Trophic Relationships in the Marine Environment, 1990, pp 130–140.
Proc. 24th Europ. Mar. Biol. Symp.
Margaret Barnes and R. N. Gibson, Editors
Aberdeen University Press

ON THE POTENTIAL IMPACT OF SHRIMPING ON TROPHIC RELATIONSHIPS IN THE WADDEN SEA

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ABSTRACT Since the early 1970s the by-catch of the shrimp fisheries in the North Frisian Wadden Sea (eastern North Sea) has no longer been landed, but discarded immediately after sorting. Mortality of fish in the catch and the sieving procedure have been investigated for different species and age groups. Dead fish from the by-catch were exposed to predators in tanks and as bait in traps. Intake of fish by seabirds was estimated by means of video recording analysis and re-catch of discards. Thus, clearance rate for fish by various predators was roughly determined. Data concerning clearance rate by harbour seals were adopted from the literature. The "Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer" provided information on densities of seals and seabirds. The total amount of fish and crustaceans present was derived from synchronous by-catch sampling in the subtidal zone (315 km^2) of the entire research area. Finally, food demands of selected predators at the highest trophic level were compared with the amount of discards produced. In June 1988 the seabird population would easily have been capable of clearing the discards of moribund roundfish. The same was true for the former seal population, which was most likely to benefit from flatfish discards.

INTRODUCTION

Since 1974 the by-catch of the shrimp fishery in the North Frisian Wadden Sea has no longer been landed, but discarded immediately after sorting (Tiews, 1983). In various investigations on the by-catch carried out in the area during the last 11 years (Lillelund & Berghahn, 1981; Berghahn, 1986) the number of dead fish—in other words, fish that had recently been discarded—was always rare. This is surprising, because shrimping intensity in the coastal area of the North Sea is extremely high, producing a large amount of discard. It might suggest a fast removal of these animals due to clearance by predation. In this study, a first attempt is made to elucidate the fate of the discarded by-catch of the shrimpers in the North Frisian Wadden Sea and to get an insight into the impact on the trophic relationships in the area.

MATERIAL AND METHODS

By-catch mortality was determined by taking samples from a defined 1-h haul on a commercial shrimping vessel before and immediately after sorting

employing a common shaking sieve (traditional type; Boddeke, 1989). The fish were transported in containers (30 l; 0.125 m^2; max 20 specimens per container according to fish size) and transferred into nine flow-through aquaria (500 l; diameter 1.5 m; flow rate 3 $l \cdot min^{-1}$) in the Biologische Anstalt Helgoland in List on Sylt Island. It always took less than 1 h to get the fish into the aquaria after they had come on board. Successive mortality was studied by keeping them in the aquaria for 5 days. Deviations from the water temperature in the field were <0.3°C. Animals were fed in excess every second day providing shrimps, polychaetes, and chopped mussel meat.

Clearance rate of the discard was investigated by feeding swimming crabs (*Liocarcinus holsatus*), shore crabs (*Carcinus maenas*), and shrimps (*Crangon crangon*) in separate aquaria with dead fish. Clearance rate was roughly determined by weighing the feed at the beginning and the end of the experiment. Deviations in the wet weight of the bait due to degradation were considered.

Traps baited with fish from discards and without bait were used to elucidate the fate of the discard in the sublittoral (Fig 1). Mesh sizes were 5 and 10 mm. Furthermore, dead fish tied on stones were exposed at the same time. The clearance rate of moribund discarded roundfish by gulls and terns was estimated by means of direct counts, photography, video recordings, and recatch experiments on a shrimping vessel. Numbers of harbour seals (*Phoca vitulina*) and seabirds in the region were provided by the "Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer".

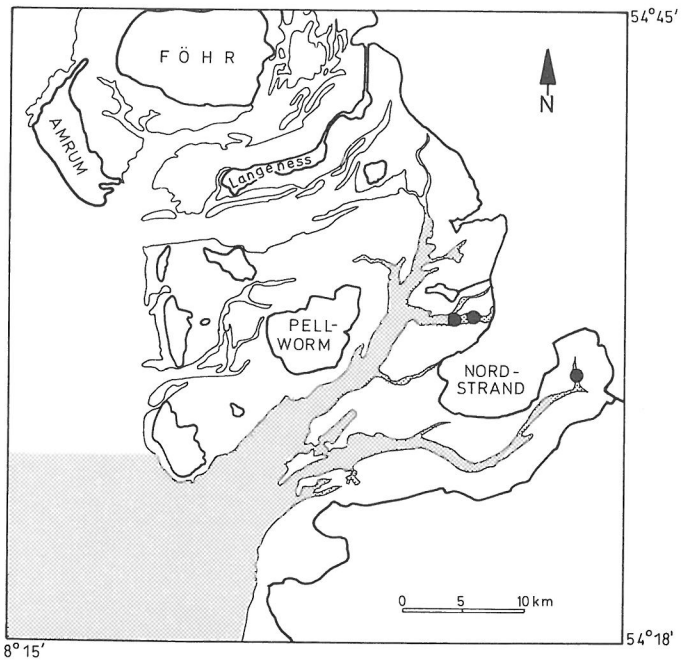

Fig 1.—Research area. Hatched area indicates subtidal zone sampled. ● exposure of traps.

The research area for calculations on the impact of shrimping was the southern part of the North Frisian Wadden Sea between the Eiderstedt Peninsula and the Isle of Pellworm (Fig 1). Shrimping only takes place in the subtidal zone. In the research area, the zone covers 315 km^2. Nearly 50% of the entire area belongs to the Wadden Sea proper.

Fishing intensity and the amount of discards were calculated for June 1988 on the basis of the landings in Husum Harbour and data provided by synchronous by-catch sampling. Sampling was carried out with the help of nine commercial vessels from the local shrimp fishery on 29 June. The fishermen removed a 10-l subsample from the unsorted catch obtained during each first and last haul and each haul at low tide. Supplementary information for each haul was available concerning the fishing ground, total catch, proportion of edible shrimp, position and time of sampling, water depth, towing speed, ship's course, and exact measurement of the gear applied. No correction was made for fishing efficiency. In two cases, selective shrimp trawls were employed, and these had to be corrected for normal efficiency (Mohr & Rauck, 1979).

RESULTS

Mortality of dab in the discards varied strongly according to the prevailing conditions such as total catch, catch processing, and maintenance. The four out of 12 experiments carried out during the season in question (water temperature 14.4 to 17.5°C) consisted of a total of 133 specimens (Table I). Mortality after 5 days was 10 to 35%. Direct observations on board revealed mortality of smelt (*Osmerus eperlanus*) to be close to 100%. Consequently, no long-term series were carried out with smelt, but 100% mortality was taken for the calculation. This rate cannot, however, be adopted for all species of roundfish. For sculpin (*Myoxocephalus scorpius*), hooknose (*Agonus cataphractus*), and eelpout (*Zoarces viviparus*) survival was very high as soon as they had reached a size at which they were no longer included with the fraction of edible shrimp in the sorting procedure (Table I).

TABLE I

Mortality of selected fish species in the by-catch of the shrimp fishery after 5 days of maintenance. The trials without sieving are given in brackets

Species	Number of trials	Total catch one codend, kg	Water temp., °C	Number of specimens	Total length, cm	Mortality, %
Dab	4	55–125	14.4–17.5	133	10–27	10–35
	(3)			(78)		(0.0–11)
Sculpin	7	70–150	14.4–18.8	52	10–20	0.0
	(3)			(17)		(0.0)
Hooknose	6	70–150	12.0–18.8	134	7–16	0.0–13
	(5)			(37)		(0.0–5)
Eelpout	4	70–100	12.0–17.6	45	13–20	0.0–17
	(4)			(28)		(0.0–13)

Laboratory experiments showed shrimps, crabs, starfish (*Asterias rubens*), and whelks (*Buccinum undatum*) to benefit from dying components of the discard. In eight experiments with crabs, food intake was 0.40–1.33 g wet wt·specimen^{-1}·day^{-1} (Table II). The demand for shrimp was 0.034–0.093 g·specimen^{-1}·day^{-1} in another four experiments (Table III). Swimming crabs and shore crabs fed on moribund fish as soon as it was discarded. Shrimps could only live on the slime in the very beginning and had to wait 3 to 4 days until degradation made the fish digestible for them.

Five field experiments with ten baited traps revealed the high attraction of fish discard for shrimps, shore crabs, swimming crabs, and starfish. According to catches with a 2-m beam trawl, whelks were not present in the area, where the traps were exposed. The number of predators was always higher in baited traps (6 to 18 specimens per trap) compared with the ones without bait (1 to 9 specimens per trap), which were exposed at the same time. During summer the bait consisting of one or two flatfish or roundfish, ranging from 9 to 17 cm in length, was half to fully digested within 3 h of exposure. Untrapped bait tied on stones was eaten up to the bones during the same time interval. Exposure of 3, 5 or 8 h had no effect on predator densities in the traps.

Total area swept during the 26 hauls of the synchronous by-catch experiment was 3.14 km^2. Sampling stations were spread over all the research area. Duplicate samples revealed the accuracy of subsampling to be satisfactory (Table IV).

Data from the by-catch and the survival experiments were used to calculate the amount of discard produced by the shrimpers operating in the research area in June 1988 (Table V). According to their food demands, the seal population in the research area alone would theoretically be capable of clearing the flatfish discards produced by the shrimpers (Table V). The same holds true for gulls and terns, although reliable estimates on the daily food intake of seabirds were only available for herring gulls (Hüppop, 1987). Preliminary results from a study on the by-catch clearance rate by seabirds showed the effectiveness of gulls following the shrimping vessels to be in the order of 80 to 90%. During daytime up to 3000 specimens were counted. Most of them were black-headed gulls, common gulls, and a number of herring gulls.

Calculations on the food intake of crabs and shrimps in the research area in June 1988 were based on the results from the clearance rate experiments (Tables II and III) and the by-catch experiment. The number of shrimps in particular was highly under-estimated due to mesh selection.

DISCUSSION

The results from this study confirm the findings of Kelle (1976/77). He demonstrated in his investigation on the survival of by-catch flatfish in the shrimp fishery that it is insufficient to keep the fish in tanks up to 8 h only. Juvenile flatfish suffer from haemorrhages during sorting (Kelle, 1977) and successive mortality can only be determined by keeping the fish for several days. The higher survival rates in this study can be attributed to the fact that Kelle had to transport the animals in relatively small containers up to 9 h until he could transfer them into aquaria. Injuries and stress during the catch

TABLE II

Daily food intake (DR) of crabs fed on fish from the by-catch of shrimpers. Weight is given as wet weight

No.	Water temp., °C	*Carcinus* Number	*Carcinus* Carapace width, cm	*Liocarcinus* Number	*Liocarcinus* Carapace width, cm	Food, g	Uptake, g	Days	DR, mg
1	11.5	14	3–5	26	3–5	352	79	5.5	360
2	15.0	7	3–6	18	3–5	324	200	6	1330
3	15.2	3	3–5	7	3–5	22	7	1	700
4	15.2	3	3–5	7	3–5	38	7	1	700
5	15.2	3	3–5	7	3–5	40	14	2	700
6	17.2	1	6	24	4–6	173	173	5.5	1260
7	18.1	22	3–5	15	3–5	372	193	4	1300
8	18.0–18.8	22	3–5	15	3–5	120	120	5	650

TABLE III

Daily food intake (DR) of shrimps fed on fish from the by-catch of shrimpers. Weight is given as wet weight

No.	Water temp., °C	Number of shrimps	Total length, cm	Food, g	Uptake, g	Days	DR, mg
1	11.5	200	4.5–6.5	290	66	5.5	60
2	15.0	150	3.0–7.0	136	27	5	36
3	15.0–16.0	119	2.0–5.5	20	20	5	34
4	17.4–17.6	54	4.0–7.0	66	20	4	93

and sieving procedure are likely to cause hyaline zones on the otoliths of the survivors similar to those described by Berghahn (1985).

Potential beneficiaries (Table V) other than seals and seabirds alone would easily be capable of handling the amount of discard produced (Wassenberg & Hill, 1987). Total numbers of crustaceans are under-estimated due to net

TABLE IV

Number of specimens in duplicate samples from the unsorted catch of the shrimpers

Species	Sample A	Sample B	Total catch, kg
June 1988			
Dab > O-group	0	4	40
	14	14	90
	2	5	70
Shore crab	0	0	40
	2	0	90
	0	0	70
Swimming crab	2	7	40
	7	2	90
	7	4	70
November 1988			
O-group dab	41	44	290
	44	70	275
	197	194	160
Smelt	1	0	290
	1	1	275
	14	14	160
Shore crab	48	56	290
	7	7	275
	19	21	160
Swimming crab	0	1	290
	13	6	275
	16	24	160

TABLE V

Basic data and calculations on the impact of shrimping in the southern part of the North Frisian Wadden Sea in June 1988

Landings of edible shrimp in Husum Harbour	78 265 kg
By-catch investigation	
Edible shrimps	810–880 kg
Flatfish discard	303 kg
Moribund roundfish	174 kg
Area swept	3.14 km^2
Research area	315 km^2
Estimated totals	
Flatfish discards	29–76 tons
Discards of moribund roundfish	17–21 tons
Dab discards	max 35 tons
Moribund dab in discards	max 3–12 tons
Smelt discards	max 6–7 tons
Potential beneficiaries	
Adult harbour seals	524
Daily food intake of harbour seals[a]	5–8.5 kg
Amount of fish consumed by seals	78–133 tons
	breeding pairs[b]
Herring gull (*Larus argentatus*)	1562
Common gull (*Larus canus*)	300
Black-headed gull (*Larus ridibundus*)	>6000
Arctic/common tern (*Sterna paradisea/hirundo*)	>1830
(sandwich tern, *Sterna sandvicensis* on Norderoog	2900)
Food intake of herring gulls[c]	17.9 tons
Crabs	>7.37 million ~~tons~~
Estimated food intake in June (1 g·day^{-1})	>7 ~~million~~ tons
Shrimps	≫400 million ~~tons~~
Estimated food intake in June (0.05 g·day^{-1})	≫600 ~~million~~ tons
Starfish	?
Whelks	?
Fish (sculpin etc)	?

[a] Sievers, 1989; [b] Kämpf *et al.*, 1989; [c] after Hüppop, 1987.

efficiency and mesh selection. Employing the conversion factors of Rumohr *et al.* (1987) on the results reported by Scherer & Reise (1981), daily rations for crabs in Tables II and V are slightly over-estimated. For shore crabs >5 cm frequently occurring in the subtidal zone of the Wadden Sea the figures are, however, under-estimated (Elner & Hughes, 1978). Consequently, 1 g wet wt·day^{-1} is a fairly reliable estimate for the daily ration of crabs. Food intake of shrimps seems to be in the right order of magnitude (Meixner, 1968; Bengtsson, 1975; Lissa, 1977). According to the results from the field experiments with baited traps, the area of olfactorial attraction of the bait is limited (McQuinn *et al.*, 1988).

The amount of discards produced by shrimping is under the influence of many factors varying throughout the year (Fig 2). The number of dead fish in the by-catch is also under-estimated by the lower gear efficiency for dead specimens. Nevertheless, it can be concluded from the predation experiments

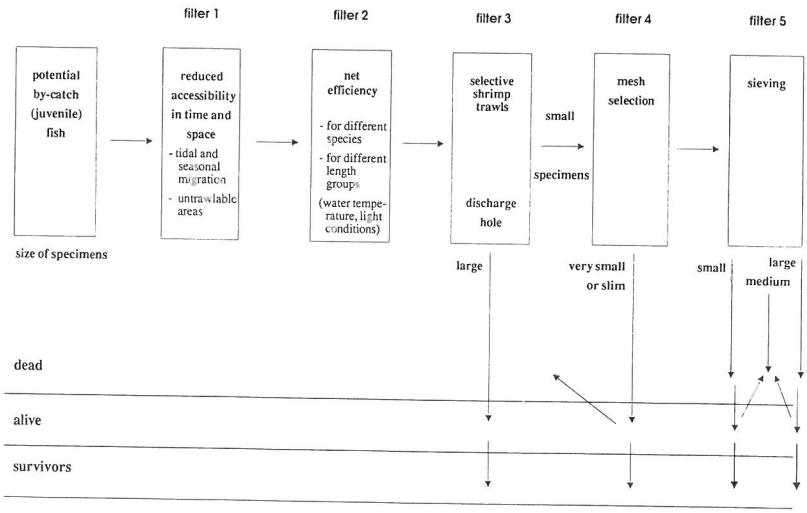

Fig 2.—By-catch of the shrimp fishery.

that the clearance of discards in the Wadden Sea occurs very rapidly. Consequently, dead fish are rare in the catches.

Even though it is still only an assumption that harbour seals play an important role in the clearance of the discards (Fig 3), evidence is provided by the following facts: seals, like seabirds (Hudson & Furness, 1988), are known to aggregate in areas with high trawl-fishery activity (Ryan & Moloney, 1988). Underwater video-recordings revealed grey seals (*Halichoerus*

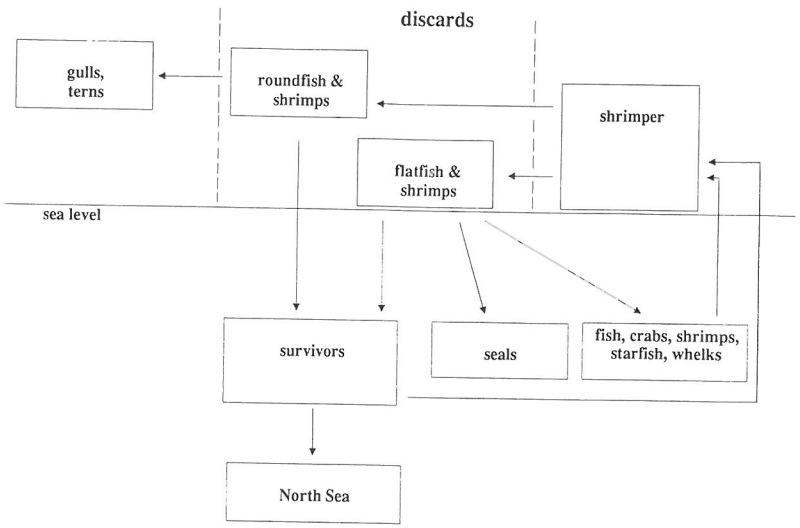

Fig 3.—Fate of discarded by-catch of the shrimp fishery.

grypus) to feed on fish, which were selected through the meshes of a codend at a water depth of 77 m (Dornheim, 1988). The seal population in the North Frisian Wadden Sea more than doubled from 1974 to 1988 (Heidemann & Schwarz, 1989). This was because hunting was prohibited in 1974. Nevertheless, landing of by-catch stopped in the same year (Tiews, 1983), thus providing a convenient food source for the seals, in particular during the breeding season. The same assumption fits the still fast-growing seabird populations in the Wadden Sea (Vauk *et al.*, 1989). The discards certainly neither caused the increase of the seal population nor of seabird populations. They are, however, likely to have promoted it. Harbour seals are known to feed opportunistically (Behrends, 1985). They prefer flatfish (Haaften, 1981), which now plays an increasing role as feed (Sievers, 1989). From 1975 to 1984 flatfish increased in number in the diet of seals in the North Frisian Wadden Sea by 20%. Up to now, flatfish contribute 58.2% to the total, which is 66.0% in weight of the diet for juveniles and 80.5% for adults (Sievers, 1989). Dab comprises about 6% in number (Behrends, 1985). In this study, calculations were specified for dab (Table V), because they do not exhibit tidally phased feeding migrations onto the submerged tidal flats (Berghahn, 1987). Shrimping is carried out exclusively in the subtidal zone. Consequently, this flatfish species is much more accessible for commercial beam trawls than plaice, sole or flounder.

In many cases, evidence has been provided for an interference of marine mammals with fisheries (Beddington *et al.*, 1985). The common assumption, however, that shrimping may diminish the food for seals has probably to be reversed. On the contrary, flatfish is the most attractive component of the discard for seals, because the flatfish suffer from successive mortalities after sorting and can easily be caught. Furthermore, fish released through the discharge funnel of selective shrimp trawls, which are obligate during the winter, are also likely to be partly preyed upon by seals.

In contrast, roundfish species either die immediately and are preyed upon by gulls and terns or, according to species and size, survive the procedure without being harmed. The calculations on the clearance of discards by herring gulls except chicks were carried out under the assumption that these birds fully depend on the discard of shrimpers. During the season in question adult herring gulls, in contrast to their chicks, rarely, however, fed on fish (Rösner, pers. comm.). Nevertheless, reliable estimates on the food intake were only available for herring gulls. The calculations are just meant to give an impression of the order of magnitude in the discard clearance potential of seabirds. Anyway, even if the adults did not consume any fish at all, the demand of their chicks alone would be considerable. Until the age of 40 days they can take up 5.4 kg wet wt of fish (Hüppop, 1987). According to Spaans (1971) the total food intake of young herring gulls in captivity during the chick stage (6 wk) is 8.3 to 9.2 kg wet wt. His graphs show the food demand during the first 4 wk to be about 3 to 4 kg. Under the realistic assumption (Rösner, pers. comm.) that each breeding pair was capable of successfully raising one chick feeding on fish to 80%, the clearance potential for discards would be in the order of 3.7 to 5.0 tons.

Because fish species and age groups are differently affected by shrimping activities, reasons for shifts in the fish and crustacean fauna of the Wadden Sea (Tiews, 1983) have to be reconsidered.

ACKNOWLEDGEMENTS

This study was partly funded by the Government of Schleswig-Holstein. Thanks are due to the fisherman H. G. Rohde and his wife, who help to organise the synchronous by-catch experiment. The staff of the Biologische Anstalt Helgoland provided facilities and technical support at the Wattenmeerstation List/Sylt. Data concerning seals and birds in the research area were made available by the Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer. G. Rauck and H. van der Veer and an anonymous referee kindly commented on the manuscript.

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