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Miina Auttila

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- challenges for conservation and monitoring

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UNIVERSITY OF
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ABSTRACT

The ringed seal (*Phoca hispida*) is heavily ice-associated and its breeding success depends on sufficient ice and snow cover. Thus, the loss of snow and ice caused by the ongoing climate change pose a direct threat to the species. In addition, changes to ecosystems and the environment induced by climate change may have indirect effects to the seals. In the present thesis, the ecology of the critically endangered subspecies (*P. h. saimensis*) of the ringed seal, which inhabits a freshwater lake in Finland, was studied. The focus of the study was on key factors that are important for the seal in the changing climate. Also novel methods for monitoring and conservation were developed.

Based on the results obtained in this study, the Saimaa ringed seal appears to be medium-sized among ringed seals. Although it lives in a unique lake habitat in the southern region of the species distribution area and differs e.g. behaviorally from the other subspecies, its growth and body condition patterns are similar to those of marine ringed seals. The Saimaa ringed seal reaches sexual maturity late (at 4–6 years of age), but dies relatively young (~10 years). Its perinatal mortality appears to be higher than was estimated earlier, but the reasons for the mortality are not fully understood. Successful nursing enables the rapid growth of the seal pup, which is essential for its survival. Typically, a snow lair provides good shelter against predators and a harsh climate, but poor snow conditions expose the seal pups to predation and disturbance by humans, elevate the risk for mortality, and may hamper growth.

Although competition for resources between the seals and fishermen is minimal on Lake Saimaa, the observed bycatch mortality was high, especially in young age groups. The results of the present study demonstrate that the seal pups recover from post-weaning nutritional deprivation in the late autumn and the peak of their bycatch mortality is seen in the late summer. This information should be taken into account in temporal extension of fishing closures.

The novel noninvasive monitoring methods (camera traps and underwater surveys) developed in this study proved to be effective tools for monitoring lair sites, and for making better estimations of natality and perinatal mortality. In addition, camera traps provided valuable information on human and predator activity at lair sites. The method of building man-made snowdrifts, which was developed in the present study, has been later used successfully to improve the seals' breeding success during winters with poor snow conditions. The man-made snowdrifts were designed to mimic wind-drifted snow and they were built before the seals' breeding season at their breeding habitat.

Predicted changes in the seals' lake habitat may also cause shifts in prey abundance, compensated body condition and increased mercury concentrations. Altogether, a decline in pup survival seems to be the most acute threat to the seals posed by climate change. There is an increasing need for novel monitoring and conservation methods in a changing climate and more effective conservation actions are necessary in order to safeguard the Saimaa ringed seal. This study, together with others suggests that ensuring the rapid growth of the seal population in Lake Saimaa would be the most effective way for helping the seals to adapt the rapidly changing climate.

Universal Decimal Classification: 504.7, 57.045, 574.3, 591.13, 591.52, 599.745.3

CAB Thesaurus: seals; Phoca hispida; climate change; population ecology; habitats; diet; feeding; morphometrics; body condition; growth; predation; pups; mortality; bycatch; monitoring; conservation; endangered species; survival; breeding places; nests; snow

Yleinen suomalainen asiasanasto: hylkeet; saimaannorppa; ilmastonmuutokset; populaatioekologia; habitaatti; ravinto; kunto; kasvu; saalistus; pennut; poikaset; kuolleisuus; seuranta; suojelu; uhanalaiset eläimet; tekopesät; lumi

Preface

The journey to the point that I am finalizing this thesis has been long and full of incidences, but luckily the length and roughness of the road did not surprise me. Working with a critically endangered "conflict" species is never easy, but when it has been hardest, our research group has been at its best. The motivation to continue has always been easy to find, some of the results and methods produced in this study have been already taken in use in the conservation of the Saimaa ringed seal and, well, I just do not know how to give up.

However, without a large group of people this work would have never been done. My warmest thanks belong to Mervi Kunnasranta, my principal supervisor. I have enjoyed working with you and I have learned a lot (not only on seals and science) from you. You created this project and made it happen, I am thankful that I had an opportunity to participate. My supervisor Markku Viljanen has done huge work for collecting funding and managing our research group in earlier years, thank you. Raine Kortet has been one of my supervisors last few years, thank you for your valuable comments on this thesis.

I gratefully acknowledge the reviewers Brendan P. Kelly and Steven Ferguson for their expertise on this thesis. I wish also to thank Brita Bishop, Holly Shiels, Kate Sotejeff-Wilson and Helen Cooper for linguistic help during these years. I wish to express my gratitude to Heikki Hyvärinen for valuable comments on the manuscripts.

I am grateful to all co-authors, it has been pleasure to work with you and your expertise in different fields has been invaluable. Especially I want to thank Mika Kurkilahti for your excellent ability to simplify complex statistical methods into understandable form, Tuula Sinisalo for sharing your knowledge on stable isotopes, Marja Isomursu for seal autopsies and Teresa Skrzypczak for bacteriological analyses. I thank the personnel of Metsähallitus, the former cooperation partners and current co-workers of mine, especially Tero Sipilä, Jouni Koskela, Raisa Tiilikainen and Pekka Heikkilä. I also wish to acknowledge Tuomo Kokkonen, who sadly passed away last year. I thank the personnel of ELY centers, especially Arto Ustinov and Jorma Tiitinen.

Greatest thanks to my colleagues in our research group including also "satellite members" Marja, Mia, Anni R., Sari, Meeri, Riikka, Lauri and Anni N. Thank you all! This thesis is based on huge amount of field work, like piling snowdrifts, setting camera traps, scuba diving, catching fish and collecting seal carcasses. I am tremendously thankful for all of you who have participated to field and laboratory work. Especially I want to thank our "field master" Terho and "seal whisperer" Juha, technicians Kari, Ilkka, Hanski and Tuomo, volunteer workers Uippa, Ekku and family Marttinen. I also want to thank local fishermen for fish samples, Teija Zetterberg and Anna-Maija Nakari for your valuable work with the diet analyses, and Matti Savinainen, Kirsti Kyyrönen and Harri Kirjavainen for technical support. I am very thankful to the entire staff of the Department of Biology.

I am most grateful to my main sponsor WWF Finland for making this research possible. In fact, the Saimaa ringed seal came to my life first time when I started to work at WWF in 2007, and after that the journey has continued, organizations have changed but the seal has stayed. I am thankful to the staff of WWF, especially to Jari Luukkonen for support and encouragement. I also want to thank other financial supporters: the Finnish Ministry of Agriculture and Forestry (Climate Change Adaptation Research Programme ISTO), the Raija and Ossi Tuuliainen Foundation, the Finnish Ministry of Environment, Center for Economic Development, Transport and the Environment for South Savo, the Regional Council of South Savo, the LIFE Saimaa Seal project (Safeguarding the Saimaa Ringed Seal), the Finnish Concordia Fund and Society for Marine Mammalogy.

There have been plenty of permits and agreements for conducting this study and I have listed the most recent and essential ones below. Permits obtained from the local Centre for Economic Development, Transport and the Environment: for collecting and storing tissue samples of the Saimaa ringed seal (permit nro: ESAELY/567/07.01/2011), and for piling snow and setting camera traps at seals breeding habitat (permit nro: ESA-2009-L-375-254). In addition, there have been permits and agreements obtained from Metsähallitus, Parks & Wildlife Finland for snowmobiling and camping in Linnansaari national park during restriction periods, for using seals' lair site location data for research planning, for using measurement data of seals for research and an agreement of confidentiality concerning the data mentioned above.

This work has taken its time, but there has been also time for friends and family. However, I have to admit that also most of you have participated to this process in one way or another, thank you for that. First I must thank all of you who have taken care of Kulo dog during these years, especially family Vehmas. I want to thank our regular Ilosaarirock quests; we have had so much fun together! Sini, Chrisse & Eeva, Sami R. and Lauri you are always a good reason to visit Helsinki. In addition to above mentioned, Sami J., Joonas & Oa, Linda, Ursula, Jussi, Sanja, Jukka and Kekä & Nina thank you for great time and company. I am grateful to my parents for always encouraging me, although it has not been always clear to them what I am doing and where I am going. Mika, my love, I am extremely lucky to have you in my life, thank you for everything.

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on data presented in the following articles, which are referred to by the Roman numerals I-III. In addition, some unpublished results are presented in the summary.

I Auttila M, Sinisalo T, Valtonen M, Niemi M, Viljanen M, Kurkilahti M and Kunnasranta M. Diet composition and seasonal feeding patterns of a freshwater ringed seal (*Pusa hispida saimensis*). *Marine Mammal Science 31: 45-65, 2015.*

II Auttila M, Kurkilahti M, Niemi M, Levänen R, Sipilä T, Isomursu M, Koskela J and Kunnasranta M. Morphometrics, body condition, and growth of the ringed seal (*Pusa hispida saimensis*) in Lake Saimaa: Implications for conservation. *Marine Mammal Science, DOI: 10.1111/mms.12256, 2015.*

III Auttila M, Niemi M, Skrzypczak T, Viljanen M and Kunnasranta M. Estimating and mitigating perinatal mortality in the endangered Saimaa ringed seal (*Phoca hispida saimensis*) in a changing climate. *Annales Zoologici Fennici 51: 526-534, 2014.*

The publications are printed with the kind permission of John Wiley and Sons (I–II) and the Finnish Zoological and Botanical Publishing Board (III).

AUTHOR’S CONTRIBUTION

The ideas for the papers were developed jointly together with the other authors. The present author was responsible for writing the original manuscripts for all the three papers. In papers I-II she also contributed to data handling and analyses, and had a minor part in modeling. The stable isotope analyses (I) and bacteriological analyses (II) were conducted by the co-authors. In paper III the present author was responsible for the data gathering and analyses.

Contents

1 Introduction

Climate change has wide-spread and varied effects on the environment, ecosystems and species. The amount of snow and ice has decreased in many areas, the sea level has risen and changes in the occurrence of many extreme weather events have been observed (IPCC, 2013). Globally, the mean temperature has increased since the late 19th century and the increase has been greater at higher northern latitudes. The concurrent loss of the Arctic sea ice has been faster than has been predicted by climate models (Stroeve *et al.*, 2012) and from 1979 a significant trend in the earlier retreat of sea ice in the spring and the later advance of the ice in the fall has been evident (Laidre *et al.*, 2015). For the Arctic marine mammals, the loss of sea ice habitats is the most critical direct consequence of a warming climate (Tynan & DeMaster, 1997; Kovacs *et al.*, 2011, 2012).

The ringed seal (*Phoca hispida*) has a wide Northern circumpolar distribution and it also inhabits two large Fennoscandian freshwater lakes. It is heavily ice-associated and well adapted to the Arctic conditions (Smith *et al.*, 1991; Kelly, 2001; Kovacs *et al.*, 2012). Its life-history events, like reproduction, molting and resting, occur on an ice platform (McLaren, 1958; Smith & Stirling, 1975; Smith *et al.*, 1991). Thus, it is typically ice-associated year round and comes out of the water exclusively on ice (Kovacs *et al.*, 2011), except in southern regions like in the Baltic Sea, in the Sea of Okhotsk and in lakes Ladoga and Saimaa where the ice cover disappears seasonally, and the seals haul out also onto terrestrial sites (Sipilä *et al.*, 1996; Sipilä & Hyvärinen, 1998; Trukhin, 2000; Harkonen *et al.*, 2008; Niemi *et al.*, 2013a). During the winter ringed seals haul out in snow dens (known as lairs) and give birth to a single pup in the shelter of the subnivean lair, where they also nurse the pup (McLaren, 1958).

For the successful breeding of the ringed seal, the ice must form in time to enable the accumulation of sufficient snow cover for the construction of a lair (Kovacs *et al.*, 2012). Moreover, the ice layer should remain stable over the nursing and molting periods. The birth lair is a key feature of the ecology of the ringed seal as it provides protection for the pup against predators and harsh climate conditions (McLaren, 1958; Smith *et al.*, 1991; Lydersen *et al.*, 1992). Due to the ringed seal's high dependence on sufficient ice and snow cover for breeding, the ongoing climate change has become a growing threat to the species (Kelly, 2001; Meier *et al.*, 2004; Stirling & Smith, 2004; Ferguson *et al.*, 2005; Laidre *et al.*, 2008; Kovacs *et al.*, 2012; Sundqvist *et al.*, 2012; Trukhanova, 2013). It has been suggested that the severe impacts of climate change will be first seen in the southern populations (Meier *et al.*, 2004).

Due to the decrease in the sea ice area, the delay in ice formation and insufficient snow accumulation, it has been estimated that the mean area of the potential habitat for ringed seal reproduction in the Arctic (north of 70°) will decrease by nearly 70% during the 21st century (Hezel *et al.*, 2012). In addition to the direct impacts of mild winters, the warming climate may have various indirect effects on the seal's survival via *e.g*. changes in water salinity and the abundance of prey, decreased body condition, increased pathogen and parasite loads, increased human presence and increased exposure to pollutants (Tynan & DeMaster, 1997; Harvell *et al.*, 1999; Learmonth *et al.*, 2006; Burek *et al.*, 2008; Laidre *et al.*, 2008; Moore & Huntington, 2008; Ragen *et al.*, 2008; Wassmann *et al.*, 2011; Trukhanova, 2013).

Distribution shifts, compromised body condition and a decline in abundance have already been observed in some ice-associated marine mammals as a response to the loss of sea ice (Kovacs *et al.*, 2011). Currently, interactions with fishery (*i.e.* bycatch) are the primary threat to most of the threatened pinnipeds, but the deterioration and loss of ice habitats due to climate change is an increasing problem for the ice-associated species (Kovacs *at al.*, 2012). During poor snow conditions the predation of ringed seal pups has increased, and pups without the shelter of the lair have been exposed also to avian predators in the Arctic and Baltic regions (Lydersen & Smith, 1989; Hammill & Smith, 1991; Jüssi, 2008). The adaptive responses of long living mammals, like seals, are typically slow. Therefore, these animals are not able to respond quickly to the effects of rapid climate change (Kelly, 2001; Moore and Huntington, 2008). Comparative studies on subspecies of the ringed seal that occupy a variety of habitats, including relict lacustrine populations, could provide insights into adaptive responses (Kelly, 2001).

1.1 THE LANDLOCKED RINGED SEAL

The Saimaa ringed seal (*P. h. saimensis*) inhabits a freshwater lake in Finland at the southern region of the distribution area of ringed seals. At present, the population size is slightly over 300 individuals and approximately 60 pups are born annually (Metsähallitus, 2015). The Saimaa ringed seal is categorized as a critically endangered subspecies both nationally (Rassi *et al.*, 2010) and internationally (Kovacs *et al.*, 2012), and it is the only endemic mammal that inhabits Finland. Today, along with the growing effects of climate change, threats to the population include bycatch mortality (especially entanglement in the gill nets of recreational fishermen), habitat degradation and the varied negative consequences of a small population size (Ranta *et al.*, 1996; Kunnasranta, 2001; Sipilä, 2003; Ministry of the Environment, 2011; Kovacs *et al.*, 2012; Niemi, 2013; Valtonen, 2014). In addition to the small population size, the low genetic diversity of the subspecies could reduce its ability to adapt to altered conditions like a warming climate (Valtonen, 2014), and due to its landlocked habitat the seal is not able to move northward.

In the beginning of the 20th century up to 1,000 seals still lived in Lake Saimaa (Kokko *et al.*, 1999), but during the last one hundred years the population size collapsed reaching its minimum (under 150 individuals) in the 1980s (Sipilä *et al.*, 1990). The main causes of the population crash were hunting, incidental bycatch mortality in fishing gear, environmental pollutants, and large human caused changes in the water level during the ice covered seasons (Hyvärinen *et al.*, 1999). Killing bounties were paid until 1948, but the Saimaa ringed seal was protected by law in 1955.

During at least 9,500 years of isolation (Nyman *et al.*, 2014) the Saimaa ringed seal has adapted to its labyrinthine freshwater habitat (Hyvärinen & Nieminen, 1990). It has survived through the earlier warm Atlantic period (*ca*. 8,000–5,800 years ago) when the Fennoscandian climate was 1–3 °C warmer than today (*e.g*. Korhola *et al.*, 2002) and the size of the seal population was significantly larger (Hyvärinen *et al.*, 1999). Nowadays, the Saimaa ringed seal differs morphologically, behaviorally and genetically from the other subspecies (Hyvärinen & Nieminen, 1990; Sipilä & Hyvärinen, 1998; Kunnasranta, 2001; Amano *et al.* 2002; Palo *et al.*, 2003; Valtonen *et al.*, 2012; Nyman *et al.*, 2014).

Snow drifts adjacent to ice hummocks and pressure ice ridges, which make typical breeding habitats for marine ringed seals (*e.g.* Smith and Stirling, 1975), do not form in Lake Saimaa. Therefore, seals dig their lairs into wind drifted snowdrifts formed at the shorelines of islands or islets (Helle *et al.*, 1984), as does the neighboring Ladoga ringed seal (*P. h. ladogensis*), which uses both shorelines and ice ridges as breeding habitats (Kunnasranta *et al.*, 2001; Trukhanova *et al.*, 2013). Since the lairs are located on the shore, a drop in the water level may lead to the collapse of the shore ice and lair, drastically compromising the seals' breeding success (Helle *et al.*, 1984; Sipilä, 1990, 2003). In order to reduce the pup mortality the outflow from Lake Saimaa has been regulated since 1991. The aim of this is to stabilize changes in the water level during the winter to less than 20 cm from freeze up to late March (Ministry of the Environment, 2011).

Adaptation to the environment is also seen in the timing of parturition. In the Arctic pups are born between March and

April (McLaren 1958, 1993; Smith & Stirling, 1975; Hammill, 1987), whereas in Lake Saimaa pups are born around a month earlier, when the ice and snow conditions are optimal for subnivean lairs (Helle *et al.*, 1984). Grey lanugo hair camouflages pups during mild winters in their rocky habitat (Kunnasranta, 2001), and weaning occurs at the age of 9–12 weeks after the ice breaks up in mid-May (Niemi, 2013; Niemi *et al.*, 2013b). Pups shed the lanugo hair during the nursing period (Niemi *et al.*, 2013b). Older seals start molting on ice, but the peak of the molt occurs on terrestrial sites in May-June (Hyvärinen *et al.*, 1995; Kunnasranta *et al.*, 2002; Niemi *et al.*, 2013a).

The Saimaa ringed seal shares its habitat with humans: there are six towns, each with over 20,000 inhabitants, and more than 60,000 cottages along the shoreline of the lake (Ministry of the Environment, 2011). The lake is used for recreational outdoor activities like fishing, boating, skiing and snowmobiling. There are over 400,000 recreational fishers fishing on the lake, and it has been estimated that 100,000–200,000 of them use gill nets (Salmi *et al.*, 2013). In addition, there are around 30 full-time and 10 part-time professional fishers fishing on the lake (Ministry of the Environment, 2011).

The use of terrestrial sites brings Saimaa ringed seals in close contact with both predators and humans (Helle *et al.*, 1984; Sipilä, 1990; Niemi *et al.*, 2013a). Despite the fact that the lairs are situated at shorelines and the seals haul out and molt on rocks, there is no evidence for predator kills on Lake Saimaa (Kunnasranta, 2001). Only one suspected case exists, where a red fox (*Vulpes vulpes*) or dog (*Canis familiaris*) penetrated into a lair and supposedly killed a seal pup (Sipilä, 2003). However, at the beginning of the 2000s the observed pup mortality increased and nearly one third of the pups born died before weaning due to poor snow conditions (Ministry of the Environment, 2011).

1.2 OBJECTIVES OF THE STUDY

The aim of this thesis was to study aspects of the ecology of the Saimaa ringed seal, focusing especially on key factors and environmental requirements that are important for the assessment of vulnerability and adaptation in the changing climate. The aim was also to develop novel methods for the monitoring and conservation of this critically endangered seal. The specific study objectives were:

- To determine the diet of pups and older seals, and to survey the seals' body condition, with a special focus on seasonal changes and on the pups (I, II).
- To study the growth and morphometrics of the seal (II).
- To examine the magnitude of pup mortality, to understand underlying factors and to develop new methods for lair site surveillance and population monitoring (III).
- To develop a method to artificially improve the seal´s breeding habitat and pup survival during mild winters (III).

2 Materials and methods

A general outline of the materials and methods is presented here. Detailed descriptions of the methods used can be found in the original papers I–III.

2.1 STUDY AREA

The studies were conducted on Lake Saimaa (61°49′N, 28°54′E) in Finland (Fig. 1). The lake is a labyrinthine water basin of about 190 km in length and 140 km in width and has an average depth of 12 m (max. 85 m) (Kuusisto, 1999). There are around 13,700 islands in the lake and the total length of the lake's shoreline is around 15,000 km. The ice cover in Lake Saimaa normally persists from late November until the beginning of May. The studies on diet (I) and morphometrics (II) covered the main distribution area of the seals (Fig. 1). The pup mortality data and underwater surveys of birth lair sites (III) covered the breeding area (Fig. 1). Lair site monitoring with camera traps and the development of a method for improving snow conditions at the breeding habitat (III) were conducted in Haukivesi and Pihlajavesi basins, where the majority of the seal population lives (Metsähallitus, 2015).

2.2 STUDY ANIMALS; SAMPLES AND MEASUREMENTS

All discovered Saimaa ringed seal carcasses are collected by state authorities, and tissue samples have been stored since the 1970s in at tissue bank jointly maintained by the University of Eastern Finland and the Parks & Wildlife Finland of Metsähallitus. The tissue samples and digestive tracts used in the diet study (I) were obtained from the tissue bank. Skulls and

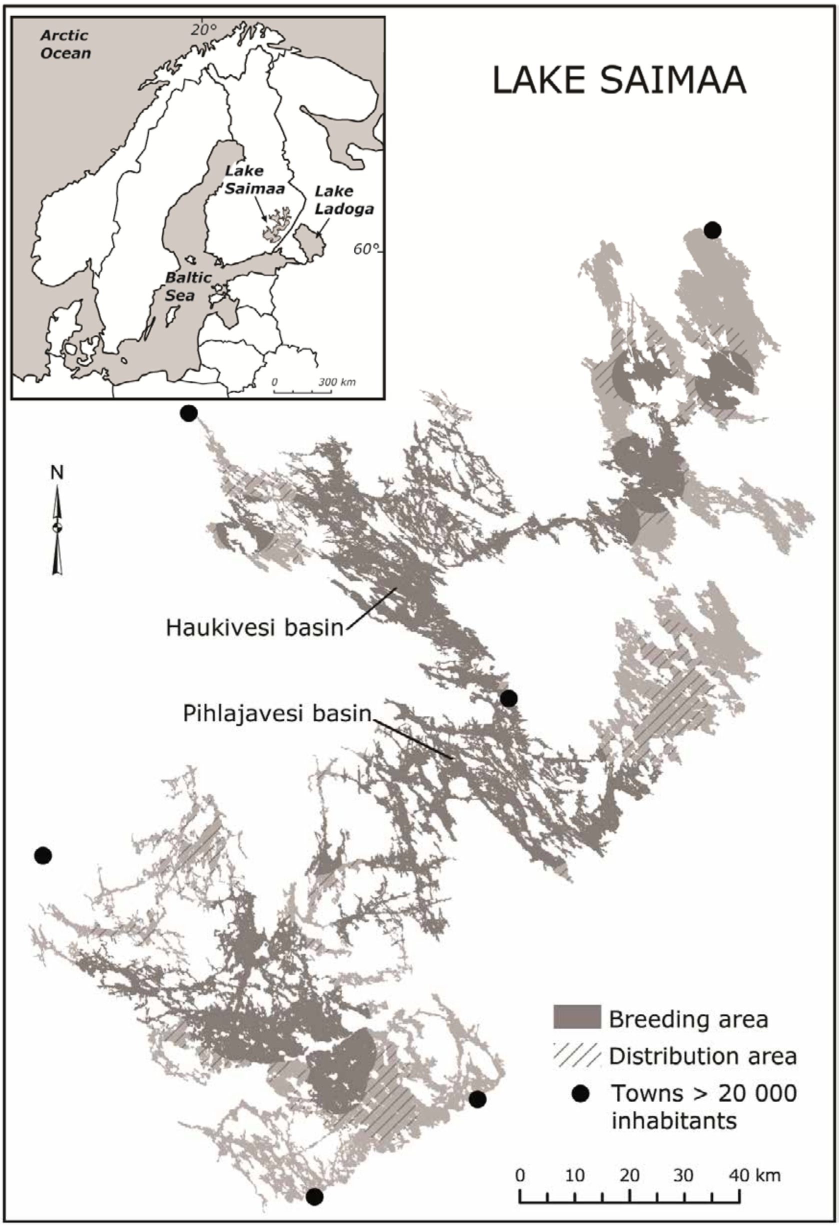

Figure 1. *Map of Lake Saimaa. The current breeding and distribution areas of the Saimaa ringed seal according to Niemi et al., (2012). Map: permit MML/VIR/TIPA/5012/15 © National Land Survey of Finland.*

bacula (II) were obtained from the Saimaa ringed seal museum collection, which is stored at the University of Eastern Finland. The carcasses were examined, and the cause of death (I–III) was determined by the Finnish Food Safety Authority Evira. The body length (from nose to tail), maximum girth, mass and blubber thickness above sternum were measured (II) during the autopsy. The mandible length (from the tip of the mandible to the most distant point on the articular condyle) and the baculum mass and length were measured for paper II. The ages of the seals (I, II) were determined by counting the cementum layers in the lower canine teeth (see Stewart *et al.*, 1996).

2.3 DIET AND STABLE ISOTOPE ANALYSES

Tissue samples and the digestive tract (stomach and intestine) contents of 54 Saimaa ringed seals, which had died during the years 2002–2010 (apart from one individual that died in 1985), were analyzed (I). The seals were divided into two age groups: pups (<1 yr, n = 31), and older seals (≥1 yr, n = 23). The undigested food items and hard parts found in the digestive tracts were determined to the lowest possible taxonomic level using the literature and a reference collection. Diet indices based on digestive tract contents (Hyslop, 1980) were calculated for the frequency of occurrence, for the relative frequency and for the prey-specific abundance.

Stable isotope values ($\delta^{13}C$ and $\delta^{15}N$) were determined from the seals whose digestive tract contents were analyzed (I). The $\delta^{13}C$ and $\delta^{15}N$ values reveal an assimilated diet and provide information on the trophic level and nutritional status of the consumers (Hobson *et al.*, 1997; Polischuk *et al.*, 2001; Phillips & Gregg, 2001, 2003; Sinisalo *et al.*, 2008). Two different tissues were chosen for the analysis due to their different turnover rates; the liver reflects the assimilation of the diet over a period of a few weeks and muscle over a period of 2–3 months prior to sampling (Tieszen *et al.*, 1983; Dalerum & Angerbjörn, 2005). Seasonal changes in $\delta^{15}N$ values of the seals were examined by dividing the seals into seasonal groups according to the time of death. Stable isotope values for several prey species collected from different regions of the lake were also analyzed.

2.4 GROWTH AND BODY CONDITION

The measurement data of 344 carcasses were used to study the growth of the Saimaa ringed seal (II). Pups (≤12 mo, n = 220) were further divided into age classes (lifespan in months) for a closer analysis of the growth during the first-year. The birth size was determined from newborn pups (n = 30) that were defined as full-term pups (see Sipilä, 2003), which, according to the autopsy reports, had not yet eaten. Growth in body length, maximum girth, mass, blubber content as a percentage of total body mass (see Ryg *et al.*, 1990a) and the blubber thickness of the pups over their first year were estimated by fitting a linear model with a nonlinear regression function. Growth in body length, maximum girth, mass, baculum length and mandible length over the seals life time were estimated using the von Bertalanffy growth function (McLaren, 1993 with different parameterization see Cailliet *et al.,* 2006). The age when the seals would achieve their full size was estimated using the age at which the 99% level of asymptotic size was achieved. Growth in baculum mass over the seal's age was estimated by fitting a linear model with a monotonic spline regression. The blubber content of ≥1 year old seals was analyzed with a linear model. This model allows the simultaneous estimation of seasonal fluctuations in blubber content and differences between sexes.

2.5 DEVELOPING MONITORING AND CONSERVATION

Altogether 306 camera traps were used to monitor the seals' breeding habitat during the breeding seasons (Table 1). Game cameras with a motion detector and an infra-red flash were placed at potential lair sites in 2010–2013 (n = 175, III) and in 2014–2015 (n = 131, additional data). Snow conditions during the winters in 2010–2013 were sufficient for lair construction, whereas the breeding seasons in 2014 and 2015 were exceptionally mild (Appendix I). The majority of the cameras were installed shortly after the lake froze in December-January and removed in April-May.

The underwater surveys for more exact natality and pup mortality estimations covered all birth lair sites and some haulout lair sites found during the annual lair censuses (see Sipilä, 2003) in 2011−2013 (III). Immediately following ice break up in early May, the lakebed around the lair was investigated by wading, snorkeling, and/or scuba diving. Pup carcasses and placentas discovered in these investigations were stored at -20 C°. Placentas (n = 57) from years 2011−2012 were examined for the presence of the *Brucella* sp. bacterium by bacteriological methods (III).

To improve the seals' breeding habitat 117 man-made snowdrifts, designed to mimic wind-drifted snow, were constructed during the years 2010−2012 from December to early February (III). The drifts were piled before the beginning of the seals' breeding season, by collecting snow from ice using snow shovels and pushers (Fig. 2). The completed man-made drifts were, on average, 0.8 m in height, 8 m in length (parallel to the shoreline) and 3.5 m in width. The snowdrifts were examined in the following April during the annual lair census.

Figure 2. *Piling a man-made snowdrift in the breeding habitat of the ringed seal in Lake Saimaa, Finland. Photo: M. Kunnasranta.*

3 Results and discussion

3.1 LIFE HISTORY PARAMETERS

3.1.1 Rapid growth from birth to weaning

The newborn ringed seal is small in size compared to other phocid seals (Kovacs & Lavigne, 1986); in Lake Saimaa it is approximately 5 kg in mass and a little less than 70 cm in length (Fig. 3, II; see also Sipilä, 2003). This is in line with observations on the sizes of newborn marine ringed seals (Chapskii, 1940; McLaren, 1958; Hammill *et al.*, 1991). The pup grows rapidly and achieves almost 90% of its first year length, 80% of its girth and 50% of its weight by the time of weaning (II). Typically, the lair provides shelter against predators and a harsh climate for the most critical first months (III), and the mother and pup actively use the birth lair site, even after the snow lair has melted (Rautio *et al.*, 2009). The ringed seal pup is able to dive already at the age of a few days (Lydersen & Hammill, 1993), but it becomes easily hypothermic before the blubber layer, which is a good insulator also when submerged, develops (Smith *et al.*, 1991). The subcutaneous blubber in a newborn pup is nonexistent, but it develops rapidly during the nursing period (*e.g.* Hammill *et al.*, 1991; Lydersen *et al.*, 1992; Sipilä, 2003; II). The pup is an active swimmer and a skillful diver and spends a considerable time in the water already before weaning (Lydersen & Hammill, 1993; Rautio *et al.*, 2009; Niemi *et al.*, 2013b). However, it uses a relatively limited area (2 km^2) during the nursing period (Niemi *et al.*, 2012).

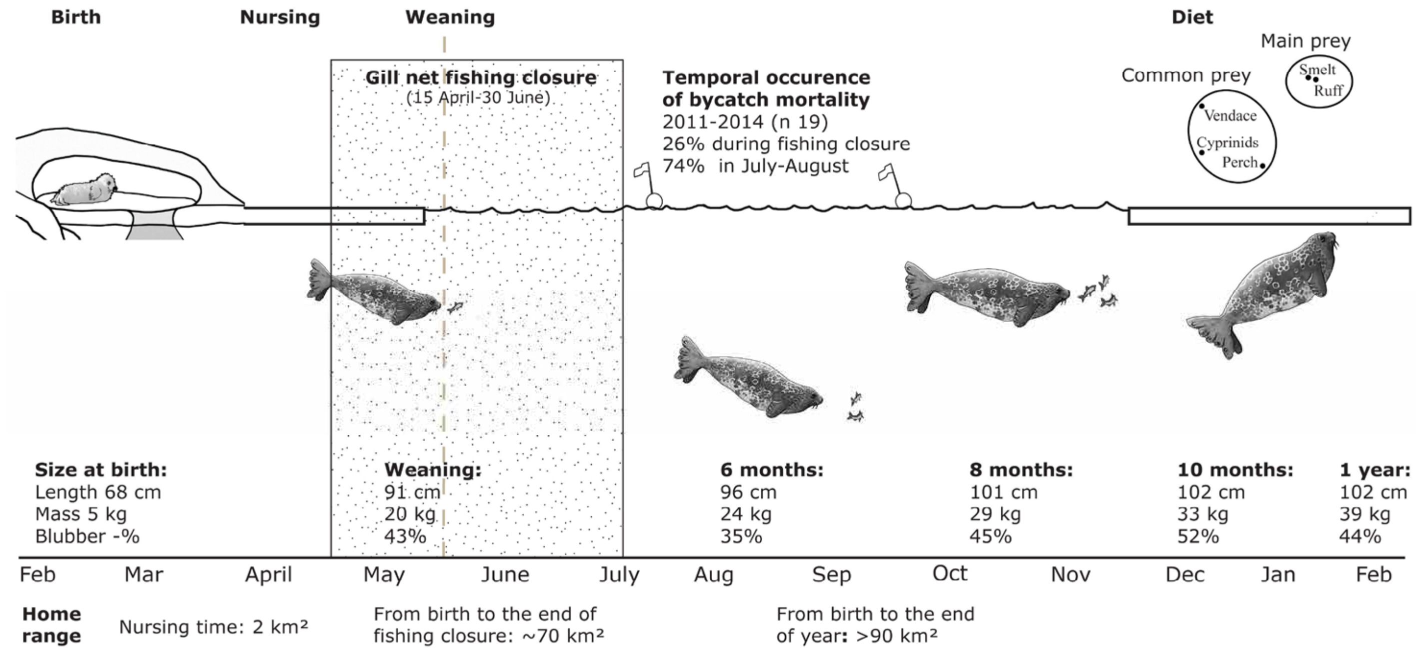

Figure 3. *First year of life of the Saimaa ringed seal. The following data sources were used in making the figure: home range sizes (Niemi, 2013), weaning time (Niemi et al., 2013b), bycatch mortality (Metsähallitus, 2015), diet (I) and body size (II).*

3.1.2 Perinatal mortality

The average lanugo pup mortality of the Saimaa ringed seal was 14%, when the snow cover was sufficient for lairs and no predation was observed in 2011–2013 (III). Altogether, the observed total mortality is higher than the earlier estimation (*ca*. 8%), which is based on a long-term lair census data under average winter conditions (Sipilä, 2003). However, the use of more effective underwater survey method for discovering pup carcasses (III) explains the increase in the detected mortality (Table 2). Mild winters, poor snow conditions and large changes (≥20 cm) in the lake's water level during the ice covered season may increase the perinatal mortality to even near to 30% (Ranta *et al.*, 1996; Sipilä, 2003; Ministry of the Environment, 2011). However, the perinatal mortality remained near the average rate also in the mild breeding seasons of 2014 and 2015 (Table 2), when man-made snowdrifts (III) offered shelter for the pups over the most critical period (see *3.2.2 Improving the seals' survival*). The magnitude of the observed mortality varied among the years (Table 2). Although the outflow actions taken to stabilize the water level were conducted in 2013, the drop in the water level was large during the ice covered season (Appendix I), and the perinatal mortality was relatively high (Table 2, III). However, there was no explanation for the similar mortality (18%) in 2011.

The causes of perinatal mortality of the Saimaa ringed seal are still not fully understood. A possible role for pathogenic infections remains largely unknown. The bacterium of *Brucella* sp., which may cause reproductive disorders (Miller *et al.*, 1999; Rhyan *et al.*, 2001; Foster *et al.*, 2002), was not detected in the seal placentas (III). Pups are exposed to relatively high amounts of mercury during gestation in Lake Saimaa (Lyytikäinen *et al.*, 2015), which might have a negative effect on their survival. Also little is known about the effects of human caused disturbance on seal breeding, but both in Saimaa and Ladoga lakes where

Table 1. *Camera traps situated at the breeding habitats of the Saimaa ringed seal in Haukivesi and Pihlajavesi basins. "Carnivore observations" is the proportion (%) of the cameras that recorded carnivores, and "Carnivore visits" is the number of separate carnivore visits observed at camera sites. Mild winters are highlighted in gray. Part of the data collected in 2010–2013 has already been published in paper III.*

	Trapping days		**Number of cameras**			**Carnivore observations (%)**		**Carnivore visits (*n*)**		
Year	**total**	**mean**	**total**	**at lair site**	**not at lair site**	**at lair site**	**not at lair site**	**total**	**at lair site**	**not at lair site**
2010	2518	97	26	7	19	57	26	11	4	7
2011	4975	106	47	24	23	50	39	34	22	12
2012	3910	80	49	28	21	43	33	45	30	15
2013	5873	111	53	10	43	60	28	35	13	22
2014	4610	72	64	47	17	45	59	115	78	37
2015	4983	74	67	38	29	84	55	239	198	41
All	26869		306	154	152			479	345	134

seals live in close contact with humans, the seals avoid potential lair sites near human induced disturbance (Sipilä, 1990; Trukanova *et al.*, 2013). The observations of humans at the vicinity of lair sites were sporadic, but the amount of the disturbance varied greatly inter-annually (III). Repeated dives into icy water before the blubber layer has grown and interruptions during nursing may have negative effects on pup growth and increase mortality risk. Moreover, in spite of the fact that no evidence for depression due to inbreeding has been detected so far, the potential impacts of the extremely low genetic diversity of the Saimaa ringed seal (Palo *et al.*, 2003; Valtonen *et al.*, 2012, 2014) cannot be ignored, as it too may influence mortality. Based on the autopsy reports and camera surveillance it seems that (contrary to the beliefs of locals) predation does not have influence on mortality during winters, if there is a sufficient amount of ice and snow (III). The situation, however, changes quickly when the sufficient snow cover is absent.

A cold environment and heavy predation from the polar bear (*Ursus maritimus*) and arctic fox (*Vulpes lagopus*) has made the small sized ringed seals seek shelter from subnivean lairs (Smith *et al.*, 1991). The above mentioned predators do not occur in Lake Saimaa region, but medium-sized carnivores pose a potential predation pressure on vulnerable pups on open ice. The first direct observation of a seal pup being killed by a predator (red fox) in Lake Saimaa was made during the mild winter in 2015. Pictures taken by a camera trap showed the attack (Fig. 4), and during the lair census the pup carcass was found on the bottom of the lake and the cause of death was verified in the autopsy. The killed pup (9.5 kg) was born in a man-made snowdrift that had partly melted already in the beginning of March. This observation confirms that the red fox, with a body mass of approximately 5 kg (Siivonen & Sulkava, 2002), is able to kill a seal pup around twice its size.

__Table 2.__ Perinatal mortality of the Saimaa ringed seal during the last ten years and numbers of dead pups observed using different methods. Pervasive underwater surveys have been conducted since 2011. The winters when snow conditions were unfavorable for lairs are highlighted in gray (see Appendix I). Data from the years 2006–2010 and 2014–2015 are obtained from Metsähallitus (2015), and 2011–2013 from paper III.

		Dead pups observed in			
Year	**Born pups**	**lair census**	**underwater survey**	**total**	**Mortality (%)**
2006	45	12	-	12	27
2007	34	8	-	8	24
2008	50	4	-	4	8
2009	44	5	1*	6	14
2010	57	3	1*	4	7
2011	56	5	5	10	18
2012	60	3	0	3	5
2013	62	7	4	11	18
2014	61	6	3	9	15
2015	56	5	4	9	16

* Several lair sites were surveyed by diving to collect placentas for genetic studies (see Valtonen *et al.*, 2015)

The camera trap data indicate that carnivores were significantly more active in the seals' breeding habitat during the mild winters. The numbers of separate observations during the mild breeding seasons were similar or more numerous annually than the total sum of visits during the four previous study years (Table 1). Only in the winters of 2014 and 2015 (except of one earlier incident) red foxes were observed to dig the lairs, and mothers and pups were seen in the pictures when the lairs had collapsed early (Fig. 4). The red fox was the most commonly observed carnivore, followed by the raccoon dog (*Nyctereutes procyonoides*) (Table 3), which is an invasive species in Finland (Kauhala & Kowalczyk, 2011). There were only four observations of the lynx (*Lynx lynx*), and neither the presence of the wolf (*Canis lupus*) nor of the brown bear (*Ursus arctos*) was recorded. The proportion (%) of raccoon dogs increased and red foxes decreased due to the warm winter (Table 3). In addition to the kill, three occasions where a pup and a red fox met and two occasions where a pup and raccoon dogs met were recorded (Fig. 4). Also once a pup and a raven (*Corvus corax*) were in a same image. All of these episodes, however, ended when the pup entered the water.

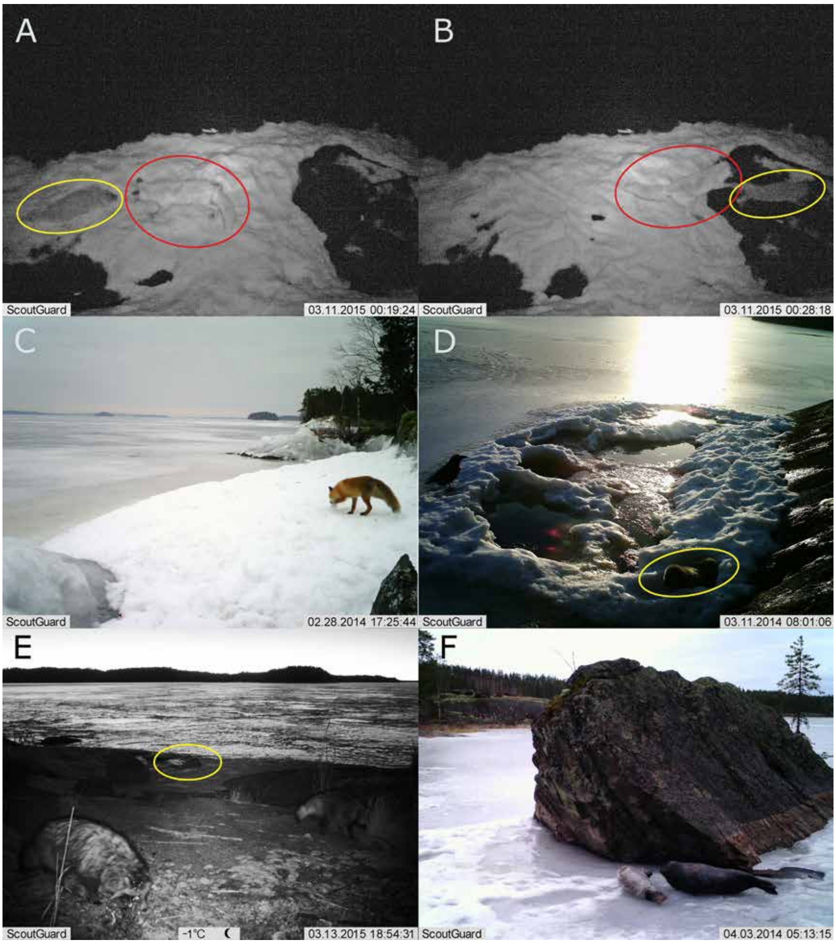

Figure 4. *Photos from the camera traps at breeding sites of the Saimaa ringed seal during the mild winters of 2014 and 2015. The first observation of a red fox attacking a seal pup (A–B), a red fox digging a birth lair (C), a pup and a raven (D) and a pup and a pair of raccoon dogs (E) at melted man-made snowdrifts, and a mother-pup pair during the nursing period (F). In the dark pictures the fox is circled in red and the pup in yellow.*

Table 3. *Proportions (%) of carnivores observed (n = 479) using the camera traps in the breeding habitat of the Saimaa ringed seal. The group "Unknown" includes carnivore observations, where the species could not be identified because of the poor quality of pictures. Mild winters are highlighted in gray.*

Winters	Red fox	Raccoon dog	Otter	Lynx	Unknown
2010-2013	68	13	8	1	10
2014-2015	56	27	3	1	12

3.1.2 Risky start for an independent life

The Saimaa ringed seal pup is weaned in mid-May after over a 9-week nursing period (Niemi, 2013; Niemi at al., 2013b). At weaning the pup is about 20 kg and its blubber content is 43% (Fig. 3, II). Although, the nursing period in Lake Saimaa is at least 3 weeks longer than that in the Arctic the body mass and blubber content at weaning are equal in both regions (Hammill *et al.*, 1991; Lydersen *et al.*, 1992). Based on the contents of the digestive tracts, the ringed seal pups forage during the nursing period, and do not fast after weaning (McLaren, 1958; I). However, the present results confirm the earlier assumption (Smith *et al.*, 1991) that the ringed seal pups suffer from nutritional deprivation after weaning (I–II). In addition to a loss in body condition that was observed in the stable isotope values (I), and a decrease in body mass and blubber, the post-weaning nutritional stress is also seen as a deceleration in growth (II). The loss in mass during the summer was short-term (approximately two months), but the recovery of the body condition took longer. The pups were 8 months old in October when they again reached the blubber content that was equivalent to what they had gained by the time of weaning (Fig. 3, II). After weaning the movements of the Saimaa ringed seal pup are random; it can travel 15 km a day and up to 25 km from its birth site by the end of June (Niemi *et al.*, 2013b) and it expands its home range during the summer and autumn (Fig. 3, Niemi, 2013).

An incidental bycatch is the most common observed cause of death of weaned Saimaa ringed seal pups (II). To mitigate the bycatch mortality the use of the most dangerous fishing gear (*i.e.* hook baited with fish and multifilament nets) are banned year-round in the seals' main distribution area (see Niemi *et al.*, 2012). In addition, gillnet fishing has been annually banned from the 15 August to the 30 June since 1982 in some regions of the breeding area, and the closure area was significantly expanded (from 64 km^2 to >2000 km^2) by 2011 (Niemi *et al.*, 2013b). Earlier, the peak in pups' bycatch mortality occurred in May–June (Sipilä *et al.*, 1990; Sipilä, 2003), but after the expansion of the closure area, it seems that the peak has shifted towards later summer. According to the data of Metsähallitus (2015), altogether 19 pups were reported as drowned in 2011–2014 and the majority of them had drowned in July–August, just after the fishing closure has ended (Fig. 3).

3.1.3 Late maturity and early death

The Saimaa ringed seal falls into the category of medium sized ringed seals (MacLaren, 1993) with an asymptotic body length of 132 cm (II). The body size of ringed seals varies greatly over their distribution area, and seasonal fluctuations in body mass are also large (Helle, 1979; Ryg *et al.*, 1990b; Smith *et al.*, 1991; McLaren, 1993). Although the fluctuation in mass complicates mass comparisons, it seems that among neighboring subspecies the Saimaa ringed seal is mid weighted with an asymptotic body mass of *ca*. 60 kg (II). The Baltic ringed seal is the heaviest (~90 kg; Helle, 1979), and the Ladoga ringed seal the lightest (~50 kg; Sipilä *et al.*, 1996) of these seals. Altogether, there is very little sexual dimorphism in ringed seals (Helle, 1979; Hyvärinen & Nieminen, 1990; McLaren, 1993), and in the present study the length of the mandible was the only growth parameter where sexual dimorphism was observed (II).

Ringed seals may live for over 40 years (McLaren, 1958), but in Lake Saimaa they die relatively young; approximately at the age of 10 years, if they survive through their first critical year (II). The Saimaa ringed seal achieves full body size approximately at the age of 4 years in body size measures (body length, maximum girth and mandible length) other than body mass, which continues to increase until at the age of 6 years (II). The growth of the baculum continues even longer into life: its growth in length ceases at about the age of 14 years, and its growth in mass continues throughout the seal's life. According to the growth of the baculum (see Ryg *et al.*, 1991), Saimaa ringed seal males reach their sexual maturity at the age of 5–6 years (II). If the age at sexual maturity is defined as the age at which asymptotic size, either in body length or mass, is achieved (see Baker *et al.*, 2010), both male and female Saimaa ringed seals reach maturity between the ages of 4–6 years. This estimation is in line with the age at sexual maturity in other ringed seals (Helle, 1980; Lydersen & Gjertz, 1987; Holst *et al.*, 1999; Krafft *et al.*, 2006; Chambellant *et al.*, 2012).

Small schooling fishes form the bulk of the diet of the Saimaa ringed seal, which is a generalist feeder foraging exclusively on fish in pelagic, benthic and littoral habitats (I). Its diet is composed of a minimum of 15 species, but it relies on the most abundant species: smelt (*Osmerus eperlanus*), ruff (*Gymnocephalus cernuus*), perch (*Perca fluviatilis*), vendace (*Coregonus albula*) and various cyprinids (I; see also Kunnasranta *et al.*, 1999). In general, the diet is similar among the different age groups, although pups feed on somewhat smaller fish than the older seals (I). Behavioral and genetic studies have suggested strong site fidelity for the Saimaa ringed seal (Kunnasranta, 2001; Niemi, 2013; Valtonen, 2014), and regional differences in the seals stable isotope values also support this suggestion (I).

The ringed seal is a capital breeder. Its blubber content fluctuates seasonally being at its highest in the winter and at its lowest after the breeding, nursing and molting seasons at the beginning of summer (McLaren, 1958; Helle, 1979; Ryg *et al.*, 1990b; Young and Ferguson, 2013). Similar patterns in the body condition of the Saimaa ringed seal were observed in the analysis of blubber content (II) and when the seals' stable isotope values were used as an indicator (I). The fluctuation and the mean blubber content were higher in females than in males (II), as has also been observed in marine ringed seals (Ryg *et al.*, 1990b).

Although the Saimaa ringed seal lives in a unique lacustrine habitat at the southern region of the species' distribution area, its growth and condition patterns (I–II) are similar to those of the Arctic ringed seals, which grow slowly, mature late, are able to live long and invest heavily on a single offspring at a time (McLaren, 1958; Lydersen and Gjertz, 1987; Smith *et al.*, 1991; Holst *et al.*, 1999; Krafft *et al.*, 2006; Chambellant *et al.*, 2012). These life-history traits together (also called the K-strategy) are connected to a relatively high probability of juvenile survival into adulthood. However, in Lake Saimaa the mortality of young age classes is extremely high and it has been estimated that almost 70% of the pups die before the age of one year (Kokko *et al.*, 1998; Sipilä, 2003).

3.2 RESPONSES TO CLIMATE CHANGE IN THE CONSERVATION OF THE SAIMAA RINGED SEAL

3.2.1 Developing monitoring

New noninvasive methods for monitoring the Saimaa ringed seal population are needed in a changing climate, when mild winters weaken the reliability of present methods and more precise knowledge on the population is needed. The current population size estimates are based on lair censuses, which are conducted annually in the spring, after the roofs of snow lairs have collapsed (Sipilä, 1990; Sipilä *et al.*, 1990). The population trends and birth rates are well known, but the reliability of the lair census suffers, when there is no sufficient snow cover. This was seen in 2014, when after the census three pups born at two sites (a pup and twins) and four haulout lairs were detected using the camera trap data. The lairs were clearly visible in the pictures, but had completely melted during the census. Camera traps are also used for collecting photo-identification data on

Saimaa ringed seal individuals. These data can be used, for example, for estimations of population size, dispersal, survival, and birth rate (Koivuniemi *et al.*, 2015).

Camera traps are an effective method for monitoring the breeding habitat and lair sites of the Saimaa ringed seal (III). It was even more effective to place the cameras at man-made snowdrifts; during the winters (2010–2013) with sufficient ice and snow cover 58%, and in the mild winters (2014 and 2015) around 90% of the man-made snowdrifts with cameras were used as lair sites. The camera data can be used to estimate the amount of human and predator activity in the seals' breeding habitat (Tables 1 and 3, III). This method also provides valuable information on the durability of the lairs, and on the behavior of the seals and predators. However, the camera traps provide information only about their immediate vicinity, and therefore, a wildlife triangle census based method (Pellikka *et al.*, 2005) might be a valuable addition for more comprehensive breeding habitat monitoring.

Underwater surveys at lair sites clearly improve the reliability of population estimates on natality and pup mortality (III). The method proved to be useful in estimating the perinatal mortality rate of the Saimaa ringed seal more precisely (Table 2). During the three years of study (2011–2013), nine dead pups were found in the surveys, and evidence for four pups being born (*i.e.* placentas found under lairs that had been determined as haulout lairs) was also discovered (III), though only few haulout lair sites were investigated. This shows that up to half of the dead pups might have remained undetected in earlier years, and some birth lairs have likely been incorrectly identified as haulout lairs in the lair censuses. A placenta was found at 46% of the birth lair sites, and the placenta samples were used for bacteriological (III) and genetic analyses: Saimaa ringed seal pups can be identified individually using DNA extracted from placentas (Valtonen *et al.*, 2015). After the underwater survey method was developed in the University of Eastern Finland, Metsähallitus has continued using it as a population monitoring tool and 3–4 dead pups have been discovered annually in these surveys (Table 2).

In addition to its effects on pup survival, climate change may also induce changes to ecosystems, which might have a negative influence on the seals' body condition. Therefore, more effective and sensitive body condition monitoring should be introduced for the early detection of potential changes in this critically endangered seal. The monitoring could be conducted by measuring the blubber thickness of seal carcasses. In addition to measuring above the sternum, also the dorsal side at about 60% of the length from nose to the flippers should be measured, since this is the optimal spot for condition estimation (see Ryg *et al.*, 1988). Also the accumulation of pollutants, especially mercury, in seals and in their diet should be monitored in Lake Saimaa on a more regular basis.

3.2.2 Improving the seals' survival

The recovery of the Saimaa ringed seal population from its decline caused by human activity has been slow. Today the population size is still small and the Saimaa ringed seal has the lowest genetic diversity ever recorded among pinnipeds (Valtonen *et al.*, 2014). Moreover, it has been suggested that the population is too small for maintaining its current genetic diversity in the long term (Valtonen *et al.*, 2014). Therefore, a population growth as rapid as possible should be ensured for this critically endangered seal.

Competition for resources between the seals and the fishermen is minimal or nonexistent in Lake Saimaa (I), but a significant aspect of encounters between seals and fishermen is the high bycatch mortality of especially young seals (Sipilä, 2003; Niemi, 2013; II). Our results demonstrate that after weaning the pups recover from post-weaning nutritional stress in the late autumn (I-II) and the peak of their bycatch mortality occurs in the late summer (Fig. 3). This information should be taken into account in the conservation of the Saimaa ringed seal. The spatial and temporal extensions of the fishing closures would improve the survival of especially weaned pups and juveniles, thus compensating for the elevated mortality caused by climate change.

In this study, a man-made snowdrift method was developed and tested in order to artificially improve the breeding sites of the Saimaa ringed seal (III). The seals accepted the man-made snowdrifts as lair sites, even when there was also wind-drifted snow available. The first pup was born in a man-made snowdrift in 2011. Although seals often use the same sites to build lairs (Helle *et al.*, 1984; Sipilä, 1990), the seals accepted more than half of the drifts that were piled at a location that had not previously been used as a lair site. Thus, it seems that man-made snowdrifts could be used also to attract the seals to build lairs in more suitable places with less human-induced disturbance during the breeding seasons.

Due to the exceptionally mild winter, no wind-drifted snow accumulated during the breeding season in 2014 (Appendix I), and the man-made snowdrift method was used for the first time as a conservation act. In addition to the coordinator Metsähallitus, our research group and altogether around 200 volunteers participated in the project. The novel know-how (see Kunnasranta *et al.*, 2014) produced during the development of this method was shared in this project. In January and early February 2014, just before the seals' breeding season, about 240 snowdrifts were piled at previously used lair sites (Metsähallitus, 2015). Over 90% of the pups that were discovered during the lair census that year were born in man-made snowdrifts.

Around 70 man-made snowdrifts were piled also in the mild winter of 2015, but only in the main breeding area, where the snow cover was least (Metsähallitus, 2015). The camera traps (*n* 25) situated in the vicinity of the man-made snowdrifts that were used as lairs in 2015 also recorded the melting process; by the end of February already 38% of the lairs' roofs had depressions in their snow surface and 16% had collapsed, and by the end of March 76% of the lairs had collapsed and 24% had melted completely. This shows that many of the roofs of the lairs collapsed early due to mild weather and rain (Appendix I), even though the snow in the man-made drifts was packed tight. Therefore, new methods and materials should be tested to create longer-lasting lair structures for the seals. Furthermore, as mild winters and a lack of snow cover make Saimaa ringed seal pups more vulnerable to predators (see above), methods to reduce the predation pressure should also be developed.

3.3 PREDICTING THE FUTURE

During the current global warming the increase in temperature measured in Finland (2.3 °C in the years 1847–2013) has been almost twice as high as the global mean increase (Mikkonen *et al.*, 2014). Especially the springs and late autumns have become warmer, whereas the change over the summer months has been smaller (Jylhä *et al.*, 2004; Tuomenvirta, 2004; Mikkonen *et al.*, 2014). A decline in the duration and depth of the snow cover, and a decline in the duration of the ice cover have been both observed and predicted (*e.g.* Elo *et al.*, 1998; Räisänen, 2008; Jylhä *et al.*, 2009; Kellomäki *et al.*, 2010; Holmberg *et al.*, 2014). Climate change will also have a significant influence on the quality of inland waters, due to, for example an increase in nutrient and pollutant runoff. Also it has been suggested that the amounts of pathogens and algal blooms will increase in the future (Murdoch *et al.*, 2007; Whitehead *et al.*, 2009).

The loss of ice and snow habitats poses direct threat to the survival of the Saimaa ringed seal pups. In addition to elevated perinatal mortality, poor ice and snow conditions may hamper growth and cause elevated mortality due to low body condition and decreased mass at weaning (Table 2, Hammill & Smith, 1991; Craig & Ragen, 1999; Smith & Harwood 2001; Hall *et al.*, 2001; Stirling & Smith, 2004; Ferguson *et al.*, 2005). Moreover, low weaning mass has been connected also to an elevated risk of bycatch mortality in Saimaa ringed seals (Sipilä & Hyvärinen, 1998). Although predictions on the effects of warming winters on human activity on Lake Saimaa are lacking, pups born without the shelter of the lair are most probably even more susceptible to human induced disturbance. Moreover, there is no doubt that a warming climate will expose the pups to new predation pressure. In addition to the red fox also the dog, the lynx, and other predators are very able to catch a seal pup when the pups do not have snow lair. An earlier spring and melting of the snow may expose the pups also to avian predators like the gulls (*Larus* sp.), the raven and the white-tailed eagle (*Haliaeetus albicilla*).

Changes in precipitation, snow accumulation and melt will cause large seasonal changes in water levels in Lake Saimaa, especially during the seal's breeding season (Veijalainen *et al.*, 2010). The change in the lake's hydrology is an additional potential climate change induced threat to the Saimaa ringed seal. In addition, if the ice covered season shortens as predicted (Jylhä *et al.*, 2009), in 100 years there will be winters without continuous ice cover and the amount of snow will decrease dramatically. Therefore permanent artificial lair structures might be needed in the future.

The various changes in the lake habitat may be compensated by changes in the body condition of the seals. In the fish communities of northern European freshwater lakes, a shift towards cyprinid and percid dominance, at the expense of coregonids and other salmonids, is the expected result of global warming (Lehtonen, 1996; Jeppessen *et al.*, 2010). This shift in the abundance of different fish species may influence the quality of the diet of the Saimaa ringed seal by decreasing the amount of energetically rich prey species, like vendace and smelt. Changes in the quality and abundance of prey, and the loss of ice, and therefore breeding and resting platforms, may have a negative effect on the seals' body condition. Due to a warmer environment also the abundance and prevalence of various pathogens might increase (Gallana *et al.*, 2013). Furthermore, stress and reduced body condition exposes to diseases and parasites, and environmental pollutants may have immunosuppressive and other negative effects (Learmonth at al., 2006; Kakuschke & Prange, 2007; Burek *et al.*, 2008; Das *et al.*, 2008). In the case of the Saimaa ringed seal the small population size and extremely low genetic diversity may weaken its resilience to a rapidly changing climate (Valtonen, 2014).

It has been estimated that climate change will increase the runoff and bioavailability of mercury (Whitehead *et al.*, 2009; Stern *et al.*, 2012). In general, mercury has been connected with reproductive disorders (like stillbirths), nerve damages and other toxic effects in mammals (Wolfe *et al.*, 1998). It has been suggested that a high mercury concentration was one of the factors that caused the drastic decline in the seal population in Lake Saimaa (Hyvärinen *et al.*, 1998). Although mercury concentrations have decreased from their peak values in the 1960s, the Saimaa ringed seal still suffers from a very high mercury contamination compared to marine ringed seals (Hyvärinen *et al.*, 1998; Lyytikäinen *et al.*, 2015). The potential increase in mercury in the seals diet forms a considerable threat in the future.

Species like the Saimaa ringed seal, which have a restricted geographical distribution and no opportunities for expanding their range as a response to climate change, are particularly vulnerable to the effects of climate change (Learmonth *et al.*, 2006). Nevertheless, the future of the Saimaa ringed seal is not hopeless; during its fairly long isolation history it has lived through the earlier warm period and has already evolved adaptations to milder climates, like the pups' gray lanugo hair and the ability to also use a terrestrial habitat for molting, resting and nursing (Hyvärinen *et al.*, 1995; Kunnasranta, 2001; Kunnasranta *et al.*, 2002; Niemi *et al.*, 2013a, b). These characteristics might help the subspecies' survive in a changing climate. The implementations of actions to stop the global warming caused by humans are however slow, and it will take a long time before the effects of depleting greenhouse gas emissions will be seen in the global climate. Therefore, effective conservation actions to safeguard the Saimaa ringed seal are needed.

4 Conclusions

This study shows that the perinatal mortality of the Saimaa ringed seal is higher than was earlier assumed, but the causes of the mortality are not fully known. Successful nursing enables the rapid growth of the seal pup, which is an essential for its survival. However, a warming climate weakens the seals breeding habitat; without the shelter of snow lairs pups are more vulnerable to disturbance, thermal stress and predation, and the predicted large changes in the lake's water level during the ice covered period might elevate pup mortality. Moreover, predators are more active in the seals' breeding habitat during mild winters. The novel noninvasive monitoring methods developed in the present study would improve the accuracy of population monitoring especially during mild winters.

The man-made snowdrift method that was developed in the present study was successfully used to compensate for the negative effects of poor snow conditions on pup survival. However, due to the mild weather and rainfall also the lairs situated in man-made snowdrifts collapsed early, which shows that the method still requires some further developing. Seal mortality in young age groups is extremely high and bycatch is the most common cause of death in weaned Saimaa ringed seal pups. The peak of the pups' bycatches occurs in July-August, just after the end of the gill net closure period, and the pups recover from the post-weaning nutritional deprivation as late as in October. These findings demonstrate that spatial and temporal extensions of the fishing closures would improve the survival of weaned pups and juveniles and compensate for the elevated mortality caused by climate change. The predicted changes in the seals lake habitat induced by climate change may also expose the seals to pollutants, pathogens and lead to compensations in body condition. At the moment it seems that the predicted increase in the concentrations of mercury is a considerable threat to this seal population. The health, body condition and pollutant concentrations of the seals should be monitored at a more regular basis in order to enable the early detection of possible changes in the seals.

This thesis clearly demonstrates that the ongoing climate change poses a considerable threat to the Saimaa ringed seal in various ways. Nevertheless, the future of this unique subspecies, which has persisted landlocked in Lake Saimaa for nearly 10,000 years, is not hopeless, but more effective conservation is necessary to make possible its survival in the long term. Stopping the climate change is a slow and challenging process and it might take more time than this small and endangered seal population might tolerate in its current state. Therefore, conservation acts should be targeted at the most acute threats, such as the extremely high juvenile mortality, and a rapid population growth should be ensured (1) by reducing the human induced mortality to the minimum, (2) by securing low disturbance levels at the seals breeding habitat and a stable water level during the ice covered season, and (3) by including the man-made snowdrift method to established conservation practices. A larger population size of the Saimaa ringed seal would ensure better prospects for its survival in a rapidly changing climate.

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Appendix I

Winter time conditions during the last ten years in Haukivesi basin, which is one of the main breeding areas of the Saimaa ringed seal. The duration of the ice covered period and the change (cm) in the water level from freeze up to ice break up (Oiva©, 20015), and information on snow cover thickness (cm), temperatures (C°) and the number of days with a mean temperature above zero, and rainfall (mm) (Finnish Meteorological Institute©). Winters with poor snow conditions are highlighted in gray.

	Ice covered period				Snow cover mean (range)			Temperature mean (days above -0)			Rainfall		
Year	**Start**	**End**	**Days**	**Water level**	**Jan**	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**	**Jan**	**Feb**	**Mar**
2006*	17.12.-05	10.5.-06	144	-9	30 (23-38)	46 (35-48)	49 (44-59)	-7 (2)	-14 (0)	-11 (1)	3	0	3
2007	10.1.-07**	24.4.-07	104	26	18 (0-28)	46 (28-49)	23 (0-48)	-6 (8)	-16 (0)	1 (23)	19	0	12
2008	12.11.-07	2.5.-08	172	26	10 (1-25)	29 (21-45)	45 (30-63)	-3 (12)	-2 (5)***	-4 (6)	31	3	6
2009	24.12.-08	8.5.-09	135	-33	24 (11-36)	32 (28-37)	38 (36-38)	-7 (4)	-8 (0)	-4 (4)	5	0	4
2010	14.12.-09	4.5.-10	141	13	37 (33-43)	61 (44-77)	71 (54-81)	-16 (0)	-12 (1)	-5 (7)	0	3	21
2011	27.11.-10	8.5.-11	162	8	45 (23-63)	72 (60-75)	65 (60-75)	-9 (2)	-15 (0)	-4 (3)	0	0	5
2012	2.1.-12	7.5.-12	126	28	35 (1-50)	50 (47-54)	51 (46-59)	-8 (2)	-12 (1)	-2 (5)	12	0	0
2013	2.12.-12	5.5.-13	154	-45	42 (33-53)	59 (53-65)	60 (54-64)	-8 (2)	-4 (1)	-10 (0)	13	6	0
2014	10.12.-13	19.4.-14	130	33	12 (0-15)	20 (13-24)	6 (0-13)	-10 (7)	-1 (18)	1 (21)	11	17	12
2015	22.12.-14	16.4.-15	115	17	27 (7-40)	37 (24-45)	12 (5-24)	-6 (5)	-2 (11)	0 (19)	21	7	38

*Only powder snow that is unfavorable for constructing lairs was present.
**Data missing; the date is estimated according to observation sites nearby.
***Data missing from 12 days.

Miina Auttila

The endangered Saimaa ringed seal in a changing climate - challenges for conservation and monitoring

An endangered ringed seal subspecies inhabits Lake Saimaa in Finland. The breeding success of the Saimaa ringed seal is dependent on sufficient ice and snow cover, and climate change has a negative effect on the survival and monitoring of the population. This thesis brings new information about the ecology of the ringed seal, focusing on factors that are vital in a changing climate, and providing novel tools for monitoring and conservation.

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