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INTERNATIONAL WHALING COMMISSION

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ABSTRACT

Diving behaviour of sei whales and vertical distribution of their prey were recorded simultaneously in 2013 JARPNII to study their feeding behaviour at micro scale. This was the first attempt of this kind of observation targeting on this species. Small acoustic time depth transmitters (pingers) were attached to two sei whales and their behaviours were recorded for 10.2 and 32.0 hours, respectively. Vertical distributions and densities (volume backscattering strength, SV) of their prey were recorded by an echosounder following swimming path of the individuals. The diving behaviour deeper than 10 m was classified into two shapes (U-shape, V-shape). It was assumed that U-shape was related to feeding behaviour, especially lunge feeding, while V-shape was related to prey searching dive. Sei whales showed diel patterns in mean diving depth (day: 19 ± 14 m and 16 ± 10 m, night: 12 ± 5 m and 10 ± 5 m). Dense scattering layers (presumably zooplankton) were observed around 40 m during the daytime, and they migrated closer to the surface in the evening. Diving depth of the whales followed the changes in the scattering layers (i.e. diving depth was same as depth of scattering layers). U-shape diving was associated with higher SV values than V-shape diving in daytime. The number of U-shape diving increased around dusk. The results suggested that sei whales frequently lunged to prey around dusk. First-Passage Time (FPT) of sei whales as an indicator of feeding was calculated using the cruise track as a proxy of horizontal movement of tagged individuals. Large FPT can be considered as feeding behaviour. FPT was increased around dusk and it was corresponding to increase in U-shape diving. Combining these results, it could be said sei whales actively fed on prey around dusk. Swimming depth of the whales was shallower than 10 m after sunset while deep scattering layers (presumably myctophids) were migrated from below 60 m to around 30 m. The results might indicate that they did not feed on prey in deep scattering layers at night. However, it could not preclude a possibility that sei whales fed on prey near surface at night because data on behaviour and prey distribution near surface could not recorded by the acoustic devices (pinger and echosounder) used in this study. The results of this study revealed that sei whales changed their diving behaviour in response to availability of their prey.

INTRODUCTION

Observations of feeding behaviours of baleen whales are widespread in recent years in parallel with development of biologging devices. Feeding behaviours of blue (Friedlaender *et al.*, 2015; Goldbogen *et al.*, 2013; Goldbogen *et al.*, 2015), fin (Friedlaender *et al.*, 2015; Goldbogen *et al.*, 2006), Antarctic minke (Friedlaender *et al.*, 2014) and humpback (Friedlaender *et al.*, 2009; Goldbogen *et al.*, 2008) whales were reported in scientific literatures. However, feeding behaviour of sei whales has not reported to date.

It is preferable to record both diving profile of whales and vertical distribution of their prey simultaneously to clarify their feeding behaviours. A small acoustic time depth transmitter (pinger) is a suitable biologging device for this purpose because it allows us to follow swimming path of an individual based on the acoustic signal. Vertical distribution of their prey along the path can be recorded an echosounder. Such attempts were made targeting on humpback and fin whales in the Gulf of Alaska (Witteveen *et al.*, 2014; Witteveen *et al.*, 2008) and similar approach was taken in this study. Pingers were deployed to two individuals of sei whales in the western North Pacific in August 2013 as a part of JARPNII to investigate their feeding behaviour. Echosounder data were recorded simultaneous while following their swim paths. Net samplings were also conducted around the area to confirm species composition of acoustic backscatterings recorded by the echosounder. This paper is a short note on the result of the observations.

There are three spatiotemporal scale to link feeding ecology of cetaceans with distribution pattern of them and the definitions are follows; at the macro scale, cetaceans migrate seasonally between feeding and breeding grounds; at the meso scale, cetaceans move over days and weeks in search of preferred local abundance of food; and at the micro scale, whales dive and search for food within localised areas (IWC, 2003). This study corresponds to the micro scale.

MATERIALS AND METHODS

Acoustic time depth transmitters (FPXG-1040-60P500T30, Fusion Inc., Tokyo, Japan) used in this study send pulses (62.5 kHz) per second and the depth data were encoded in them. The weight of the transmitter was 6 g in air. Maximum duration of the batteries and detection range were 48 hours and 800 m, respectively. Transmitted signals were received by a transducer with four channels (bow, port, starboard and bottom sides) and processed by a receiver (FRX-4001, Fusion Inc., Tokyo, Japan) onboard a research vessel (RV), *Shunyo-maru* (887 gross tons). The transducer was hull-mounted at a depth of 4.3 m below the sea surface. The transmitters were tethered to small titanium spearheads (3.8 cm in length, 1.45 cm in maximum head width and 4 g in air) by polyethylene (Dyneema) fishing line with linear strength of 55 kg. The spearheads were loosely attached to titanium shafts (12.15 cm in length) with an expectation that the transmitters and spearheads were detached from the shafts once they hit whales. The titanium shafts were attached to carbon bolt arrows. The spearheads and shafts were made by Koreisangyo (Yokohama, Japan). The tags were shot by compound crossbows from the bow decks of the survey vessels. The length of the vessels is about 70 m and the height of the bow deck from sea surface is about 8 m. Based on visual observations, it was considered that there was no obvious reaction by the individuals to the deployment and in subsequent observations. The RV followed the tagged individuals based on relative swimming direction processed by received signals.

A calibrated quantitative echosounder, Simrad EK60 (Simrad, Horton, Norway), with a 120 kHz transducer was used to record volume backscattering strength, SV (dB), as index of prey density. The transducer was hull-mounted at a depth of 4.3 m below the sea surface. Trawl and plankton net sampling were conducted at 5 and 4 stations respectively around the area where the behaviours were observed. The sampling was conducted at the predetermined stations rather than targeting specific acoustic backscatters. Acoustic backscatter was processed by using a software, Echoview 4.9 (Myriax, Hobart, Australia).

Depth data were imported into programs IgorPro version 6.12 (WaveMatrics, Oregon, US), and Ethographer package version 2.01 (Sakamoto *et al.*, 2009) for Igor Pro were used to detect diving behaviours. Starting and end points of diving behaviour were set as 3 m. Individuals were considered as in diving when they stayed more than 5 seconds in the water column deeper than 5 m. If there was a gap more than 15 minutes without depth data between successive signals, the data were excluded from the analysis. Mann-Whitney U-test was used to test whether maximum depth and duration of each whale showed diel patterns. Considering sunrise and sunset at local time, from 5:00 to 19:00 was conventionally defined as daytime while the rest as nighttime.

Time Allocation at Depth (TAD) index was calculated following Fedak *et al.* (2001). This index varies 0 to 1 and represents difference between dive shapes. Diving behaviour deeper than 10 m was classified into two shapes based on TAD: U-shape (TAD $\geqq$ 0.7) and V-shape (TAD < 0.7). Previous studies suggested that U-shape dives of baleen whales indicate feeding dive, especially lunge feeding, while V-shape dives indicate travelling or prey searching dive (Croll *et al.*, 2001; Goldbogen *et al.*, 2006; Martin *et al.*, 1998). It is considered that the dive shapes reflected bottom time portion of dive time. SV values at maximum dive depth in each dive were extracted from echosounder data. SV values were integrated in every 5 min of the cruise tracks, and in each 1 m depth bin. The horizontal resolution (i.e. 5 min) was set as the mean diving interval of two individuals was 5 min. Mann-Whitney U-test was used to test whether SV values were different between U and V shapes. Correlation between TAD and SV were tested using simple linear regression.

Two behavioural states (travelling and area restricted search [ARS]) of sei whales in the Atlantic were categorized using switching state-space model based on satellite tracking data (Prieto *et al.*, 2014). ARS, which is assumed to be related to feeding behaviour (Bailey *et al.*, 2009), can also be detected using First-Passage Time (FPT, in seconds [s]) (Fauchald and Tveraa, 2003). This is defined as the time taken to cross a circle of a given radius, which is centred around an animal's position (Bailey *et al*., 2009).Because the tracking system used in this study could not detect accurate horizontal location of tracking individuals, the cruise track was considered as a proxy of horizontal movement of tagged individuals for calculation of FPT as we followed them within 800 m range based on acoustic signals from the transmitters. Positions of the RV were recorded by using GPS every second and GPS data was resampled for 2 minutes interval to calculate FPT. FPT is defined as the time required for a whale to cross a circle with a given radius and can be considered as reasonable measure for the search effort along the path. The radius of the circle which can be considered as scale of ARS was estimated by using Ethographer. Large FPT in the circle implies ARS.

Near surface temperature was also recorded continuously along the paths of the RV. Mean temperature along the paths was calculated to investigate oceanographic conditions encountered by the tagged individuals.

RESULTS AND DISCUSSION

Diving behaviour of one individual of sei whale (S-1) was observed for 10 hr 11 min from 10:16 to 20:27 on 13 August 2013, while the other individual (S-2) was observed for 31 hr 59 from 10:37 on 14 August to 18:36 on15 August 2013. Because of technical problem of data recording, one (21 min) and two (1 hr 11 min and 1 hr 10 min) long gaps without signal were existed for S-1 and S-2, respectively. The number of dives for S-1 and S-2 was 119 and 387 respectively while mean dive depths and the standard deviations (SD) throughout the observation periods were 17.9±12.6 m with maximum depth of 57 m and 14.2±9.6 m with maximum depth of 48 m, respectively. Mean dive durations for S-1 and S-2 were 3.2 min and 3.0 min, respectively. The result of U-test (U-test) suggested that dive durations in daytime were longer than nighttime for both individuals ($p < 0.05$) (Table 1). They tended to dive deeper in daytime than in nighttime although the difference was not statistically significant. Diving depth of both individuals coincided with the changes in dense scattering layers observed in shallow water (Fig. 1).

Two prominent dense scattering layers were observed while tracking whales. The shallow one was observed around 40 m in the daytime but it migrated to near the surface in the afternoon. In the nighttime, scattering layers migrated from water depth deeper than 60 m to around 30 m. Maximum SV observed in the daytime and nighttime was around -80 dB and -72 dB, respectively. Species identification based on echosounder data could not be conducted as multifrequency data were not available. However, results of trawl sampling indicated that Japanese anchovy (*Engraulis japonicus*) was distributed around the target area near the surface in daytime while both anchovy and myctophids were distributed in the water column. It could be assumed that deep scattering layers observed in the nighttime mainly consisted of myctophids. The results of plankton net sampling showed that copepods, mainly *Neocalanus* spp., were dominant in wet weight in the samples apart from gelatinous planktons. It could be assumed that shallow scattering layer observed in the daytime was mainly consisted of copepods.

U-shape diving was associated with higher SV than V-shape diving for both individuals (U-test : $p < 0.05$) (Table 2). The result of linear regression suggested that TAD were positively correlated with SV for both individuals ($p < 0.05$). The radius of the circle of S-1 and S-2 which could be considered as scales of ARS were estimated as 2.7 km and 1.4 km respectively. FPT were getting larger from 15:00 to 20:00 and the decreased subsequently as indicated in the path of S-2 (Fig. 2,3). Large FPT was related to high SV and U-shape diving (Fig. 3). Means of near surface temperatures and the SDs encounter by S-1 and S-2 were 15.1 ± 0.08 °C and 15.0 ± 0.10 °C, respectively. Near surface temperature encountered by sei whales were stable along the paths of horizontal movement. The results of spatial distribution study of sei whales using a generalized model (GAM) suggested high density of this species was expected around 15 °C (Murase *et al.*, 2016: SC/F16/JR7) while GAM for modelling prey consumption of this species was not indicated such a peak along SST gradient (Tamura *et al.*, 2016: SC/F16/JR16). Combining these results, it can be hypothesized that spatial distribution of sei whales at meso scale are largely determined by oceanographic conditions such as SST instead of prey availability. Sei whales then search for their prey within the optimal oceanographic conditions at micro scale.

Both individuals dived to shallow scattering layer continuously in the daytime though the diving depths varied widely. However, they dived sequentially once the density became relatively high and the diving depths were concentrated to the dense scattering layers especially in the afternoon. After sunset, swimming depth became shallower around 10 m. *Neocalanus* spp. is one of the important prey species of sei whale in the western North Pacific (Konishi *et al.*, 2009). It was reported that *Neocalanus* spp. was mainly distributed at shallower than 40 m and have weak diel vertical migration (Kirby *et al.*, 2007). It was also reported that *Neocalanus* spp. was distributed around 30 m, and migrate around 10 m at night (Seki and Shimizu, 1998). It was observed that *Neocalanus* spp. formed dispersed small-dense patches at dawn, while it formed large patches from dusk to midnight (Tsuda *et al.*, 1993). These observations reported in the past corresponded to diel change of shallow dense scattering layers observed in this study. It can be said that sei whales change their diving depth in response to change in distribution depth of their prey to maximize their feeding efficiency.

The results of this study revealed that sei whales swam near surface and rarely dived to the depth of deep scattering layers distributed around 30 m at night where myctophids were distributed. The behaviour corresponded to the fact that myctophids were not recognized as main diet of sei whales in recent years (Konishi *et al.*, 2009). However, it can not preclude a possibility the sei whales fed near surface in night as data on behaviour and prey distribution near surface could not recorded by the acoustic devices (pinger and echosounder) used in the study. Small FPT values in nighttime might not be implied that sei whales do not feed in night because they are known as skimming feeder as well and they might not change their swimming path frequently while they are skimming. Generally, baleen whales are considered as visual predators (Friedlaender *et al.*, 2009; Hazen *et al.*, 2009). However, it was hypothesized that sei whales were feeding near surface in night based on the observations in the southwestern Gulf of Maine that rates of their calling were reduced in night when a copepod, *Calanus finmarchicus*, moved to near surface due to the diel migration (Baumgartner and Fratantoni, 2008). A Digital acoustic recording tag (DTAG) can be an alternative biologging device to detect feeding behaviour near surface an as analysis method was developed for this purpose recently (Owen *et al.*, 2015). Recording of prey distribution using echosounder near surface is challenging because of existence of near surface dead zone. Net sampling and/or continuous plankton recorder might be alternative options for echosounder.

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Table 1. Means and standard deviations (SD) of maximum diving depth (m) and diving durations (seconds, s) by day and night for two individuals of tagged sei whales (S-1 and S-2). Maximum recorded values are also shown. Results of Man-Whitney U test to test difference between day and night are also shown.

ID			**Day**	**Night**	**Mann-Whitney U test**
S-1	Max. depth (m)	mean±SD	19 ± 14	12.2 ± 5.4	$p = 0.083$
		Max.	57	26	
	Duration (s)	mean±SD	207 ± 141	134.4 ± 126.4	$p < 0.05$
		Max.	736	545	
S-2	Max. depth (m)	mean±SD	16 ± 10	9.5 ± 5.1	$p < 0.05$
		Max.	48	31	
	Duration (s)	mean±SD	201 ± 159	120 ± 95.4	$p < 0.05$
		Max.	657	460	

Table 2. Means of volume backscattering strength (SV, dB) value of each diving types (V- and U-shapes) for two individuals of tagged sei whales (S-1 and S-2).

	SV mean (dB)		**Mann-Whitney**
ID	**V-shape**	**U-shape**	**U test**
S-1	-86.0	-80.0	$p < 0.05$
S-2	-80.6	-78.8	$p < 0.05$

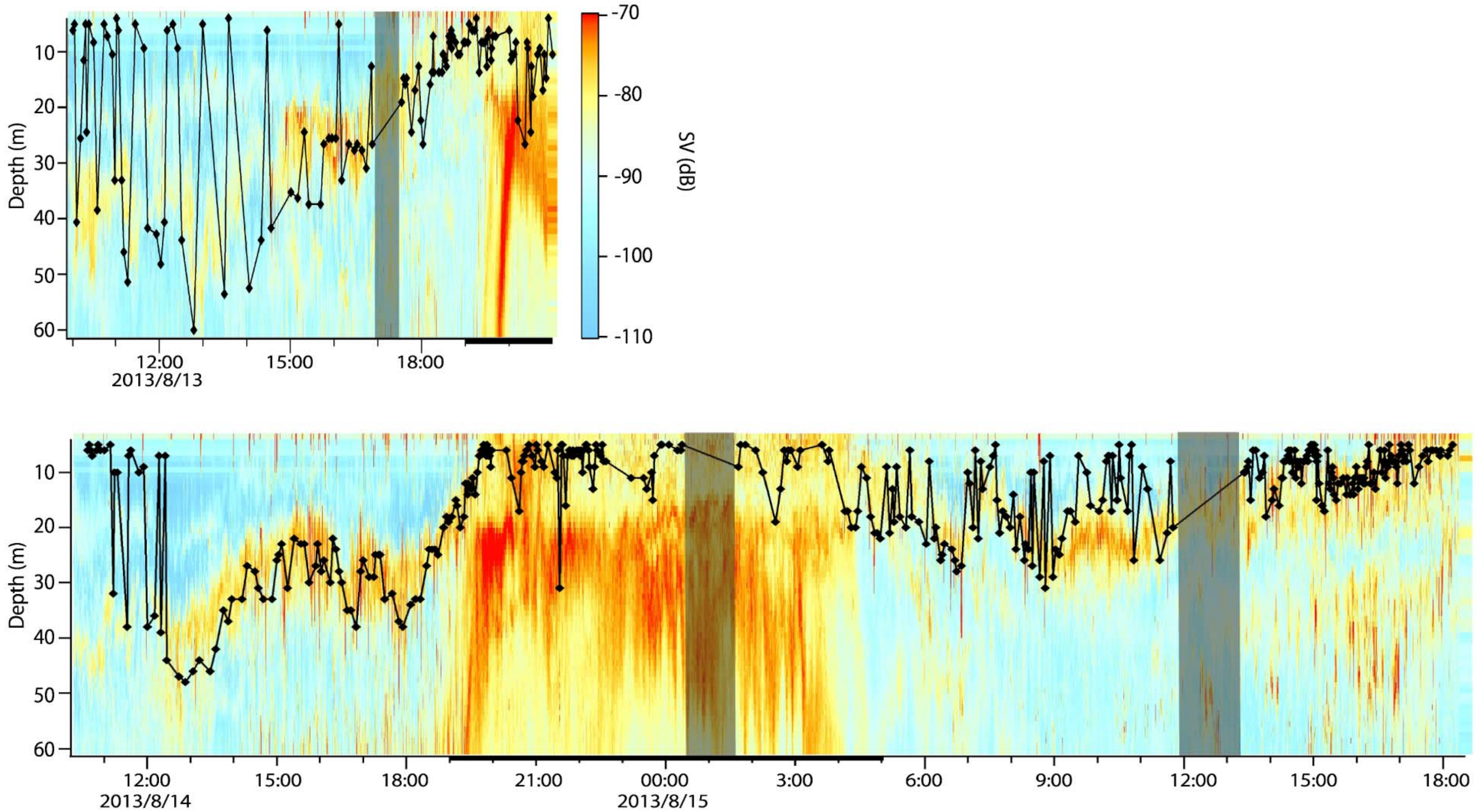

Fig.1. Maximum diving depth of each diving (filled circle) of sei whales (upper panel: S-1, lower panel: S-2) is overlaid on the echogram. Strong volume backscattering strength (SV) is assumed to be related to high densities of prey. Grey shadow indicates gaps without depth data and black bar along the timeline means nighttime (19:00 to 5:00).

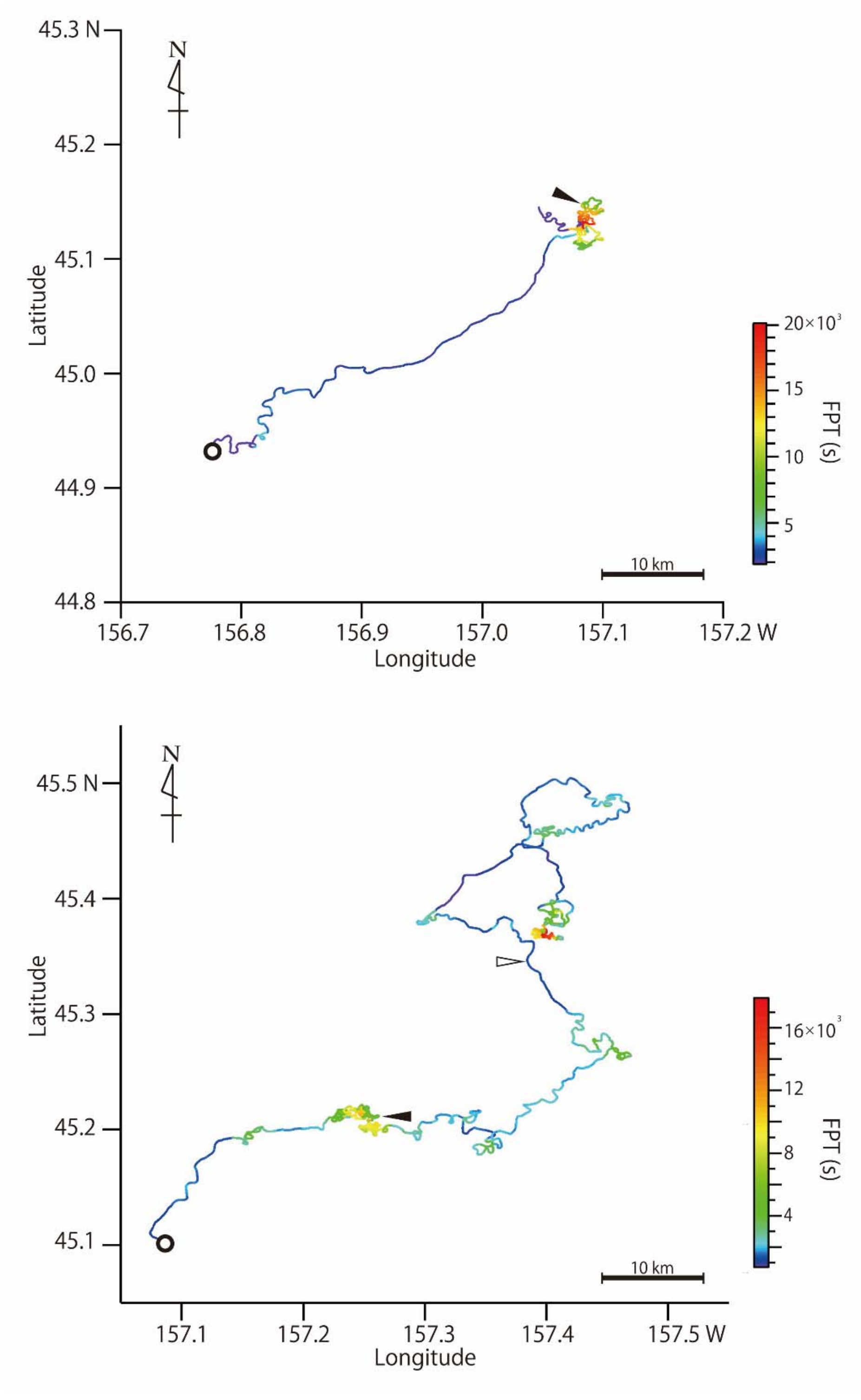

Fig. 2. Cruise tracks of survey vessel as a proxy of swimming path of tagged sei whales (upper panel: S-1, lower panel: S-2). First-Passage Time (FPT) along the track was also shown. White circle indicates the starting point of tracking. Black and white arrows indicate time of sunset and sunrise respectively.

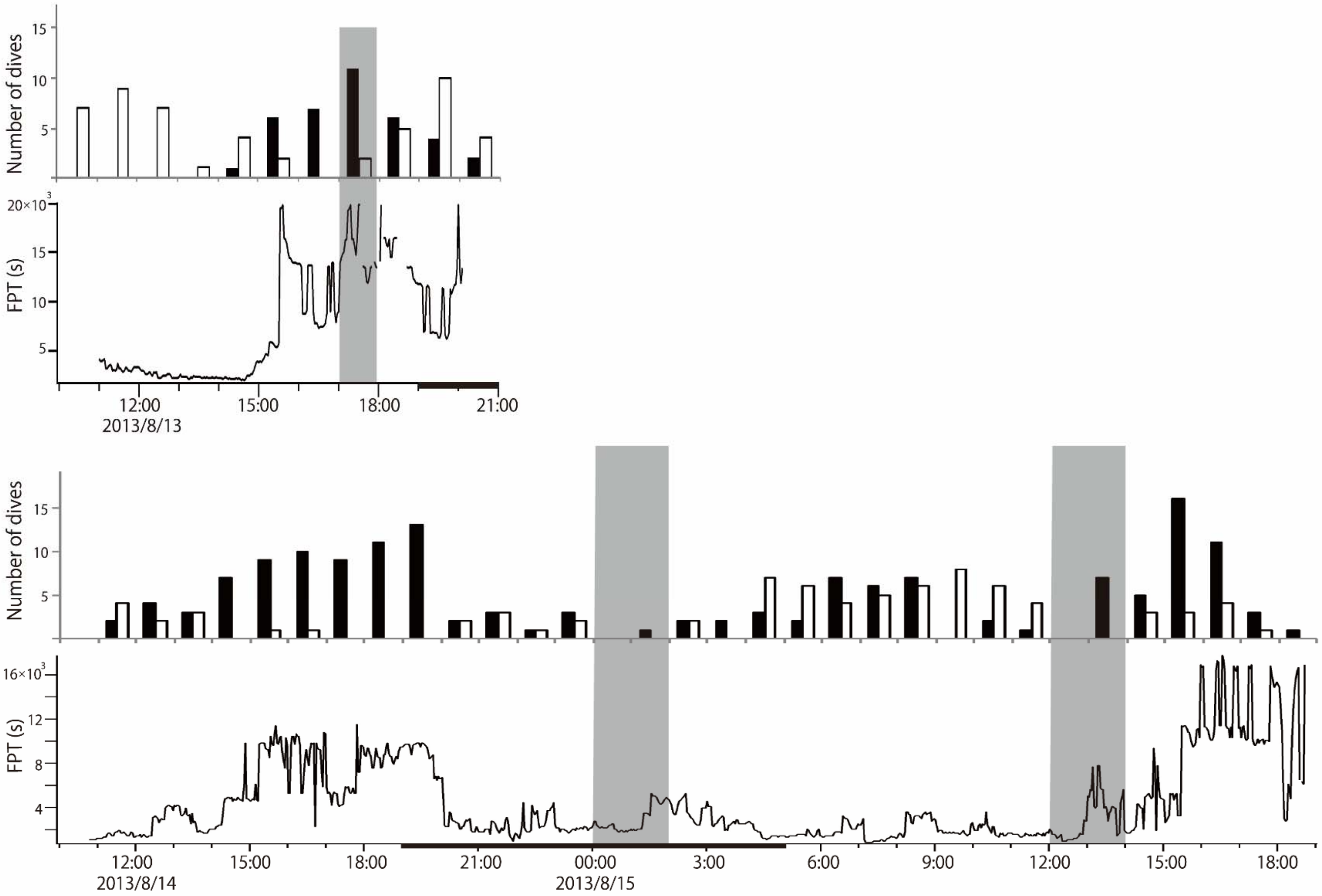

Fig.3. Number of U-shape (black bar) and V-shape (white bar) and first passage time (FPT) along the tracking paths of tagged sei whales (upper panel: S-1, lower panel: S-2). Grey shadow indicates gaps without depth data.