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NOTE

Schooling of the vertically migrating mesopelagic fish *Maurolicus muelleri* in light summer nights

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ABSTRACT: Vertically migrating *Maurolicus muelleri* arrested their nocturnal ascent below the peak zooplankton concentrations during light summer nights at 62° N. At 69° N, the behavior was further modified, with *M. muelleri* forming schools in the upper layer at night. We suggest that *M. muelleri* used schooling as an antipredator strategy due to the absence of dark periods.

KEY WORDS: Planktivorous fish · Acoustic scattering layer · DVM · Midnight sun

Organisms at high latitudes must cope with extreme light conditions. Waters north of the Arctic circle are characterized by midnight sun in summer and continuous darkness in winter. This certainly affects both feeding opportunities for visual predators (e.g. Suthers & Sundby 1996) and risk of predation. In this note, we address the diel vertical migration (DVM) behavior of the mesopelagic planktivorous fish *Maurolicus muelleri* (Müllers pearlside) in the absence of dark nights during summer.

DVM provides a trade-off between catching food and avoiding predators (Clark & Levy 1988). In Norwegian waters, the daytime depth of *Maurolicus muelleri* varies between ~50 and 200 m, depending on fish size and light conditions (e.g. Giske et al. 1990, Baliño & Aksnes 1993, Kaartvedt et al. 1996). Vertically migrating individuals exploit shallow zooplankton concentrations at dusk and dawn, when light intensities are sufficient for visual predation on plankton, but acceptably low for protection against predation by visually hunting piscivores (so-called 'antipredation windows'; Clark & Levy 1988, Rosland & Giske 1994, 1997). *M. muelleri* generally spends the night between these periods at subsurface depths (Giske et al. 1990, Giske & Aksnes 1992, Baliño & Aksnes 1993, Goodson et al. 1995, Torgersen et al. 1997).

As nights become less dark, the optimal vertical distribution for simultaneously catching food and avoiding predators is altered. We studied the DVM behavior of *Maurolicus muelleri* at 2 locations in the summer of 1993; from 4 to 12 June in Storfjorden, western Norway (62° 2' N, 6° 3' E) and from 3 to 4 August in the Norwegian Sea (69° N, 9.4° E). Fish distribution was mapped by SIMRAD EK 500, 38 kHz echo sounders, and target identification was done by Harstad trawl (Nedreaas & Smedstad 1987) and Åkra trawl (Valdemarsen & Misund 1995).

In Storfjorden, we observed dielly migrating scattering layers (SL; Fig. 1) that appeared to consist almost exclusively of *Maurolicus muelleri*. Of 5 tows with Harstad trawl aimed at the SL during different phases of the diel cycle, *M. muelleri* on average constituted 95% of the fish catches by weight (100, 100, 100, 96, 78%), with a maximum catch of 94 kg *M. muelleri* nautical mile^{-1}. One tow directed above the SL resulted in no *M. muelleri*. The only other major group represented in the catches was jellyfish, with a maximum catch of 15 kg nautical mile^{-1}, obtained in a tow between 39 and 50 m.

Maurolicus muelleri ascending from a mid-day depth of 150 to 200 m never migrated to the surface at night, but aggregated at about 20 to 40 m (Fig. 1). They thereby excluded themselves from the higher standing stock of potential zooplankton prey in the uppermost 12 m (revealed by concurrent sampling; Skjoldal et al. 1993), though they migrated into waters characterized by maximum relative fluorescence and intermediate zooplankton abundance (Skjoldal et al. 1993). Hydrographic gradients from 20 to 12 m (34.4 to 32.6 psu and 8.1 to 8.9°C) should not represent a barrier to further

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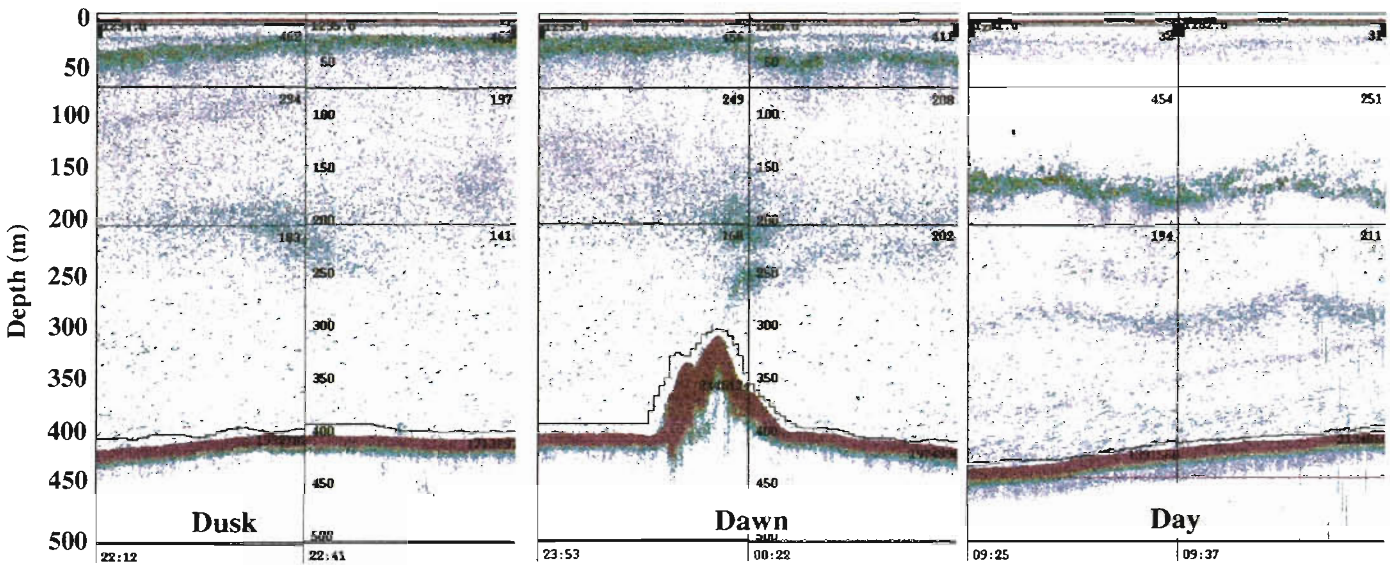

Fig. 1. Vertical distribution of *Maurolicus muelleri* in summer illumination at 62° N. Echogram (EK500, 38 kHz) obtained by RV 'Johan Hjort' in Storfjorden, western Norway from 6 to 7 June 1993 by day, dusk/night and night/dawn. The distribution of the scattering layer did not change during the intermediate night period not shown in the figure. Times are GMT. Color scale (see Fig. 2) refers to volume backscattering strength (dB). Vertical lines delineate nautical miles. Digits in upper right corners give integrated echo levels (S_A) for the outlined 'blocks', calculated by the Bergen Echo Integrating system (Foote et al. 1991)

upward migration, as *M. muelleri* is observed to cross corresponding, and even stronger gradients (Baliño & Aksnes 1993, author's unpubl. results). Hence, we suggest that the ascent ceased because of the light summer night.

Nighttime surface light values varied between ~1 and 10 µmol m^{-2} s^{-1} (measured by a Li-Cor quantum sensor), and about 3% of the surface light reached 20 m. The estimated nocturnal light intensities at the top of the scattering layer (~0.3 to 3×10^{-1} µmol m^{-2} s^{-1}) correspond to previously published maximum values experienced by vertically migrating *Maurolicus muelleri* when they arrive in surface waters at dusk (Rasmussen & Giske 1994, Rosland & Giske 1994, Bjelland 1995). Therefore, these light values would allow visual feeding throughout the night. Accordingly, no midnight sinking was observed (Fig. 1), in concordance with results by Rasmussen & Giske (1994) for May, but in contrast to studies carried out during darker periods of the year (see previous references). Although echograms selected from only 1 night are presented in Fig. 1, the distribution of *M. muelleri* was studied throughout 6 nights between 4 and 12 June, and similar distributions were observed each night.

At even higher latitudes, days become longer and summer nights even less dark (though there still is a marked diel change in light levels), with periods of midnight sun north of 67.3° N. This may imply absence of antipredation windows when planktivores can harvest the food sources of upper waters while remaining sheltered against piscivores. One consequence might be that vertically migrating organisms (like *Maurolicus muelleri*) cannot enter the upper, productive layers through several summer months. The light cycle might thus actually constrain the geographic range where vertically migrating species could prosper (Sameoto 1989). Alternatively, they may alter their antipredator behavior, making harvesting of the plankton in the continuously illuminated upper layers possible. Schooling appears to be the appropriate antipredator strategy for the Antarctic krill *Euphausia superba* during southern polar summers (Lancraft et al. 1989, Hamner 1996), and schooling tends to increase among planktivorous fish when exposed to danger of predation (Magurran 1990).

This indeed seems to be the case for *Maurolicus muelleri*. At 69° N in the Norwegian Sea, we obtained acoustic records of nocturnal schools near the surface, which we ascribe to *M. muelleri* (see below). These schools appear as red dots of the upper water layer (Fig. 2). Note that schools recorded from a moving vessel will appear particularly small in shallow waters due to the narrow acoustic beam close to the transducer (see Misund et al. 1996).

We made 1 tow with an Åkra trawl to identify these targets. The trawl was equipped with an inner net of 11 mm mesh size to retain small organisms, and flotation was used to restrict sampling to near the surface. In total, 212 kg *Maurolicus muelleri* were captured (75 kg nautical $mile^{-1}$), constituting 94% of the total

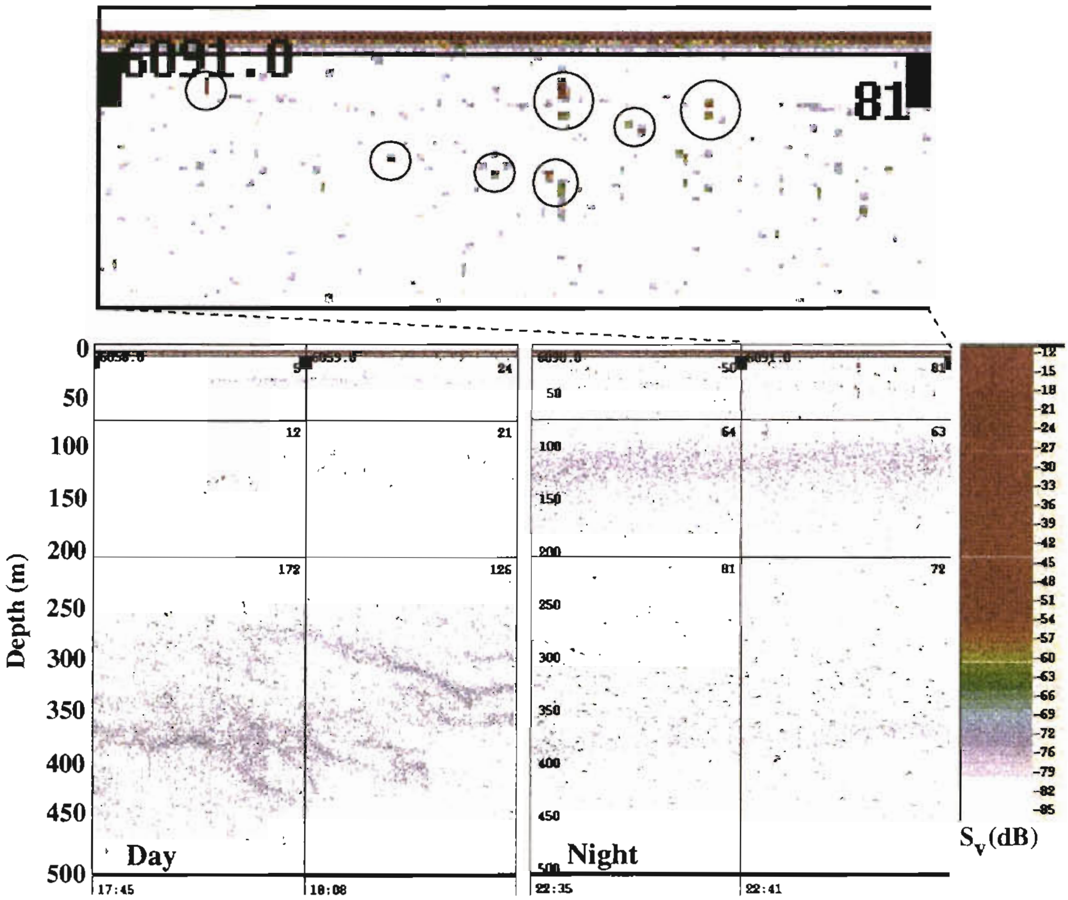

Fig. 2. Vertical distribution of *Maurolicus muelleri* in summer illumination at 69° N. Echogram (EK500, 38 kHz) from day and night from 3 to 4 August 1993 obtained by RV 'G.O. Sars' in the Norwegian Sea. Times are GMT. Color scale refers to volume backscattering strength (dB). Vertical lines delineate nautical miles. Digits in upper right corners give integrated echo level (S_A) for the outlined 'blocks', calculated by the Bergen Echo Integrating system (Foote et al. 1991). The upper 75 m of one nautical mile is expanded, and targets interpreted as schools by their strength/vertical extension are encircled

fish catch. Krill was the other major constituent in the catches, with 44 kg nautical mile^{-1}. Mackerel (*Scomber scombrus*; 9 captured individuals) had stomachs filled with *M. muelleri*.

We conclude that the schools consisted of *Maurolicus muelleri*. No 'typical' SL which could account for the high catches appeared in the echograms, nor did the trawl catch alternative targets possibly accounting for the acoustic records. Schools of herring form similar visual acoustic signatures, but normally result in much higher integrated echo levels (e.g. Misund et al. 1996).

The total abundance of *Maurolicus muelleri* in this case was much lower than in the example from Storfjorden (cf. the integrated echo levels given in Figs. 1 & 2), but the fish concentrations in the schools were higher than in the fjord (cf. the color code of the echoes). Our recordings (3 to 4 August) were done ~10 d after termination of the midnight sun period, but nights were still light.

The literature provides a few examples of daylight near-surface schooling of mesopelagic fish that normally carry out DVM (Alverson 1961, Marchal & Lebourges 1996). On both occasions, the fishes (*Benthosema pterota* and *Vinciguerria nimbaria*) were chased by tuna in waters near the equator (off the coast of Costa Rica and in the northern equatorial current, respectively). We speculate that schooling also in these cases may have been related to the local light regime. Like high latitudes, equatorial regions represent an extreme regarding light climate, in this case due to very swift switching between daylight and darkness. The short dusk and dawn periods imply short antipredation windows. Hence, in the morning the fishes could become rapidly exposed to diurnal predators. Schooling as a strategy to extend the feeding period in upper layers, or as an immediate defense response when encountered by predators, may then be beneficial.

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