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Non-invasive monitoring of endangered Ladoga ringed seal (*Pusa hispida ladogensis*) (Carnivora: Phocidae) using photo-identification

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ABSTRACT. Based on imagery taken at summer coastal haul-out sites on the islands of the Valaam Archipelago in northern Lake Ladoga in 2019 and 2020, a photo-identification database for the endangered Ladoga ringed seal (*Pusa hispida ladogensis*) has been developed. We based individual identification on unique patterns visible on the seal pelt and demonstrated the utility of this approach to ringed seal monitoring. The current version of the database contains 537 individual seals. When possible, the sex and age class of individuals were recorded, as well as individual resightings within one day, intra- and inter-seasonal resightings. At the haul-outs, the female-to-male ratio was about 1:1.16, and 2.3% of the animals were young-of-the-year. The intra-season resighting percentage was 2% in 2019 and 2.3% in 2020, whereas the inter-annual resighting rate was only 1.3%, indicating low haul-out site fidelity and substantial rotation across seal groups using the islands during the open-water season.

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Неинвазивный мониторинг ладожской кольчатой нерпы (*Pusa hispida ladogensis*) (Carnivora: Phocidae), находящейся под угрозой исчезновения, с использованием фотоидентификации

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РЕЗЮМЕ. С использованием метода фотоидентификации создана база изображений ладожской кольчатой нерпы (*Pusa hispida ladogensis*) на основе снимков, собранных в местах формирования летних береговых залежек нерпы на островах Валаамского архипелага в северной части Ладожского озера в 2019 и 2020 годах. Для индивидуальной идентификации использовался уникальный рисунок, сохраняющийся на шкуре нерпы в течение всей жизни и пригодный для визуального распознавания особей. Мы продемонстрировали применение метода фотоидентификации для мониторинга кольчатой нерпы. Текущая версия базы данных содержит 537 особей. По возможности регистрировались пол и возраст животных, а также отмечались повторные встречи в течение суток, внутри- и

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межсезонные. Соотношение самок и самцов на залежках было приблизительно 1:1.16, и 2.3% животных были представлены детенышами первого года жизни. Внутрисезонная частота повторных встреч составила 2% в 2019 году и 2.3% в 2020 году, а межгодовая — всего 1.3%, что свидетельствует о низкой степени привязанности отдельных особей к определенным местам залегания и значительной ротации в группах тюленей, находящихся на залежках в течение сезона открытой воды.

КЛЮЧЕВЫЕ СЛОВА: ладожская кольчатая нерпа, Ладожское озеро, мониторинг исчезающих видов, фотоидентификация, база данных.

Introduction

Monitoring free-ranging marine mammal populations is a difficult endeavor that necessitates high-tech, labor-intensive, and expensive technologies. Nonetheless, monitoring population abundance, distribution, and health is critical for preserving some species that have become endangered in recent decades. Traditional methods of studying marine mammals, such as visual counts, opportunistic observations from vessels, or selective removals of individuals, began to blend into the background with the development of biotelemetry methods that allow studying animals without direct removal from nature, using remote technologies for measurement and control (Cooke *et al*., 2004; Hey & Nebel, 2012; Horning *et al*., 2019). Instrumental approaches gradually replacing traditional methods include satellite tagging and animal tracking (e.g., Solov'eva *et al*., 2016; Hamilton *et al.,* 2018; Gjelts *et al*., 2000), acoustic monitoring (e.g., Van Parijs *et al*., 2009; Jones *et al*., 2014; Sanguineti *et al*., 2021), combined multi-spectral aerial surveys (e.g., Chernook *et al*., 1999; 2018; Conn *et al*., 2014, 2021) or unmanned vehicle surveys (e.g., Seymour *et al*., 2017; Johnston, 2019; Krause *et al*., 2021), and others. The photo-identification (photo-ID) tool is one of many remote methods for obtaining vast volumes of data on wild marine mammal populations. The use of hand-held, high-resolution cameras (e.g., Titova *et al*., 2018), airborne photography (e.g., Koski *et al*., 2015), or trail cameras (Koivuniemi *et al*., 2016, 2019) allows for the collection of photos of individuals to be used for individual recognition-based studies.

The re-identification approach has long been utilized for marine mammals, such as Northern fur seals (*Callorhinus ursinus*) and Steller sea lions (*Eumetopias jubatus*), with their pelts branded with unique numbers (Scheffer, 1950; Burkanov & Loughlin, 2005; Hastings *et al*., 2009; Isono *et al*., 2010; Permyakov *et al*., 2014). Such individuals might be later detected, matched against existing records in databases, and so followed throughout their lives. Similarly, tagging seals with numbered plastic tags affixed to the animal's rear flippers or adhered to the head (Wiig & Øien, 1988) allows them to be re-identified over time. These methods, however, have several drawbacks, including the need to physically capture animals for branding or tagging, as well as the limited lifespan of certain types of tags (Bradshaw *et al*., 2000; Pistorius *et al*., 2000). In cetacean research, photo-ID is broadly and successfully utilized since individual whales and dolphins can be distinguished by the unique shape and/or coloration of their dorsal fins or flukes (Katona *et al*., 1979; Neumann *et al*., 2002), or body color patterns like orcas (*Orcinus orca*; Towers *et al*., 2019). Natural markers exist in these situations, therefore capturing and artificially labeling individuals is unnecessary.

Many species of true seals, such as ringed seals (*Pusa hispida*), gray seals (*Halichoerus grypus*), and harbor seals (*Phoca vitulina*), have natural markings on their pelt (Yochem *et al*., 1990; Koivuniemi *et al*., 2016; Vincent *et al*., 2001) and these unique patterns of rings, spots, or stripes in some species remains unchanged throughout their lives (Koivuniemi *et al*., 2016). These pelage patterns can be reliably identified in high-quality photographs and thus serve as natural markers. The photo-ID method in this case is fully non-invasive: no animals must be captured, and the use of cameras with high-quality optics enables image collection from a large distance in either manual or automatic mode, minimizing disturbance. The collection of seal imagery does not require a formal photography protocol, allowing researchers to use photographs contributed by local residents or visitors outside of a specialized study, boosting the number of unique identifications and resightings.

The Ladoga ringed seal (*P. hispida ladogensis* Nordquist, 1899), a freshwater subspecies of the ringed seal that lives in Lake Ladoga in northwestern Russia, is one of the few true seal species with a life-long pattern on their pelts that allows for individual identification. The Ladoga seal population was heavily exploited in the twentieth century, and it is thought that commercial and sport hunting contributed to a 60% decline in the population between the 1930s and 1970s (Sipilä, 2016). The harvest of Ladoga seals was banned in the Soviet Union in 1980 (Sipilä & Hyvärinen, 1998), and the subspecies became listed in the Red Data Book. Several population surveys conducted at the close of the twentieth and beginning of the twenty-first century revealed a possible partial recovery of the Ladoga seal population to 5000–8000 seals as of 2012 (Trukhanova, 2013; Trukhanova *et al*., 2013). The population is nonetheless threatened by mortality from fishing gear (Trukhanova *et al*., 2012, 2021), habitat deterioration due to a warming climate limiting ice cover available to seals during the breeding season (Trukhanova, 2013), and recreational and industrial activities in the lake water area during the summer.

Due to the low frequency of population surveys, finding alternative ways to monitor the Ladoga ringed seal population is essential in order to detect changes in population size, health, or demographic rates in a timely manner. There are numerous knowledge gaps regarding the Ladoga seal's behavior, distribution and movements, social interactions, site fidelity, and many other aspects of the seal's life history. Photo-identification may be able to provide the tools required to address these gaps. This method has never been applied to the Ladoga ringed seal before, and there is no existing database that may serve as a foundation for using photo-ID to follow individual seals throughout their lives.

The goal of this study is to test the applicability of non-invasive photo-identification technique to routinely solve the Ladoga ringed seal population monitoring-related tasks.

Material and methods

Data collection — The study was carried out on the islands of the Valaam Archipelago (Fig. 1A), where the largest aggregations of seals on Lake Ladoga may be seen basking along the island coasts and on the partially submerged stones during the open-water season. Western Sosnovy, Eastern Sosnovy, and a group of Krestovy islands, comprising Krestovy, Lisy, and Krainy islands, are among the most frequent haul-out sites for these seals (Agafonova *et al*., 2007). The distance between the islands is from 300 m to 3 km. Each island was divided into either 200 m by 200 m or 100 m by 100 m grid cells for data recording purposes, and the photographs taken were assigned to one of the cells (Fig. 1B–D).

The study was conducted over the summers of 2019 (Season 1) and 2020 (Season 2). From June 12 to August 10, 2019, observers worked on Eastern Sosnovy, Western Sosnovy and Lisy islands photographing hauled-out seals using digital hand-held cameras. Seals were present on the islands for a total of 39 days. Observers generally approached the haul-outs from shore early in the morning and photographed the seals they saw while taking care to avoid disturbing resting animals. The distance between the photographers and the seals varied between 10 and 70 m in different locations. Between June 12 and July 2, 2020, three teams of observers photographed seals on Eastern Sosnovy, Western Sosnovy, or on the Krestovy islands. Observers photographed seals three times a day and each time spent up to two hours moving from one haul-out to another. Morning survey typically took place from 8 to 10 a.m., afternoon — from 1 to 3 p.m., and evening — from 6 to 8 p.m. When the sea state on the Beaufort scale was 3 points or lower, observers conducted observations

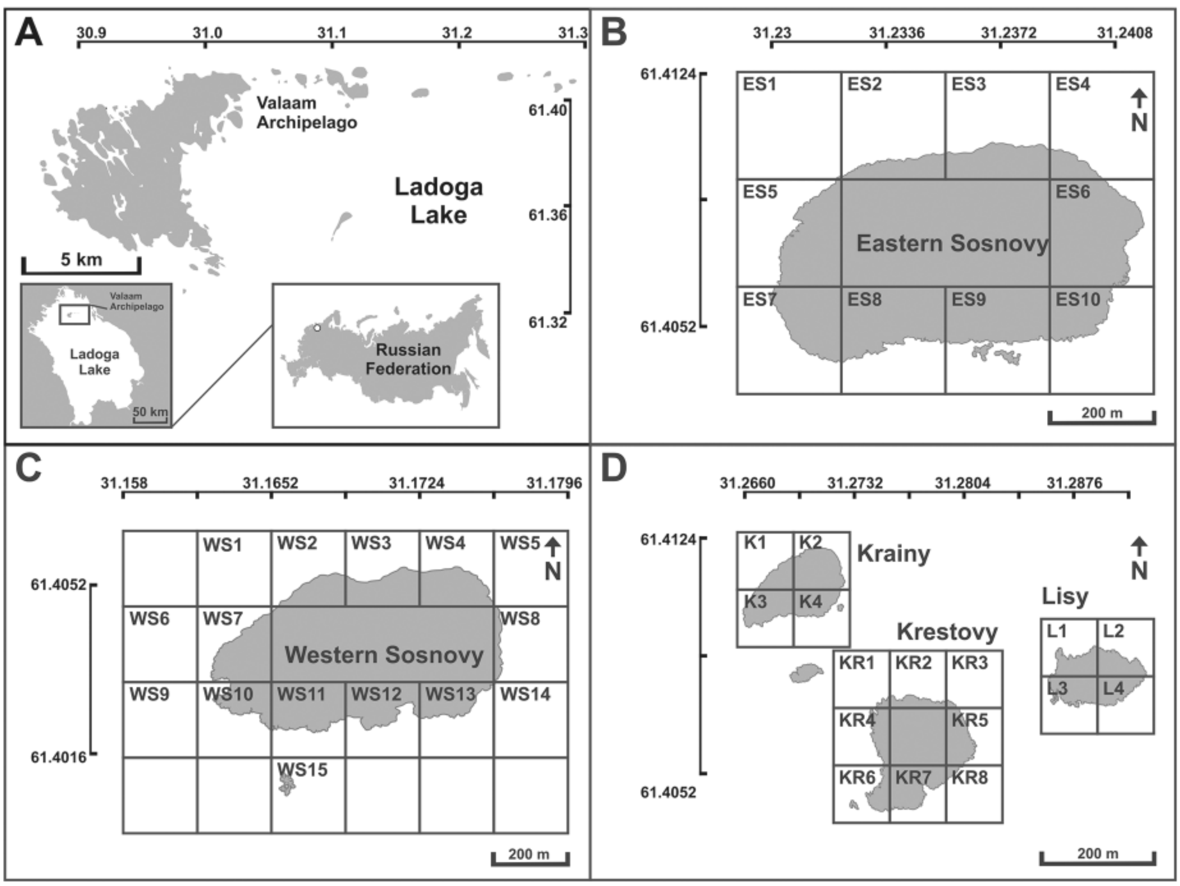

Fig. 1. Ladoga Lake and the Valaam Archipelago (A), with the grid cells defined for Eastern Sosnovy (B), Western Sosnovy (C), and the Krestovye islands (D).

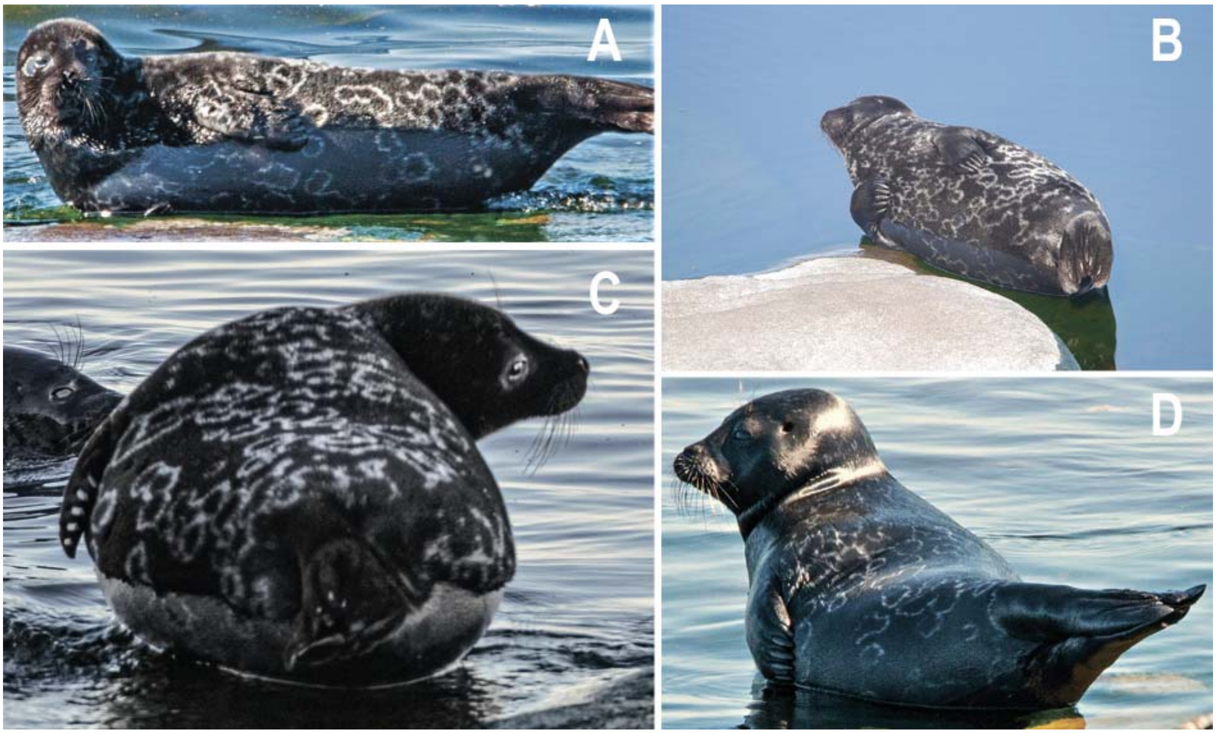

Fig. 2. Ladoga ringed seal imagery example used for individual pattern recognition: an individual 573 sighted twice in 2020 (A and C), a female Ladoga seal (B), and a young-of-the-year (D).

on Krestovy Island at 8 a.m. and 1 p.m., then traveled by boat to Lisy Island to photograph seals there before returning to Krestovy Island for the evening survey. There were nine trips to Lisy Island in total, and seals were observed on seven of them. During the study period, no seals were seen on Krainy Island. The seals were photographed on all 17 days that they were present at the haul-outs. To maximize image quality, the photographers were instructed to take portrait photographs of seals, individually or in small groups, that were mostly dry with the fur pattern clearly visible, and to avoid taking pictures against the sun or at dusk. Prior to starting photographing, the observers visually counted seals at the haul-outs and recorded the number of seals on land and in the water.

In addition to the hand-held photographs, trail cameras were set up on the islands in 2019 (n = 23 cameras) and 2020 (n = 10 cameras), collecting imagery in time-lapse mode to track seal abundance at the haul-outs over time (see Trukhanova et al., 2023). We were interested to see whether image quality from trail cameras would be sufficient for pattern recognition under the present study condition.

Imagery analysis — The collected images were cropped around an individual seal, their brightness, contrast, and sharpness were all manually adjusted to improve pattern visibility. Then, the images were categorized into five classes based on their quality: 5 — the best quality, with a clearly visible pattern, sharp, and with natural color reproduction; 4 — the pattern was clear but not so sharp, requiring some computer processing; 3 — the pattern is mostly visible but the image is not sharp or the pattern is only partially visible; 2 — very little of the pattern is discernible; low-quality image; 1 — the pattern is nearly or completely unrecognizable; very low-quality image. Even high-resolution images could be classified as class 1–2 owing to unrecognizable patterns caused by glare from the sun, wet fur, or poor lighting (e.g., the animal was in the shade or photographed against the sun). If the same individual was photographed multiple times during one survey, the best quality image (in some cases — 2–3 images) was retained. With a few exceptions, only high-quality 3–5 class pictures were selected for the study. To minimize duplicate identification of the same individual when photographed at different angles, we exclusively used images of the left side of the seals (Fig. 2) for photo-identification.

The following metadata were provided for each selected photograph: location, date, time, and photographer's name. Each photograph was visually inspected before being uploaded to the online repository under a unique name that included information on the assigned identifier, date, and time of encounter, as well as the site where an animal was photographed. For example, the photograph titled "417 15–06–2020 kr6 aft 5" indicates that this animal was given a unique individual identifier of "417", that it was photographed in a grid cell "kr6" on Krestovy Island on the afternoon of 15–06–2020, and that the image is of class 5 quality. An additional photograph of the same individual had a "(1)" added to the file name. To identify an individual, observers examined the entire visible area of the seal body and, if possible, picked a few local areas with distinctive traits that were easy to recognize and situate on the body in relation to other features and seal body parts. Upon identification, additional data were entered into the metadata table, including the animal's sex (if it could be identified reliably based on genital openings) and age class (young-of-the-year or adult, where a young-of-the-year could be identified by a large head and fore flippers relative to their body size).

Before a new image was added to the database, it was manually compared to all of the seal photos that had previously been uploaded. If a pattern match was detected, the date, time, and location of the resighting were recorded in a separate row in the metadata table, and the resighted individual was assigned an existing identifier. With one exception, seals photographed multiple times during the same survey (for example, during the same morning survey) were not considered resighted during that survey and were not included in the database (see Results for details). In 2020, seals photographed more than once on the same day, e.g., during the morning and afternoon surveys, were considered resighted. Following the processing of the complete image dataset, the entries made by less experienced observers were double-checked by researchers with extensive experience in seal identification. To eliminate false-positive resightings, all matches were double-checked regardless of the observer's experience.

The metadata table and the Ladoga Seal Photo-ID Database (v. 1.0/2023) containing imagery in jpeg format are available at online repository (https://www.ebi.ac.uk/biostudies/studies/S-BSST1051) and will be updated as new imagery becomes available. Data exploration was performed in the R programming environment (R Core Team, 2019).

Results

In 2019, we observed on average 29 (max = 149) seals per day in all study sites combined, and a cumulative total of 1089 seals was available for being photographed during the entire study period on Eastern Sosnovy and Lisy islands (no counts were performed on Western Sosnovy). In 2020, an average daily count was 177 (max = 416) and a cumulative total was 3226 seals on all islands surveyed (Table 1). The initial processing dataset consisted of 3467 hand-held-camera-made photos of categories 1 to 5 (Table 1), with all seal sides included and duplicative pictures of the same individual from the same survey mostly excluded. Therefore, around 80% of seals counted on the haulouts were photographed by the observers. Images collected by trail cameras were inspected and proven unsuitable for individual pattern recognition (1–2 category when zoomed in to individual seals).

The dataset generated 150 unique database entries in 2019 and 387 entries in 2020 with individuals photographed only from the left side at a resolution suitable for reliable identification (mostly categories 3–5). Eastern Sosnovy Island had the most database records (259), followed by Western Sosnovy (134), while Lisy (75) and Krestovy (69) islands had the fewest seals identified. All in all, of the seals present at the haul-out sites, 13.7% were identified from their left side and included in the database in 2019 and 11.9% — in 2020.

In 2020, nine seals were identified as young-of-the-year (2.3% of the identifications for Season 2) and the rest of the individual seals added to the database in both years were adults. Sex could be visually determined for 57.3% of the identified seals (Table 2). Among these, 134 were females (46%) and 156 were males (54%). Assuming random sampling of hauled-out seals, the female-to-male ratio at the haul-outs was roughly 1:1.16.

In both seasons combined, 27 seals (5% of all identified individuals) were resighted at least once (Table 3). Ten (2.6% of individuals identified in Season 2) of the resightings were same-day resightings reported only in 2020 due to the fact that three surveys were conducted each day in that year. The majority of same-day resightings were males photographed twice on the same island in the same or neighboring grid cells. One male was seen hauled out on Western Sosnovy Island twice on June 11, 2020, in the morning and afternoon, and then again on the same day evening by observers on Krestovy Island. A young-of-the-year was resighted on Eastern Sosnovy within one hour on the morning of June 12, 2020. After hauling-out in one location, where

Table 1. Photo-ID field effort and material collected in 2019–2020.

Study period	Location	Cumulative number of seals counted	Cumulative number of seals photographed (all sides)	Total number of unique seals id-ed (left side)
12/06/19–10/08/19	Eastern Sosnovy	642	583	129
	Western Sosnovy	n/a*		15
	Lisy	447		6
12/06/20–2/07/20	Eastern Sosnovy	1229	2884	130
	Western Sosnovy	832		119
	Krestovy	499		69
	Lisy	666		69
Total		4315	3467	537

*regular counts were not performed.

he was first photographed, the seal was disturbed and moved to another grid cell about 1 km away from its original location. Within a season, the interval between seal sightings, excluding same-day resightings, ranged from one day, when a seal stayed overnight at a haul-out site, to 33 days when an animal apparently returned to the haul-out after foraging. One female was photographed three times within one season, on June 11, 13, and 23, 2020, on three different islands.

Resighting rate was 2% in 2019 and 2.3% in 2020, excluding same-day resightings. Seven of the seals that used the Eastern Sosnovy Island haul-outs in 2019 returned to Valaam Archipelago in 2020, but only one of them returned to the same island, whereas all the others were seen on different islands — Western Sosnovy, Krestovy, or Lisy. The inter-annual resighting rate was 1.3%.

Discussion

Manual photography of Ladoga ringed seals at summer haul-outs with high-resolution digital cameras has proven to be an effective method for obtaining a representative sample of the population. Despite the considerable distances between the photographers and the animals, a large portion of the images taken were acceptable for visual pattern recognition in seals. Large haul-outs of Ladoga ringed seals in the Valaam Archipelago, often consisting of several hundred animals (Agafonova *et al*., 2007; Agafonova & Sokolovskaya, 2018), provide a unique opportunity to obtain a large sample size in a relatively short study period without the need to conduct an extensive search for seal aggregations and with little time to spent traveling between haul-out locations.

The trail cameras installed on the Valaam Archipelago island shoreline overseeing the haul-out sites collected images suitable for counting the number of seals on the stones and in the water (Trukhanova *et al*., 2023), but their quality was not sufficient for pattern recognition in the majority of cases, contrary to what Koivuniemi *et al*. (2016) anticipated. The effective distance between a trail camera and the animal should be no more than three to four meters to capture images adequate for identification (Koivuniemi *et al*., 2016). The Ladoga seal spends most of its time at the water's edge or on partially submerged stones away from the shoreline or woodland edge where

Table 2. Sex ratio of Ladoga ringed seals photographed at Valaam Archipelago haul-outs.

Island	Eastern Sosnovy		Krestovy		Lisy		Western Sosnovy	
Sex \ Year	2019	2020	2019	2020	2019	2020	2019	2020
Female	30	37	0	12	2	16	4	37
Male	28	46	0	24	2	20	3	39
N/A	73	47	0	33	2	33	8	43

Table 3. Ladoga ringed seal resightings in 2019–2020 grouped by resighting category (extraction from the Ladoga Seal Photo-ID Database v.1.0). Cell — grid cell id. Time — time of surveys: morning (“mrng”), afternoon (“aft”), or evening surveys (“evng”). YOY — young-of-the-year. Note that seals marked * appeared in more than one resighting category.

Database ID	Date	Location	Cell	Time	Sex	Age
Same day resightings						
403	11.06.2020	Western Sosnovy	ws11	mrng	M	Adult
403	11.06.2020	Western Sosnovy	ws10	aft	M	Adult
403	11.06.2020	Krestovy	kr6	evng	M	Adult
413	14.06.2020	Krestovy	kr6	mrng	F	Adult
413	14.06.2020	Krestovy	kr6	aft	F	Adult
521	12.06.2020	Western Sosnovy	ws11	mrng	n/a	Adult
521	12.06.2020	Western Sosnovy	ws10	aft	n/a	Adult
526	13.06.2020	Western Sosnovy	ws13	mrng	n/a	Adult
526	13.06.2020	Western Sosnovy	ws13	aft	n/a	Adult
527	13.06.2020	Western Sosnovy	ws13	aft	M	Adult
527	13.06.2020	Western Sosnovy	ws13	evng	M	Adult
543	12.06.2020	Eastern Sosnovy	es10	mrng	M	YOY
543	12.06.2020	Eastern Sosnovy	es7	mrng	M	YOY
579	16.06.2020	Western Sosnovy	ws13	evng	M	Adult
579	16.06.2020	Krestovy	kr7	mrng	M	Adult

Table 3. (*termination*)

620	15.06.2020	Eastern Sosnovy	es3	mrng	n/a	Adult
620	15.06.2020	Eastern Sosnovy	es3	evng	n/a	Adult
647	21.06.2020	Western Sosnovy	ws10	evng	M	Adult
647	21.06.2020	Western Sosnovy	ws10	mrng	M	Adult
654	11.06.2020	Western Sosnovy	ws11	mrng	M	Adult
654	11.06.2020	Western Sosnovy	ws10	aft	M	Adult
Intra-seasonal resightings						
36	08.06.2019	Eastern Sosnovy	es	n/a	n/a	Adult
36	11.07.2019	Eastern Sosnovy	es	n/a	n/a	Adult
71*	30.06.2019	Eastern Sosnovy	es	n/a	M	Adult
71*	02.08.2019	Eastern Sosnovy	es	n/a	M	Adult
168	11.07.2019	Eastern Sosnovy	es	n/a	n/a	Adult
168	12.07.2019	Eastern Sosnovy	es	n/a	n/a	Adult
407	12.06.2020	Krestovy	kr6	mrng	M	Adult
407	13.06.2020	Western Sosnovy	ws13	evng	M	Adult
479	10.06.2020	Eastern Sosnovy	es9	evng	M	Adult
479	11.06.2020	Eastern Sosnovy	es7	mrng	M	Adult
482	23.06.2020	Eastern Sosnovy	es8	mrng	F	Adult
482	11.06.2020	Western Sosnovy	ws13	mrng	F	Adult
482	13.06.2020	Krestovy	kr6	mrng	F	Adult
520	14.06.2020	Eastern Sosnovy	es7	mrng	F	Adult
520	16.06.2020	Eastern Sosnovy	es3	mrng	F	Adult
531	13.06.2020	Western Sosnovy	ws13	evng	M	Adult
531	14.06.2020	Western Sosnovy	ws13	aft	M	Adult
564	29.06.2020	Eastern Sosnovy	es7	evng	n/a	Adult
564	19.06.2020	Western Sosnovy	ws13	evng	n/a	Adult
573	15.06.2020	Western Sosnovy	ws13	mrng	F	Adult
573	14.06.2020	Eastern Sosnovy	es10	evng	F	Adult
696	13.06.2020	Eastern Sosnovy	es7	mrng	M	Adult
696	12.06.2020	Eastern Sosnovy	es7	evng	M	Adult
Inter-seasonal resightings						
32	11.06.2019	Eastern Sosnovy	es	n/a	n/a	Adult
32	13.06.2020	Krestovy	kr6	mrng	n/a	Adult
71*	10.06.2020	Western Sosnovy	ws13	aft	M	Adult
152	11.07.2019	Eastern Sosnovy	es	n/a	M	Adult
152	17.06.2020	Lisy	lis3	aft	M	Adult
153	11.07.2019	Eastern Sosnovy	es	n/a	n/a	Adult
153	14.06.2020	Krestovy	kr7	aft	n/a	Adult
255	14.07.2019	Eastern Sosnovy	es	n/a	M	Adult
255	14.06.2020	Western Sosnovy	ws13	aft	M	Adult
257	14.07.2019	Eastern Sosnovy	es	n/a	n/a	Adult
257	14.06.2020	Eastern Sosnovy	es8	mrng	n/a	Adult
316	14.07.2019	Eastern Sosnovy	es	n/a	n/a	Adult
316	14.06.2020	Lisy	lis4	aft	n/a	Adult

trail cameras could be securely installed. Each island has a significant number of locations where animals can potentially come out to rest, and the use of each of those locations depends on many factors, most notably the water level, wind direction and strength, and wave height. Therefore, it is hard to predict where traps should be installed in order to capture close-up photographs. Furthermore, unlike their sister subspecies, Saimaa ringed seals (*Pusa hispida saimensis*), for whom the use of trail cameras has been shown to be effective for photo-ID data collection (Koivuniemi *et al*., 2016, 2019), Ladoga seals exhibited a cautious behavior in relation to unknown items (i.e., trail cameras) set at haul-out sites. Moreover, the use of trail cameras in Lake Saimaa was possible due to a very low population size and high level of site fidelity (Biard *et al*., 2022) of Saimaa seals, when a few dozen cameras allowed to sample almost the entire population within a few years (Koivuniemi *et al*., 2016, 2019). On Lake Ladoga, this method proves to be ineffective due to the large seal abundance, therefore continuing to use hand-held cameras is recommended for further populating the photo-ID database for population monitoring purposes.

As soon as the ice on Lake Ladoga melts, Ladoga ringed seals arrive to the Valaam Archipelago's coastal haul-outs (Agafonova *et al*., 2007). Adults complete their annual molt there and then use the islands for resting in between foraging trips. The biggest haul-outs are usually seen in June, when many animals are still molting, after which their numbers begin to decline (Agafonova *et al*., 2007). Seals are typically observed on the islands until late September, when the fall storms start, but occasionally stay longer until the ice begins to form in November (Sokolovskaya, unpubl.). Several noteworthy observations were made by analyzing the composition of seal groups utilizing the haul-outs of the Valaam Archipelago. It was previously reported that the majority of the young seals haul-out on islands separate from the adult seal aggregations (Sokolovskaya, unpubl.). Our data confirmed that the haul-outs are mostly occupied by adult animals, but young-of-the-year can be encountered too, albeit in small numbers. This is consistent with the observations by Agafonova *et al*. (2010) who reported that the pups made up less than 1% of the total number of the seals hauled-out on the islands. The haul-outs on the Valaam Archipelago are mixed-sex, with females and males hauling-out in approximately equal proportions on all of the islands we studied.

Our study indicates that seals move freely between haul-outs, including across sites on different islands. Telemetry research revealed that Arctic ringed seals (*P. h. hispida*) are capable of traveling up to 39.8 ± 1.3 km/day on average (Oglof *et al*., 2021), with a mean travel rate of 0.92 m/s (SE = 0.014 m/s; Harwood *et al*., 2012). The straight-line distance between Western Sosnovy and Krestovy islands is around 6 km, allowing animals to move from one location to another in a short time, as shown in the case of the male seen on different islands within a few hours. According to our findings, a seal might use a haul-out site on one island in one year and then haul out on another island in the following season. Consequently, individual ringed seals randomly utilize available haul-out locations in the Valaam Archipelago and do not exhibit high levels of fine-scale site fidelity in relation to summer haul-outs.

The largest number of seals simultaneously present on a single day in 2019 on Eastern Sosnovy Island alone was 149, according to visual counts conducted throughout the study period. With 150 animals in the database (129 of them from Eastern Sosnovy) and only 2% intra-seasonal resighting rate, it is evident that a significant rotation was happening at the haul-outs, with new individuals coming to and others leaving the sites as the season was progressing. On all study islands, a maximum of 416 seals were counted simultaneously in 2020. There were 387 new individual identifications with very low intra- and inter-seasonal resighting rates, supporting the rotation hypothesis. The high rate of seal rotation at the Valaam Archipelago confirms its role as a seasonal refuge for a significant fraction of the Ladoga seal population. The actual number of seals using the haulouts there is likely much larger than could be expected based on direct count data alone.

The photo-identification approach utilized in this study has several obvious limitations, including the fact that collected photographs require time-consuming processing, the database requires stringent image quality criteria, and there is a possibility of human error. The transition to automated seal identification software offered by machine learning technologies could overcome these constraints. Automatic pattern recognition software for ringed seals was in development at the time this study was conducted, and it showed promising results when tested on Saimaa ringed seal imagery (Chehrsimin *et al*., 2017; Nepovinnykh *et al*., 2018, 2020; Chelak *et al*., 2021). Unfortunately, because the imagery available from Lake Ladoga haul-outs is of inferior quality (due to longer shooting distances and multiple animals present in hauled-out groups), the trials run with the Ladoga seal image test dataset reported low recognition precision (Gromov et al., 2023). As a result, under the current study, it was decided to proceed with more labor-intensive and time-consuming visual identification. However, significant progress was made in parallel with our work to improve pattern recognition precision when analyzing Ladoga ringed seal imagery (Lushpanov, 2020; Nepovinnykh *et al*., 2022). Our hope is that in the future, technological advances in pattern recognition software will allow us to quickly process new images added to the Ladoga seal database. Such technology would significantly decrease the time required for image processing and make the photo-identification approach more efficient, reliable, and suitable for long-term monitoring of this subspecies. Meanwhile, the Ladoga ringed seal photo-identification database developed under this study can be used for behavioral and morphometric research, as well as individual survival, movement, and site fidelity analyses, and, ultimately, non-invasive population monitoring.

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