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Short Communication

Assessment of mortality of Antarctic krill (*Euphausia superba*) escaping from a trawl

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ABSTRACT

The overall purpose of this study was to estimate the mortality of Antarctic krill (*Euphausia superba*) that escape from the most common mesh size used for codends (16 mm) in the current commercial fishery. The experiment was carried out off the South Orkney Islands (60°35′S, 45°30′W) using a covered codend sampling technique for retaining escaped krill, which thereafter were observed in holding tanks to monitor their mortality rate. Our results suggest that krill with smaller body lengths suffered higher mortality. However, sampling depth, haul duration and catch accumulation as well as handling effects onboard, such as exposure to temperature differences, likely increased the mortality rates in our experiment. The results indicates that mortality of krill which escape trawl nets is relatively small, suggesting that krill, in common with many other crustacean species, are fairly tolerant to a process of capture-and-escape.

1. Introduction

Indirect fishing mortalities, or 'unaccounted' mortality, include those of organisms that die after either escaping from, or being discarded from, fishing gear due to injury, and these injuries may also make them more vulnerable to predators (Naidu, 1988; McLoughlin et al., 1991; Chopin et al., 1996). It is important to consider this unaccounted mortality as a factor in the overall management of a fishery (Jean, 1963; McLoughlin et al., 1991).

The fishery for Antarctic krill (*Euphausia superba*), hereafter krill, is the largest by tonnage in the Southern Ocean. It has expanded during the last decade and is expected to continue to grow (Nicol et al., 2012). The fishery is targeted towards krill swarms using pelagic trawl technology. Typically, large conventional midwater trawls (e.g. 60 m × 50 m mouth opening) is towed for up to an hour and landed catches are of the order of ten tonnes (Budzinski et al., 1985). Some of these trawls have been emptied at surface by a pumping system but more usually the catch is landed on deck. A more recent developed "eco-harvesting technology" (patent WO2005004593), supply krill continuously to the vessel from the submerged trawl (usually small nets with 20 m × 20 m mouth opening) to the production deck through a vacuum hose attached to the codend. This technology allows for catch rates in the order of ~800 tonnes per day.

The trawl nets applied in the krill fishery differ in design and mesh configuration. Some trawls have small meshes throughout the trawl, while other trawl designs have large meshes in the mouth area with successive reduction in the trawl panels towards the small meshed codend. It is highly likely that differences in applied fishing technologies will influence differently the degree of escapement and escape mortality. Mathematical modelling techniques and practical experiments on size selection of krill have suggested that krill can escape from some of the smallest commercial meshes used in the fishery (Krag et al., 2014). However, information on the mortality of escaped krill in the primary scientific literature is virtually non-existent. Both the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and its Scientific Committee are urgently requesting information on the effects of different fishing gear on krill escape and an assessment of the indirect mortality of krill on the krill stock (e.g. CCAMLR, 2009).

The aim of this study was to make initial attempts to monitor the subsequent mortality rates of escaped krill by employing a covered codend technique (Kaiser and Spencer, 1995; Broadhurst et al., 2006) followed by surface observations made in holding tanks. These results and experiences will form the crucial basis for the design of additional extensive escape mortality studies.

2. Materials and methods

The observations were carried out near the South Orkney Islands (60°35′S, 45°30′W) in January–February 2014. The vessel used was the FV *Saga Sea* (Aker Biomarine AS) a Norwegian, 96 m, 6000 hp

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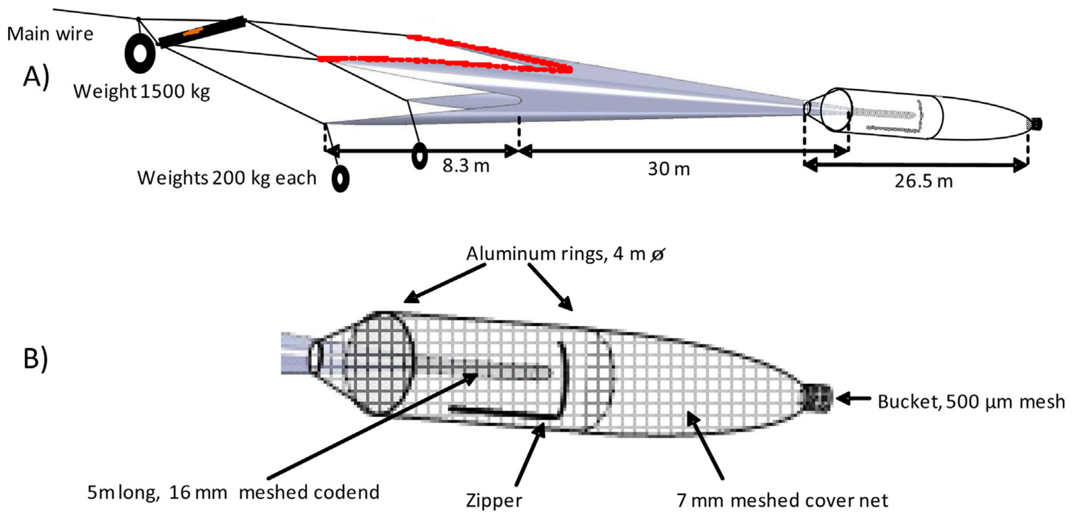

Fig. 1. (A) covered codend sampling technique, (B) cover net system.

Table 1
Operational conditions during covered codend experiments off the South Orkney Islands, January 2014.

Haul No.	Towing duration (min)	Max towing depth (m)	Temp max depth (°C)	Temp surface (°C)	Salinity max depth (PSU)	Salinity surface (PSU)	Catch weight 16 mm codend (kg)	Total catch 7 mm cover (kg)
1	29	148	−1.094	−0.083	34.03	33.07	93	95
2	13	60	−0.914	−0.012	33.71	32.20	108	22
3	19	111	−1.200	0.637	34.14	33.27	61	3.5
4	16	64	−1.005	0.529	33.85	33.33	159	28

commercial ramp trawler. For this study, a 30 m long scientific survey trawl ‘Macroplankton trawl’ was used (see Krafft et al., 2010), it had a 6 m × 6 m mouth and 7 mm mesh size (stretched mesh) net from the opening to the codline. To mimic escapement in a commercial trawl a 5 m long codend with 16 mm diamond mesh netting was constructed (a standard mesh size used in commercial gear) and mounted to the trawl body. A 26.5 m long net covering the codend (also 7 mm stretched mesh) was mounted to collect potential krill escaping. To prevent the cover net from masking the codend, the cover net was stretched out by two aluminum rings (4 m diameter). The cover was provided with a zipper for easy access to the codend catch. To protect escaped krill from further mechanical damage caused by tearing against the cover net, the rear part was attached to a 5 L hard plastic bucket with small holes covered by 500 µm mesh netting on the inside (Fig. 1). Hydrographical data were acquired using a SAIV CTD sensor mounted to the trawl beam, logging at 10-s intervals, and a Marport^{TM} depth and temperature sensor was attached to the headline. Speed over ground was kept close to 2.0 knots, the same speed used during commercial towing, and the wire speed was 5 min/100 m during hauling. The tow duration varied from 13 to 29 min (Table 1).

Of a total of eight hauls, four were successful in catching krill in both the codend and in the cover. The non-successful hauls were associated with difficulties closing the codend and with no catch in the cover. When a trawl was landed on deck, a random sample of krill from the covered codend-bucket was promptly distributed among 3–4 plastic aquariums (16 L in capacity, perforated with 5 mm diameter holes) filled with surface water. The closed plastic aquariums were then submerged into a 1000 L holding tank and inspected every 12 h to assess krill mortality. The holding tank was fitted with a light cover, hydrological conditions were continuously monitored with an oxygen sensor (Oxyguard Handy Polaris 2) and a mini CTD (Star–Oddi), and the water was changed every 12 h. During the visual inspections, dead krill were removed from the aquariums, counted and their length measured (±1 mm) from the anterior margin of the eye to the tip of the telson excluding the setae, according to Marr (1962). The body condition (damaged/not damaged) of each dead krill was assessed visually.

The relationship between the density of individuals per aquarium and mortality was examined using regression analysis (Proc REG) and any potential body length-dependent mortality was tested using an analysis of variance (Proc NPAR1WAY, SAS Institute Inc., Box 8000 Cary, NC, USA) with a significance level of 0.05%.

3. Results

The temperature and salinity levels of the krill’s natural habitat and the holding tank differed. The water in the holding tank was supplied from the vessel’s surface seawater intake, and was c. 2.5 °C warmer and of slightly lower salinity (Tables 1 and 2). The proportional mortality rates varied between and within hauls, viz. haul 1: 38–94%, haul 2: 11–71%, haul 3: 23–60%, and haul 4: 1–6% (Fig. 2). The mortality increased substantially from 24 to 48 h in hauls 1 and 2 (Table 3). No such effect was found in the krill collected from hauls 3 and 4. Haul 1 differed from the other three hauls in many respects. It had both a longer towing time and maximum depth compared

Table 2
Holding conditions of escaped krill collected in covered codend tows.

Haul. No.	Temp (°C) mean ± SD	Temp (°C) range	Salinity (PSU) mean ± SD	Salinity (PSU) range	Oxygen mg/L mean ± SD	O_2 Sat. (%) mean ± SD
1, 2	1.70 ± 0.41	0.67–2.16	32.32 ± 0.13	31.88–32.52	9.75 ± 3.70	91.68 ± 3.70
3, 4	1.51 ± 0.19	1.11–2.20	30.86 ± 2.77	30.48–32.40	9.70 ± 3.86	90.50 ± 3.86

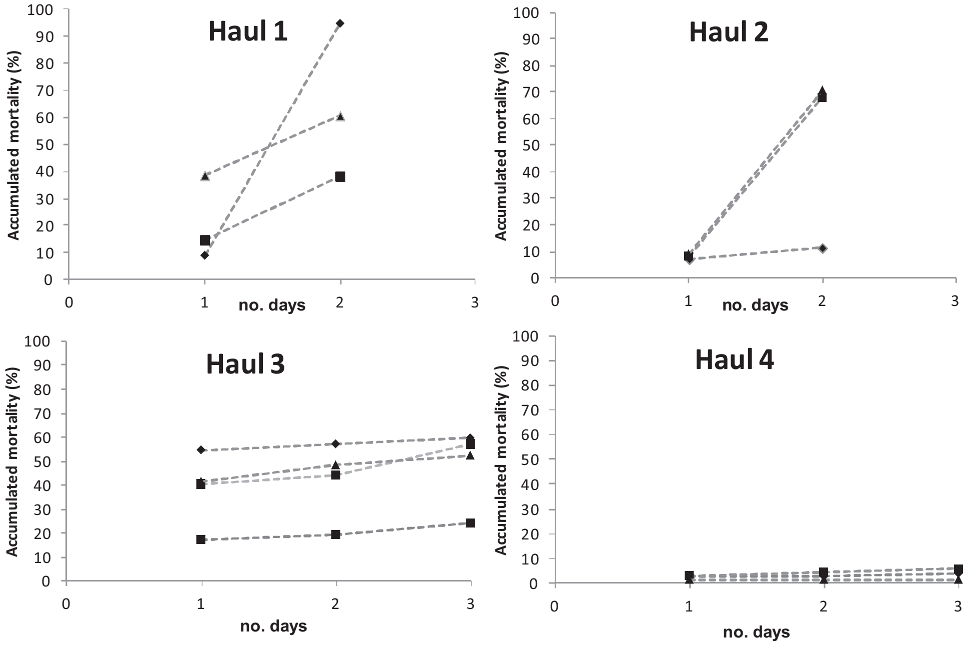

Fig. 2. Accumulated mortality for escaped krill caught in a covered codend after 24–72 h in the holding tank.

to the other hauls. This haul also recorded similar catch levels in the codend and in the cover, in contrast to the other three hauls (Table 1). Haul 1 also remained at the surface for a longer period due to technical difficulties, which unintentionally prolonged the final retrieval of the catch.

Few dead krill displayed visual signs of damage. However, this was difficult to judge since their bodies often were decayed, and so these data are not included in any further analyses.

Small body length resulted in higher mortality. The average body length of all dead krill was 37.0 ± 5.4 mm, while live krill were 39.5 ± 5.5 mm (Table 4).

4. Discussion

The purpose of this study was to perform initial experiments to estimate the mortality rate of krill escaping from the most common mesh size used in the pelagic trawl fishery for krill. Potentially increased predation of escaping krill could not be investigated or verified using our study design. The study aims to mimic the process of a realistic commercial capture process, from krill entering the trawl mouth, to the transportation down the trawl body and then encountering the mesh in the codend. In a commercial capturing process, escaped krill will ideally be released back into the water masses outside of the trawl body, which differ from the conditions provided during the experiment by being subjected to additional physical stress and environmental change in the cover. Full-scale survival experiments are extremely challenging technically (Main and Sangster, 1988; Suuronen et al., 1995, 1996a,b; Broadhurst et al., 2006; Ingòlfsson et al., 2007) and we found that the mortality rate of escaped krill is probably affected by haul duration and environmental differences between the fishing depth and the subsequent holding facilities.

Parameters such as prolonged time in the cover net could expose the animals to longer periods of mechanical stress caused by the fishing gear. Physiological stress may also occur when crustaceans are raised through a thermocline and also when they enter the lower salinity surface waters (Harries and Ulmestrand, 2004). Krill are stenotherm crustaceans mainly habituating waters <3.5 °C and sudden water temperature changes might impact on their physiological performance and behavior (Flores et al., 2012). The multiple factors affecting the mortality of krill associated with collection in the cover net, hauling and retrieval as well as the artificial holding facilities; keeping the escapees away from their natural environment, suggests that our results must be considered as maximum values for actual mortality of escaped krill.

The increasing mortality observed after 24 h for hauls 1 and 2 could be related to the higher density of krill in the 16 L aquariums compared with the last two hauls (Table 4). However, no notable difference was observed in the oxygen concentrations between the various holding tanks (Table 2). Stress tolerance of krill at high-density levels should also be high since they naturally occur in highly dense swarms. It is possible that the mortality pattern difference between hauls 1 and 2 vs. hauls 3 and 4 has other explanations. The physical contact and pressure that occurs between the individuals located in the accumulated catch may e.g. increase the chance of physiological damage. Catches both in codend and cover were high for hauls 1 and 2, but catches were large also for haul 4 were mortality was low during the holding time; hence more likely it is a combination of factors causing the observed pattern. In this

Table 3
Results from regression analysis to investigate relationships between density of krill and mortality rates after 24–72 h in captivity, in krill caught using the covered codend method.

Fit statistics	Hauls 1 and 2		Hauls 3 and 4		
	24 h	48 h	24 h	48 h	72 h
F-value	0.22	41.52	6.23	1.43	0.04
Probability	0.66	0.003	0.055	0.28	0.84
Number	6	6	7	7	7

Table 4
Comparison of body lengths of krill from covered codend experiments that died and remained alive during onboard holding.

	F-value	Probability	Dead	Alive	Dead (*n*)	Alive (*n*)
Pooled	103.5583	<0.01	37.00 ± 5.4	39.5 ± 5.5	1092	906
Exp1	9.6034	0.002	36.9 ± 5.3	37.8 ± 4.8	909	471
Exp2	55.6876	<0.0001	37.6 ± 6.1	41.3 ± 5.5	183	435

regard the duration from actually hitting an aggregation of krill to hauling the catch on to deck could be important, but not possible to measure during this study. The highest mortality was observed among the krill from haul 1, which had large catches both in codend and in cover, it also was the longest and deepest haul. The experimental conditions were more optimal for the two last hauls, with respect to the gentlest exposure to the number of multiple conditions that might contribute to increased mortality, leaving the mortality rates observed in hauls 3 and 4 to being most representative. Further elimination of results that are probably influenced by large differences in environmental factors (natural environment vs. experimental) and exposure to rough physical conditions during the catching process, suggest that haul 4 was the most benign and that the true mortality range is, at most between 1% and 6%.

In Krag et al. (2014) an L50 value (50% retention length) for krill was estimated at 32.72 mm for the commercially used 16 mm mesh size, similar to the mesh used in this experiment. This would mean that individuals larger than 33 mm that manage to escape will experience increased mechanical contact with the mesh as they pass through it, such that we could expect large individuals to show the highest mortality rate. On the contrary, our results suggest that small body length predicts higher mortality. Crustaceans are more tolerant compared to other taxa due to their durable exoskeletons and limb autonomy (Hill and Wassenberg, 1989; Cabral et al., 2002; Broadhurst and Uhlmann, 2007). However, individuals in the early post molt phase tend to be most vulnerable to injury (Wassenberg and Hill, 1989; Kruse et al., 1994; Milligan et al., 2009) because the shells of smaller krill tend to be softer than those of larger krill.

Our results suggest that krill are probably fairly tolerant to the process of capture-and-escape, which is consistent with studies involving other crustaceans (Hill and Wassenberg, 1989; Cabral et al., 2002; Broadhurst and Uhlmann, 2007). The method used here appears suitable for the assessment of mortality in krill, which escape trawl nets. However, future studies should try to increase the number of hauls sampled to increase the accuracy of the estimated mortality, simultaneously attempts should be made at reducing experimental induced factors that increase mortality after escape. Previous studies have also pointed out the general problem of establishing adequate controls for such experimental work so as to estimate the impact of unintended effects arising from holding the krill in tanks, viz. the “severe logistical constraints associated with their collection and housing” (reviewed in Broadhurst et al., 2006). If this study leads to future similarly designed studies on the mortality of escaped krill, attempts should be made to establish a baseline control by selecting individuals from the catch that seem apparently unaffected, prior to making the experimental observations in tanks.

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