ICES Journal of Marine Science, 57: 1416–1420. 2000
doi:10.1006/jmsc.2000.0920, available online at http://www.idealibrary.com on IDEAL®

Effects of shrimp fisheries on reefs of *Sabellaria spinulosa* (Polychaeta)

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Vorberg, R. 2000. Effects of shrimp fisheries on reefs of *Sabellaria spinulosa* (Polychaeta). – ICES Journal of Marine Science, 57: 1416–1420.

Intensive beam-trawl fishery on brown shrimps (*Crangon crangon*) occurs along the German North Sea coast. Fishing effort has increased constantly over recent decades. Simultaneously, changes in the benthos of the Wadden Sea have been observed. Besides shifts in species composition of the communities and the disappearance of oyster beds, there has been a distinct decline in the occurrence of *Sabellaria* reefs. Investigations were carried out to establish whether or not shrimp fisheries might be responsible for the decrease of the reefs. Underwater video techniques enabled direct observation to be made of the fishing gear in action on the sea bottom. The pictures revealed that shrimpers may trawl over the robust reef structures without causing visible damage. These findings are corroborated by the results of field experiments performed on the reefs of *Sabellaria alveolata* on the French Atlantic coast, and also by empirical calculations of the load of the fishing gear and the compressive strength of the reef. Reasons for the decline of *Sabellaria* reefs on the German North Sea coast are discussed with respect to natural and anthropogenic changes in the physical environment.

Key words: anthropogenic impact, sabellarian reefs, shrimp fisheries, Wadden Sea.

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Introduction

Reef-building polychaetes of the family Sabellariidae occur worldwide on the shores of temperate seas, and their colonies form massive constructions in various different shapes and sizes. The species *Sabellaria spinulosa* is known from all European coasts, except for the Baltic, indeed reefs of *S. spinulosa* have been known along the German North Sea coast for more than 100 years (Meyn, 1859; Möbius, 1893). In former times about 20 reefs were recorded in the Wadden Sea area, but today only three remain (Vorberg, 1995).

Fisheries for brown shrimps (*Crangon crangon*) with beam trawls have been carried out for more than 100 years along the German North Sea coast. Despite a considerable decrease in the number of vessels, the fishing effort (fished area per unit time) increased considerably in the 1980s (Berghahn and Vorberg, 1997). The beam trawl used today in commercial shrimp fisheries (Fig. 1) is 8–9 m wide. The parts of the fishing gear that make contact with the sea bottom are mainly the shores and the rollers of the ground rope. Tickler chains are not used.

Beam-trawl fisheries are often held responsible for changes in the benthos of the Wadden Sea (Reise, 1982; de Groot, 1984; de Jonge and de Jong, 1992). Riesen and Reise (1982) were the first to put forward the hypothesis that the trawls of shrimpers have destroyed the sabellarian reefs mechanically. However, specific investigations to verify this hypothesis have not been reported. Therefore, our aim was to assess the impact of beam trawls on sabellarian reefs and to clarify the role of shrimp fisheries in the context of the reduction of the reefs in the Wadden Sea.

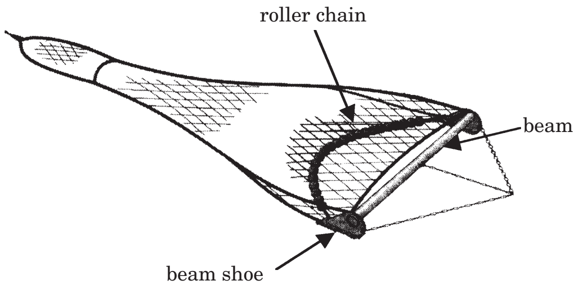

Figure 1. Typical beam trawl used in commercial shrimp fishery (after Lindeboom and de Groot, 1998).

Methods

The force exerted on the bottom due to weight of the gear must be calculated for the iron shoes and for the rubber rollers separately. First, the different components of a 9 m beam trawl were weighed. Using the contact surface, the force due to weight can be assessed. However, such values refer to the conditions on land, and are subject to fundamental changes in water on account of buoyancy. Moreover, the vertical force applied by the trawl warp attached to the beam during a fishing operation has to be taken into consideration. Beam and shoes are lifted off the bottom (vertical force vector V) as a function of the angle between warp and seabed (α) and the tractive force of the vessel (tf):

$$V = \sin\alpha \times tf$$

To get an impression of the impact that a reef can withstand, small sample sections (5 cm × 5 cm × 5 cm) were tested for their load-bearing capacity until fracture. The samples were dry-sawn out of the lower, centre, and top part of a fairly large, cylindrically shaped reef fragment (built by *S. spinulosa*) of about 30 cm in height and a surface area of 12 cm in diameter. To avoid destruction of an existing reef by sampling as well as to avoid sawing through living worms, a fragment was used that had been exposed to the air for more than a year. However, the stability of fresh reef material is expected to be higher, because the organic cement produced by the worms to build up the tubes is destroyed by air oxygen (Vovelle, 1965). Therefore, the estimates of compressive strength have to be regarded conservative. The test was conducted by the Hamburg Construction Materials Testing Institute.

An underwater camera was fitted in a trawl shoe to record the behaviour of the fishing grear as it passed over a sabellarian reef in the North Frisian Wadden Sea near the island of Amrum (Berghahn and Vorberg, 1997). The technical equipment used was an OSPREY monochrome low-light level camera (OE 1323) connected over a 150 m long umbilical with a control unit (OE 1236) on board the shrimp vessel. The pictures were recorded on a VHS video tape recorder.

Optimal conditions to perform a controlled "before/after"-experiment were found on a periodically exposed reef of 30 hectares on the southwest coast of the island of Noiroutier (France), built by *Sabellaria alveolata*. During high tide the extensive reef was trawled with a 3 m research trawl equipped with ten rollers, as used in the commercial shrimp fishery. Because of restrictions imposed by the French authorities, the gear had to be used without a net. Reef sections inside a test area of 30 m × 50 m were swept six times. The area was revisited during low tide following the experimental fishing.

Table 1. Summary of forces related to the weight of beam+shoes and of rubber rollers of a shrimp beam trawl resulting in pressure on the sea bottom.

	Beam+shoes	Roller
Weight on land (kg)	550	6.5
Weight difference in water (%)	− 13	− 60
Vertical force (kg)	− 165	—
Contact surface (cm^2)	2400	20
Pressure ($kg\ cm^{-2}$)	0.13	0.13

Information on reef growth is a prerequisite to assess the nature and extent of possible destruction caused by the fishery. *In-situ* measurements of undisturbed tube growth of *S. alveolata* were conducted from July to October. In addition, about 2 cm of reef material was removed from the surface at a wave-exposed reef section, at the windward side, upon the roof of the reef and at the leeward side. At each point, experimental plots of 100 cm^2 were laid out for measuring both undisturbed growth and growth after disturbance. Measurements of tube growth within these areas were made by means of 10 cm long screws, which stuck out 3 cm fixed in such a way as to result in a 3 cm rise above the reef surface. Observation intervals for undisturbed reef growth were 14 days, whereas the disturbed areas were controlled daily until the destroyed parts of the tubes were restored completely.

Depending on the extent of data available and their distribution type, the t, U, Lord, Welch, and Weir tests were used in statistical analyses to check for significance (Lozan, 1992). All tests were based on an error probability of 5%.

Results

Fishing gear impacts

A summary of the forces due to weight of the beam and two trawl shoes and the weight of a single rubber roller including shaft and fitting are given in Table 1. The weight of the beam and the shoes is distributed over a contact surface of 2 × 1200 cm^2; i.e., the pressure under the shoe is roughly 0.23 $kg\ cm^{-2}$. The load on the substrate exerted by the weight of a roller could not be measured exactly. Because of its cylindrical shape the contact surface is minimal on hard substrate and increases when the rollers sink in the soft bottom. Assuming a contact surface of 20 cm^2, which roughly corresponds to the conditions encountered on a hard sandy bottom, the force due to weight of a roller is approximately 0.33 $kg\ cm^{-2}$. Weight loss in water amounts to some 13% for the iron parts (beam and shoes). For a rubber roller including shaft and fittings, the weight loss was determined experimentally (60%).

Table 2. Dimensions (length, L; width, W; height, H (mm); density, D (kg dm^{-3}) and compressive strength (S; N mm^{-2}) of different vertically positioned blocks within a sabellarian reef segment.

Location	L × W × H	D	S
Lower part	52 × 51 × 52	0.90	0.15
	50 × 49 × 51	0.97	0.11
Centre	50 × 49 × 48	0.99	0.27
	51 × 48 × 44	1.00	0.24
Upper part	50 × 48 × 48	0.97	0.34

A shrimp vessel with an engine power of around 200 hp develops a maximum tractive force of roughly 2000 kg. Usually, trawling is performed at about half the maximum possible engine power (1000 kg), which is distributed over two sets of gear and at a trawling speed of 3 to 4 knots. As the ratio of warp length to water depth is generally constant in shrimp fishery (3:1), the vertical force vector is one third of the tractive force of the vessel (based on α 19°). Therefore, the vertical force is 165 kg per beam, which reduces the pressure of the shores to 0.13 kg cm^{-2}, the same value as for the rubber rollers (Table 1).

The load-bearing capacity of the sample sections was different (Table 2), with the highest values for the top part of the reef block and the lowest values for the bottom part. The average compressive strength was 0.22 N mm^{-2}, corresponding to 2.2 kg cm^{-2}.

The pictures taken by the video camera revealed that the rollers had no problem in running over the reef sections. In this particular case, reef structures were shallow and rose to a height of 30 to 40 cm over the bottom. The rollers regularly jumped off the reef surface and had bottom contact for 39% of the overall trawling time (duration of observation: 20 min). When touching the reef surface, the rollers stirred up the top sediment layer, producing clouds of fine-grain material. Damage to the reef construction itself could not be observed.

Initially no problems were encountered in pulling the 3 m beam trawl over the study area. However, on crossing a very high reef section, the beam became caught and was bent out of shape. After the experiment at low tide, there were no signs of reef sections having been destroyed. However, the trawl shoes had left clear impressions, especially where they had made contact with the upper edges of the reef. All traces caused by the fishing gear had disappeared four to five days later due to the building activities of the worms.

Tube growth of *Sabellaria alveolata*

The experimental destruction of the reef surface did not seem to harm the worms. After three days at most, the experimental area could no longer be distinguished from its surroundings. Undisturbed growth in August was 0.9 mm day^{-1}. In September/October the average undisturbed growth at the three different measurement points was 0.7 mm day^{-1}, while the average daily growth after removing 2 cm of surface was 4.4 mm day (Fig. 2). The growth during the restoration phase was significantly higher than undisturbed growth. The position of the measurement points appeared to be of less influence. There were no statistically significant differences in growth between the windward side, the roof and the leeward side of the reef.

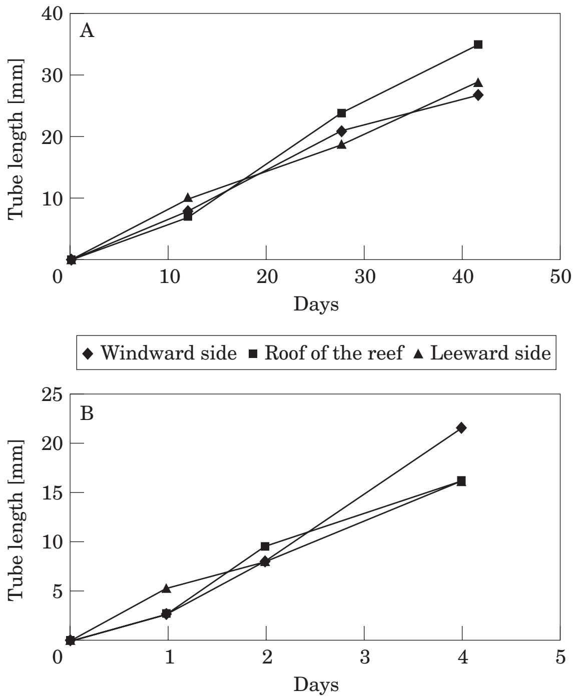

Figure 2. Tube growth of *Sabellaria alveolata* in September/October: Upper panel undisturbed growth (average: 0.7 mm day^{-1}); Lower panel growth after removing 2 cm of reef surface (average: 4.4 mm day^{-1}). Note different scales of the axes.

Discussion

Compared to beam trawls used for flatfish fisheries (Lindeboom and de Groot, 1998), the force due to weight exerted by the shrimping gear on the sea bottom is only half as high. Shrimp trawls can be regarded as relatively light fishing gear with low impact on the sea bottom (Rumohr *et al.*, 1994; Vorberg, 1997). Also, *Crangon* fisheries along the German North Sea coast have been assessed as basically non-destructive (Stock *et al.*, 1996).

The compressive strength measurements suggest that sabellarian reefs are highly stable constructions. Although the reef section used in the tests had been exposed to air for more than a year, compressive strength was considerable. The highest load-bearing capacity was observed for the upper part of the reef block where mechanical impact by the fisheries may occur. The mean value of 2 kg cm^{-2} determined is in agreement with the observation that people can walk during low tide over the reef surface without doing visible damage. A person weighing 80 kg and wearing rubber boots can create a pressure of approximately 1.5 kg cm^{-2} under his feet. The fishing gear of a shrimp vessel in operation causes only one tenth of this pressure (Table 1). Previous investigations (Vorberg, 1997) have shown that the rollers often do not make contact with the bottom and least so when passing hard bottoms like a sabellarian reef. Furthermore, taking into account the fact that rollers exert relatively little pressure, the conclusion seems justified that those used in *Crangon* fisheries cannot cause damage to reef constructions. The trawl shoes could not be observed directly by means of underwater television, but appear to have permanent bottom contact (Vorberg, 1997). The force due to weight exerted on the bottom is equal to the pressure caused by the rollers, but traces of the shoes were the only signs of damage detectable on the reef surface in the fishing experiment. Nevertheless, these traces were of no significance for the development of an intact sabellarian reef. Provided that the organisms are not killed or removed from their tubes, the natural growth and capacity for repair is such that they can rebuild destroyed parts of their dwellings within a few days (Gruet, 1971).

These findings relate exclusively to short-term effects following once-only disturbance. The possibility of impairment by shrimping in the medium to long-term cannot be ruled out in the event of intensive fishing, despite the relatively light gear. In addition, the rollers may sometimes have difficulty running over very high and steep reef edges. When the ground rope becomes entangled, a section of reef may still be destroyed. However, such problems appear to be of less importance. Fishermen have always tried to avoid reef contact, because entanglement could damage to their gear. Therefore, it is understandable that recent reefs are found in areas of intensive shrimp fishing activity. Reports on the destruction of sabellarian reefs by shrimp fisherman in former days (Riesen and Reise, 1982) must be treated with caution. The vessels used around the mid-20th century were fitted with low-powered diesel engines capable of producing 30 to 75 hp (Detlefsen, 1984). In case of entanglement their tractive force was too low to release gear or to damage the robust reef construction.

Because shrimp fisheries seem of little significance as a cause of the decline in sabellarian reefs in the Wadden Sea, other possible factors must be considered. Long-term studies conducted in France and Great Britain (Caline *et al.*, 1992; Wilson, 1971) have shown that processes occurring within the reefs are highly dynamic. The natural development is characterized by four phases: larval settlement, growth, stagnation and destruction (Gruet, 1982). Each developmental stage is influenced by numerous factors such as currents, weather conditions, competition for food and space, coastal engineering, sediment dumping (Vorberg, 1995). Interpretation of the significance of the various abiotic and biotic factors clearly requires detailed knowledge of the natural development processes in the reef. On account of the complex and dynamic relationships existing within the reef, as well as between reefs and their environment, it is difficult to explain the decline of the sabellarian reefs in the Wadden Sea.

However, consideration of the variables acting on a reef does reveal the crucial role of the currents, which represent the only factor influencing all developmental phases (Vorberg, 1997). The current plays a decisive role in the distribution of the planktonic larvae, as well as in the supply of tube-building material and nutrition. Studies on *S. alveolata* in France revealed that the larval supply required for reef formation and development comes from elsewhere (Caline *et al.*, 1992). At the appropriate time of year, large numbers of *Sabellaria* larvae used to be found in the Wadden Sea (Heiber, 1988). In view of the fact that current investigations confirm the presence of larvae offshore (Husemann, 1992), it is reasonable to suppose that changes in the currents prevent the transportation of a sufficient quantity of larvae into the Wadden Sea. Changes in current patterns also mean changes for the reef itself. Faster currents can lead to erosion, slower currents to sedimentation. Conversely, if a sabellarian reef survives for decades at one particular location, as applies to two reefs in the North Sea (Vorberg, 1997), this is evidence of little or no fluctuation in current conditions.

The search for reasons for the decline must focus on changes in current patterns in the Wadden Sea. Apart from natural disturbances caused by tidal currents, storm tides or ice winters, there have also been a number of anthropogenic measures and effects associated with them, for example the building of causeways to the islands, dyking, jetties, coastal-protection structures, dredging work and sediment dumping. The results presented suggest that these factors may be more important in relation to changes observed in the Wadden Sea than the impact of the shrimp fishery.

Acknowledgements

The study was supported by the Federal Environmental Agency, Environmental Research Plan of the Minister of the Environment, Nature Conservation and Nuclear

Safety of the Federal Republic of Germany (Grant 108 02 085/01), and by the state of Schleswig-Holstein. This is publication No. 348 of the project Ecosystem Research Wadden Sea. The author thanks "Aktion Seeklar", Verein zum Schutz der Meere e. V., Hamburg, for travel funding.

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