SPECIAL ISSUE (NIFS 2022): SHORT COMMUNICATION
eISSN 2234-1757
Fish Aquat Sci. 2023;26(11):669-677
https://doi.org/10.47853/FAS.2023.e59
FAS Fisheries and Aquatic Sciences

First satellite tracking of a free-ranging spotted seal (*Phoca largha*) from the Baengnyeongdo Island

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Abstract

The spotted seal (*Phoca largha*) in the Yellow Sea has declined due to poaching and habitat destruction. To aid conservation efforts, Argos satellite tracking were used to monitor the movements of a free ranging spotted seal around Baengnyeongdo Island. The satellite-transmitting tag successfully attached to the seal provided 1,556 location data collected during 107 days. The seal mostly moved between two haul-out sites, Yeonbong Rock and Mulbeom Rock. From October 6th to December 12th, the seal stayed within a 7 km radius of Yeonbong Rock. However, as the signal was lost, it was not possible to identify when the seal started to migrate from Baengnyeongdo Island to winter breeding area. This study provide understanding into the habitat preferences and movement patterns of spotted seals around Baengnyeongdo Island, contributing to the conservation and management of this species. Further research with more individuals and different age groups is essential to understand their habitat preference and develop effective conservation measures for the spotted seal population in the Yellow Sea.

Keywords: Satellite tracking, Spotted seal, Distribution pattern, Conservation

Introduction

The spotted seals (*Phoca largha*) were abundant in the Yellow Sea. According to a study conducted in the winter breeding grounds of the spotted seal in the Bohai Sea, China, in the 1940s, approximately 8,000 individuals were inhabit the region (Dong & Shen, 1991; Yan et al., 2018). However, due to poaching and habitat destruction caused by obtaining leather, traditional medicine, and meat within China, the population has recently declined to around 1,500 individuals (Dong & Shen, 1991; Yan et al., 2018). Among the remaining spotted seals, the population on Baengnyeongdo Island has fluctuated around 200–300 individuals annually since the start of the survey in 2006, with a peak of 322 individuals recorded in 2008 (MOF, 2019).

Coastal development activities such as land reclamation, dredging, and construction, along with increasing maritime transportation, have been deteriorating the habitat for marine species (Barbier et al., 2011; Hawkins et al., 2017; Wenger et al., 2017). Moreover, the ongoing global climate change has been causing rapid ecological changes in the population dynamics of

Received: Aug 3, 2023 **Revised:** Oct 25, 2023 **Accepted:** Oct 25, 2023
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various, including the spotted seal species (Anderson et al., 2013; Moore et al., 2008).

With a lifespan of over 40 years and being a top predator in marine ecosystems, the spotted seal, with its wide distribution range and excellent mobility, may appear relatively resilient to ecological disturbances and environmental changes (Boveng et al., 2009). However, due to the slow reproductive rate, with only one offspring being born at a time and a long time taken for the offspring to reach reproductive age, population decline and subsequent recovery become extremely challenging.

In response to these challenges, the Cultural Heritage Administration of Korea designated the spotted seal as natural monument No. 331 in accordance with the Cultural Heritage Protection Act of 1982. The spotted seal was designated as the natural monument not only endangered from the perspective of conserving native species, but it has unique ecological feature of inhabiting underwater as marine mammal (CHA, 2003).

Subsequently, as interest in the value of biological resources and the need for protection increased, the concept of "endangered species" for the conservation of ecosystems and the prevention of species extinction was introduced, and the first legal protection system for endangered species was established by the Ministry of Environment of Korea. The Ministry of Environment designated six species of pinniped recorded in Korean peninsula as endangered species, under the Natural Environment Conservation Act of 1998, thus establishing a legal basis for the conservation of pinnipeds (NIBR, 2018).

Furthermore, the Ministry of Oceans and Fisheries in Korea enacted the Conservation and Management of Marine Ecosystems Act in 2006, designating 46 protected marine species to conserve marine biological diversity. For those species whose population size is deemed insufficient for continued survival or require special measures for protection, such as the spotted seal, the law provides a legal basis for necessary actions, including breeding and restoration. Similar to the Natural Environment Conservation Act, it also includes the six pinniped species known to occur in the country as protected marine species (MOF, 2022).

Thus, the spotted seal is included by all three categories of natural monument, endangered species, and protected marine species in Korea. While the criteria for designating protected species under these three laws may differ, their purpose is the same: to conserve species facing extinction.

The National Institute of Fisheries Science (NIFS), has been conducting surveys to assess the spotted seal habitat and analyze the threats since 2006, focusing on its major habitat on Baengnyeongdo Island. Recently, efforts have been made to strengthen the conservation and management of the endangered spotted seal through genetic information analysis and the acquisition of physiological and ecological data. Efforts towards the conservation of the spotted seal involve practical measures such as rescuing trapped or stranded individuals and successfully releasing them.

Understanding the seasonal movements and habitat preference of spotted seal is crucial for effective conservation management. During their life cycle, spotted seals migrate seasonally, completing their breeding in the Bohai Sea during winter and then starting on a southward migration, spending summers in the Shandong Peninsula and Baengnyeongdo Island before returning to the Bohai Sea in late autumn (Wang, 1986). Although extensive research has been conducted in Chinese waters regarding habitat utilization patterns by using satellite tags (Han et al., 2013), limited information is available from the spotted seal in the summer feeding grounds, such as Baengnyeongdo Island. Even though spotted seals can potentially travel distances exceeding 100 km per day (Trukhin et al., 2021), it remains unknown whether they utilize other areas adjacent to Baengnyeongdo Island or coastal regions for foraging activities. Previous studies focusing on individual identification and occurrence surveys have only been conducted at two haul-out sites, Mulbeom Rock and Yeonbong Rock (Kim et al., 2010; Park et al., 2010) thus lacking information on how the seals utilize other locations near the Island as potential habitats. To address this knowledge gap, this study tried capture of free ranging spotted seals with bio-logging techniques, employing ARGOS satellite-transmitting tags to precisely track the movements of spotted seals. Although previous studies have been conducted on rescued individuals in Korea (An et al., 2014), no studies have yet applied satellite tracking to wild individuals. Therefore, our study aims to capture spotted seals at the haul-out sites in Baengnyeongdo Island, attach satellite-transmitting tag, and perform location tracking, providing valuable insights into their seasonal movements and habitat preference for conservation of the spotted seals.

Materials and Methods

Study site

The study attempted at Mulbeom Rock and Yeonbong Rock, haul-out sites for spotted seals near Baengnyeongdo Island (Fig. 1). Mulbeom Rock is located approximately 700 meters offshore

https://doi.org/10.47853/FAS.2023.e59

from the northeastern part of Baengnyeongdo Island, comprising several rocks surrounding three gently sloping reefs. During high tide, Mulbeom Rock is completely submerged, but during low tide, it provides a suitable haul-out sites for spotted seals.

The existence of prey such as rock fish (*Sebastes schlegelli*) and greenling (*Hexagrammos otakii*) (Park et al., 2018), make it the most preferred habitat for spotted seals in Baengnyeongdo Island. Yeonbong Rock is a rocky islet located approximately 3 kilometers southwest of Baengnyeongdo Island. It consists of numerous large and small rocks used as haul-out sites by spotted seals. Although Yeonbong Rock has a larger area than Mulbeom Rock, it has steeper rocks, providing relatively narrow spaces for spotted seals to stay compared to Mulbeom Rock. Therefore, smaller number of animals are haul out at this area.

Capture and tag attachment

To assess the distribution of spotted seals and to apply satellite tracking study, the Cetacean Research Institute of NIFS conducted surveys in the haul-out sites of Baengnyeongdo Island in 2021 (in April, June, August, and November). The surveys were conducted during low tide, which was expected to have the highest number of seal observations in the site. An outboard vessel (2.99 ton, 115 HP) was used for this study.

Prior to directly counting the seals, drone (Mavic 2, DJI) was employed to initially assess the number of spotted seal individuals, ensuring that they did not react to the drone noise by maintaining an altitude of 30 to 50 meters. Subsequently, the vessel (2.99 ton, 115 HP) approached within approximately 100 meters from the haul-out sites to observe the behavioral cue of resting individuals, using naked eyes or binoculars (Trinovid 10×42BN, Leica, Wetzlar, Germany).

We prepared the satellite-transmitting tag, SPOT-293A (Wildlife Computers, Redmond, WA, USA) designed for tracking horizontal movements of free-ranging pinniped. It has

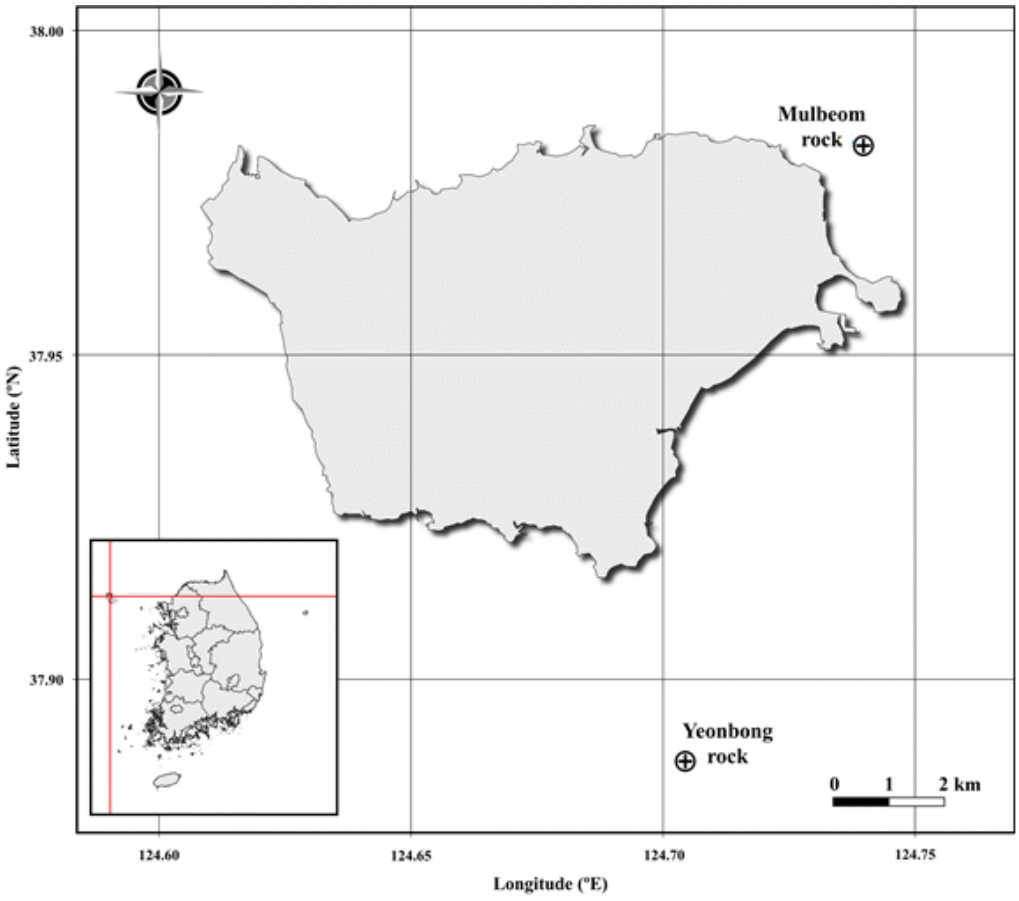

Fig. 1. Map of Baengnyeongdo Island and survey sites, Mulbeom Rock and Yeonbong Rock (cross mark).

dimensions of 71.5 mm in length, 54 mm in width, and 24.1 mm in height, weighing 110 g. Its external surface is epoxy-coated to resist water damage and designed to withstand the animals' movements.

On August 26, 2021, during the third field survey, an attempt was made to capture and attach tag to a seal. Prior to this, the basic settings of the tag to be used in the study were configured using the Tag Agent (Wildlife Computers). The position information was programmed to transmit 250 times per day, with the reference time set to Coordinated Universal Time.

Before approaching around the Mulbeom Rock with the vessel, the location and age of individual seals resting on the rocks were preliminarily determined. Care was taken not to startle the seals into the water, and the vessel circled around the rocks, gradually familiarizing the seals with external irritation like vessel approach and noise. We decided to capture a juvenile seemed approximately two years old, resting on top of the rock. When seals became less nervous, the vessel quickly approached the rock. Three researchers jumped off the vessel immediately, and rushed to the target animal before dive into the water. A stainless hoop net (diameter: 80 cm, mash size: 30 mm) was used to capture a juvenile spotted seal. To attach the tag, an instant adhesive (Loctite 401, Henkel, Düsseldorf, Germany) and epoxy adhesive (VT-146, Vital Technical, Rawang, Malaysia) were applied. The tag was attached to the fur behind the neck of the animal. After waiting for approximately 3 minutes for the adhesive to set, the seal was released on the rock (Fig. 2).

Data processing

The tag provides real-time location information of the tagged individuals through the ARGOS satellite service, which is then made available on the web site. The ARGOS system has been

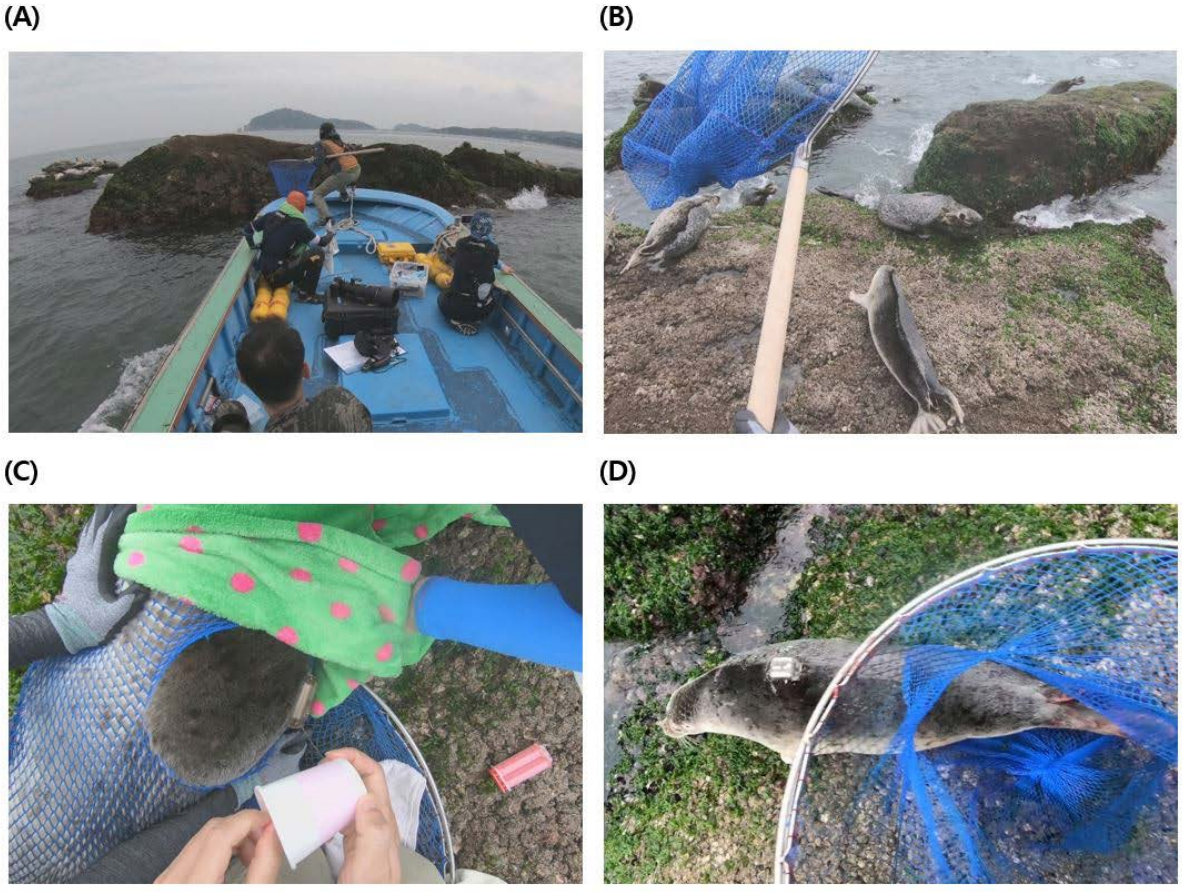

Fig. 2. Tagging of a spotted seal with SPOT-293A satellite-transmitting tag. A: Approach to the Mulbeom Rock for the catch. B: Catch of the seal for satellite tracking. C: Tag attached to the fur behind the neck of the animal. D: Releasing of a tagged animal.

https://doi.org/10.47853/FAS.2023.e59

used in wildlife tracking research since the 1980s and is widely employed in marine mammal studies (Stewart et al., 1989; Vincent et al., 2002). After release, the location information of the released seal was checked daily through the ARGOS homepage (https://argos-system.cls.fr/).

The location data that was pre-filtered by ARGOS (Kalman filter algorithm) was used and additional manual filtering was applied to eliminate the locations detected on the land outside the 100 m zone from the water. The data was plotted using 'Heatmap' plugin in QGIS software (version 3.28.7, QGIS, Zürich, Switzerland) to visualize the distribution pattern of the tagged animal. Kernel density estimation (KDE) algorithm was used 50% (home range) to 95% (utilization range). The bandwidth was set to 2 km considering the seal's horizontal mobility and the margin of error in satellite data. KDE is determined by assessing the provability of an animal's usage of a particular area, which is derived from the number and spatial arrangement of locations and the relative amount of time an animal spends in a given area (Rechetelo et al., 2016).

Results

The signal from the tag was first received on August 28th, two day after release. Subsequently, the signal continued for 107 day until December 12th. During the period, a total of 1,556 location data were collected. The signal data was mostly collected between 8:00 and 16:00, when the Argos satellite passed over the survey area.

The analysis of the kernel home range and utilization range revealed that the individual primarily moved between the haul-out sites of Yeonbong Rock and Mulbeom Rock. However, the kernel home range was concentrated around Yeonbong Rock, where the animal mostly stayed for resting. The utilization range primarily covered near the haul-out sites. It was never recorded visiting the northwest part of the island (Fig. 3).

During the first two days after release, no signals from the seal were detected. The first signal was received on August 28th, but the signal quality was poor, making it impossible to determine the location. On August 29th, a location signal was confirmed, indicating that the individual had moved to Yeonbong Rock, another haul-out site approximately 12 km away from the release point. The seal stayed near Yeonbong Rock for four days. On September 2nd, the seal returned to the release location of Mulbeom Rock, and stayed in that area until September 5th. On September 6th, it moved to the area between Mulbeom Rock and Yeonbong Rock, approximately 5 km southwest of Mulbeom Rock, and actively traveled around the eastern and northern seas of Baengnyeongdo Island until September 12th. On September 13th, it stayed near Mulbeom Rock, and on the night of the 14th, it moved back to Yeonbong Rock. The movement patterns were recorded relatively accurately, and between 19:57 and 23:20, it slowly moved a distance of 8.7 km along the sea, approximately 1–1.5 km away from the coastline.

The seal stayed at Yeonbong Rock for a short period before returning to Mulbeom Rock from September 18th to September 21st. From September 22nd to October 3rd, it went back to Yeonbong Rock again, but then shorty stayed at Mulbeom Rock from October 4th to October 5th. The movement pattern shows that the animal moves back and forth between Yeonbong Rock and Mulbeom Rock.

During the period of signal loss from October 6th to December 12th, the individual stayed mostly around Yeonbong Rock within a radius of 7 km. No location signals were detected from the northwest of Baengnyeongdo Island during the survey period.

It was expected that the seal would migrate northward from Baengnyeongdo Island to Bohai Bay in China in early December, but the signal was lost, preventing confirmation of the migration route. The relevance between the signal discontinuation and the seal's movement changes associated with its northward migration is unclear. However, until the signal was lost, the seal's movement pattern was normal, and the tag maintained a battery voltage of 3.4 V, which is close to a full battery voltages. Tag fails when its battery voltages drop to around 3.0 V, so it cannot perform to capacity (Hart et al., 2021). Based on this, it is presumed that the tracking device naturally detached from the animal rather than not sending a signal due to battery drop.

Discussion

Capture and tag attachment

In Korea, there has been no experience of capturing seals for the scientific purpose. There have been several experiences of releasing rescued spotted seals with satellite tags attached (An et al., 2014). This is the first attempt of live capture of wild spotted seal. While various methods are being attempted in Russia, Japan, and China to capture spotted seals (Han et al., 2013; Kobayashi et al., 2009; Solov'eva et al., 2016; Trukhin et al., 2021), the specific environment and ecological conditions in Baengnyeongdo Island is different from the habitats in other area. Therefore, there are limitations to directly apply the same capture methods used in

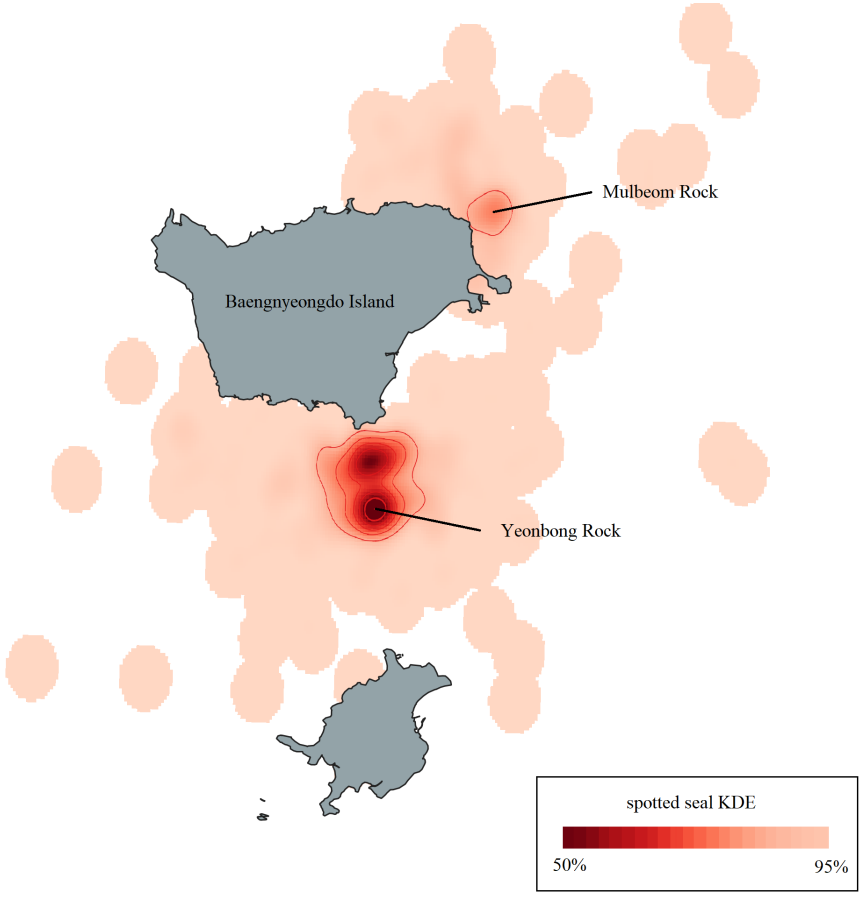

Fig. 3. Distribution pattern of the released spotted seal at Baengnyeongdo Island with kernel home ranges (50%, dark red) to utilization range (95%, pale red). KDE, kernel density estimation.

other countries to Korea.

Baengnyeongdo Island is located within the demilitarized zone (DMZ), making it difficult to install specific gear on site to capture seals. Therefore, the most practical capture method is considered to be approaching the animals quickly and capturing them directly. However, during the capture process, if other individuals resting at the haul-out site are startled and disturbed repeatedly, it could reduce the preference of the site. Therefore, if attempts at regular capture are made each year, it would be necessary to explore methods for capturing them underwater as well.

Lehtonen & Suuronen (2010) modified a salmon trap to capture gray seals successfully. Although fishermen in Baengnyeongdo Island does not use salmon trap-like gear, there are many stow nets installed and spotted seals are bycaught every year in this area (MOF, 2019). However, unlike the salmon trap, the stow net is totally submerged fishing gear. Therefore, if a spotted seal once enters the gear, it cannot come out to the surface to breathe, resulting in death by suffocation. There is a need to develop suitable gear to quantify and live capture the spotted seals effectively.

After capturing the animals, in most of case, epoxy adhesives have been used to attach the tags (Jeffries et al., 1993; Stewart et al., 1989). However, due to the time consuming for the attachment to set, cyanoacrylate instant adhesives were used for temporary fix, and then, epoxy adhesive was applied around the edge of the tag to solid attachment. Through this study, it has been confirmed that instant adhesives provide fast setting up for rapid release. However, the use of instant adhesive could be a cause of short attachment duration. Nevertheless, using instant adhesives is viable option when rapid release is needed in limited situations.

https://doi.org/10.47853/FAS.2023.e59

Satellite tracking

The habitat range of the seal was very limited around Baengnyeongdo Island. Even among spotted seals that visit Baengnyeongdo Island from spring to autumn, there were individuals that consistently stayed until the northward migration for breeding, while others did not. In a satellite tracking study conducted on the same Yellow Sea population by Zhuang et al. (2023), some individuals recorded movements covering an area of 12,060 km^2 during a 6-month tracking period. On the other hand, some individuals remained in their breeding grounds in the Bohai Sea throughout the year. Thus, while spotted seals exhibit certain patterns of migration, not all individuals show the same migratory characteristics. It has been suggested that photo-identification methods could reveal the presence of both resident and transient individuals in the Baengnyeongdo Island (Kim et al., 2010).

Further consideration is needed regarding the attachment positions of seals. The reception rate was higher near the haul-out site, whereas it was not as high when the animals were in the open sea. If, as in previous studies such as Trukhin et al. (2021), the tags were attached above the animals' heads, there might have been more opportunities for exposure above the water, leading to a higher reception rate. In the future, if circumstances allow, attaching the tags above the animals' heads should be considered to improve the reception rate.

This study shows the first results of satellite tracking on wild spotted seal in Korea. However, the study had clear limitations as it focused on only one young spotted seal. Since each individual may have different preferences for habitat suitability, it is necessary to attach tags to a more diverse range of individuals of different age groups to understand their habitat preference patterns in the waters near Baengnyeongdo Island. Spotted seals are known to migrate northward between November and December and arrive at the Bohai Sea, as the breeding season approaches in early winter (Wang, 1986). However, previous studies mostly involved releasing animals from the Bohai Sea in spring, which is the season of their southward migration (Han et al., 2013; Zhuang et al., 2023). Therefore, to gain a precise understanding of their northward migration route, it is necessary to attach tags to the seals between October and November and release them. With further satellite tracking studies on a larger number of seals in the future, a better understanding of the fall-winter northward migration timing and routes of the spotted seal can be expanded.

Conservation measures with bio-logging technology

Conservation of marine mammals will become increasingly important in the future. This issue affect global fisheries economy. The U.S. Marine Mammal Protection Act (MMPA) 101(a)(2) prohibits the import of seafood and its products produced from fisheries that result in the death or injury of marine mammals. The United States requires exporting countries to provide scientific data that measures the bycatch rates of marine mammals in specific fisheries and demands the establishment of marine mammal protection programs. Through fishery-specific comparability finding, seafood products from those fisheries are eligible for export to the United States only if they are recognized as implementing conservation plans equivalent to the U.S. bycatch reduction program. Studying the distribution patterns of marine mammals can contribute to establishing marine protected areas and developing fisheries policies that aim to reduce bycatch of these animals. By understanding their distribution and habitat preferences with bio-logging technology, more effective conservation measures can be implemented to safeguard marine mammal populations and their ecosystems.

The International Union for the Conservation of Nature (IUCN) has classified spotted seals as a species of "Least Concern" (Boveng, 2016) due to the abundant population size. However, the spotted seal population in the Yellow Sea has declined, necessitating conservation measures. Spotted seals are the only pinniped species that regularly inhabit Korean waters. Baengnyeongdo Island is an important habitat for spotted seals. The conservation value of the spotted seals provides guidance for policy directions in restraining or delaying development projects near their habitats and determining the necessary investments for their management and preservation (Kwon et al., 2013). If effective seal conservation policies are implemented, the seal population along the Coast of Baengnyeongdo Island is likely to increase. However, this might create conflicts with fishing activities, making it essential to assess the distribution patterns of the seal's habitat to be prepared.

Bio-logging technology has advanced dramatically over the past decades taking advantage of technological developments in computers, data storage, and battery capacity, and the miniaturization of tags and sensors. It is anticipated that the significance of bio-logging in the fields of biological and environmental science will continue to increase (Holton et al., 2021). These methods are revolutionizing fisheries science, shedding light on the behaviors of animals and the environments they encounter when out of sight. Tracking data using bio-

logging technology can help inform conservation policy and management, including reductions in fisheries bycatch, and the design and administration of marine protected areas and important habitats (Hays et al., 2019).

Researchers of the NIFS collects movement patterns and environmental data with bio-logging to various marine animals such as Pacific cod (*Gadus macrocephalus*), giant octopus (*Enteroctopus dofleini*), and snow crab (*Chionoecetes opilio*) as well as spotted seals (An et al., 2014; NIFS, 2022, 2023). Whenever researchers handle animals, they should critically assess whether the data acquired justifies the potential risk to the individual and ensure that all necessary precautions are taken to minimize that risk (Wilmers et al., 2015). By carefuly considering these points, bio-logging will be serve as a cutting-edge research technology that enables continuous monitoring of fluctuations in fisheries resources and marine life due to factors such as climate change and anthropogenic pollution. It is expected to overcome the limitations of traditional field survey. Bio-logging studies will contribute to establishing a scientific basis for to the recovery of fishery resources and marine mammal populations.

Competing interests

No potential conflict of interest relevant to this article was reported.

Funding sources

This research was supported by a grant from the National Institute of Fisheries Science, Ministry of Ocean and Fisheries (R2023057).

Acknowledgements

Not applicable.

Availability of data and materials

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval and consent to participate

This research has been approved by the Institutional Animal Care and Use Committee of National Institute of Fisheries Science, Korea (2021-NIFS-IACUC-9). A spotted seal capture and tagging procedures were carried out under license number 2021-1139 (July 6, 2021) issued by the Cultural Heritage Administration of Korea.

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