Vol. 598: 147–151, 2018
https://doi.org/10.3354/meps12636

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published June 28

NOTE

Diel vertical migration of chub mackerel: preliminary evidence from a biologging study

Tohya Yasuda[1,*], Naoki Nagano[2,3], Hajime Kitano[2]

[1]Seikai National Fisheries Research Institute, Japan Fisheries Research and Education Agency, 1551-8 Taira-machi, Nagasaki 851-2213, Japan

[2]Fisheries Research Institute of Karatsu, Faculty of Agriculture, Kyushu University, 59-2 Oka, Karatsu, Saga 847-0132, Japan

[3]Faculty of Agriculture, University of Miyazaki, Gakuen-kibanadai-nishi-1-1, Miyazaki 889-2192, Japan

ABSTRACT: Fishes in the genus *Scomber* are migratory species specialised for rapid and efficient swimming, and are also of high commercial value. Despite advances in understanding the horizontal distribution and migratory behaviour of *Scomber* species, knowledge remains limited about their vertical movement patterns. This paper presents a proof of concept showing the potential for using biologging techniques to help understand the vertical movement patterns of a scombrid. The vertical swimming behaviour of 1 chub mackerel *S. japonicus* was measured at 10 s intervals for 166 consecutive days from November to April with an electronic tag. The tagged fish showed a normal pattern of diel vertical migration (DVM) that involved movement from shallow depths at night to greater depths during the day. However, this pattern of DVM broke down or reversed on a short-term basis during the overall recording period. In addition, the fish modified the depth and amplitude of DVM in response to the vertical gradient of the water temperature. Consequently, even though the tagged individual used a wide range of depths uniformly (0 to 130 m), it remained within potentially physiologically adequate ambient water temperatures in a vertically and seasonally heterogeneous thermal environment.

KEY WORDS: DVM · *Scomber* · Biotelemetry · Behaviour · Tag

INTRODUCTION

Globally, the genus *Scomber* contains 4 species: Atlantic mackerel *S. scombrus*, Atlantic chub mackerel *S. colias*, spotted chub mackerel *S. australasicus*, and chub mackerel *S. japonicus*. All 4 species are migratory pelagic fish that are of high commercial value; it is therefore important to understand their movement patterns to implement appropriate management and conservation actions. For instance, information about the horizontal and vertical movement patterns of fishes might enable us to understand how they interact with fisheries, and could assist with implementing stock assessments that capture some of the spatial variability of migratory fishes (Carvalho et al. 2015). The horizontal movements of *Scomber* species have been investigated using various techniques (Uriarte & Lucio 2001, Yasuda et al. 2014). However, information about vertical distributions remains limited for all *Scomber* species, even though it could provide important insights into their movement patterns (Castonguay et al. 1992, Nøttestad et al. 2016).

Biologging techniques using electronic tags are being increasingly used in fish studies, yet few tags have been deployed on small pelagic fishes, like *Scomber* species (Cooke et al. 2011). A recent study showed how biologging techniques could be used to record the vertical swimming behaviour of *S. japonicus* successfully under laboratory conditions (Yasuda et al. 2015). In the present study, we used this biolog-

*Corresponding author: ytohya@affrc.go.jp

ging technique on wild *S. japonicus*, allowing us to describe the first records of vertical swimming behaviour for this species under natural conditions.

MATERIALS AND METHODS

Fieldwork was conducted in the coastal area of Tsushima Island, Japan, from 31 October to 1 November 2016. The tagging experiment was conducted according to the Guidelines for Animal Experimentation of the Seikai National Fisheries Research Institute, Japan Fisheries Research and Education Agency (No. 2013001). The experimental fish were collected by angling from a fishing boat at night. Tag attachments were subsequently conducted on the boat over the same time frame. The fish were anaesthetised with eugenol (about 5 ppt solution), measured for fork length (cm) and then held on a platform for tag attachment. Using a water pump, seawater was circulated through the mouth of the fish to aid respiration during the tag attachment. Due to a technical difficulty, we could not measure the body mass of fish on the boat. Body mass (g) of fish was therefore estimated by the power function of fork length (cm) from other individuals measured in a previous study (Body mass = $0.0062 \times \text{Fork length}^{3.2446}$, $R^2 = 0.7264$, $n = 59$, $p < 0.0001$; Yasuda et al. 2015).

Two types of data storage tags (LAT2500, LOTEK Wireless; DT, Biologging Solutions) were used to record the swimming behaviour of chub mackerel. The LAT2500, which is equipped with depth, temperature, and light sensors, is approximately 8 mm in diameter, 35 mm in length, and weighs 3.6 g in air. The DT is equipped with depth and temperature sensors and is approximately 11 mm in diameter, 33 mm in length, and weighs 6.0 g in air. Depth, temperature, and light were measured at 10 s intervals. The tags were deployed on the fish by using implantation or external attachment methods. Details of the attachment methods have been published in a previous study (Yasuda et al. 2015). In addition, a plastic-tipped dart tag (PDX, Hallprint) was attached externally near the dorsal fin of the fish with a surgically implanted tag.

We surgically implanted 10 LAT2500 and 9 DT tags, and externally attached DT tags to 6 fish, for a total of 25 tagged fish. The mean ± SD fork length of the fish was 32.7 ± 1.8 cm. The ratio of tag mass to fish body mass was less than 1.4 %, and was assumed not to influence survival, growth, and swimming behaviour of the fish (Yasuda et al. 2015). All fish were released near the point of capture immediately after tag attachment.

RESULTS

Two fish with surgically implanted DT tags were recaptured by fishermen. One fish was recaptured 41 d after tagging by an angler on the coast of the southern part of Tsushima Island, about 40 km southwest from the release point (see Fig. S1 in the Supplement at www.int-res.com/articles/suppl/m598p147_supp.pdf). Unfortunately, we could not retrieve the tag from the fish because the fisherman detected the dart tag attached externally on the fish but did not detect the electronic tag implanted in the peritoneal cavity of the fish. The second fish was recaptured 166 d after release by a commercial purse seine fishery operating along the west coast of the Goto Islands, located about 200 km southwest from the release point. Recapture by angling suggests active foraging by the tagged fish. Recapture by the purse seine fishery suggests that the tagged fish formed a school with other individuals. Our results demonstrate that it is possible to measure the vertical swimming behaviour of chub mackerel using electronic tags.

Fine-scale time-series data from the 1 electronic tag that we were able to retrieve revealed that this tagged chub mackerel exhibited clear diel vertical migrations (termed DVMs) throughout the entire recording period. The tagged fish changed the depth and amplitude of DVM (i.e. differences were detected between day and night depths) in response to the vertical gradient of water temperature. For example, when a thermocline developed at a depth of about 50 m during November, the tagged fish performed DVMs below the thermocline, and never ascended to the surface layers (Fig. 1A,B, see also Fig. S1). When the thermocline collapsed during December, probably because of vertical mixing of water in winter, the fish used the sea surface layers (Fig. 1C,D). As a result, even though the tagged fish used a wide range of depths uniformly from 0 to 130 m throughout the overall recording period (Fig. 1E), more than 80 % of ambient temperature data fell within a limited range from 16.0–19.9°C (Fig. 1F).

The tagged chub mackerel changed its depth, amplitude, and pattern of DVM. The individual showed a common pattern of DVM (termed normal DVM) that was characterised by a large amplitude of movement, including ascent into shallow water around dusk, remaining in the surface layers at night, followed by descent to greater depths at dawn where it remained during daylight hours. However, this normal pattern of DVM broke down or reversed direction for approximately 1 mo in February and March 2017, and on several other days over the

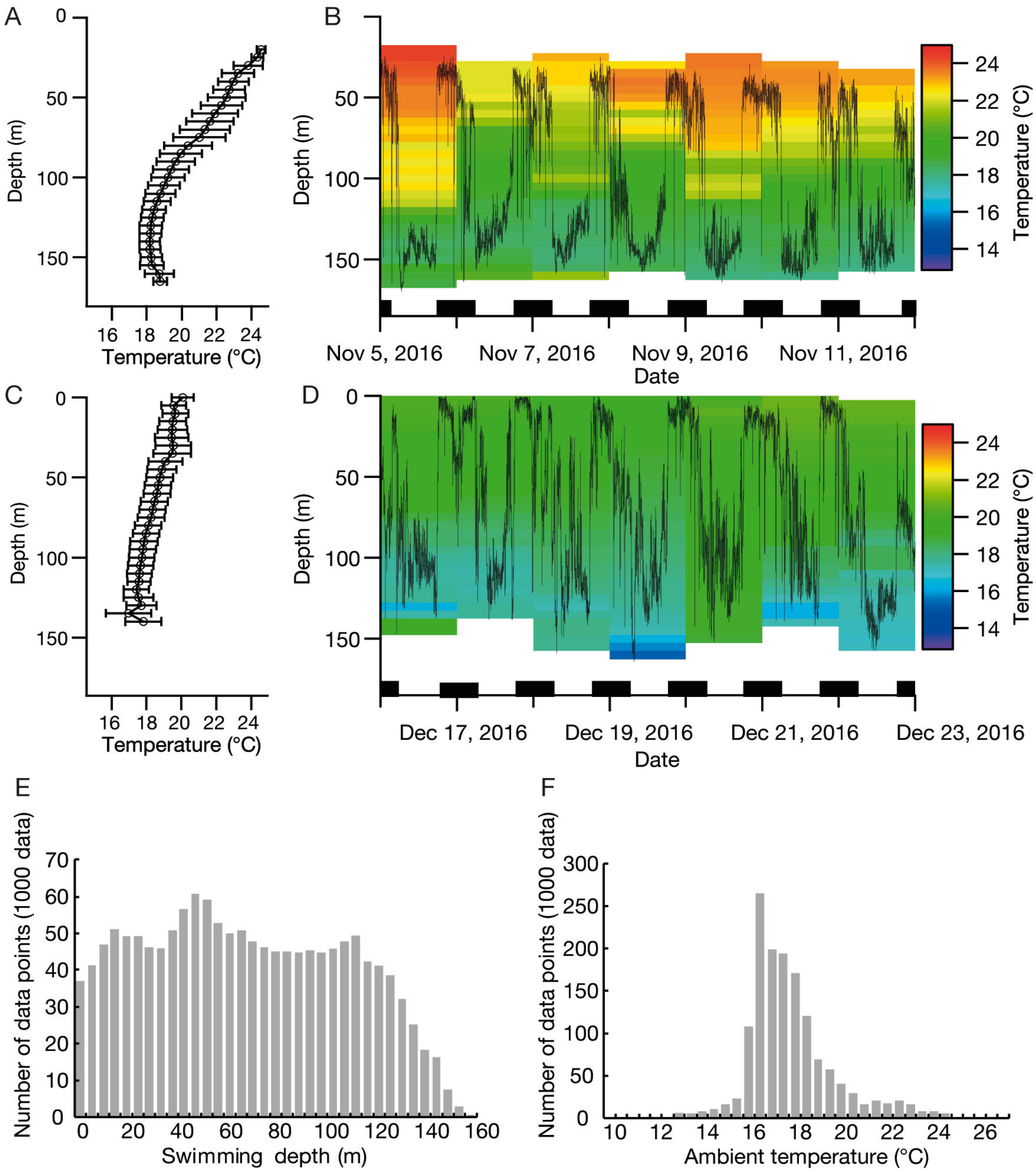

Fig. 1. Example of temperature-related changes in the amplitude of diel vertical migration of a chub mackerel. All data came from a single tag. (A,C) Vertical distribution of ambient water temperature during November and December 2016. Mean ± SD temperature is indicated at each 5 m depth interval. (B,D) Time series of swimming depth during 1 wk in November and December 2016. Background colour images indicate daily mean ambient water temperatures at each 5 m depth interval. Black bars across the *x*-axes indicate nighttime (18:00–05:59 h). (E,F) Data distributions of swimming depth and ambient water temperature of the tagged fish for the overall recording period. Mean ± SD swimming depth and temperature were 74.7 ± 43.1 m (range: 0.1–180.0 m) and 18.1 ± 1.85°C (range: 12.7–25.0°C), respectively

course of the deployment (Fig. 2). These periods coincided with the spawning season of the species (Yukami et al. 2009).

DISCUSSION

Our results demonstrate the potential of biologging techniques for enhancing our understanding of the fine-scale movement patterns of *Scomber* species. This study describes the unique behavioural patterns of *S. japonicus* in the East China Sea based on data from a single fish. However, we anticipate that future studies using this technique would allow us to perform quantitative (statistical) and comparative analyses among different habitats and different *Scomber* species under dynamic ocean environments.

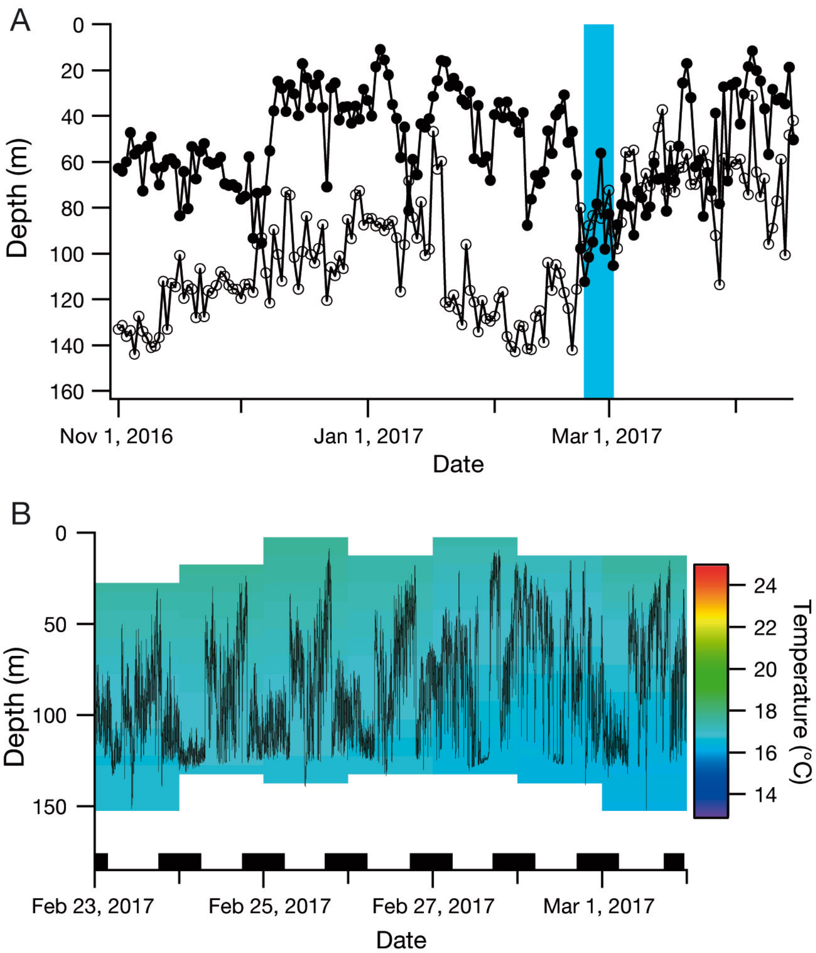

Fig. 2. Example of the change in the amplitude and diel pattern of vertical migration of a chub mackerel. All data came from a single tag. (A) Time series of daily mean swimming depth during the day (○) and at night (●) for the overall recording period. The blue box highlights the time span shown in (B). (B) Detailed time series of swimming depth in February 2017, showing reverse diel vertical migration. Black bars across the *x*-axes indicate nighttime (18:00–05:59 h). Background colour indicates daily mean ambient water temperatures at each 5 m depth interval

Because *S. japonicus* is an obligate ectotherm that lacks physiological mechanisms for regulating body temperature (Roberts & Graham 1979), it can exhibit 2 major types of behavioural adaptations to avoid potentially unsuitable temperatures and to exist successfully in a dynamic, heterogeneous thermal environment (Wurtsbaugh & Neverman 1988, Sims et al. 2006). Our data showed that the tagged *S. japonicus* changed the depth and amplitude of DVM in response to the vertical gradient of water temperature. As a result, the ambient water temperatures of the fish were maintained within suitable temperature ranges (cf. Schaefer 1986, Yasuda et al. 2014) in a vertically heterogeneous thermal environment. Similar temperature-related habitat selection has also been suggested in studies of Atlantic mackerel (Castonguay et al. 1992, Nøttestad et al. 2016).

Chub mackerel might modify their behaviour to exploit vertically moving food resources. Major prey items of adult chub mackerel in the study area include marine planktonic crustaceans and mesopelagic micronekton fishes (H. Tanaka unpubl.). Zooplankton and their predators generally exhibit normal DVM (Hays 2003). In the study area, these organisms were observed at depths ranging from 28 to 115 m at night and more than 150 m during the day (Ohshimo 2004, Tanaka et al. 2013). These depth ranges and diel patterns might be consistent with the DVM of chub mackerel. However, we found that the chub mackerel exhibited short-term reverse (or ambiguous) DVMs during the recording period. The tagged fish moved horizontally from the release point to the recapture point in the overall recording period (see Fig. S1). This behavioural pattern might be attributed to changes in habitat type and behaviour of prey items (Sims et al. 2005, Nøttestad et al. 2016). Alternatively, reverse (or ambiguous) DVM patterns of chub mackerel might be associated with reproduction (Tsuda et al. 2014).

The distribution of predators might also affect the behavioural patterns of mackerel. However, reports on the distribution of predators in our study area are limited. The DVMs of large piscivorous fishes (Pacific bluefin tuna *Thunnus orientalis* and dolphinfish *Coryphaena hippurus*) are usually performed above and/or across the thermocline (Furukawa et al. 2014), which is a clearly different pattern from that documented for the chub mackerel. Thus, the vertical habitats of chub mackerel might not overlap much with these large piscivorous fishes.

Biologging techniques generate high-quality data in terms of accuracy and resolution. The low recovery rate (4%) in this study suggests that obtaining a robust sample size with this approach may be challenging and will require considerable effort. However, data from even a small number of tags could be a useful complement to other approaches, such as ship surveys and otolith microchemistry, for understanding the ecology of mackerels.

Acknowledgements. We thank K. Zenimoto, H. Suzaki, R, Kawaguchi, K. Fujioka, staff of the Saga Genkai Fisheries Research Development Center, and staff of the Nagasaki Prefectural Institute of Fisheries for providing help with the fieldwork and the data sampling. We also thank 3 anonymous reviewers for providing constructive comments. S. Furukawa helped with drawing the images of the time-series data. The present study was partly supported by JSPS KAKENHI Grant Number JP15K18736.

LITERATURE CITED

Carvalho F, Ahrens R, Murie D, Bigelow K, Aires-Da-Silva A, Maunder MN, Hazin F (2015) Using pop-up satellite archival tags to inform selectivity in fisheries stock assessment models: a case study for the blue shark in the South Atlantic Ocean. ICES J Mar Sci 72:1715–1730

Castonguay M, Rose GA, Leggett WC (1992) Onshore movements of Atlantic mackerel (*Scomber scombrus*) in the Northern Gulf of St. Lawrence: associations with wind-forced advections of warmed surface waters. Can J Fish Aquat Sci 49:2232–2241

Cooke SJ, Woodley CM, Eppard MB, Brown RS, Nielsen JL (2011) Advancing the surgical implantation of electronic tags in fish: a gap analysis and research agenda based on a review of trends in intracoelomic tagging effects studies. Rev Fish Biol Fish 21:127–151

Furukawa S, Tsuda Y, Nishihara GN, Fujioka K and others (2014) Vertical movements of Pacific bluefin tuna (*Thunnus orientalis*) and dolphinfish (*Coryphaena hippurus*) relative to the thermocline in the northern East China Sea. Fish Res 149:86–91

Hays GC (2003) A review of the adaptive significance and ecosystem consequences of zooplankton diel vertical migrations. Hydrobiologia 503:163–170

Nøttestad L, Diaz J, Penã H, Søiland H, Huse G, Fernö A (2016) Feeding strategy of mackerel in the Norwegian Sea relative to currents, temperature, and prey. ICES J Mar Sci 73:1127–1147

Ohshimo S (2004) Spatial distribution and biomass of pelagic fish in the East China Sea in summer, based on acoustic surveys from 1997 to 2001. Fish Sci 70:389–400

Roberts JL, Graham JB (1979) Effects of swimming speed on the excess temperatures and activities of heart and red and white muscles in the mackerel, *Scomber japonicus.* Fish Bull 76:861–867

Schaefer KM (1986) Lethal temperature and the effect of temperature change on volitional swimming speeds of chub mackerel, *Scomber japonicus.* Copeia 1986: 39–44

Sims DW, Southhall EJ, Tarling GA, Metcalfe JD (2005) Habitat-specific normal and reverse diel vertical migration in the plankton-feeding basking shark. J Anim Ecol 74:755–761

Sims DW, Wearmouth VJ, Southall EJ, Hill JM and others (2006) Hunt warm, rest cool: bioenergetic strategy underlying diel vertical migration of a benthic shark. J Anim Ecol 75:176–190

Tanaka H, Sassa C, Ohshimo S, Aoki I (2013) Feeding ecology of two lanternfishes *Diaphus garmani* and *Diaphus chrysorhynchus.* J Fish Biol 82:1011–1031

Tsuda Y, Yamamoto S, Yamaguchi H, Ohnishi T, Sakamoto W, Murata S (2014) Vertical movement of spawning cultured chub mackerel (*Scomber japonicus*) in a net cage. Aquaculture 422-423:136–140

Uriarte A, Lucio P (2001) Migration of adult mackerel along the Atlantic European shelf edge from a tagging experiment in the south of the Bay of Biscay in 1994. Fish Res 50:129–139

Wurtsbaugh WA, Neverman D (1988) Post-feeding thermotaxis and daily vertical migration in a larval fish. Nature 333:846–848

Yasuda T, Yukami R, Ohshimo S (2014) Fishing ground hotspots reveal long-term variation in chub mackerel *Scomber japonicus* habitat in the East China Sea. Mar Ecol Prog Ser 501:239–250

Yasuda T, Nagano N, Kitano H, Ohga H, Sakai T, Ohshimo S, Matsuyama M (2015) Tag attachment success can be temperature dependent: a case study of the chub mackerel *Scomber japonicus.* Anim Biotelem 3:48

Yukami R, Ohshimo S, Yoda M, Hiyama Y (2009) Estimation of the spawning grounds of chub mackerel *Scomber japonicus* and spotted mackerel *Scomber australasicus* in the East China Sea based on catch statistic and biometric data. Fish Sci 75:167–174

Editorial responsibility: Elliott Hazen, Pacific Grove, California, USA

Submitted: December 4, 2017; Accepted: May 11, 2018
Proofs received from author(s): June 13, 2018