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Optical and acoustic camera observations of the behavior of the Kuril harbor seal *Phoca vitulina stejnegeri* after invading a salmon setnet

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Abstract

It has previously been confirmed that Kuril harbor seals *Phoca vitulina stejnegeri* cause damage to the chum salmon *Oncorhynchus keta* set-net fishery along the east coast of Hokkaido, Japan, but the level of damage has increased markedly with the recovery of their population in recent years. In this study, we attached an optical camera (TrawlCamera) and a Dual-Frequency Identification Sonar (DIDSON) acoustic camera to a set net to observe the behavior of seals as they invaded the set net and the number of salmon inside the net to help inform the development of modified fishing gear. Salmon were observed at all times during daytime with the TrawlCamera, while seals were only observed once. Observations using the DIDSON in its low-frequency mode confirmed that the behavior of seals became vigorous from around sunset to nighttime within the recording time (15:30-21:00). Observations with the DIDSON's high-frequency mode showed that the overall lengths and body widths of seals ranged from 1.0 to 1.6 m and 0.15 to 0.35 m, respectively, while their swimming speeds ranged from 0.4 to 2.6 m/sec, increasing around sunset and declining into the night. These results imply that seals mainly invade the set net from evening to nighttime to predate on salmon.

Keywords Kuril harbor seal・fishery damage・set net・behavior・acoustic camera

Introduction

Conflicts between fisheries and seals in terms of both bycatch and fishery damage have been reported recently (Lunneryd et al. 2003; Jounela et al. 2006; Lundström et al. 2010; Hale et al. 2011; Cronin et al. 2014; Holma et al. 2014) and are becoming more frequent due to an increase in seal populations as a result of conservation management and a resulting decrease in fish populations as a fisheries resource. However, strategies for managing seals have not yet been established (Butler et al. 2011).

Seals have become a serious problem in Hokkaido, northern Japan, particularly along the northeast Pacific coast where they are the top predator in the marine ecosystem. Several seal species occur in this area, but only the Kuril harbor seal *Phoca vitulina stejnegeri* has a number of haul out sites from the Nemuro Peninsula to Cape Erimo (Niizuma et al. 1980; Fig. 1) which is considered to be its largest habitat. The population of this species in the Erimo area has recently recovered at least to 600 individuals (Kobayashi et al. 2014) following conservation efforts in response to its decline to 150 individuals in the 1970s due to excessive hunting and habitat destruction. Damage to the coastal fishery by the Kuril harbor seal was confirmed in the 1980s (Itoo and Wada 1983) and has increased markedly following the recent recovery of its population. In particular, this species is frequently caught as bycatch and causes remarkable fishery damage around Cape Erimo, as its haul out sites are located near the set net fishery that targets chum salmon *Oncorhynchus keta* in this region. This has inevitably led to fishermen suffering economic damage, as the commercial value of a large amount of fish (sometimes up to several tons in one haul) has been reduced due to the feeding damage caused by seals invading the net. For example, in 2014, economic damage to the salmon set net fishery in the Erimo area reached approximately 63,000,000 yen (Ministry of the Environment in Japan 2016).

Seal-induced damage to passive fishing gear such as gillnets (Königson et al. 2007, 2009; Cosgrove et al. 2015) and trap nets (Königson et al. 2013) has also been reported frequently in Europe over the last decade. Two main countermeasures can be used to reduce fishery damage and prevent seal bycatch: preventing seals from accessing the fishing gear (Jacobs and Terhune 2002; Fjälling et al. 2006) and improving the fishing gear (Lunneryd et al. 2003; Lehtonen and Suuronen 2004; Suuronen et al. 2006). In the case of trap fishing gear, the most effective approach seems to be improving the fishing gear to control the invasion of seals, e.g., by installing a wire grid over the entrance of the bag net of a trap net (Lehtonen and Suuronen, 2004; Suuronen et al. 2006). Such a device may also be effective in the salmon set net fishery around Cape Erimo, where seals cause severe damage to fish in the bag net. However, the salmon set net in this area is very large, with an inlet diameter of the bag net exceeding 2 × 2 m, making it difficult to use a similar approach. In addition, although it has been confirmed that seals increase the damage to fish in the set net, little is known about how and when they invade the set net and their behavior once inside.

This study aimed to clarify the behavior of seals after invading the set net and its relationship to appearance of salmon using an underwater optical camera and acoustic camera to help inform the development of modified fishing gear. Optical camera can be used to evaluate the number of seals and when they appear but require a known-sized object near the target to measure size as well as artificial lights under light-limited conditions, which may affect the behaviors of both the seals and fish. A Dual-Frequency Identification Sonar (DIDSON) system has recently been developed that uses sound pulses to give near-video-quality images even in dark or turbid water where optical systems fail, and can also evaluate the size and distance of the objects (Boswell et al. 2008; Burwen et al. 2010, Ochi and Yamasaki, 2018). Therefore, we considered that using a combination of optical and acoustic systems would be the best approach for observing seals and fish inside the set net.

Materials and methods

Survey area

Observations were conducted at the second nearest set-net system from Cape Erimo in Hokkaido, northern Japan (Fig. 1) on August 21–22 and 24–25, 2014, immediately before the beginning of fishing season (September to November) with the permission of Hokkaido Prefecture. Several set-net chains are placed along the 30-m isobath during the salmon fishing season (September–November) around the cape. One of these chains has two set nets that are arranged side by side in a long row from the inshore to offshore area. Each set net is bilaterally symmetrical and has a long lead net, body net, middle bag net, and bag net on each side (Fig. 2). The shoreside net in Fig. 1 that was employed in this study was 269 m long and had a bag net that was 30 m long × 12 m wide × 12 m deep. The upper side of the body net and middle bag net is opened, but that of bag net is closed with a ceiling net. Fish are led into the bag net and only this is then hauled onto the boat twice per day in the early morning and afternoon.

Underwater optical camera

An underwater optical camera (TrawlCamera LowLux Camera +1 LED; JT Electric Ltd.) was used for daytime observation of the behavior of the seals and salmon. The light-emitting diode (LED) lamp that was equipped on the camera was turned off to prevent it from disturbing the behavior of the animals. The camera was installed toward the entrance of the bag net from the top of the end line of the funnel net (Fig. 3) at the afternoon hauling and retrieved at the morning hauling. The recording format was set to mpeg 4 (1080 pixels, 30 frames per second [fps]) and the maximum recording time was about 20 hours. Since the observation on August 21–22 was targeted at the morning, the start time of recording was set at 17:00 with timer. In the observation on August 24-25 targeted at the afternoon, the recording was started at 12:00.

Acoustic camera (DIDSON)

The DIDSON acoustic camera system (Sound Metrics Co.) has two frequency modes: high (1.8 MHz) and low (1.1 MHz). In the high-frequency (HF) mode, the images are sharper but the range is shorter than in the low-frequency (LF) mode. It has also been shown that images obtained in the HF mode can be used to measure the shape and size of an object (Holmes et al. 2006; Burwen et al. 2010). We set the scanning range to 10–20 m in the LF mode and 3–5 m in the HF mode. The recording time for one observation period was about 5 hours (battery duration) centered on sunset (15:30-21:00) with a sampling rate of 2 fps.

The images recorded by the DIDSON are projected in a fan shape, with the detection distance as the radius and centered on the view angle in the horizontal plane. In this study, the DIDSON was tilted at an angle of 90° to photograph a plane that crossed near to the mouth of the funnel at the entrance of the bag net, and was suspended from the wire frame of the set net to sit in the water (Fig. 3). The DIDSON was placed near the sidewall of bag net when using the HF mode since the detection range was shorter. Approximately 3 hours before sunset, the DIDSON was set up from a small boat and recording started immediately after installation. The LF-recorded images were used to count the number of seals observed every 15 minutes, while the HF-recorded images were used to determine the body lengths and widths and the swimming speeds of the seals. These were performed based on the measured distance to the target with DIDSON using ARIScope (Sound Metrics Co.) which is processing software of the acoustic camera. In addition, to reduce errors in measurement, images of individuals showing straight-line move were employed.

Results

Underwater camera observations

The number of salmon that were observed per hour during the daytime based on the recorded images are shown in Fig. 4. Salmon were frequently observed during the daytime but none were observed between around sunset and sunrise probably due to the light conditions being lower than the detection limit of the camera. Only one seal was observed near the camera on a single occasion at 17:45 on August 24. We estimated at least this seal was young (yearling -sub adult) as a reference to neck thickness and the ratio of head size to body length (Niizuma 1986; Kobayashi et al., unpubl. data, 2017), though the precise length was unable to measure from the image because of no objects nearby for comparison.

Behavior of seals observed with the DIDSON

Fig. 5 shows the example image recorded by DIDSON. The projected direction was downward as unexpected in the case of observation with HF mode, because the position of DIDSON was more unstable than the case with LF mode. Therefore, there was a shadow which seems to be the bottom of bag net on the left side in Fig. 5 (b). Seals frequently appeared during the two observation periods that covered 5 hours around sunset. The images recorded in the HF mode were sharp and generally capable of determining the kind of object (i.e., seal or fish), though occasionally there was difficulty in distinguishing between small seals and salmon. By contrast, although the objects recorded in the LF mode were not clear and difficult to identify, it was possible to measure their approximate size and observe their movements (Fig. 5(a)). Thus, we categorized objects that moved quickly and were > 1 m as seals, as this matches the characteristics of this species. We were unable to identify the individuals from only still images recorded using either frequency mode, however.

The number of seals that appeared every 15 minutes during the two observation periods are showed in Fig. 6. We considered the appearance frequency to represent the relative activity of the seals since the same individuals were likely to have been recounted. No seals appeared soon after the start of recording presumably due to caution about the small boat that was used to install the acoustic camera. However, the seals became vigorous from around sunset through to the end of recording (21:00) in the result of LF mode. In the observation with the HF mode, the number of seals was less than that of LF mode and was considered to be not fully reflected the activity of seals due to shorter range.

The body lengths and widths of seals estimated from images recorded in the HF mode ranged from 0.65 to 1.94 m (n = 57, mean ± SD = 1.33 ± 0.27 m) and from 0.17 to 0.40 m (n = 66, mean ± SD = 0.27 ± 0.06 m), respectively. The body lengths of the seals changed every 15 minutes during the observation periods, suggesting that the seals were frequently replaced. The swimming speed ranged from 0.42 to 2.60 m/s (n = 42, interquartile range = 0.64–1.33 m/s) with a mean speed of 1.10 ± 0.56 m/s (median = 0.98 m/s), and was faster around sunset (1 hour before and after sunset) than in any other period (Mann Whitney U-test, $p < 0.029$), when it frequently exceeded 1.5 m/s (Fig. 7).

Discussion

Behavior of seals in the set net

The present study revealed the behavior of seals inside a set net. Both the optical and acoustic cameras detected salmon in the set net during daytime. By contrast, only one seal was detected on one occasion in the daytime by the optical camera, while the acoustic camera frequently observed seals from evening to night. This implies that seals become active and invading set net around this time, though it is necessary to observe other time zones through nighttime to early morning in future. Similar activity times have previously been reported for other seals in the same sub-species, including *P. v. vitulina* in Scotland (Thompson and Miller, 1990) and *P. v. richardii* around the Oregon coast, USA (Wright et al., 2007). An increased swimming speed was also observed around sunset (> 1.5 m/s; Fig. 7), which is similar to the average speed of gray seals *Halichoerus grypus* in captivity when descending toward baits (1.71 m/s; Gallon et al. 2007). Thus it appears that the seals invaded the set net and fed of salmon from around sunset to nighttime. Similarly, Lydersen (1991) reported that ringed seals *Phoca hispida* in Svalbard in the Barents Sea haul out during the daytime and actively submerge for feeding from evening to night. Seals may have several advantages under light-limited condition as it is considered that they can detect prey using their whiskers, which sense the water disturbance generated by their prey (Dehnhardt et al. 1998; Wieskotten et al. 2010). For example, seals have probably learned that no fishermen appear at the set net after sunset and so invading the set net at this time allows them to feed for longer without disturbance. It is also likely that fish can escape from predators more easily in daylight and so feeding under light-limited conditions will reduce their energetic costs.

Our acoustic camera recorded the seals with various body lengths, which were ranged from 0.65

to 1.94 m. However, in the eastern Hokkaido, most of kuril harbor seals caught by salmon set net as bycatch were young individuals (Kobayashi et al. 2005; Haneda et al. 2017). This suggested that some skilled seals could easily enter and leave the salmon set nets. It may be adequate that examining countermeasures against these skilled seals is effective for reducing fish damage in set net fishery. Actually, the management of conflict between people and seals frequently focuses on the selective removal of the so-called ‘problem’ or ‘rogue’ seals (Graham et al. 2011).

Prevention of seal invasion into the bag net

One approach for controlling the invasion of seals into the bag net is the installation of obstructions at the entrance. Lehtonen and Suuronen (2004) attached a rigid frame with a vertical lattice of steel wire at the trapezoid shaped entrance (height, upper, and lower base = 1.2 m, 1.2 m, and 0.8 m, respectively) of the bag net of a salmon trap net. However, this approach would be difficult to apply to the set nets used in the Erimo area because they are much larger (entrance of bag net = 2 × 2 m or more) and the net is often moved by the strong tidal current, which reaches 1 knot at times, causing the entrance of the set net to deform. Therefore, use of a grid that is constructed from soft materials that can match any changes in shape to the entrance would be more suitable in the Erimo area. Furthermore, considering the maximum swimming speed of seal in the set net (2.60 m/s), it is necessary to use strong materials like a Dyneema having same strength as steel wire so that cannot be broken by their rushing.

The addition of a grid to the entrance of the bag net will not only minimize the invasion of seals but may also disturb the migration of fish into the net. Based on the observed body width (0.17 to 0.40 m) obtained from the DIDSON images, a grid size of 15 × 15 cm would control the invasion of seals, as few had a body width of < 15 cm even among the pups. Suuronen et al. (2006) previously suggested that a grid of < 15 cm could control the pups of gray seal, but they also stated that the catch efficiency would decrease remarkably when using such narrow spacing. The chum salmon that are caught by the set net fishery in the study region would be able to physically pass through a grid with 15-cm spacing as their fork lengths range from 50 to 90 cm and their weights range from 1.0 to 7.0 kg. It has been shown, however, that a passing rate of 100% will not be achieved even if the fish can physically pass through the mesh because they will become cautious of the net, as shown in an experiment using juvenile chum salmon (Fujimori et al. 2000). Therefore, it will be necessary to examine which size and material of grid is most appropriate for attaching to the set net in this region by using a comparative experiment at sea or a tank experiment. In addition, the color of the grid should be low contrast to the color of the ocean in the area, as is the case with gillnets (Wardle et al. 1991), to further reduce the visibility and thus avoidance of the grid by salmon.

Our study demonstrated that seals mainly invade the set net in the Erimo area from evening to night. Thus, it would be reasonable to attach grids to the bag net at the afternoon hauling and detach them at the early morning hauling since salmon will find it difficult to see the grid at night, reducing any avoidance behavior. The exact specification of the grid and the effect of the grid in the field remains to be determined, and so we intend to conduct further experiments in the near future to examine the use of grids to control the invasion of set nets by seals.

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Figure captions

Fig. 1. Location of the salmon set net employed in this study and the haul out site of the Kurill harbour seal (*Phoca vitulina stejnegeri*) in Cape Erimo, Hokkaido, Japan.

Fig. 2. Diagram of the salmon set net that was employed in this study. Observations were made of the bag net on the south side.

Fig. 3. Positions of the underwater camera (TrawlCamera) and the Dual-Frequency Identification Sonar (DIDSON). The DIDSON was tilted at 90° and suspended from the wire frame of the bag net when LF mode observation and fixed near the side wall of bag net when HF mode observation.

Fig. 4. Number of salmon observed each hour with the underwater camera. No image could be obtained when there was low illuminance. SOR and EOR means start and end of recording, respectively.

Fig. 5. Example images of a seal swimming into the bag net at night captured with the Dual-Frequency Identification Sonar (DIDSON) in (a) LF: low-frequency mode and (b) HF: high-frequency mode. Each number along the side of sector shows the distance in meter.

Fig. 6. Number of seals detected inside the bag net every 15 minutes using the Dual-Frequency Identification Sonar (DIDSON) in (a) LF: low-frequency mode and (b) HF: high-frequency mode.

Fig. 7. Swimming speeds of the seals as measured by the Dual-Frequency Identification Sonar (DIDSON) with HF mode. Circles represent the measured values every 15 minutes and short bars represent the mean values. The boxplot on the right summarizes all of the data.

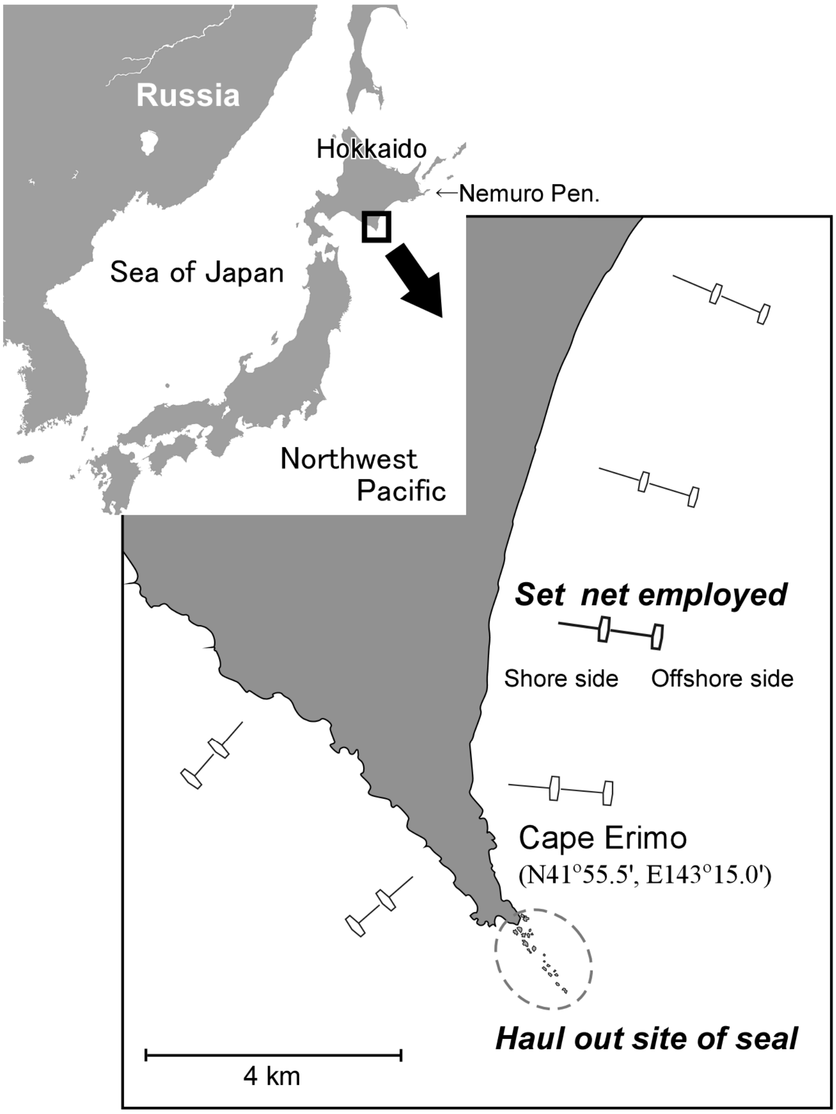
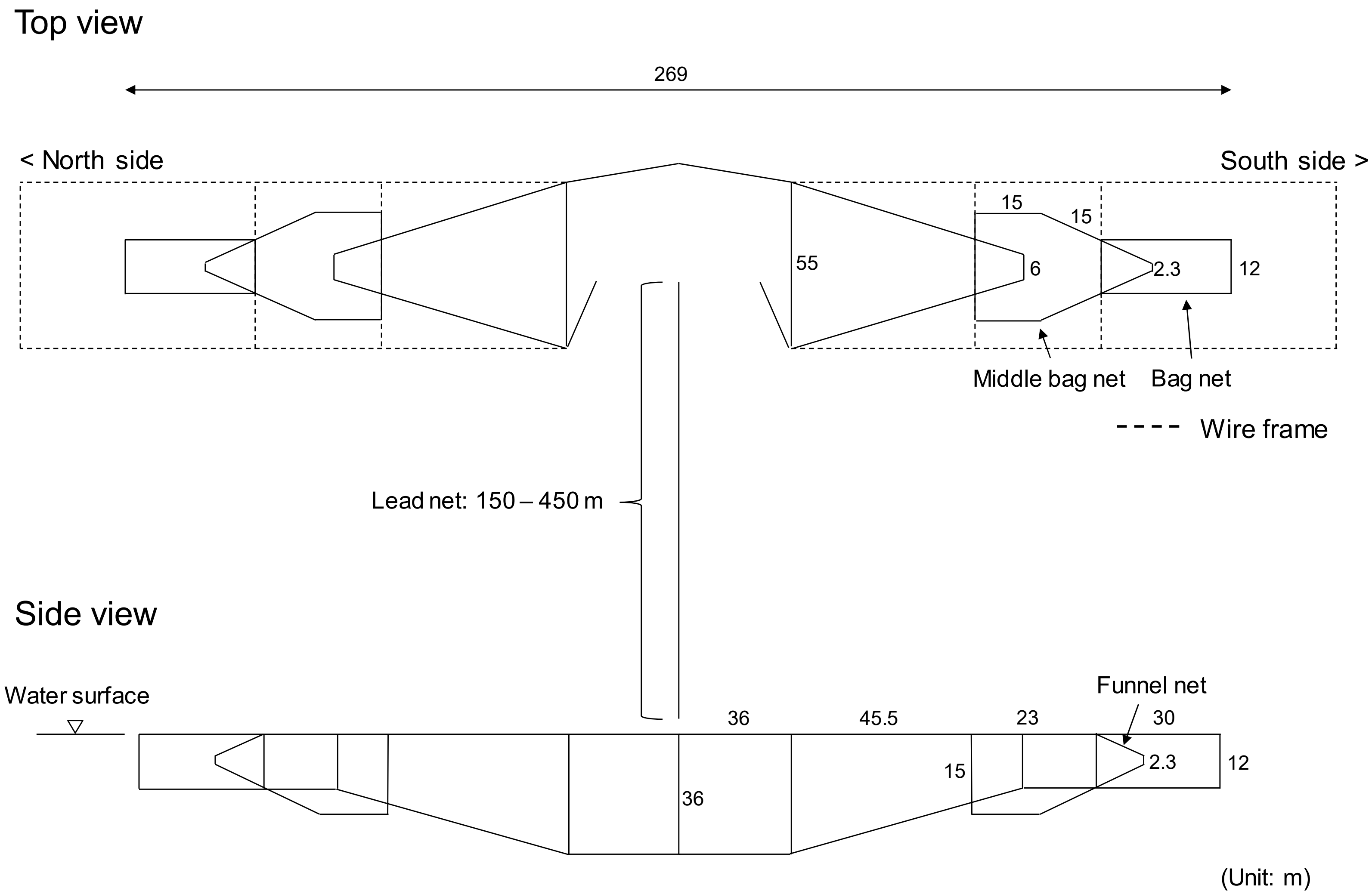
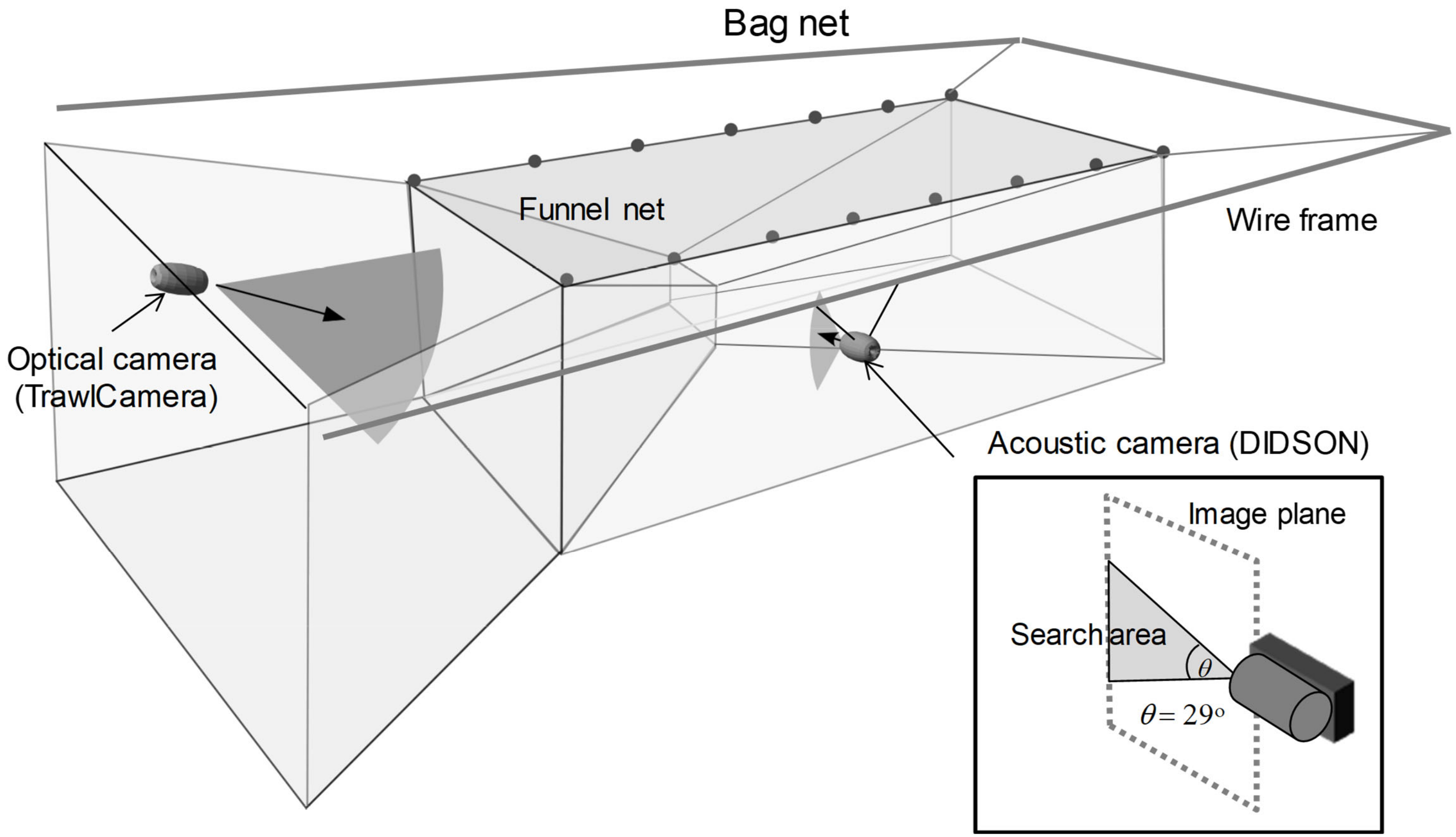

Russia
Hokkaido
←Nemuro Pen.
Sea of Japan
Northwest
Pacific
Set net employed
Shore side
Offshore side
Cape Erimo
(N41°55.5', E143°15.0')
Haul out site of seal
4 km

Figure 1



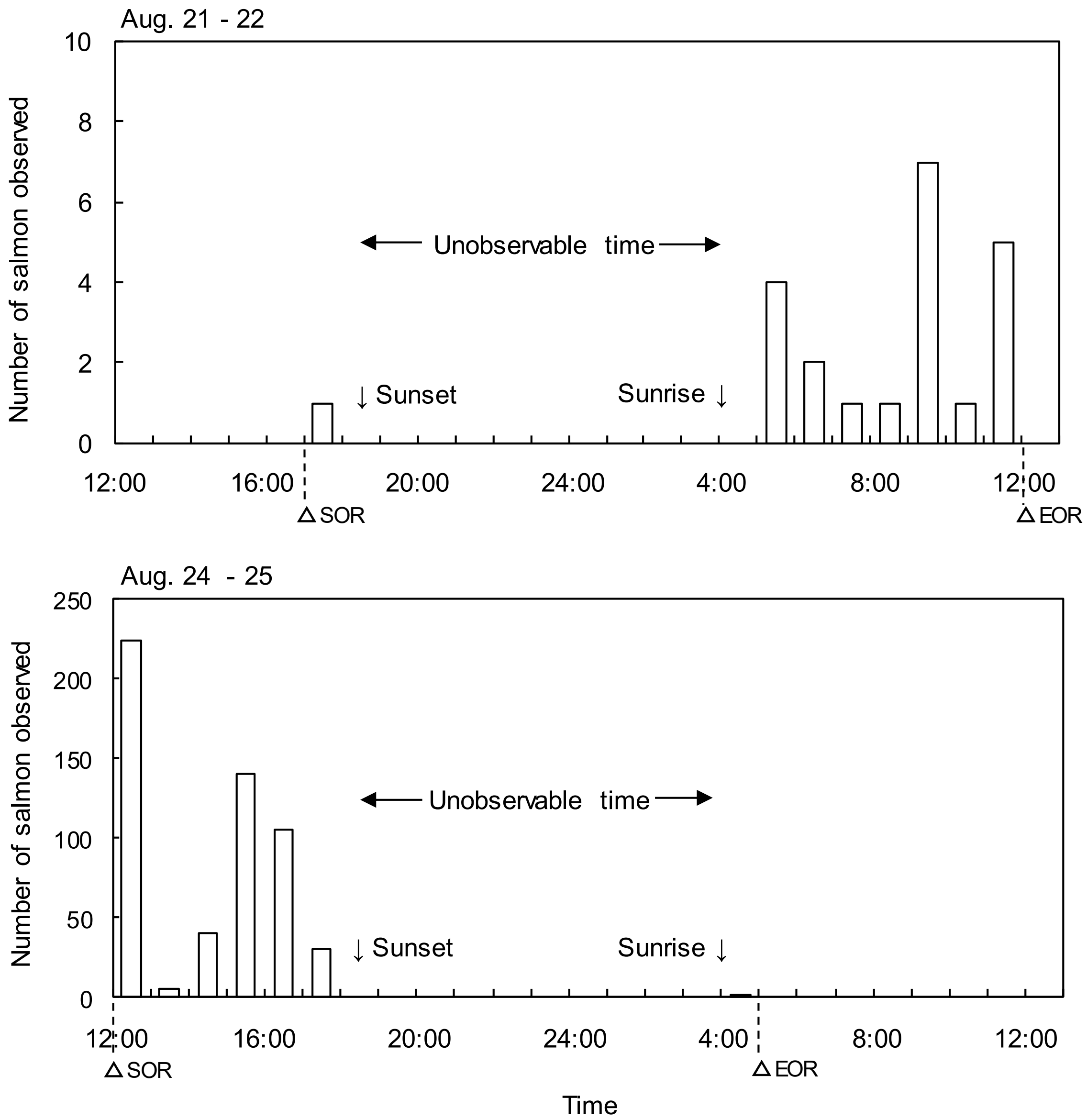
Top view
269
< North side
South side >
15
15
55
6
2.3
12
Middle bag net
Bag net
Wire frame
Lead net: 150 – 450 m
Side view
Water surface
Funnel net
36
45.5
23
30
15
2.3
12
36
(Unit: m)

Figure 2



Bag net
Funnel net
Wire frame
Optical camera
(TrawlCamera)
Acoustic camera (DIDSON)
Image plane
Search area
θ
θ= 29o

Figure 3



Aug. 21 - 22
Number of salmon observed
Unobservable time
↓ Sunset
Sunrise ↓
12:00
16:00
20:00
24:00
4:00
8:00
12:00
SOR
EOR
Aug. 24 - 25
Number of salmon observed
Unobservable time
↓ Sunset
Sunrise ↓
SOR
EOR
Time

Figure 4

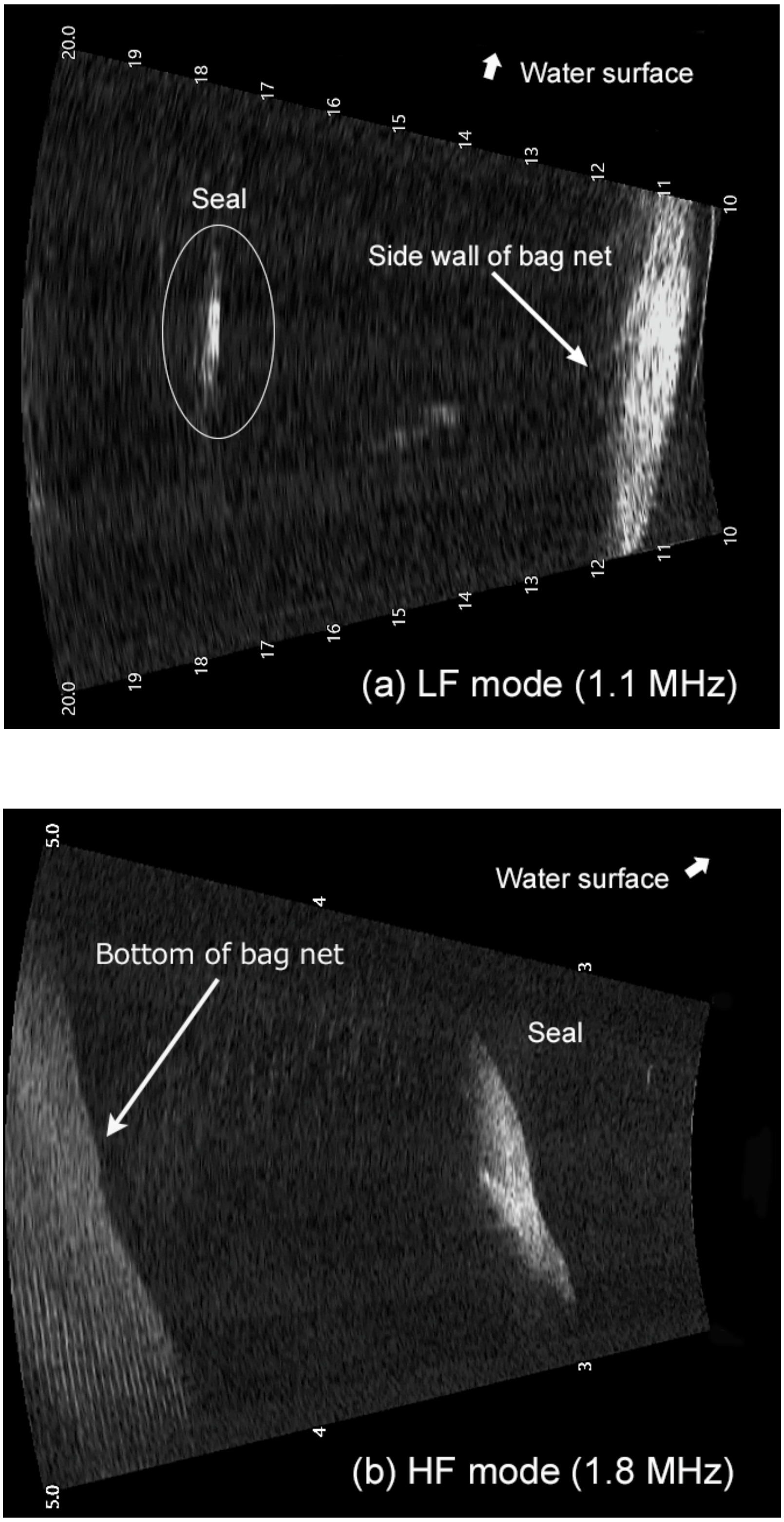

Water surface
Seal
Side wall of bag net
(a) LF mode (1.1 MHz)
Water surface
Bottom of bag net
Seal
(b) HF mode (1.8 MHz)

Figure 5(a), (b)

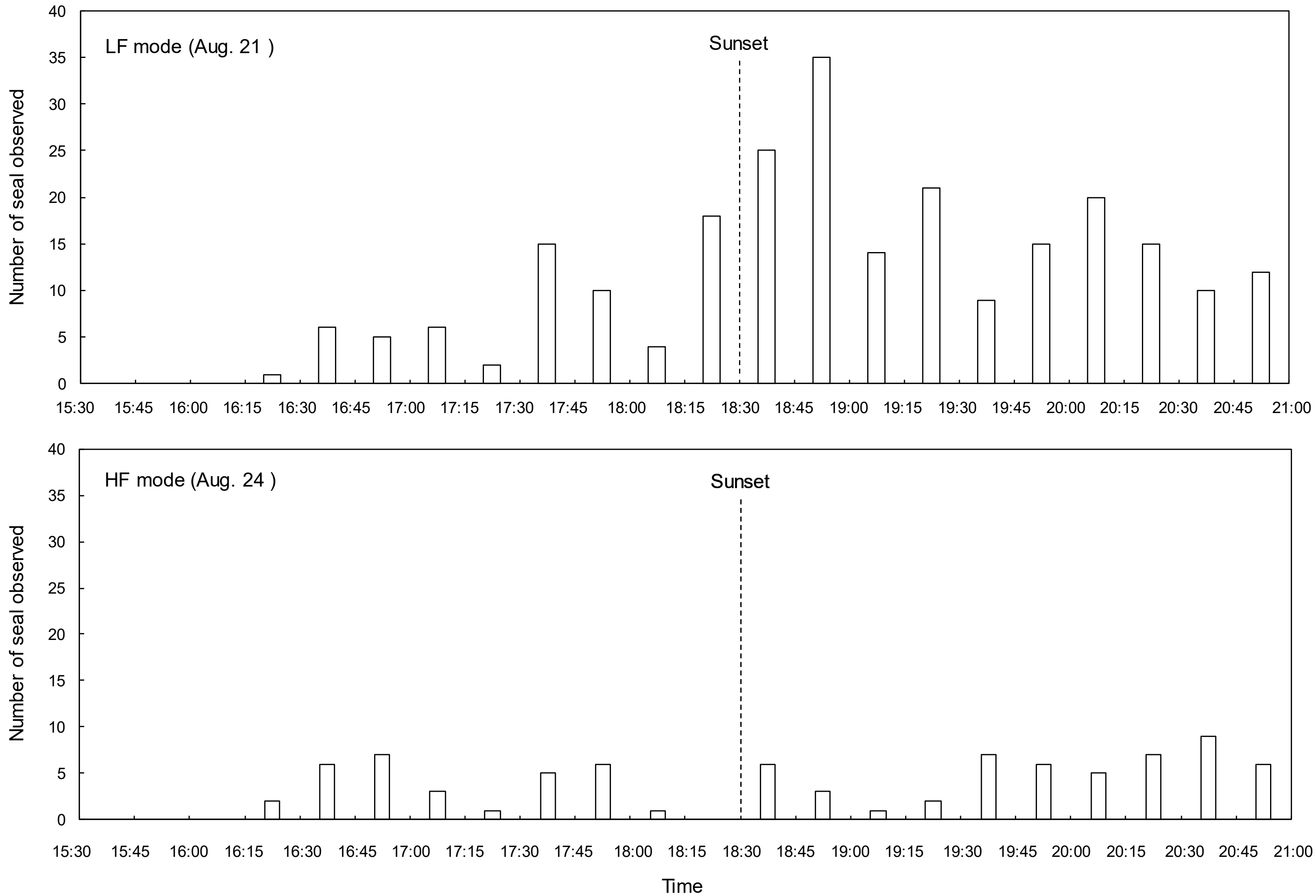

LF mode (Aug. 21)
Sunset
Number of seal observed
40
35
30
25
20
15
10
5
0
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
17:45
18:00
18:15
18:30
18:45
19:00
19:15
19:30
19:45
20:00
20:15
20:30
20:45
21:00
HF mode (Aug. 24)
Sunset
Number of seal observed
Time

Figure 6

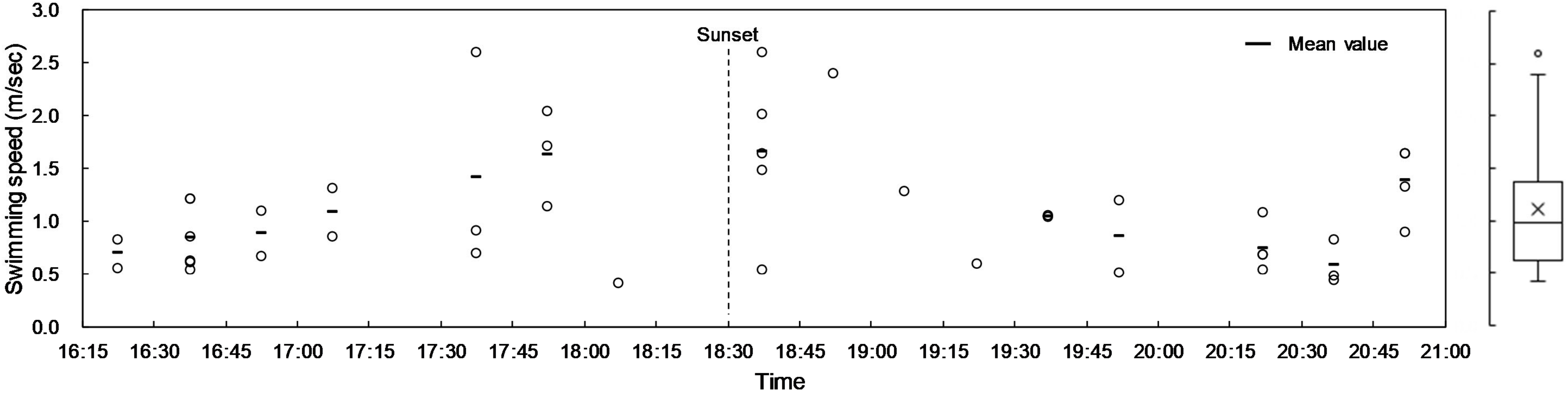

Sunset
Mean value
Swimming speed (m/sec)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
16:15
16:30
16:45
17:00
17:15
17:30
17:45
18:00
18:15
18:30
18:45
19:00
19:15
19:30
19:45
20:00
20:15
20:30
20:45
21:00
Time

Figure 7