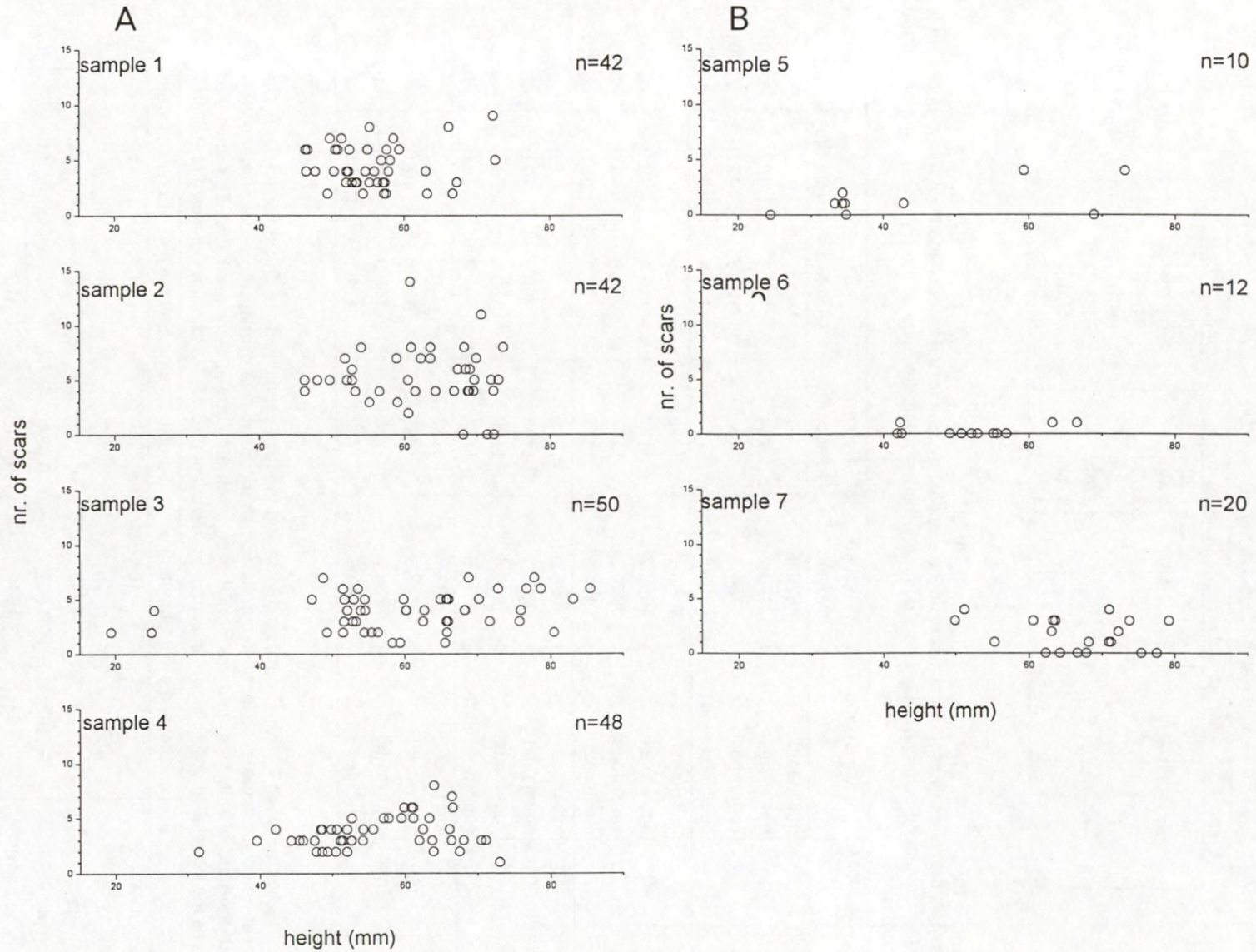


Fig. 1. A. Scar/size ratios. The absolute number of scars for each shell height is given for the samples from the Oyster-Grounds. B. The absolute number of scars for each shell height is given for the samples from the Canadian east coast.

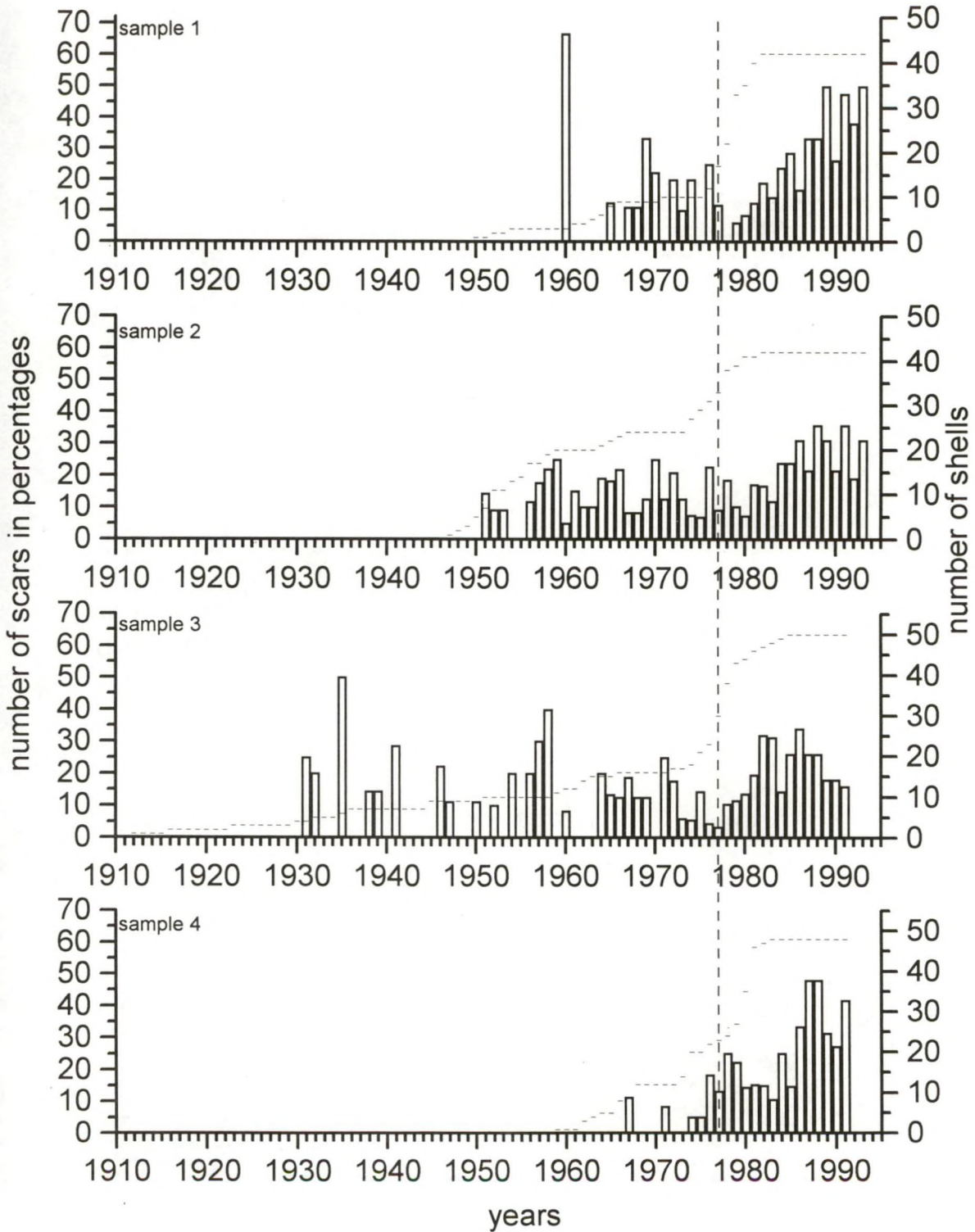


Fig. 2. Occurrence of scars on *Arctica* shells. Each bar represents the relative occurrence of scars (damaged & repaired increments) per year. The number of shells with a scar in a certain year is given as a percentage of all shells studied for that year. The horizontal lines indicate the number of shells studied for each year. Data before the vertical dashed line are regarded as not representative due to a limited number of shells.

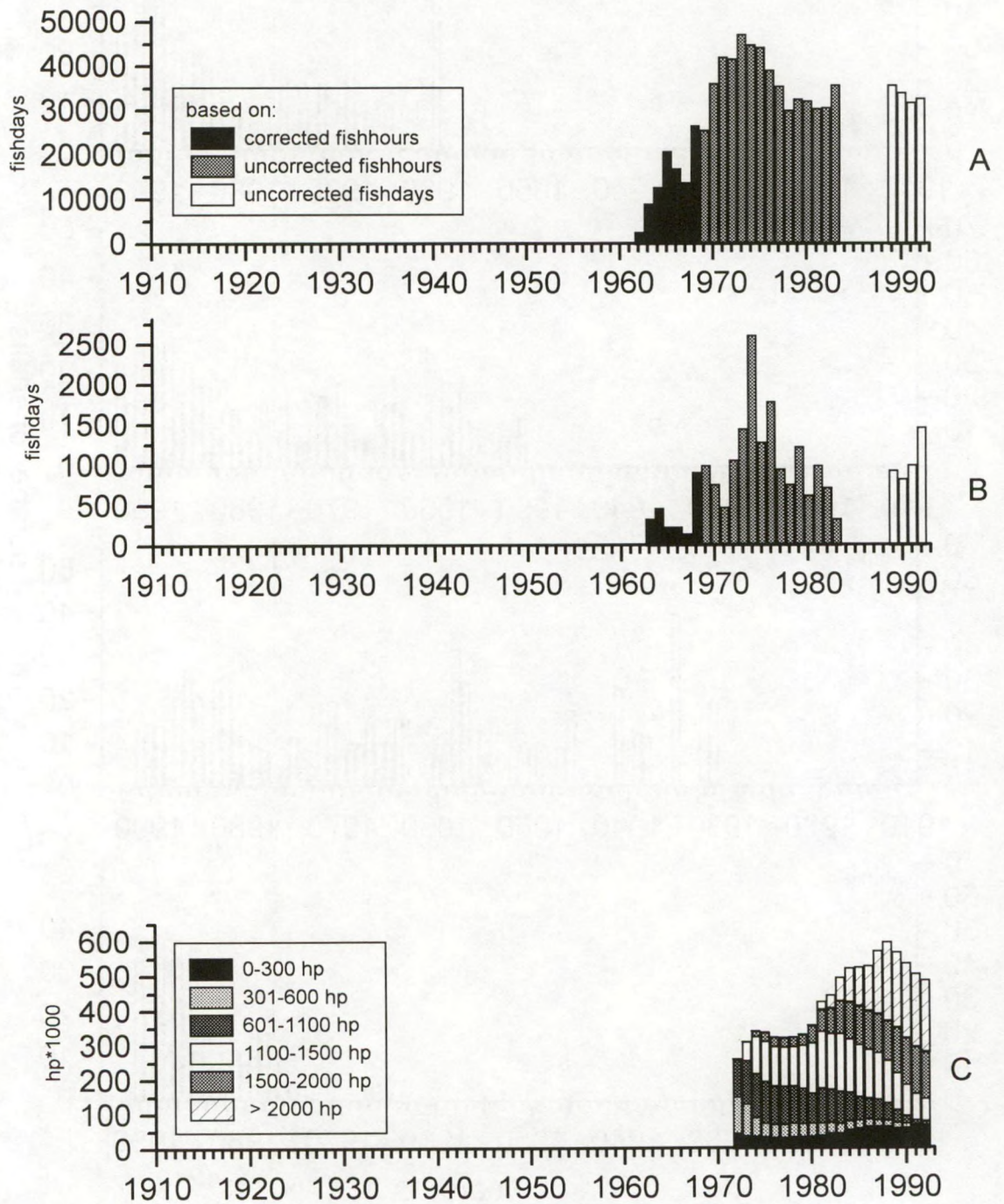


Fig. 3. Beamtrawl effort and -capacity. The beamtrawl effort (RIVO; WELLEMAN, 1989) in fishdays (time at sea in days) for the whole North sea (A) and ICES quadrant 37-F4 (B). The gap between 1984 and 1989 is caused by missing data. 3C represents the composition of the Dutch beamtrawl fleet.

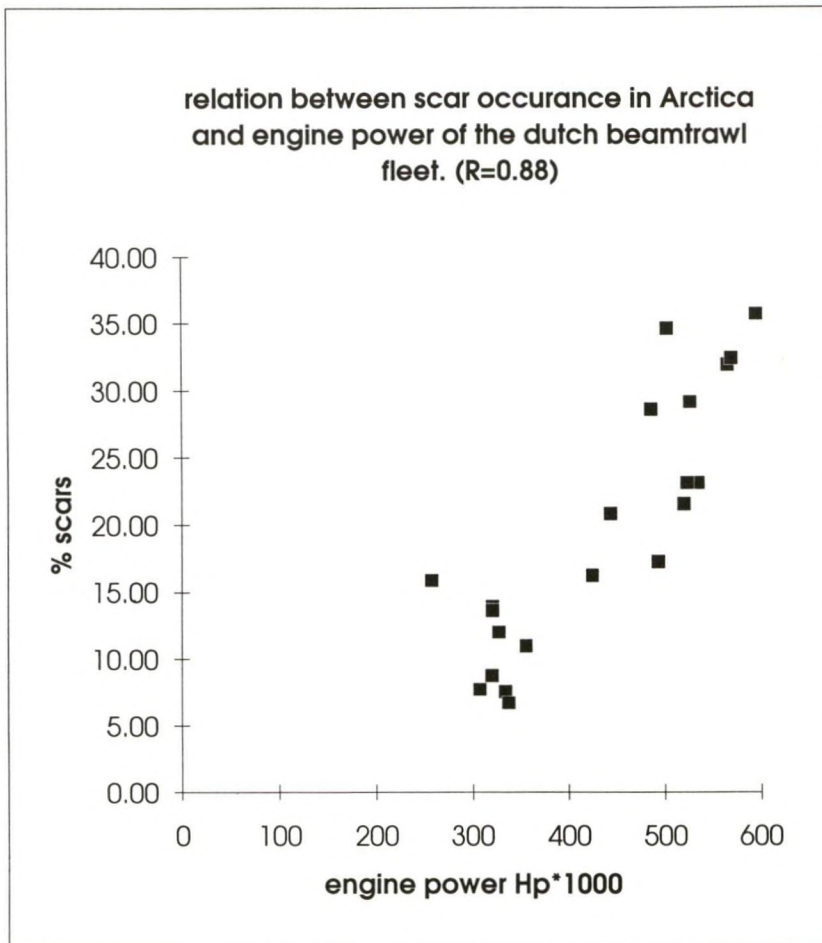


Fig 4. Graphical display of the correlation between the average scar incidence and the development of the Dutch beamtrawl fleet expressed as engine power.

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