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Original Research Article

Occurrence of the Kuril Harbour Seal (*Phoca vitulina*) at a small fixed fishing net in Akkeshi Bay, Hokkaido, Japan

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Humans frequently come into conflict with marine mammals that compete for the same resources, such as seals exploiting the same areas as industrial fisheries. To develop efficient interventions to minimize the negative impact of seals on fisheries, it is essential to understand the behaviour of seals in the fishery area, such as where and when they occur. The present study characterizes an instance of human–seal conflict, using acoustic telemetry to examine patterns in the occurrence of three Kuril harbour seals (*Phoca vitulina*) around a small fixed set-net in Akkeshi Bay, eastern Hokkaido, Japan, in late spring in 2009. To examine the environmental variables affecting the occurrence of Kuril seals around the net, 3 Kuril seals were captured and tracked using an acoustic monitoring system. Two of the tracked individuals (a male and a female) usually came to the net in the evening, and at high tide, but the seals were never present at times when fishing occurred (04:00–07:00 h), which indicates that they actively avoided human activity in the coastal fishery. Seals did not appear in the net after the fishery season (April), a behavioural characteristic that suggests that these seals were adults that used a nearby haul-out site during the breeding season (May–June). A third individual, an adult male, never occurred near the net. These observations demonstrate the extent to which individual seals vary in their interactions with human activities. Given the current selective removal of seals in the fishery area by controlled killing or driving away, these findings have the potential to inform targeted management intervention to minimize conflict between economic and conservation interests.

Key words: human-seal conflicts, harbour seals, small set-net, Akkeshi Bay -Japan, acoustic telemetry system

INTRODUCTION

The production of seafood for human consumption has led to long-running and widespread conflicts with many wild marine mammals around the world. One type of global human–marine mammal conflict that has recently increased in intensity is that between coastal fisheries and seals, which damage both the catch and the fishing gear (*e.g.*, northern Sweden; Lunneryd et al., 2003). In Japan, the Kuril harbour seal (*Phoca vitulina*, henceforth "Kuril seal") is resident in eastern Hokkaido all year round. Itoo and Shukunobe (1986) estimated that during the 1940s, the population of Kuril harbour seals that lived along the southeastern coast of Hokkaido was 1500–4800, based on the observations of Inukai (1942a,b). The population was estimated at only a few hundred in 1970s (*e.g.*, Hayama 1988), and the causes of that decline may have been commercial harvesting of the seals and human activities including coastal fisheries (*e.g.*, Itoo and Wada 1982). In particular, the annual hunt was estimated to be at least 250–300 individual seals (Itoo and Syukunobe 1986). Moreover, bycatch from salmon set-net fisheries has also been reported (*e.g.*, Wada et al., 1991). The commercial harvest ended in the late 1980s, and the harbour seal population has thus been increasing for

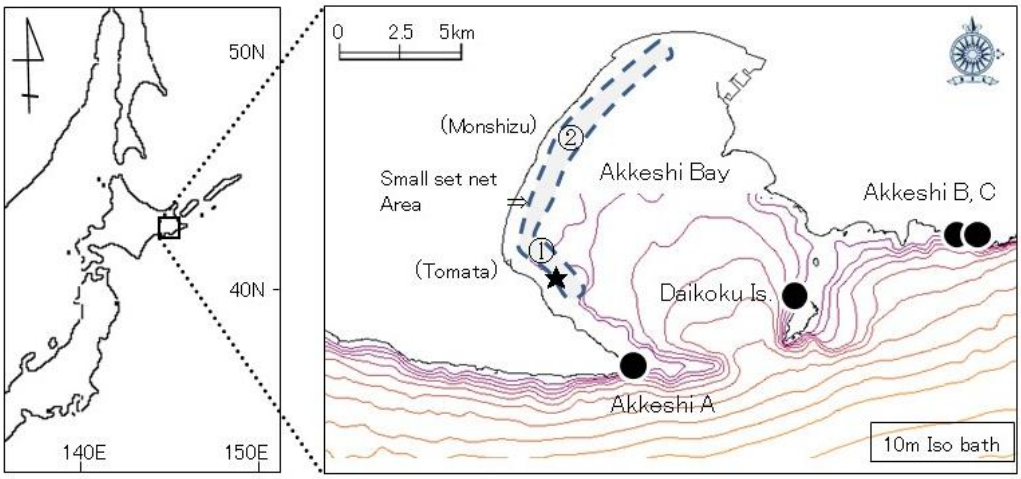

Figure 1: The study area: Akkeshi Bay, eastern Hokkaido, Japan, showing 10 m isobath diagram.●: Kuril seal haul-out sites; ①② seal trapping location, ★: receiver position

almost 30 years (Kobayashi et al., 2014). The second-largest Kuril seal haul-out site in Japan is on Daikoku Island in the Akkeshi area of Hokkaido, where recent observations have identified over 300 seals. In concert with this increasing population, in the 1980s, Itoo and Wada (1982) reported damage caused by seals in this area to fish caught in salmon set-nets and gillnets during the autumn. More recently, damage to fish has also been reported from gill nets and small fixed nets during the spring (March-May) in Akkeshi Bay (Kobayashi et al., 2010).

To develop efficient interventions to reduce the interactions between seals and fisheries, it is essential to understand the behaviour of seals in the fishery area, such as where and when they occur. Direct observation of seal behaviour is not straightforward, with the observation of nocturnal activity at sea being a particular challenge, but biologging methods can be used effectively to overcome these constraints.

In the present study, we use acoustic telemetry to track and characterize the behavioural patterns of Kuril seals in the fishery area in Akkeshi Bay.

MATERIALS AND METHODS

Study area

This study was conducted in the spring (April-June) of 2009 in the Akkeshi area, eastern Hokkaido, Japan (Figure 1). The town of Akkeshi has a population of about 11,000, of which approximately 1,500 people over the age of 15 years were employed in the fishing industry as of 2010 (Akkeshi town 2015). Akkeshi Bay supports many coastal fisheries, including spring/autumn salmon set-nets, small fixed nets and dragnets, as well as production of other marine resources such as Kombu seaweed and shellfish. Usually, a small fixed net can catch several tens of fish species, but only several dominant fish species (Sweke et al., 2006), and damage to seals can also occur. The fishes caught in this area include sailfin sandfish (*Arctoscopus japonicus*), righteye flounder (Pleuronectidae)Pacific herring (*Clupea pallasii*), icefish (*Salangichthys microdon*), saffron cod (*Eleginus gracilis*) and fluvial sculpin (family Cottidae) (Kobayashi et al., 2013). The spring small set-net used in the present study is generally worked by fishermen once a day, around 04:00–07:00 h, except on Sundays and public holidays. In 2009, the fishing season for small set-nets in Akkeshi Bay was March 21st–May 15th (56 days in total).

Four Kuril seal haul-out sites exist in the Akkeshi area: Daikoku Island and Akkeshi A, B, and C (Figure 1). Daikoku Island is an uninhabited island, with a coastline of 6 km, located near the mouth of Akkeshi Bay. This is the second-largest haul-out site (>300) in Hokkaido, Japan.

Acoustic telemetry monitoring system

Kuril seal behaviour was tracked using an acoustic monitoring system. The transmitter was a V16P-5H unit (VEMCO Ltd., Halifax, Canada), and the receiver a VR2W unit (VEMCO Ltd, Halifax, Canada). During a scan, the receiver listened regularly on each frequency for pinger pulses (69 kHz), and the time interval between detected pulses was recorded (Voegeli et al., 1998).

The transmitter used in this study measured 105×15×15 mm and weighed 52.0 g. Pinger pulses had a frequency of one every 10–30 s (mean 20 s), giving a battery lifespan of approximately 178 days. The receiver had a battery life of approximately 15 months and an average coverage of 300 m.

The receiver was installed at a small set-net for icefish (*Salangichthys microdon*) (net no. 44 in the Tomata area, Akkeshi bay; N43°02' 03", E144°45' 34") (Figure 1)

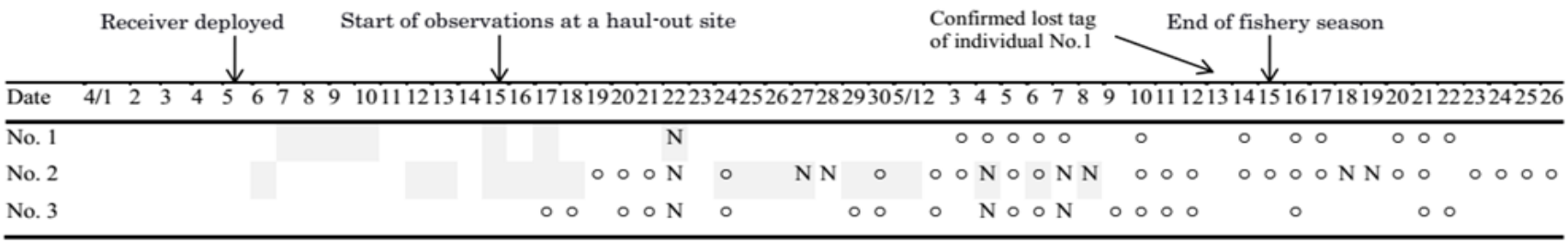

Figure 2: Overview of seal behaviour around the set-net and at the haul-out site on Daikoku Island. Black columns show occurrence at the net (acoustic telemetry records), ○ shows when seals were observed at Daikoku Island, and N denotes days when the haul-out site was not surveyed because of poor weather (e.g., mist). Individual no. 3 was never recorded by the receiver.

approximately 120 m from land at a depth of approximately 2 m. The receiver was installed on April 5th 2009, between 16:00 and 18:00, and collected data until 11:30 on April 28th. It was then reset and run uninterrupted until the end of the fishing net set for this net (26th May 2009).

Seal tagging and observation

Kuril seals were caught at two locations in Akkeshi Bay (Figure 1) in early April 2009 using box or bag traps (Kobayashi et al., 2011). The age class of each seal was estimated based on observable characteristics, following Niizuma (1986). Seals were then anesthetized, measured, and tagged with neoprene on the head and with a plastic tag on the rear flipper (Fujii et al., 2005). A radio transmitter was attached to each seal's neck using glue (Loctite 401). In total, 3 seals (2 males, 1 female) were captured and tagged (Appendix 1). This study was conducted in accordance with institutional, national, and international guidelines concerning the use of animals in research and the sampling of endangered species (Hokkaido University Rules and Regulations 2007; The Mammal Society of Japan 2009).

Tagged seals were observed at a haul-out site at Daikoku Island. The haul-out site was surveyed hourly for tagged individuals every day between 05:00 and 16:00 h, except in bad weather. All study individuals were observed on Daikoku Island until at least June (Figure 2), indicating that the study did not substantially affect the seals' behaviour and fitness.

Environmental variable

Hourly tidal data (cm) were obtained for the nearest marine recording site, Kushiro town (N42°59′ E144°22′), from the Japan Meteorological Agency (2011). Hourly mean wind speed (m/s) was obtained from the nearest terrestrial recording site, Akkeshi Chipomanai (N42°56′ 3″ E144°44′ 1″), and also from the Japan Meteorological Agency (2011).

Statistical analysis

Seals were defined as staying away from the net (outside the receiver area) when the receiver did not record a pulse for longer than three times the pulse frequency, e.g., for the lowest pinger frequency in this study (once every 30 s). Pulses would have to be received at least every 90 s for a seal to be classed as being inside the receiver area. The time that each seal stayed at the net ("stay time") was calculated as the time between the first and last pulses in each set of continuous pulse records meeting this criterion. The mean swimming speed of seals has been reported to be approximately ±2 m/s, with maximum speeds of approximately 3–4 m/s (e.g. Bowen et al., 2002). Therefore, it was assumed in this study that seals would take 1–5 min to pass through the coverage range of the receiver (300 m). Differences in hourly stay time among seals were evaluated using an appropriate non-parametric alternative: Wilcoxon signed-rank test and Kolmogorov–Smirnov (KS) test.

To examine the environmental variables affecting the occurrence of Kuril seals around the net, we fitted a Poisson distribution generalized linear mixed model (GLM) with a logit link function. All variables were used at a one-hour resolution; the dependent variable was the number of readings registered by the receiver on the hour at each hour of measurement and the explanatory variables were day, each hour time, and environmental variables the magnitude of each environmental variable on the hour at each hour of measurement.

The full model was:

Number of readings registered by the receiver at each hour of measurement = day + time

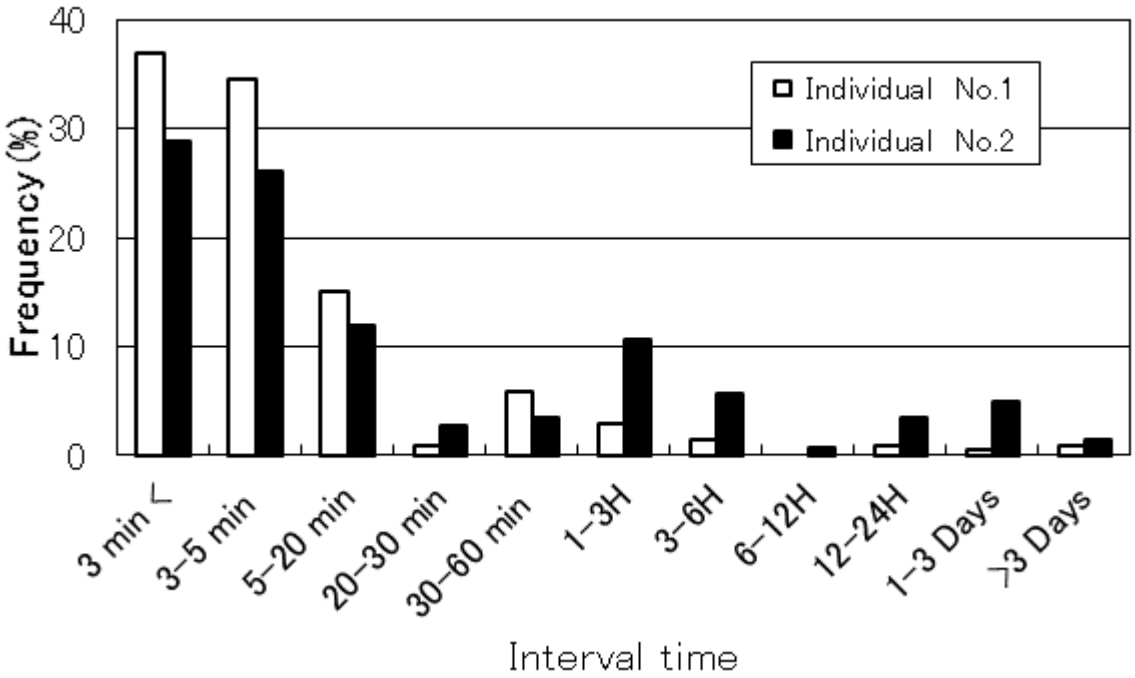

Figure 3: The time interval between each seal's occurrences at the net, presented as a percentage of total records.

(every 60th minute) + tide (cm) + mean wind speed (m/s) + interactions between these variables.The importance of each factor was evaluated by selecting the most parsimonious model based on Akaike's Information Criterion (AIC). All statistical analyses were performed using R, version 3.2.3 (R Development Core Team, 2015).

RESULTS AND DISCUSSION

Seal occurrence around the net

In total, 1,368 pulses were received from individual no. 1 (adult female) over 7 days (April 7th–22nd), and pulses from individual no. 2 (adult male) were detected 870 times over 17 days (April 6th–May 8th). No pulses were recorded from individual no. 3 (adult male), and no records were received from any seal after the fishing season ended (May 15th) (Figure 2). Individuals no. 1 and no. 2 were never recorded at the net at the same time. These two individuals occurred on 28.0% (7 occurrence days/25 days of receiver activity) and 52.0% (13/25 days) of recording days in April, respectively, and on 0.0% (0/26 days) and 15.4% (4/26 days) in May. The total duration of occurrence near the net was 607.2 min (mean stay time per day 86.5 ± 77.4 min) for individual no. 1 and 343.2 min (mean stay time per day 20.1 ± 43.5 min) for individual no. 2, with individual no. 1 having a significantly longer total recording duration (Wilcoxon signed-rank test, $p < 0.05$). Stay time per visit, however, did not vary between these seals (no. 1: 4.3 ± 0.7 min, N = 142 visits; no. 2: 4.2 ±0.7 min, N = 81 visits; KS test, $p > 0.05$). There was no daily variation in stay time for either seal (KS test, $p > 0.05$). The interval between occurrences of the seals around the net was mostly 5 min or less, but occasionally over 3 days passed between occurrences (Figure 3).

In general, foraging habitat selection by harbour seals depends on small-scale habitat differences, but habitat use also differs between individual seals (Tollit et al., 1998).

Individual no. 1 was not recorded after late April, but was only observed at a haul-out site. Although this female seal lost her tag halfway through the study period, it is notable that she showed signs of pregnancy when she was initially caught. In the pre-breeding period, adult female harbour seals make regular trips between the haul-out site and foraging areas, but around the time of breeding, these trips stop as females spend much longer at the haul-out sites (Thompson et al.,1994).

Moreover, haul-out patterns vary between geographical areas and seasons, probably in accordance with regional and seasonal dietary variation as well as differing demands across different phases of the seals' life cycle (Niizuma 1986). Although female no. 1 was only recorded in the fishery area during early April, she spent more time there than individual no. 2.

No records were obtained from individual no. 3, an adult male caught in a different area (Monshizu; individuals no. 1

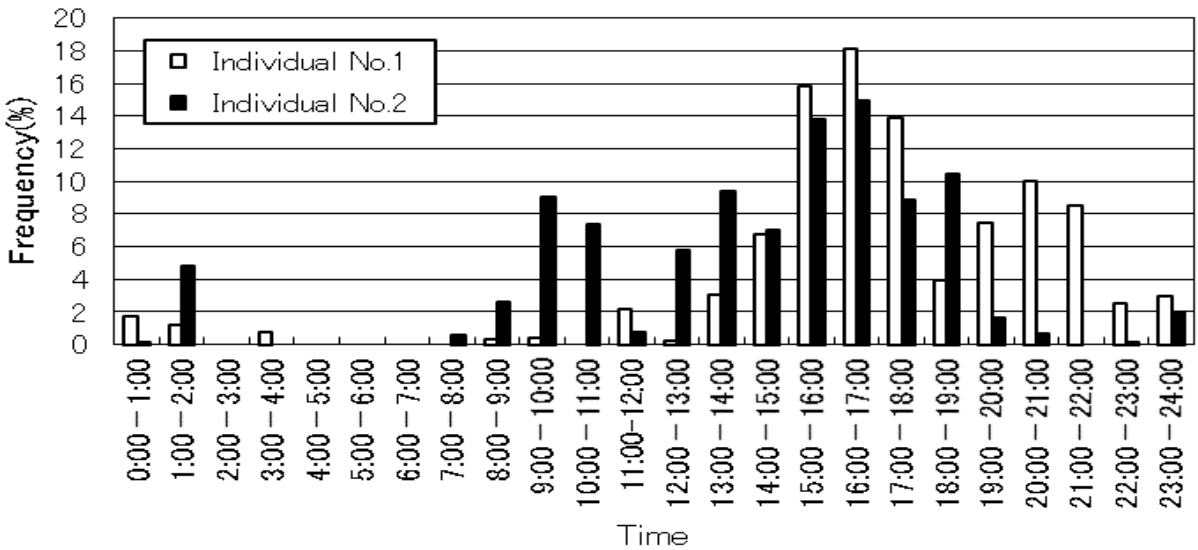

Figure 4. The time of each seal's occurrence at the net, presented as a percentage of total records

Table 1. Results for the generalized linear mixed model (GLM) explaining the occurrence of seals at the net in relation to fishery catch area and environmental variables.

	Estimate	Std. Error	Z value	Pr (> |Z|)
(Intercept)	-2.150e+06	2.115e+05	-10.165	< 2e-16 ***
Date	1.070e-01	1.053e-02	10.165	< 2e-16 ***
Time	8.246e+04	9.593e+03	8.595	< 2e-16 ***
Tide	1.283e+04	1.242e+03	10.330	< 2e-16 ***
Wind	2.248e-01	3.874e-02	5.802	6.55e-09***
Tide×Wind	-2.224e-03	4.488e-04	-4.955	7.25e-07***
Date×Time	-4.104e-03	4.757e-04	-8.595	< 2e-16 ***
Date×Tide	-6.835e-04	6.181e-05	-10.330	< 2e-16 ***

and no. 2 were caught in the Tomata area, near where the receiver was deployed). Collectively, this suggests that individual no. 3 was either not feeding around the Tomata fishery area or feeding in a different area. Harbour seals have a lek-like terrestrial mating system, and from the pre-breeding season to the mating season, intense male-male competition has been reported (Hayes et al., 2004), which demands that much be spent at the haul-out site (Niizuma 1986). To further elucidate these various explanations of seal behaviour, a challenge for future studies is to simultaneously deploy many receivers in this area.

Environmental variables affecting occurrence around the net

The best-fit model describing the occurrence time of seals around the net showed that most records were received at high tide levels and during the evening and night (Table 1; Figure 4). Throughout the tracking period, records were never received between 04:00 and 07:00 h, which is the time of highest activity in the fishery, suggesting that the seals avoided human activity. However, there was no relationship between seal activity and breaks in fishery activity resulting holidays. Some fishermen use the fishery area to repair their nets during holidays; therefore, the holidays might have not actually affected seal behaviour near the nets.

The times at which the two recorded seals occurred most frequently at the net differed (KS test, $p < 0.001$), but seals occurred in the evening at 16:00–18:00. Seals show a strong preference to haul out at low tide, and a diel rhythm in haul-out behaviour has been described during months with day–night cycling and midnight sun (Niizuma 1986). Previous work has reported a preferential haul-out period of 03:00–08:59, with the night period (21:00–03:00) spent at sea (Frost et al., 2001).

Another explanation for when and how often seals occur around set-nets might ultimately involve prey availability or feeding behaviour, as wind speeds had an effect in the model (Table 1).

A study of human–seal conflict in Scotland has shown that only a small number of individuals appeared to be using

rivers and thus interfering with fisheries, which allows conflict management to focus on the selective removal of so-called 'problem' or 'rogue' animals (Graham et al., 2011). In this study, tracked individuals (captured near the set-net area) frequently and carefully visited the fishery area. The results of the present study provide further insights into individual seal behaviour around economically important fishing gear, and will thus help to inform effective management of human–seal conflict in this area.

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Conflict of interests

The authors declare that they have no conflicting interests

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Appendix 1. Overview of the sampled Kuril seals

Number	Capture location (lat., long.) / trap type	Capture date	Release date	Sex	Age (yr)	Weight (kg)	Total length (cm)	Body length (cm)	Chest girth (cm)	Note
1	① (N43.00363, E144.44379) / Box trap	4/1/2009	4/1/2009	F	>4	60.0	144.0	128.0	97.0	pregnant
2		4/4/2009	4/4/2009	M	>7	135.0	186.0	166.0	136.0	
3	② (N43.02.251, E144.46737)/ Bag trap	4/6/2009	4/7/2009	M	>7	105.0	170.0	155.5	118.5	