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NOTE

Starfish damage as an indicator of trawling intensity

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ABSTRACT: Two species of starfish, *Asterias rubens* and *Astropecten irregularis*, were collected from areas in the Irish Sea that are subjected to different intensities of commercial beam trawling. A side-scan sonar survey revealed that the observed abundance of trawl marks correlated with the reported levels of fishing at the sampling locations. The incidence of starfish, of both species, with damaged or regenerating arms increased with increasing fishing intensity. The severity of damage, i.e. the number of regenerating arms, also increased with fishing intensity. The proportion of starfish with damaged or regenerating arms may provide a useful short-term (1 to 2 yr) biological indicator of physical disturbance by demersal fishing gears.

KEY WORDS: Starfish · Fishing intensity · Indicator species · Beam trawl

Recent reports have highlighted the secondary effects of towed gear fishing methods, i.e. effects other than the removal of target species (Bergman & Hup 1992, North Sea Task Force 1993, Kaiser & Spencer 1994, 1995, 1996a, Thrush et al. 1995). Demersal fishing gears, particularly beam trawls, were identified as having the greatest potential to cause long-term changes in some benthic communities. It is estimated that some areas of the southern North Sea are swept, on average, 3 times per year by gears that penetrate the seabed (Anon. 1995a). However, fishing effort is distributed patchily, depending on the nature of the seabed, the occurrence of target species and the locations preferred by fishermen (Rijnsdorp et al. 1991). Hence, while some areas of the seabed are heavily fished, others may remain relatively undisturbed. Concern about the vulnerability of fragile and long-lived species to fishing disturbance has led to the suggestion that some areas should be closed to fishing (e.g. de Groot & Lindeboom 1994). The implementation of these measures, on scientific grounds, requires a measure of the micro-distribution of fishing effort at a scale more refined than ICES (International Council for the Exploration of the Seas) statistical rectangles (1° Longitude, 0.5° Latitude) (Rijnsdorp et al. 1991). This problem could be resolved either by using satellites to track fishing vessels, or by using biological indicators as a measure of fishing activity.

Long-lived and/or fragile species have been suggested as useful indicators of fishing disturbance (Anon. 1995b). However, the use of these species is only valid if their historical occurrence in a particular area can be verified. Species that survive physical contact with fishing gear, but that sustain some form of semi-permanent or permanent damage, e.g. a lost limb or a scarred shell, may be better indicators of disturbance. Witbaard & Klein (1994) found that the incidence of sand grains incorporated into repairs in the shell matrix of the bivalve *Arctica islandica* (L.) increased coincidentally with the expansion of the Dutch beam trawling fleet operating in the southern North Sea. Examination of shell scars in this long-lived species provides a historical picture of fishing disturbance. However, this technique is time consuming, and *A. islandica* is localised in its distribution.

Echinoderms, in particular asteriods and ophiuroids, are damaged to varying degrees as demersal trawls pass over them or when they pass into the codend (Wassenberg & Hill 1993, de Groot & Lindeboom 1994, Kaiser & Spencer 1995). However, they are highly resilient and have low fishing mortality because of their regenerative abilities (de Groot & Lindeboom 1994, Kaiser & Spencer 1995). Regenerating tissues, which may indicate damage resulting from trawling, are distinctive in the starfishes *Asterias rubens* and *Astropecten irregularis*, which are widespread and common in the North and Irish Seas. The aim of the present study was to ascertain whether the incidence of tissue damage in starfish could be used as an indicator of the local intensity of beam trawling.

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Methods. Total fishing effort, expressed as hours fished, for each ICES statistical rectangle in 1994 was extracted from Ministry of Agriculture, Fisheries and Food (MAFF) fisheries statistics for beam trawlers with an engine power <300 hp or >300 hp. These statistics were used to select 3 sites in the northeastern Irish Sea that represented a gradient of annual beam trawl effort: very light off the northeast coast of Anglesey (depth 30 to 40 m), medium off the River Mersey estuary (depth 26 to 30 m), and heavy off Fleetwood (depth 32 to 42 m) (Fig. 1). For the purpose of this study, it has been assumed that the small and large trawlers fished 4 m and 12 m beam trawls respectively. Although 12 m beam trawls are twice as heavy as 4 m beam trawls (weight in air: 7 t and 3.5 t respectively), both gears penetrate the seabed, are targeted at the same species, and have broadly similar effects on the epibenthic invertebrates examined in this study (de Groot & Lindeboom 1994). The area swept by trawlers using 4 m and 12 m beam trawls in each ICES rectangle was calculated by

$$\text{Area swept (km}^2\,\text{yr}^{-1}) = v \times w \times h \quad (1)$$

where v is trawling speed, km h^{-1} (small trawlers, 7.56 km h^{-1}; large trawlers, 13.23 km h^{-1}), w is width of 2 beam trawls (0.008 or 0.024 km), and h is number of hours fished in 1994.

For each ICES rectangle, the area swept per annum was then expressed as a percentage of the total sea area within that rectangle (Table 1).

Decca coordinates of recent local beam trawling activity within these areas were obtained from the MAFF District Inspector (NW) for fisheries. Each site was surveyed acoustically along a 2 nautical mile track with EG & G 260 dual frequency side-scan sonar set at 150 m range to port and starboard. The number of distinct beam trawl marks was counted and their orientation noted. Subsequently, samples of the epibenthic community were obtained using a lightweight 2.8 m beam trawl, which was designed to maximise the catch rate of epibenthic species (for details see Kaiser & Spencer 1996b). A minimum of 8 replicate tows were made at each site, the duration of which varied depending on the abundance of starfishes on the ground: 3.5 min Anglesey, 10 min River Mersey, 15 min Fleetwood. Differences in the abundance of starfishes at each site were presumed to be related to sediment type rather than fishing effort (Anglesey, coarse sand, gravel and shell; River Mersey, muddy sand; Fleetwood, mud). All fishing operations were undertaken with the RV 'Corystes'.

Table 1. Total area swept by all beam trawlers in 1994, derived from Eq. (1), expressed as percentage of sea area

Area	ICES rectangle	Hours fished <300 hp	Hours fished >300 hp	Area swept (km^2 yr^{-1})	% sea area swept
Anglesey	35E5	1670	0	99	4
River Mersey	35E6	2199	66	153	12
Fleetwood	36E6	23823	1148	1413	50

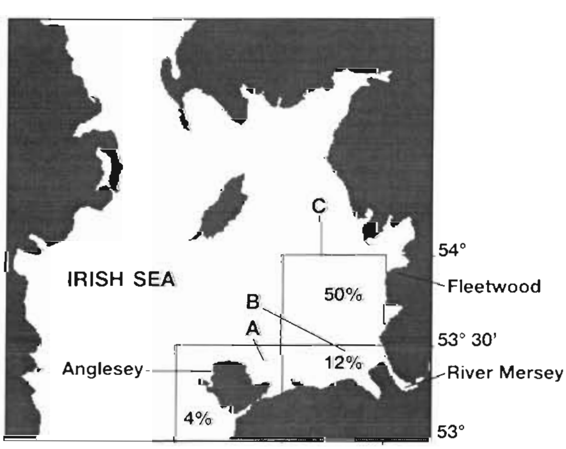

Fig. 1. Location of the 3 ICES statistical rectangles in the northeastern Irish Sea that experienced different intensities [expressed as % sea area swept per annum (1994)] of beam trawling. A: off Anglesey; B: off the River Mersey; C: off Fleetwood

Two species of starfish, *Asterias rubens* and *Astropecten irregularis*, were sorted from the entire catch of each 2.8 m beam trawl tow. These species are rarely damaged by this sampling gear; however, when starfish were encountered with freshly damaged tissues, they were excluded from the analysis. *A. irregularis* were not categorised at the Anglesey site as there were insufficient numbers for statistical purposes. For each species, individuals were categorised by the number of their damaged or regenerating arms. As the total number of starfish varied between each tow, the data were standardised as percentages for presentation purposes. Differences between sites in the proportions of starfish with damaged arms were ascertained by using the chi-squared test on unstandardised data. In pair-wise tests between each site, expected values were calculated from the proportion of damaged and undamaged starfish found at the site subjected to the lowest fishing effort. For example, to test for a difference between the Anglesey and Fleetwood (n = 830, damaged 349:undamaged 481) populations, the expected ratio of damaged:undamaged starfish was 15:85 (ratio at Anglesey), giving actual values of 125:705. The mean weight of *A. rubens* in each tow (Anglesey and Fleetwood only) was calculated by

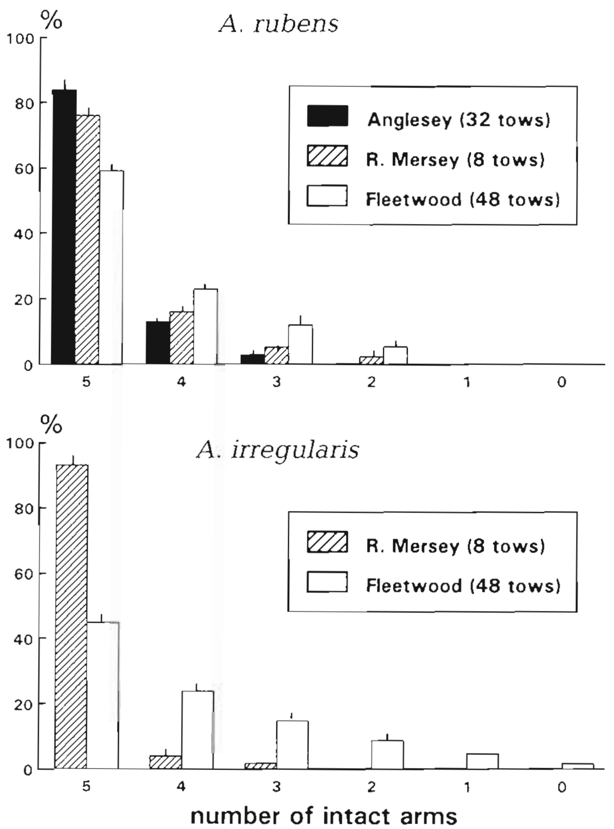

Fig. 2. The mean percentage of the populations of 2 species of starfish, *Asterias rubens* or *Astropecten irregularis*, with different numbers of regenerating arms from 3 sites subjected to low (Anglesey), medium (River Mersey) and heavy (Fleetwood) fishing intensity

dividing the total wet weight of starfish (measured on a motion compensated balance to a precision of ±5 g) by the total number of individuals. The difference in mean starfish weight between sites was tested using a *t*-test.

Results. *Asterias rubens* were significantly larger off Fleetwood than those off Anglesey (Fleetwood, 32.0 ± 1.9 g; Anglesey, 21.0 ± 1.1 g; $t = 13.5$, df = 68, $p < 0.0005$). A significantly larger proportion of the population of *A. rubens* caught off Fleetwood had damaged or regenerating arms compared with those from either the River Mersey or Anglesey sites (Fig. 2) (Fleetwood, n = 830 vs Anglesey, n = 752, $\chi^2 = 150.4$, $p < 0.0001$; Fleetwood vs Mersey, n = 553, $\chi^2 = 14.3$, $p < 0.001$; Mersey vs Anglesey, $\chi^2 = 13.5$, $p < 0.001$). The severity of damage was greatest off Fleetwood, where some animals were found with 5 regenerating arms (Fig. 2). Similarly, 55% of the *Astropecten irregularis* caught off Fleetwood, n = 1089, had damaged arms compared with only 7% off the River Mersey, n = 968 (Fig. 2) ($\chi^2 = 838.4$, $p < 0.0001$). There was a significant relationship between the percentage of the population of *A. rubens* with damaged arms and the percentage of the sea area swept by beam trawls annually in each ICES statistical rectangle:

$$x = 1.30 + 9.80y \quad (r^2 = 0.99, p < 0.03) \qquad (2)$$

where x = % population with damaged arms, and y = ln % sea area swept by beam trawls.

Examination of the side-scan sonar records indicated 114 pairs of 12 m wide beam trawl marks running in a north/south direction off Fleetwood (57 marks per nautical mile surveyed) (Fig. 3). These marks were clearly definable, but additional fainter marks indicated that the true level of fishing effort was much greater. Only 26 pairs of 4 m wide beam trawl marks, running in a north/south direction, were observed off the River Mersey; but, again, fainter marks indicated more intensive fishing in the recent past (Fig. 3). No trawl marks were observed at the Anglesey site.

Discussion. As anticipated from the fisheries effort data, the number and size of the trawl marks observed using the side-scan sonar indicated that the 3 ICES statistical rectangles are subjected to different intensities of fishing disturbance which are ranked Fleetwood > R. Mersey > Anglesey. The beam trawls used off the River Mersey appear to be 4 m wide (ascertained from the scale on Fig. 3), which would further reduce the overall effects of fishing disturbance compared with the 12 m gear used offshore at Fleetwood (de Groot & Lindeboom 1994). There appears to be a strong correlation between the incidence of arm loss or regeneration in starfish and fishing intensity. Furthermore, the proportion of starfish with >1 arm regenerating was greater in the areas subject to the most beam trawling effort (Fig. 2). However, it must be stressed that the sampling sites probably do not reflect the average fishing effort data for each statistical rectangle. Rijnsdorp et al. (1991) found that the distribution of fishing effort within a statistical rectangle was very patchy. It may be better to consider the occurrence of arm loss as a qualitative index of fishing effort, using categories such as low, medium and heavy fishing disturbance rather than deriving values from fishing effort data.

Both species of starfish can survive physical injury, usually the loss of one or more arms, that results from direct contact with a beam trawl (Kaiser & Spencer 1995). The presence of regenerating arms provides a quantifiable short-term biological record of the frequency of encounters with fishing gear. Some arm loss may occur as the result of increased predation activity in recently trawled areas (Kaiser & Spencer 1994), but there were few natural predators, e.g. the larger starfish species *Luidia sarsi* and *Marthasterias glacialis*, in any of the areas surveyed.

Although a greater proportion of the *Asterias rubens* caught off Fleetwood had lost more body tissues than

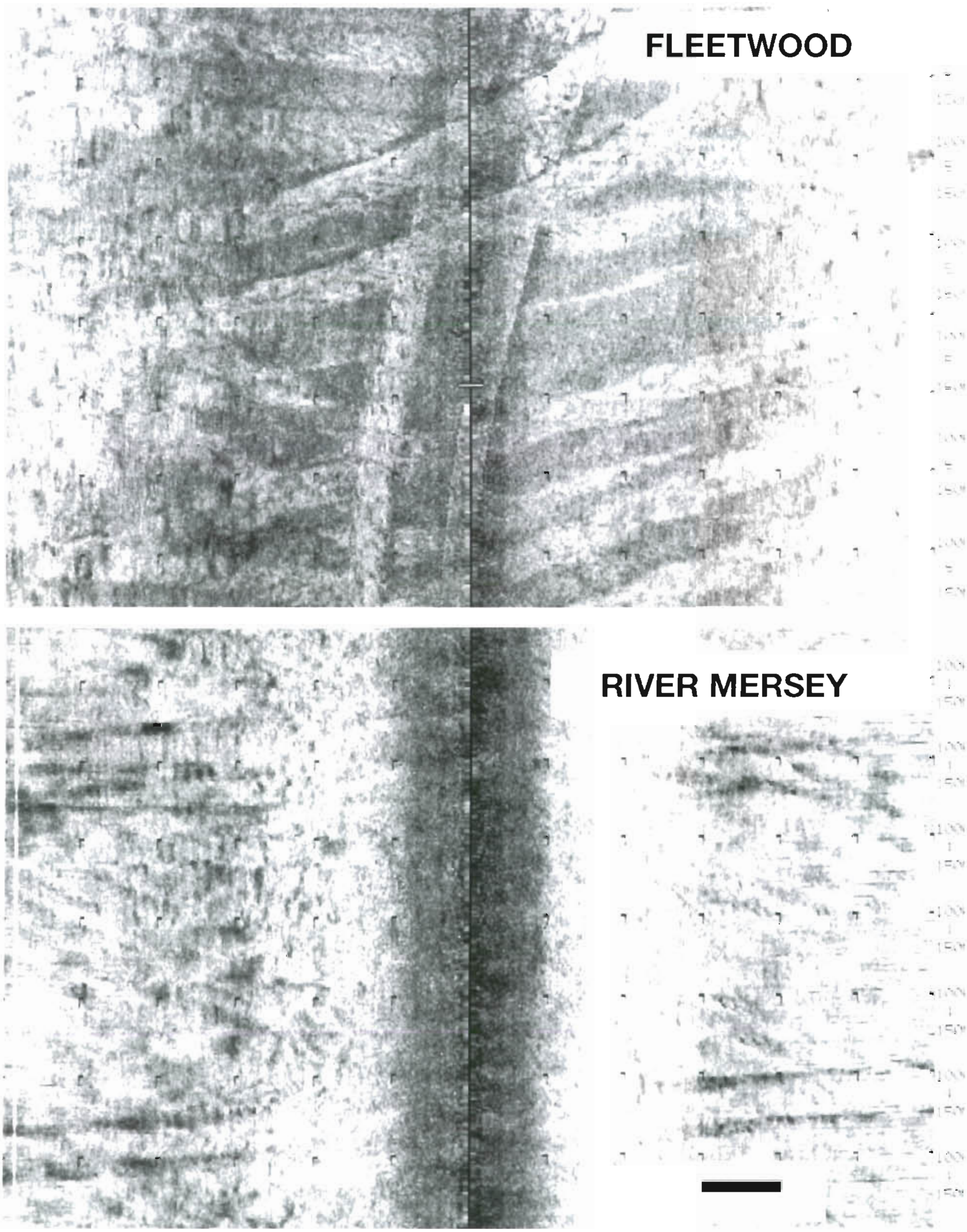

Fig. 3. A portion of the side-scan sonar record showing pairs of 12 m wide beam trawl marks on muddy ground off Fleetwood, and pairs of 4 m wide beam trawl marks off the River Mersey. The trawl marks run in a north/south direction. Scale bar = 25 m

those caught at the Anglesey site, their body weight was greater. This difference may be associated with the productivity of the different communities at the 2 sites, an *Amphiura filiformus* community at Fleetwood and a deep *Venus (Clausinella) fasciata* community at Anglesey (Mackie 1990). Alternatively, the increased weight may be attributable to a greater proportion of ossified tissue found in animals that are in the process of regeneration (Emson & Wilkie 1980, Lawrence 1991).

The present study suggests that starfish may be useful organisms for indicating the intensity of local fishing disturbance by demersal gears. The index of fishing disturbance, arm regeneration, is easily and rapidly measured and could be undertaken in conjunction with annual groundfish surveys. This, in turn, could greatly improve the resolution of estimates of the distribution of fishing effort, and provide a means of measuring its micro-distribution.

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