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The survival of skates (Rajidae) caught by demersal trawlers fishing in UK waters

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ABSTRACT

Skates and rays are a common component of mixed demersal fisheries, and large quantities may be discarded. Given their biological vulnerability, understanding the fate of these elasmobranchs is of management concern. Estimates of discard survival are needed for modelling the possible benefits of management measures. In this study, the focus is on the Bristol Channel skate fishery, where on-board holding tanks were used to assess the short-term rates of survival of trawl-caught skates (Rajidae). From monitoring the survival rates of 162 fish kept in specially designed on-board holding tanks for periods of up to 72 h, the short-term rate of survival was 55%. Visual inspection of "health" at time zero was a good indicator of survival, because 79% of skates with a poor health score did not survive. Mortality rates for fish of moderate health and good "health" were 16% and 5%, respectively. This information allows one to predict the consequences of fishing practice on discard survival using a larger dataset on fish scored for health before tagging and release. The proportion in poor condition on capture is positively correlated with estimated codend weight, so technical modifications to fishing gear aimed at reducing unwanted by-catch would increase the survival of discarded skates. Combined with information on discarding rates in the study area, the results indicate that discard mortality removes almost as many fish from the skate stock as are landed commercially.

1. Introduction

Global catches of skates and rays (batoids) have more than doubled since 1970, with >200,000 t being caught in 2006 (FAO, 2008). This trend of increasing fishing pressure on the fish is of growing international concern (Stevens et al., 2000; Dulvy et al., 2000), and some of the larger batoids have disappeared from parts of their former range (Brander, 1981; Rogers and Ellis, 2000). The principal rationale behind many of these concerns is that the life history of elasmobranchs (late age-at-maturity, low reproductive output, slow growth) makes them vulnerable to overfishing, and that the large size of batoids in particular makes them susceptible to capture in fishing nets even from a young age (Ellis et al., 2008). Bonfil (1994) reported that global catches of sharks and skates (750,000 t) may represent half of what is actually being caught, and that large quantities subsequently discarded. Understanding the fate of discarded fish post-capture is therefore of management concern. Moreover, estimates of discard survival are required if fisheries managers are to gauge the efficacy of potential management measures.

Although many skates (Rajidae) are landed in mixed demersal fisheries, targeted fisheries also operate in certain areas and at certain times of the year. The Bristol Channel fishery (Fig. 1) is one of the UK's most notable target fisheries for skates, with annual landings (by weight) accounting for 20% of the total skate landings of England and Wales. Skates caught in the Bristol Channel (ICES Division VIIf) are currently valued at approximately €1.5 million annually. The main skate species in the Bristol Channel are *Raja clavata*, *Raja microocellata*, *Raja brachyuran* and *Raja montagui*. *Leucoraja naevus* is found in the outer parts of the Channel and other skates are found occasionally (Ellis et al., 2005). These species are the main ones of the local commercial fisheries (Cefas, unpublished data). It has been estimated that of the estimated 3.8 million skates (3237 t) caught annually in this region, 2.2 million (823 t; 60% by number, 20% by weight) are subsequently discarded (Enever et al., 2007).

Broadhurst et al. (2006) reviewed the results of 80 published studies that quantified the survival rates of >120 different species of fish. Of these, just two field-based studies (Stobutzki et al., 2002; Laptikhovsky, 2004) assessed the survival rates of batoids following their capture in trawl fisheries. Trawl fisheries are thought to be responsible for fifty percent of the estimated 81 million tonnes of fish annually landed worldwide (Kelleher, 2005). Furthering our understanding to the factors that affect survival rates of batoids

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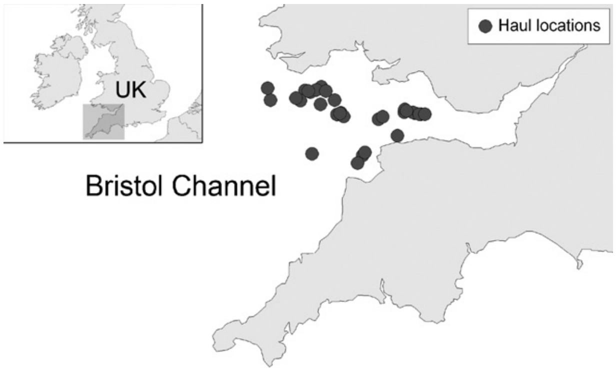

Fig. 1. The Bristol Channel showing haul locations by vessel.

in trawl fisheries is important for their effective management. In addition, understanding discard mortality alongside other sources of mortality will contribute to a better understanding of their population dynamics (Bonfil, 1994; Stevens et al., 2000; Revill et al., 2005). In this work we assess the survival rates of skates captured by commercial fisheries in one area of northern Europe, and describe some biological and physical factors that affect the survival of skate discards.

2. Materials and methods

2.1. The survey

The study was conducted on board two commercial trawlers operating typical twin-rig otter trawls, both with a track record of catching skates in the Bristol Channel (Fig. 1). Seven trips ranging from 3 to 5 days long were made during May and August 2007 (Table 1). In all, 32 tows were conducted in areas where the vessel would normally fish for skates, all made at towing speeds of 3–5 knots in water 30–60 m deep.

2.2. Skate survival

Short-term survival of discarded skates was assessed for two haul durations, 16 tows of a duration "normal" in commercial practice (2.7–4.3 h; referred to subsequently as commercial tows), and 16 shorter tows (0.75–2.0 h; referred to as short tows) (Table 2). Skates caught in seven of the commercial tows, the first from each trip, were held in tanks for approximately 3 days (Fig. 2), a limit imposed by trip duration. The experiments therefore provided short-term survival estimates only, although most fish mortality (93%) was within the first 24 h. When sorting commercial catches, there is inevitably a period of time before the unwanted fish are discarded, primarily because of the deployment of the gear for the next tow and the initial processing of the catch. To account for this, skates taken in the commercial tows were selected randomly from the fish pound and placed in holding tanks between 10 and 20 min after the catch had been brought on board. In all, 124 skates from seven commercial tows were kept in the holding tanks for up to 64 h. For trips conducted on Vessel 1, half the tanks were filled with skates from commercial tows and the other half with fish caught in the short tows. It was not possible to conduct short tows on Vessel 2, so all tanks were filled with skates from commercial tows only (Table 2). After the short tows, skates were taken immediately from the sorting pounds and placed in one of 12 holding tanks. In all 38 skates from nine short tows were kept in the holding tanks for up to 64 h.

Table 1
Summary of trips and hauls sampled, and the mean tow durations and codend weights for short tows and commercial tows.

Vessel	Trip	Departure–arrival date	Short tows			Commercial tows		
			No. of hauls	Mean tow duration (S.E.)	Mean haul weight (S.E.)	No. of hauls	Mean tow duration (S.E.)	Mean haul weight (S.E.)
1	1	07–10/07/07	5	0.9 (0.1)	80 (13)	5	4.0 (0.1)	253 (30)
1	2	23–26/07/07	6	1.1 (0.2)	98 (18)	3	4.1 (0.1)	204 (28)
1	3	27–30/07/07	5	1.2 (0.2)	67 (22)	4	3.8 (0.5)	161 (18)
2	4	01–03/04/07	(–)	(–)	(–)	1	4.5 (n.a.)	(–)
2	5	30/04–02/05/07	(–)	(–)	(–)	1	4.3 (n.a.)	(–)
2	6	21–25/08/07	(–)	(–)	(–)	1	2.7 (n.a.)	(–)
2	7	27–29/08/07	(–)	(–)	(–)	1	3.0 (n.a.)	(–)
Total			16	1.0 (0.1)	82 (10)	16	3.9 (0.2)	210 (19)

Values in parentheses refer to the standard error (S.E.) of the estimate. n.a.: insufficient data for estimation of S.E. (–): no data. *Vessel 1*: length overall, 14.95 m; gross tonnage, 50; main engine, 358 kW; net spread, 21.3 m; bridle length, 55 m; rockhoppers, 36 cm; codend, 85 mm mesh diameter constructed from 4 mm single braided twine. *Vessel 2*: length overall, 14.98 m; gross tonnage, 34; main engine, 298 kW; net spread, 20.1 m; bridle length, 46 m; rockhoppers, 36 cm; codend, 80 mm mesh diameter constructed from 4 mm single braided twine.

Table 2
Survival rates, holding duration, and mean lengths of skates held in vivier tanks from commercial tows and short tows.

Trial	Tow duration (h)	Species	Length (cm)	Mean time in tank (h)	*n*	Survival rate (%)
Commercial tow	3.2 (0.2)	*Leucoraja naevus*	35.0 (1.4)	48.0 (0.0)	6	33
	3.1 (0.1)	*Raja microocellata*	43.6 (0.9)	58.5 (1.9)	39	51
	3.9 (0.2)	*Raja brachyura*	41.3 (2.9)	48.0 (0.0)	11	55
	3.9 (0.1)	*Raja clavata*	55.4 (2.1)	60.6 (0.8)	68	59
Mean	3.6 (0.1)		49.4 (1.3)	58.2 (0.8)	124	55
Short tow	0.8 (n.a.)	*Raja brachyura*	90.0 (n.a.)	64.0 (n.a.)	1	0
	0.8 (0.0)	*Raja brachyura*	58.3 (2.0)	64.0 (0.0)	3	67
	0.8 (0.0)	*Raja clavata*	69.1 (1.4)	64.1 (0.8)	34	91
Mean	0.8 (0.0)		68.8 (1.5)	64.1 (0.7)	38	87
Land-based trial	n.a.	*Raja clavata*	66.2 (1.4)	72.0 (0.0)	5	100

Values in parentheses refer to the standard error of the estimate. n.a.: insufficient data for estimation of S.E.

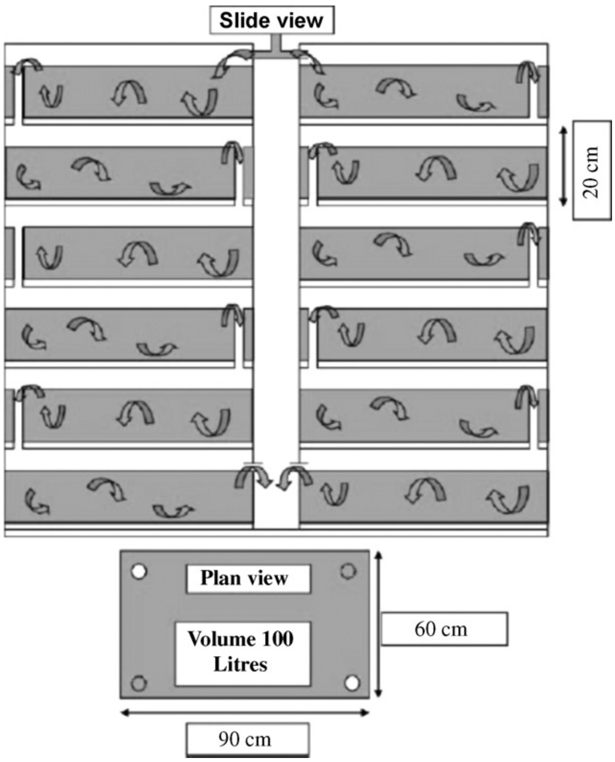

Fig. 2. Schematic of the survival tanks showing two stacks of six compartments. Four stacks were used in total; two for short tows and two for commercial tows, i.e. 24 compartments in total.

No more than two fish were placed in each holding tank and for the duration of the study, all tanks were supplied with a constant flow of fresh seawater (15–20 l/min). Water temperature and oxygen saturation were monitored at regular intervals throughout; oxygen saturation did not fall below 85%, and no feeding took place during the period of observation.

For the short-term survival trials, 162 skates from five species were used: *Raja naevus* ($n = 6$), *Raja microocellata* ($n = 39$), *R. montagui* ($n = 14$), *R. clavata* ($n = 102$) and *R. brachyura* ($n = 1$). At intervals of approximately 0, 6, 24, 48 and 72 h, the fish in the holding tanks were checked and recorded as dead or alive; dead rays were removed from the tanks. Death was judged by lack of movement of any muscle, gill cover, spiracle or wing, and *rigor mortis* (upward curling of wings).

Death of skates in the holding tanks could have been attributable to the trauma during the catching and discard process, but it could also be a direct consequence of being retained in the holding tanks. To assess this issue further, an experiment was carried out on land using skates captured in the wild 1 month previously. These fish were held in aquaria ashore, and fed daily to ensure that they were healthy prior to the experiment. The skates, of length 62–70 cm, were placed in holding tanks (Fig. 2) supplied with a constant supply of fresh seawater (15–20 l/min) and monitored for 72 h; there was no feeding during the period of the experiment.

2.3. Skate health assessment

At the start and end of the tank trials, the fish were given a score (1, 2 or 3) to define their health. The criteria for the scores were: 1 (poor health), dead or nearly dead, no body movement, slight movement of spiracles; 2 (moderate health), limp body/wing movement and spiracle movement; 3 (good health), vigorous wing/body movement and rapid spiracle movement.

In addition, another 900 skates from eight commercial tows ($n = 521$) and eight short tows ($n = 379$), were assessed and assigned a health score, tagged and released back into the sea. That sample included 139 *R. clavata*, 526 *R. microocellata* 82 *R. montagui* and 153 *R. brachyura*. Tag-and-recapture data from those fish will be used to assess longer term survival. This data is not yet available and are not used in this work.

2.4. Estimating codend weight

Total codend weight was estimated for each of the 28 tows conducted on Vessel 1 to determine its effect on the health status and survival of skates. In these tows 43 species of fish were caught and identified, for which length–weight conversion factors for 33 were available. These 33 species represent 99% (12,394) of the total number of the haul-raised fish caught by that vessel in the study (12,481). Of these length–weight relationships, 21 were calculated from weight-at-length data collected during Cefas research vessel cruises in ICES sub-area VII between 2002 and 2005 (>40,000 weight-at-length records from 13 cruises), and another 12 length–weight relationships were sourced from the scientific literature (Deniel, 1984; Dorel, 1986; Coull et al., 1989; Froese and Pauly, 2006). Where possible, the relationships were selected to match closely the ICES sub-area and period of this study. However, they do not take into account variations in sex or season. For the remaining 1% of fish, an estimator for length–weight relationships is calculated by assuming that $b = 3$ (Houghton and Flatman, 1978) and taking the mean value for condition factor "a" from all other species, i.e. $W = 0.005125L^3$.

Total fish catch was then added to the weight of benthic invertebrates, crustaceans, seaweeds and inorganic material, estimated from the number of baskets (ca. 32 kg per full basket (5 stone)), to estimate a total catch weight for each haul. Both vessels used twin-rig trawls, so the total catch weight was halved to estimate the catch in a single codend. It was this single codend weight that was used to analyse the effects of capture on health status and survival.

2.5. Analysis of the factors affecting skate survival

Logistic regression models (SPSS, 2007) were used to analyse the possible factors impacting the survival of skates in the holding tanks. The dependent variable was survival; the independent variables analysed were sex, species, total length of skates, health status at time zero, single codend weight, haul depth, whether the skates were subjected to commercial or short tows, and their tank position (i.e. whether the position in the stack of holding tanks was a factor in their survival).

The same method was also used to investigate how these independent variables (excluding holding tank position) may have affected the health status of the 900 skates tagged and released. As health score 1 was associated with much lower survival (see Section 3), we recoded health status into a binary variable (health score 1 = 1, health score 2 and 3 = 2) and used this as the dependent variable. The independent variables used are codend weight, species, and total length of skates, haul depth, sex, species composition in the codend and whether the skates were subjected to commercial or short tows.

3. Results

3.1. The Bristol Channel skate fishery

The catch rates on Vessel 1 ranged between 2.3 (*R. montagui*) and 9.4 (*R. microocellata*) fish per hour. There was a 1:1 sex ratio for *R. montagui* and *R. clavata*, but females dominated catches of *R. microocellata* (3:1) and *R. brachyura* (4:1). Skate composition (all

Table 3
Catch rates and sex ratios of species caught for trips carried out on Vessel 1.

Species	CPUE (number)	CPUE (kg)	Male:female ratio	% Weight of catch
Raja brachyura	2.7	6.9	1:4.0	1.3 (0.6)
Raja microocellata	9.4	20.6	1:3.1	7.1 (3.1)
Raja montagui	2.3	3.2	1:1.1	3.0 (1.2)
Raja clavata	2.6	8.8	1:1.0	2.7 (1.3)
Total	17.0	39.5	1:1.2	14.1 (4.6)

Values in parentheses refer to the standard error of the estimate. Cpue in numbers (*n*) or weight (kg) caught per hour fishing.

species combined) ranged from 0 to 42% and averaged 14 ± 4.6% of the catch weight (Table 3).

3.2. Skate survival

In all, 124 skates (four species) from commercial tows were held in the on-board holding tanks for an average of 58 h. Of these, 68 survived, a short-term survival rate of 55%. Survival rates between species were similar (Table 2).

From the short tow trials 38 skates (three species) were held for an average of 64 h. Of these, 33 survived, a short-term survival rate of 87%. All five *R. clavata* in the land-based holding tanks survived for 72 h (Table 2).

3.3. Analysis of the factors affecting skate survival

Logistic regressions of factors affecting skate survival in the holding tanks showed that the health score (at time zero) was the only significant variable ($p < 0.001$). Some 79% of the skates entering the holding tanks with a health score of 1 did not survive. In contrast, just 16% with a health score of 2 and 5% with a health score of 3 died. The high rate of survival of fish assessed as being in good condition gives reassurance that the mortality observed here was not a consequence of the fish being held in tanks. With health score included in the model, there was no effect of species ($p = 0.42$), experiment (short or commercial tows) ($p = 0.20$), sex ($p = 0.31$) on survival rate. The fish length was just short of being significantly related to survival ($p = 0.06$). Health score at time zero is therefore a good indicator of survival.

Removing health score at time zero from the model allowed us to evaluate the effect of other factors on survival. There was a significant effect of experiment (i.e. between short tows and commercial tows) and sex on survival rates. Males were significantly more likely to die than females at time zero ($p = 0.043$), but this was not a function of their length. Skates from the shorter tows were significantly more likely to survive the duration of the trial than those from commercial hauls ($p = 0.011$).

As health score at time zero is, in our opinion, an excellent predictor of subsequent survival, we used our larger dataset on health score of the 900 skates tagged and released to examine determinants of survival rates of discarded skates. The mean health score of skates sampled in the commercial tows was 1.4 ± 0.7, with just 10% of skates in good health (score 3). By contrast, mean health score in the short tows was higher, at 2.0 ± 0.8, with 35% of skates in good health. In both the short and the commercial tows, *R. microocellata* and *R. montagui* had the lowest proportion of fish in good health, and *R. clavata* the highest (Table 4). *R. brachyura* were in poor condition in the commercial hauls (just 4% with score 3), but were in much better condition when taken from short tows (57% with score 3). Logistic regression was used to examine the effect of fish length, haul depth, haul duration, sex, species and codend weight on a skate's health score at time zero for the 900 tagged skates.

Codend weight ($p < 0.001$), species ($p < 0.001$) and sex ($p = 0.006$) significantly affected the health score of trawl-caught skates. As codend weight increased, the number of skates with poor health (health score of 1) increased.

4. Discussion

We estimate that 55% of skates returned to the sea in the Bristol Channel skate fishery will survive for at least 2 days. Although 45% of skate caught in the commercial tows died whilst in the holding tanks a small proportion from the short tows also died (13%) (Table 2). On one trip there was 100% survival of the skates from short tows. Similarly, in the trial carried out on land, skates from an aquarium were kept in the same holding tanks for 3 days; all survived. Some 95% of the fish in good condition at time zero survived, indicating that the holding tanks had little negative effect on the survival of the skates and those that died did so as a result of the capture process. Laptikhovsky (2004) reported broadly comparable survival rates in eight species of skate (average 59%, range 0–75%, $n = 66$) caught onboard a trawler fishing off the Falkland Islands. A recent study by Stobutzki et al. (2002) modelled the survival of elasmobranchs caught in trawl fisheries off northern Australia. The survival of batoids in that analysis was estimated at 40%.

The low number of control experiments meant there could have been experimental effects that would have increased the estimated survival rate. However, this study is more likely to have overestimated the level of discard survival. The limitations of the method meant that only short-term estimates could be ascertained. Increasing the retention time of the skate may have shown a reduction in the number surviving. Moreover, the results presented here do not account for the susceptibility of discarded skates to predation or infection once discarded. Interactions between Common gulls (*Larus canus*) on the discarded skates were observed in this study. Additionally, discarded skates may be consumed or mortally

Table 4
Mean health scores, lengths, and percentages of skate species in good health (health score 3) tagged and released after being caught in commercial tows and short tows.

Trial	Latin name	*n*	Mean health score	Occurrence at health score 3 (%)	Length (cm)
Commercial tow	*Raja brachyura*	83	1.4 (0.6)	4	60.6 (13.4)
	Raja microocellata	317	1.3 (0.6)	6	59.6 (11.5)
	Raja montagui	40	1.2 (0.4)	3	48.0 (8.5)
	Raja clavata	81	1.9 (0.9)	35	62.4 (15.2)
Total		521	1.4 (0.7)	10	59.3 (12.7)
Short tow	*Raja brachyura*	70	2.4 (0.7)	57	56.1 (12.5)
	Raja microocellata	209	1.7 (0.8)	18	57.4 (11.3)
	Raja montagui	42	1.9 (0.8)	24	44.4 (7.1)
	Raja clavata	58	2.6 (0.7)	69	65.5 (12.8)
Total		379	2.0 (0.8)	34	57.0 (12.6)

Values in parentheses refer to the standard error of the estimate.

injured by bottom scavengers during their recovery period (Hill and Wassenberg, 2000; Laptikhovsky, 2004). The 55% survival rate presented here should therefore be considered a maximum survival rate.

R. clavata had the highest rate of survival and health score in this study. This study suggests that this species is more robust to the capture and discard process than *R. microocellata*, *R. brachyura* or *R. brachyura*. One reason for this could be the more accentuated spinulose of *R. clavata* relative to the much smoother skin of the other species, which offers it better physical protection. In this study, male survival was 45%, significantly less than female survival, 65% ($p = 0.043$). This finding is supported by other studies showing a poorer rate of survival of male skates (Stobutzki et al., 2002; Laptikhovsky, 2004). Given that female sharks have thicker skins than males (to afford them protection from males biting them during copulation (Litvinov, 2006; Pratt and Carrier, 2001), it is may be that such sexual dimorphism in elasmobranchs benefits female discard survival.

Some 79% of skates entering the holding tanks with a health score of 1 (poor health) died. Our data suggest that an important factor in ensuring short-term survival in trawled skates is that they are caught and discarded before their health score drops below 2. Managing the species and sex of fish being caught in a mixed demersal fishery is difficult. However, this study suggests that skates with lower health scores were derived from catches with a higher codend weight. Mandelman and Farrington (2007) also find that increased codend weight significantly reduces the short-term survival rates in spiney dogfish (*Squalus* acanthias) caught by Northwest Atlantic bottom-trawlers. The correlation between catch weight and survival of discarded skate is likely to be due to the skates being subjected to increased compression in the codend leading to more injuries (Mandelman and Farrington, 2007; Revill et al., 2005). The method for estimating codend weight using length–weight conversions and baskets of benthic material was limited. By assigning a fixed weight (32 kg) to a basket of benthic material the difference in composition of the baskets was not accounted for. However, benthos made up a mean 5.2% of the total weight of the catches, therefore, the method of estimating benthos weight is unlikely to have had a notable effect on catch weight estimates. Catch composition, of both benthos and fish, may also have effected the survival of skate, but it was not possible to assess this in this study.

Estimates of the quantity of fish discarded by demersal otter trawlers in ICES sub-area VII (the study area) are 36% by weight and 64% by number (Enever et al., 2007). The results from this research suggest that a reduction in the quantity of fish discarded could lead to increased survival of discarded skates. By transferring proven selective trawl designs (e.g. square mesh panels (Graham et al., 2002; Enever et al., 2009) and square mesh codends (Catchpole et al., 2006)) to the Bristol Channel skate fishery, further to a reduction in overall discards, an increase in the discard survival rate of skates could be an additional benefit.

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