FEATURE ARTICLE: NOTE

Piscivorous fish patrol krill swarms

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ABSTRACT: Dense swarms of the krill Meganyctiphanes norvegica in the Norwegian Sea were patrolled by large, piscivorous fish, which apparently use the krill swarms as feeding grounds in their hunt for planktivores. For the krill, patrols of piscivores may add to the generally accepted anti-predator benefit of the swarming behavior. The fact that krill swarms govern small-scale patchiness of large piscivores emphasizes the key role of krill in oceanic ecosystems.

KEY WORDS: Swarms · Fish · Anti-predator benefits · Behavioral cascades · Meganyctiphanes norvegica

INTRODUCTION

Many species of krill form social aggregations (swarms and schools). This behavior affects reproduction, feeding, energy consumption and interactions with predators (Ritz 1994, 2000). The major benefit of swarming is generally presumed to be protection from predation, mainly derived from evasion and dilution factors once an attack is launched (e.g. O’Brien & Ritz 1988). However, swarms may also attract and make krill vulnerable to predators capable of exploiting such dense concentrations (Nicol & O’Dor 1985, Ritz 1994). In this note we report a novel observation of recurrent associations between krill swarms and large piscivorous fish in the northern Norwegian Sea. We suggest that piscivores use krill swarms as feeding grounds in their hunt for planktivores attracted by the swarms. For the individual krill, such patrols of large piscivores would add to the generally accepted anti-predator benefit provided by the swarming behavior.

MATERIALS AND METHODS

The studies were carried out during a research cruise with RV ‘G.O. Sars’, which had mainly been allocated the task of assessing herring in the Norwegian Sea. The results reported here were collected on 24–25 May 2004 at a site that appeared to be particularly rich in krill and fish (~70° N, 4° E). We applied SIMRAD EK 60 echo sounders at 5 frequencies (18, 38, 70, 120, and 200 kHz; settings in Table 1). The beam width of the transducers was 7°, except for the 18 kHz transducer, which had a beam width of 12°. Post-processing of data was done by the Sonar 5 Pro- (Balk & Lindem 2002) and Sonar 6-MP software, and echograms were visualized in Matlab.

Acoustic targets were captured by a pelagic trawl with a vertical opening of ~30 m (a so-called Åkra
The acoustic size distribution of fish was assessed in 2 ways. Split-beam echo sounders enable \textit{in situ} measurements of target strength (TS) for individual fish, which is a function of fish size (Ehrenberg & Torkelson 1996). TS measurements were done at long range. Therefore, strict criteria were used to avoid multiple targets (Table 1). Results included here are based on manually tracked individuals that could be clearly seen as separate targets. This procedure reduced sample size in the analysis. Additionally, we assessed size distribution by visually examining 40 log R echograms, where the colors (strength) of individual targets are independent of range (results not shown).

The acoustic records revealed swarms of krill that were located between 100 and 200 m depth both during the day and the light summer night at 70° N (Figs. 2 & 3). The trawl was too coarse to capture the

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**RESULTS AND DISCUSSION**

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krill quantitatively. Nevertheless, a catch of several kg of ~26 mm long *Meganyctiphanes norvegica* was made when targeting 1 of the swarms. Capture of krill from this swarm was documented by the trawl eye during sampling. We roughly estimated the volume of a typical swarm at ~380 000 m³, and numerical densities at ~200 ind. m⁻³, suggesting a total biomass of ~11 t per swarm.

Underneath most swarms was a ‘stack’ of fish that could extend almost 100 m below the krill (Figs. 2 & 3). Some individuals were also located inside, or close to the swarms (Fig. 2). Surprisingly, the strength of the acoustic echoes suggested that these fish commonly (but not exclusively) were large piscivores rather than smaller planktivores. Two trawl tows between 200 and 300 m depth captured four 6 to 10 kg (60 to 110 cm) large saithe *Pollachius virens*, which was the only fish likely to be the source of these strong echoes. The red targets just beneath the swarm are ascribed to saithe. The fish echoes below ~250 m are ascribed to blue whiting. The ship moved at ~2.5 knots during the recording period. Time is UTC

![Acoustic records at 120 kHz of a krill swarm and associated fish at night on 25 May 2004 (~70° N, 4° E). The swarm was virtually invisible at 18 kHz (not shown). Color scale refers to echo intensity (Sv), with grey showing the weakest and reddish-brown the strongest echoes. The red targets just beneath the swarm are ascribed to saithe. The fish echoes below ~250 m are ascribed to blue whiting. The ship moved at ~2.5 knots during the recording period. Time is UTC.](image)

Fig. 3. Acoustic records at 120 kHz of a krill swarm and associated fish at night on 25 May 2004 (~70° N, 4° E). The swarm was virtually invisible at 18 kHz (not shown). Color scale refers to echo intensity (Sv), with grey showing the weakest and reddish-brown the strongest echoes. The red targets just beneath the swarm are ascribed to saithe. The fish echoes below ~250 m are ascribed to blue whiting. The ship moved at ~2.5 knots during the recording period. Time is UTC

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For the individual krill, patrols of large piscivores would add to the anti-predator benefit of the swarming behavior (‘the enemy of my enemy is my friend’). Saithe may benefit from the stronger aggregation and higher exposure of its planktivore prey. If our interpretations are correct, then the losers in the game are the planktivores, which will suffer from higher predation risk when foraging on prey patrolled by predators. Whether consumption and repelling of planktivores by piscivores may in fact be instrumental in encouraging swarming behavior of krill remains to be investigated.

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LITERATURE CITED


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