Ocean Management, 9 (1984) 177–190
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

The Impact of Bottom Trawling on Benthic Fauna of the North Sea

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(Accepted for publication November 17, 1983)

ABSTRACT

This paper reviews the impact of bottom trawling — beam- or groundtrawl — on animals of the sea bed. The area of study is restricted to the North Sea, however, the final conclusions have a far wider application. Protests against the use of trawls date back to the period of their introduction; for northwest Europe this was the thirteenth century, and it still evokes protests up to the present day. Trawling does affect benthic life, the trawl penetrates up to 30 mm into the soil, depending on the substrate. All types of trawls are basically similar in their action on the bed. Beam trawls with tickler chains catch much more benthos than do ground trawls without tickler chains. Some groups of animals suffer far more damage than others, e.g. echinoderms. It is not unlikely that in the long-term a shift in species and numbers may occur along the same lines such as has been found in the German Wadden Sea where polychaetes are on the incline and molluscs and crustaceans on the decline.

INTRODUCTION

The origin of trawling is veiled in obscurity. For certain is that trawls were known in northwestern Europe in the thirteenth century. It has long been the practice, especially in the trawl fisheries for flatfish (sole, plaice), to rig the ground rope of the net with chains and to use several "tickler" chains arranged across the mouth of the net, otter- or beam trawl, in such a way as to travel in advance of the ground rope.

Main and Sangster (1979, 1981, 1983) studied bottom trawling gear (light and heavy) on both sand and hard ground. The sand clouds produced by the trawl doors contribute to the fish-capture process and are essential, espe-

0302-184X/84/$03.00

cially in clear water. Dutch beam trawls at present use up to 15 ticklers. The average weight per beam trawl is about 8–10 ton, with a maximum of 12 ton. To protect the belly of the nets, especially of beam trawls, and to enable them to be used on rough grounds, chain mats are applied.

It is very likely that complaints about the use of trawls, with or without chains and the like, date from the period of the introduction of such gear in the waters of northwestern Europe. In the old days they arose from fishermen not using the gear; at the present time environmentalists add their concern. The aim of this paper is to evaluate the existing knowledge as to the true effects of using heavy bottom-trawl gear.

The area of study is in fact restricted to the North Sea, but the final conclusions will have a far wider application. Due to logical historical reasons, the controversy trawl gear—effect on benthic life and fish stocks has drawn the most attention. The subject was discussed at the 58th ICES–Council Meeting in Copenhagen in 1970, when the "Liaison Committee" asked the members of the "Gear and Behaviour Committee" (the present Fish Capture Committee) to procure detailed information on the influence of trawls and dredges on the sea bed (ICES Council Resolution 1970/S: 1) This recommendation resulted in international investigations, especially in the United Kingdom, The Netherlands and Belgium.

THE EARLIEST TIMES

Complaints concerning the use of trawl gear are known from the 13th and 14th centuries in the United Kingdom and from the 16th century in The Netherlands. The complaints concerned the mesh-size as well as the deleterious effects of the use on young fish, fry and benthic life as a source of food for larger fish. In the United Kingdom in 1350 and 1371 already acts were passed in Parliament to banish the use of trawls and insisting that the "ancient" statutes for the preservation of fry of fish should be strictly observed. Trawls are referred to as "trynk" nets and "wondyrchoun". The latter resembles the Dutch word used for a trawl up to the mid-20th century, "wonderkuil". As it summarizes the problem very well, the following translation from the original Norman French text in the Rolls of Parliament is worth quoting (Anonymous, 1921) "Your said Commons pray that whereas in divers places of your said realm in creeks and havens of the sea, where before these times good and plentiful fishing was wont to be, to the great profit of the realm, which is partly destroyed and made valueless for a long time to come by some fishermen who have during the past seven years by a new craftily contrived kind of instrument, which among themselves is called Wondyrchoun, made in the form of a drag for oysters, which is of unusual length (outre mesure long): To which instrument is attached a net of so small a mesh (si espesse) that no kind of fish, however small, that enters it can pass out, but is forced to remain within it and be taken. And besides this, the great long iron (feer) of the Wondyrchoun presses so hard on the ground when fishing that it destroys the living slime and the plants growing on the bottom under the water (La slym crascete et flurs de la terre desouz la eawe illeoqes), and also the spat of oysters, mussels, and of other fish, by which the large fish are accustomed to live and be nourished." The reply to this 14th century petition could have been written in the present day: "Let commission be made by certain qualified persons to inquire and certify to the truth of the allegation made, and theron let right be done in the Court of Chancery."

Likely the trawl described was similar to the type used in France in the 18th century, "5 or 6 fathoms long and the width of the iron frame about 14 feet" (Jenkins, 1920).

A similar request by fishermen in The Netherlands is known from 19 April, 1583 to Prince William of Orange. They expressed also their concern for the state of the sea bed after passage of the trawl; it would become rough and likely less fish would be caught in future at these localities.

RECENT TIMES

In the 19th century the use of trawls — otter- and beamtrawls — came in for similar criticism. Dutch fishermen protested against the use of "wonderkuilen" (trawls), used by one or two vessels (pair-trawling), in the shallow Zuiderzee (now IJsselmeer); it would destroy young fish to such a degree that it would affect the yield of commercial-sized species. In fact, they repeated the same complaints as made by former Zuiderzee fishermen from the island of Marken in 1786 (Beaujon, 1884). And the same argument led to the prohibition of using trawls to catch eel in the IJsselmeer in the nineteen-sixties. Rivalry between neighbouring fishing towns often played a role in all this. Many trawlermen are indeed convinced that their operations do change the sea bed. Some of them believe in the beneficial effects, namely by increasing the growth of animal forms growing up from the sea bed by weeding out the old specimens; others accept that the heavy ground ropes and chains destroy the food sources of fishes by breaking protective shells and structures. In the United Kingdom around 1863 the trawl again came under attack; however, the complaints could be disposed of.

In 1938 Graham investigated the effect of the use of tickler chains on the plaice fishery in the southern North Sea (Graham, 1955). He came to the following conclusion: damage to the fish food species trawled over in the main area of the North Sea plaice cannot be serious. This was concluded after comparing catches of plaice and benthic fauna in areas used by the trawl fisheries with areas around light vessels where fishing was prohibited (LV *Haaks* and LV *Terschelling*). Direct attack, trawling a number of times over the same ground, followed by bottom grabbing, showed that it did break full-grown heart urchins and paddler crabs, however, it did hardly any damage to brittle stars, flat stars, razor shells, *Mactra* and *Tellina*. Doubtless, trawling with tickler chains broke up and flattened out the living structures of the reef-building worm *Sabellaria*. However, it was considered that they would recover and survive. Furthermore *Sabellaria*-communities are relatively rare in the open sea, the fishing ground used for the experiments.

Arntz and Weber (1970) investigated the food of cod and dab in the Kiel Bay (Baltic). They observed that in the stomach contents of their species an extraordinary amount of the bivalve *Cyprina islandica* started to appear after trawling began in the area. It was concluded that the fish were feeding on molluscs crushed by the otter-trawl doors. This fits very well with the well known fishermen's lore that a trawler fishing along the trawl path made by another trawler some hours before will, on the average, catch more fish. It is assumed that the fish are attracted by odours from the crushed benthic animals.

THE ICES-INVESTIGATIONS 1970–1973

At its 58th Council Meeting in Copenhagen in 1970, the International Council for the Exploration of the Sea (ICES) adopted the following resolution (C. Res. 1970/S/1)—"Members of the Gear and Behaviour Committee be urged to take action on the Liaison Committee's request for information about the effect of trawls and dredges on the sea bed."

The origin of this resolution was based on a serious complaint by the French delegates to ICES that Dutch sole beam trawlers with heavy chains and chain mats were causing permanent damage to the sea bed. Up to then this had never been noticed by the fishery laboratories bordering the North Sea. True, local complaints were brought forward by inshore fishermen who discovered that with their equipment they could not trawl as before on their specific trawling grounds (sheltered bays) after these had been visited by heavy trawlers. These trawlers tore rocks and boulders out of the seafloor which remained on the bottom for long periods before becoming sanded in again.

In fact, long afterwards the origin of the French complaint came out. French scientists observed that in sheltered bays of the island of Corsica the bottom topography was drastically changed after heavy trawl/gear had been used. However, the almost tideless Mediterranean, and the fact that there were hardly any watercurrents in the affected bays, conditions unknown in the North Sea retarded the recovery rate of the sea bed in the extreme. This observation coupled with the successful sole and plaice beam trawling of other member states, gave rise to the French complaint. However, the investigations proved to be worth analysing in more detail as it was unrealistic to assume the same arguments against trawling would never be raised again; in fact, since then they arose on two occasions; once internationally in the framework of the EEC fisheries and once at a national level.

Bridger (1970) investigated complaints by inshore fishermen who claimed that their fishing grounds were being damaged by heavy trawl gear. Tickler chains had torn boulders out of the sea bed. Prior to the experiments he carried out, the bottom was surveyed by divers. It consisted of stones and boulders well buried in the sand with shells and also local patches of flint. Trawl gear with ticklers was then used on the ground. It was observed that the chains only disturbed a thin layer of the top sand and that they rode over stones and boulders that were reasonably well buried in the sand. Stones that were torn out of the bottom were displaced several feet by the trawl. After that, in most cases, the trawl passed over them. The complaints of the fishermen who used the ground with light gear were substantiated. Light trawls sustained far more damage than the heavier gear from the displaced stones. Trawl doors completely obliterated the natural sand ripples over the track. The quantity of benthic marine life brought up in the net was about ten times greater when a heavy tickler was used than when the same net was used without a tickler.

De Groot and Apeldoorn (1971) studied the effects on the bottom fauna of a beam trawl (2 cm mesh) in relation to the number of tickler chains. The results are given below for some animals; the catch rate increased as if they were passive objects, comparable with lifeless matter such as lumps of peat.

Coelenterates

Hydrozoans (seafirs). The damage to the *Tubularia* species (mainly *T. indivisa*) was great; however, this effect was mainly caused by the drag of the belly of the net along the bottom. The meshes of the belly were filled with the pulp of *Tubularia*, and a red liquid of meshed individuals very frequently oozed out of the cod end during the hauling process. The meshes of the trawl were equally filled with or without the use of tickler chains. We must assume that nearly all *Tubularia* in the trawl path will be destroyed by any tow net used.

Ctenophores (comb-jellies) and Scyphozoans (jelly fish). Nearly all individuals were destroyed due to the pressure in the trawl. There was no effect of the ticklers on the amount caught.

Bryozoans (sea-mats)

Notwithstanding the considerable quantities caught in the trawl, the damage to the individuals was insignificant. They could be shoveled back into the sea almost intact.

Nemertea (ribbon worms)

There was some damage to this group caused mainly by the ticklers through the ploughing effect. The amount of the damage was hard to estimate, as these worms are easily swept through the meshes; the number caught is therefore very low. However, in a bottom sample of 1 m^2 we collected about 30 of these worms.

Annelids (bristle worms)

Several species were collected (*Nereis*, *Arenicola*, *Pectinaria*, and *Lanice* species). The damage to these worms may be considerable, especially to *Pectinaria* and *Lanice*. On one of our hauls the whole net was filled with crushed *Pectinaria* and sand.

Crustaceans–decapods

Eupagurus species were caught in large numbers. However, nearly all hermit crabs survived their stay in the net and on the deck. There was an increase of about 1.6 times in the catch when four ticklers were used.

Portunus species, swimming crabs, are partly damaged. The number caught increases five times when five ticklers are used instead of none. There was only a slight increase of about 1.2 times in the catch of *Crangon* (shrimp) when the number of tickler chains was increased to four.

Molluscs

Cephalopods. All cephalopods, *Sepia*, *Sepiola*, *Loligo*, were killed or badly damaged during the fishing process. There was, however, no relation between the number of ticklers used and the amount of damage done. There was a strong influence of the towing speed on the numbers caught.

Bivalves. Of the bivalves investigated only the *Ensis* and *Solen* species (razorshells) were badly damaged owing to the ploughing effect of the ticklers. The long thin shells were wipped out of the sand. Most other bivalves such as *Spisula, Mactra, Venus* and *Cardium* species sustain the ticklers very well. The number of living bivalves caught by the trawl was very low compared with the amount of dead seashells. The amount of dead shells in the catch increased by about 1.7 times when four tickler chains were used instead of none.

Echinoderms

Echinoids. Especially *Echinocardium* (sea potato) was heavily damaged through the action of the tickler chains. The number of damaged sea potatoes increased with the number of ticklers used. From the bottom samples we know that they lie burrowed nearly 10 cm deep in the sand. There was an increase of about 3.4 times in the catch when the number of tickler chains was increased to four.

Asteroids. The number of starfishes caught (*Asterias* and *Astropecten*) increased rapidly when using ticklers. The percentage of damaged specimens was about 3%. There was about a 3-fold increase in the catch when the number of tickler chains was increased to four.

Ophiuroids. Brittle stars behaved in a different way from the starfishes. The ticklers had a reduced effect on the number caught. There was only an increase in the catch of about 1.3 times when the number of tickler chains was increased to four. However, owing to pressure, about 3/4 of the numbers caught were badly damaged. We never found regenerated brittle stars, as was often observed in starfishes. Therefore we have to assume that the damaged brittle stars do not survive their stay in the net.

The catch rate of some animals or groups of animals increased with number of ticklers to more than 300% compared with using no ticklers at all, e.g. *Echinocardium* and starfish (*Asterias*). It is understandable that they behave in this way, as they do not move or only move very slowly, as if they were lifeless matter. Embarrassing, however, is the fact that the swimming crab behaves in the same way. Another group of animals was caught in smaller number than we should expect if they were completely passive (150–300%). The damage done to this group by the ticklers was comparatively small, as bryozoans, *Astropecten* and *Eupagurus* are hardly affected by the fishing process. However, we have to consider that on board of commercial vessels these animals will be badly affected by exposure. Again another such group (100–150%) consisted of scyphozoans, shrimp and brittle stars.

Less squid were caught with more ticklers; however, the catch increased with the towing speed. This is quite understandable, for a pelagic living species will easily escape a slow-moving trawl.

Houghton et al. (1971) studied the effects of double-beam trawling in relation to otter trawling to assess its influence on life in the sea. In relation to bottom fauna it was found that large quantities of invertebrates are caught by a heavily chained beam trawl. The extent of damage to these animals depends on the quantity of debris caught with them. The beam trawlers' catch contained a relative higher proportion of burrowing species than those of the otter trawlers; especially echinoderms (*Acanthocardia*, *Astropecten*, *Echinocardium*, brittle stars) and *Corystes* (crustaceans).

Margetts and Bridger (1971) continued the work started by Bridger (1970). Instead of an otter trawl, the effects of a beam trawl were studied. The aim was to make direct observations both of the bottom over which the trawl passed and an untrawled area. Notwithstanding that the experiments were not designed to evaluate the effects of trawling on zoobenthos, some interesting observations were made.

Trawl tracks could be identified up to 3½ h after passage of the trawl. The marks left by the beam-trawl heads (shoes) were straight ruts of the same width. The trawl never did dig deeply into the bottom. Tracks could be well distinguished on a muddy-sand bottom and far less clearly on hard coarse sand and a soft muddy bottom. Stones were displaced by the chains over short distances. Benthic life was not very abundant; however, the following species were observed: *Corystes*, hermitcrab, tube worms, whelk, brittle stars and *Astropecten*. A number of these were seen apparently undamaged in the trawl path. Tube worms re-opened and whelks and starfish were soon on the move again. However, also damaged species, e.g. *Corystes* and brittle stars, with broken claws or arms were seen.

De Groot (1972) studied the influence of a beam trawl upon the sea bed with a transit sonar. This type of sonar records an acoustic plan of the sea bed, showing sand waves and changes in sea-bed material and texture. The principle of operation is simple; a fixed transducer transmits a fan-shaped beam, very narrow in the horizontal plane, to one side of the vessel's track. After transmission, echoes are received from a narrow strip of the sea bed. As the vessel advances, successive scans are recorded and accumulated to form an acoustic plan of the sea bed. The experiments were carried out on an important sole-fishing ground. The gear used was a double 6-m shrimp trawl (2 cm mesh) with ten tickler chains, a chain mat, weighing in total approx. 2200 kg. each. The following conclusion can be drawn from the experiments, that the disturbance of the bottom by the trawl depends mainly on the type of bottom and the current velocity. The disturbance was most distinct when the bottom was soft and sandy. After about 150 min the trawl

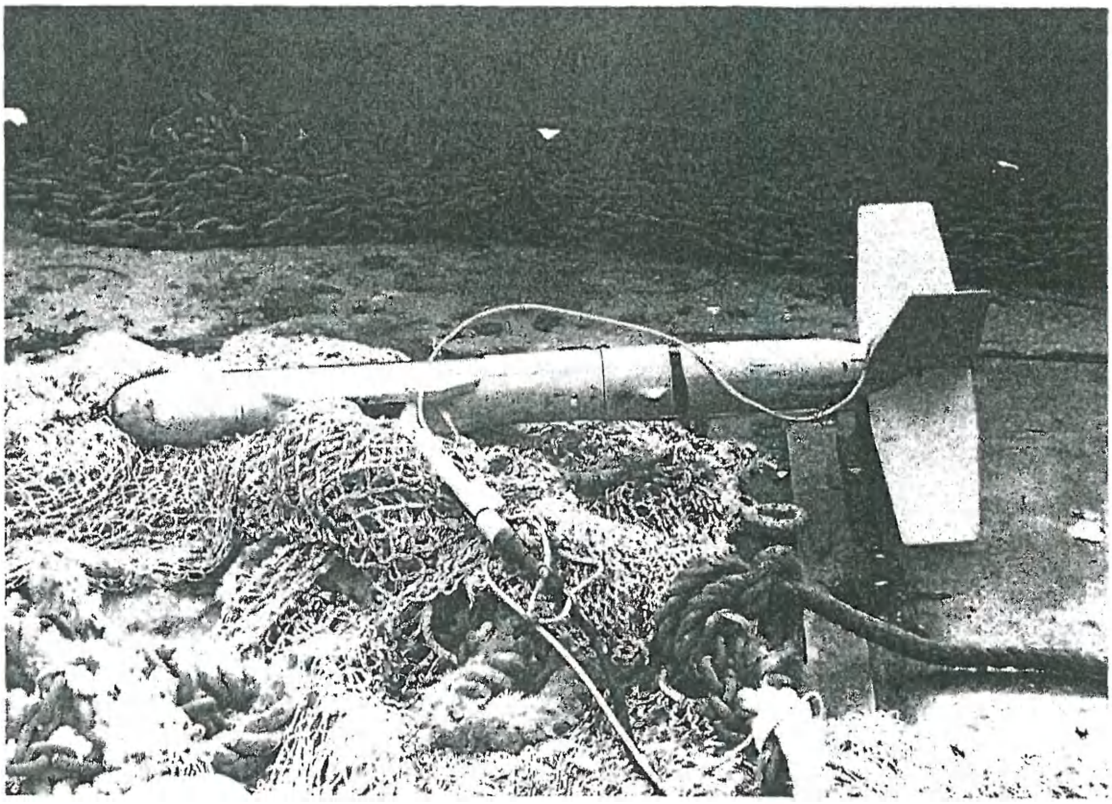

Fig. 1. E.G. and G. sidescan sonar used for recording the markings on the sea bed caused by double beam trawling.

path was still well visible. Probably the track is soon erased in a muddy bottom. After about 30 min the track was only moderately visible. The impact of the beam trawl upon a hard sandy bottom is only slight, as about 75 min after trawling the track was obliterated.

Bridger (1972) made observations on the penetration into the sea bed of tickler chains on a beam trawl. He used two types of markers. With these devices (small sticks) implanted in the sea bed he was able to measure how deep the trawl disturbed the ground. This was between 0 (not measurable) and 27 mm, even for a trawl rigged with fifteen tickler chains. These results demonstrate that, except on very soft mud or silt, the effect of an array of tickler chains is likely restricted to the upper 10 mm of the sea bed. It is further likely that the maximal disturbance will not exceed 30 mm in depth. It is interesting to note that the trawl caught large quantities of infauna, especially *Echinocardium*. It is very reasonable to assume that this species lies very close to the surface. Their presence in the catch was no proof that the gear has been digging more deeply into the sea bed.

De Clerck and Hovart (1972) repeated the English and Dutch experiments in Belgian waters. Their results underwrite the findings of the other experi-

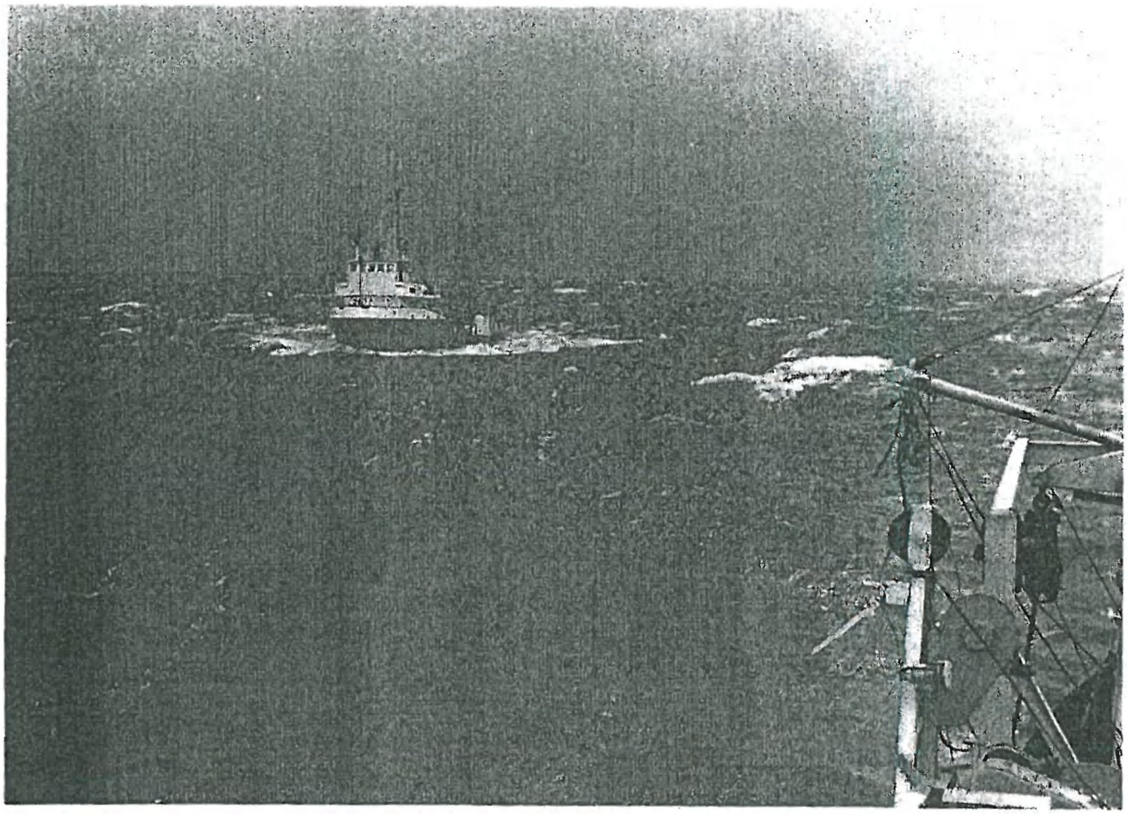

Fig. 2. The trawler is followed by a research vessel recording the trawl track on the sea bed with sidescan sonar.

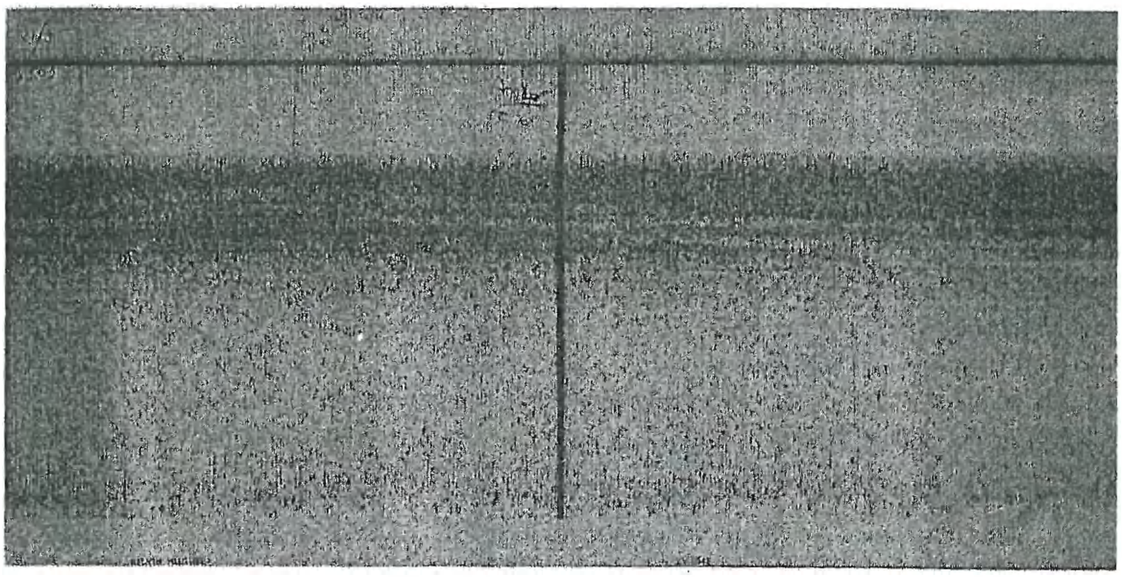

Fig. 3. The markings of double beam trawling on the sea bed, situation $2\frac{1}{2}$ h after passage of the trawls. Cleaver Bank, North Sea.

ments. Their feeling also was that the digging effect into the sea bed of the beam trawl with chains is rather limited.

Caddy (1973) made underwater observations on the tracks of otter trawls and dredges in bottom sediments with the aid of a submersible in the Gulf of St. Lawrence. The tracks left by trawling covered at least 3% of the sea floor. The markings were mainly caused by the trawl doors. The tracks of the scallop dredges could be distinguished from the trawl tracks. It was found that scallop dredges were destructive to the sea bed. They bring fine sediment into suspension, by their action they cover gravel beds with a sand surface and they appreciably roughen the bottom. Furthermore, the scallop dredge catches about the same amount of scallops as it destroys in its wake (13–17%). Caddy observed that fish and crabs were attracted to the trawl path within 1 h after fishing and were observed in the tracks at densities 3–30 times those observed outside the tracks.

De Graaf and De Veen (1973) could attribute differences in percentages of regenerating arms of starfish (*Asterias rubens*) sampled in the North Sea and Dutch inshore waters (Wadden Sea, Scheldt-estuary) to the specific fishing gear. In contrast with the North Sea, hardly any beam trawling for sole takes place in the inshore waters. They concluded that the fishery and especially the beam trawl is mainly responsible for damaged starfish, resulting in the phenomenon of regenerating arms. Significant differences were found between shrimp beam trawls using no tickler chains and sole beam trawls using a number of tickler chains.

Very pertinent to the present evaluation is the work carried out in the German Wadden Sea in relation to the distribution in time of macrobenthos (Riesen and Reise, 1982; Reise, 1982). They were able to demonstrate long-term changes in the marine ecosystem and to attribute them to human impact: the expanded shellfish culture (mussels) and the shrimp fisheries. They studied data collected from 1923–1926 on the distribution of macrobenthos of subtidal shallows and channels. They compared this with their own records of sampling in the same localities in 1980. It was observed that the faunal composition was substantially altered during the last half century. It was understood that severe winters have their known effects on benthic macrofauna. Molluscs are far more sensitive to low temperatures than are polychaetes. This in fact explains the relative abundance of the latter after severe winters. However, the changes in faunal composition cannot be explained this way. Riesen and Reise observed an overall shift in abundance and species composition. The number of individuals per unit area increased. Molluscs and crustaceans decreased in species number and diversity since the 1920's, whereas polychaetes increased. It should be noted that in the area of investigation (near Sylt) the mussel culture expanded rapidly at the cost of oyster culture. The oyster has vanished completely in the area and oyster beds of the past are the mussel banks of today.

The *Sabellaria*-reefs in the area are now completely lost. This was caused by local shrimp fishermen clearing the ground of obstacles with their trawl gear. Reefs are a hindrance as they cause extensive net damage. Recovery of the damaged *Sabellaria*-reefs, or recolonization, did not take place as the substrate has been completely changed.

The increase in turbidity presumably caused by large-scale engineering activities such as the building of dams, may be responsible for the loss of the extensive subtidal seagrass beds (*Zostera marina*) in the area.

In addition to the macrobenthos data from 1923–1926 mentioned above, Reise (1982) also studied old records from Möbius collected in 1870 on the distribution and diversity of benthic species in oyster beds. Of 101 common species known to inhabit the intertidal and subtidal soft bottom in 1869, 28 species since then have decreased in numbers, mainly because oyster beds, *Sabellaria*-reefs and seagrass beds have disappeared. Almost all losses occurred in the subtidal zone. Increases were observed in 30 species, mostly belonging to the intertidal zone. Remarkable is the high proportion of polychaetes which may find its origin in human interference with the habitats.

CONCLUSIONS

Complaints in connection with the use of trawls, whether beam- or ground-trawl and with or without chains, presumably date from the period of the introduction of the gear. At least the nature of the complaints remains very similar, from the thirteenth century till the present day. The fact that one fisherman, or a certain fishing port or nation is more successful than others is the main spring of the protests. Relatively new is the involvement of environmentalists with life in the sea; however, they use the age-old arguments all over again. From the work performed under the aegis of ICES it is possible to derive a clear picture of the effects of bottom-trawling upon benthic life. Trawls, beam- or ground trawl, as well as dredges are basically similar in their action on the sea bed. It makes no sense to consider the destructive effects of the various types of gear separately. Tickler chains and chained ground ropes rigged to the gear all act in the same way. Chainmats cause no greater effects on the sea bed than an array of ticklers. The effect of the passage of a trawl over the sea bed varies greatly with its nature, silt, mud, sand, hard sand, gravel or rocky. The direct visibility of the marking depends upon how the tide is running. When there is little or no tidal current, the markings persist for hours or even days. Resuspension of coarse sediments by the action of the gear is of short duration and sediment will soon settle again after the passage. The finer components will be shifted and spread by tidal currents. Under normal working conditions, trawls influence only the top layer of the sea bed; penetration will be up to 30 mm on muddy ground and 10 mm on sandy ground. In tidal waters the surface of the sea bed is by no means permanent, but is in a constant state of change and surface sediments will be moved and redeposited. In these waters the physical effects of trawling on the sea bed cannot be permanent. Tickler chains are an essential part of present-day trawling gear. The fact that sand clouds are produced by trawls contributes to their catching performance. A beam trawl with tickler chains catches far more benthos (debris), about ten times as much as a ground trawl without ticklers. On some grounds, otter trawls with ticklers catch too much benthos for economic working. Some groups of animals, e.g. hydrozoans, echinoderms (e.g. heart urchin) suffer heavy damage by trawling, others escape relatively easily (e.g., marine gastropods, hermitcrabs). It is not unthinkable that there are long-term effects, shifts in macrobenthos composition, in the North Sea. These will develop along similar lines to those shown for the German Wadden Sea. The trend will presumably be a shift to a relative increase in polychaetes and a relative decrease in molluscs and crustaceans, but this will not lead to a food shortage for the fish stocks in the North Sea. At present there are no indications; there is no lowering of the condition factor, no reduced growth, rather in fact an accelerated growth of various species.

Summarizing, it is a proven fact that bottom trawls influence benthic life in a negative way. However, as we accept fisheries as a method to support our food supply and as the damage is relatively small, these negative effects may considered to be acceptable. There is enough food available to sustain the fishstocks, so no negative effects on fish stocks are to be expected.

Due to the action of trawls, large quantities of benthic animals become available as a food source for fishes. Benthic life is very well adapted to survive the harsh regime in their habitat. Temporary covering or uncovering due to sand movement is not exceptional and they will survive. Still a shift in species distribution and numbers from one group or groups of animals to some others cannot be ruled out in the long-term. As this shift is in principle reversible it constitutes no major threat to benthic life.

REFERENCES

Anonymous, 1921. The history of trawling: its rise and development from the earliest times to the present day. Fish. Tr. Gaz., 38 (1974): 21–71.

Arntz, W.E. and Weber, W., 1970. *Cyprina islandica* L. (Mollusca, Bivalvia) als Nahrung von Dorsch und Kliesche in der Kieler Bucht. Ber. Dt. Wiss. Komm. Meeresforsch., 21 (1/4): 193–209.

Beaujon, A., 1884. The history of Dutch seafisheries; their progress, decline and revival. International Fisheries Exhibition, London 1883. Clowes, London, 306 pp.
Bridger, J.P., 1970. Some effects of the passage of a trawl over the sea bed. ICES C.M. 1970/B: 10 Gear and Behaviour Comm., 8 pp., 4 figs. (mimeo).
Bridger, J.P., 1972. Some observations on the penetration into the sea bed of tickler chains on a beam trawl. ICES C.M. 1972/B: 7 Gear and Behaviour Comm., 6 pp., 1 table, 2 figs. (mimeo).
Caddy, J.F., 1973. Underwater observations on tracks of dredges and trawls and some effects of dredging on a scallop ground. J. Fish. Res. Board Can., 30: 173–180.
Clerck, R. de and Hovart, P., 1972. On the effects of tickler chains. ICES C.M. 1972/B: 15 Gear and Behaviour Comm., 9 pp., 2 figs. (mimeo).
De Graaf, U.H. and De Veen, J.F., 1973. *Asterias rubens* and the influence of the beam trawl fishery on the bottom fauna. ICES C.M. 1973/K: 37 Shellfish and Benthos Comm., 5 pp., 2 tables, 4 figs. (mimeo).
De Groot, S.J., 1972. Some further experiments on the influence of the beam trawl on the bottom fauna. ICES C.M. 1972/B: 6 Gear and Behaviour Comm., 3 pp. 12 figs. (mimeo).
De Groot, S.J. and Apeldoorn, J.M., 1971. Some experiments on the influence of the beam trawl on the bottom fauna. ICES C.M. 1971/B: 2 Gear and Behaviour Comm., 4 pp., 1 figs. (mimeo).
Graham, M., 1955. Effect of trawling on animals of the sea bed. Deep Sea Res., 3, Suppl., 1–6.
Houghton, R.G., Williams, T. and Blacker, R.W., 1971. Some effects of double beam trawling. ICES C.M. 1971/B: 5 Gear and Behaviour Comm., 11 pp., 6 figs. (mimeo).
Jenkins, J.T., 1920. The Sea Fisheries. Constable and Company Ltd. London, p. 16.
Main, J. and Sangster, G.I., 1979. A study of bottom trawling gear on both sand and hard ground. Scottish. Fish. Res. Rep., 14, 15 pp.
Main, J. and Sangster, G.J., 1981. A study of sand clouds produced by trawl boards and their possible effect on fish capture. Scottish. Fish. Res. Rep., 20, 20 pp.
Main, J. and Sangster, G.I., 1983. Fish reactions to trawl gear. A study comparing light and heavy groundgear. Scottish. Fish. Res. Rep., 27, 17 pp.
Margetts, A.R. and Bridger, J.P., 1971. The effect of a beam trawl on the sea bed. ICES C.M. 1971/B: 8 Gear and Behaviour Comm., 9 pp. (mimeo).
Reise, K., 1982. Long-term changes in the macrobenthic invertebrate fauna of the Wadden Sea: are polychaetes about to take over? Neth. J. Sea Res., 16: 29–36.
Riesen, W. and Reise, K., 1982. Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgoländer Meeresunters., 35: 409–423.