SCANDINAVIAN WOLF ECOLOGY AND MANAGEMENT FROM A MULTISPECIES PERSPECTIVE, 2015-2017.

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Objectives and scientific context

Throughout much of the world's temperate forests carnivore populations re-colonize formerly inhabited ranges (Enserink and Vogel 2006). This rapid re-colonization has important implications for the function of ecosystems but also because wolves cause wildlife-human conflicts (Sjölander-Lindqvist 2009, Gangås et al. 2013). In Scandinavia, the wolf (*Canis lupus*) population has doubled its size during the last five years and in some areas the density is comparable to saturated populations (Mattisson et al. 2013). Thus, there is a potential for a significant impact on the ecosystem through limitation or behavioral changes of prey ultimately affecting vegetation, competition with other carnivore species, changed conditions for the flow of biomass for scavengers, and intensified conflicts with humans (Ray et al. 2005).

Scandinavia is to a large extent different to many of the areas where wolves previously have been studied because Scandinavia is under heavy anthropogenic influence and because protected areas such as national parks are small relative to the spatial used by large carnivores (Jedrzejewski et al. 2007, Mattisson et al. 2013). Long-term research on large carnivores is often a prerequisite for generating data that are of interest for both the scientific and the management community (Ray et al. 2005, Terborgh and Estes 2010). Our long-term project has generated highly relevant research for a variety of management issues and contributed with scientific based knowledge on several different aspects of large carnivore ecology (see status report). For the next three-year period our objective is to focus on the following research areas: refining methods for wolf population estimation; examining the effects of human harvest on wolf population size, structure and genetic constitution; interactions with other guild members; predation dynamics in areas with multiple prey; and linking wolf demography to genetics, spatial characteristics and human attitudes.

Objectives, research questions and state of knowledge

1.a Evaluation of methods used for monitoring
Central to management of wildlife populations are data on population size, development and distribution. To date, wolf population monitoring in Scandinavia has relied on methods closely related to total counts combined with individual identification from DNA and collaring of wolves (Liberg et al. 2012, Wabakken et al. 2014). A recent SKANDULV-lead

evaluation of the monitoring system identified several aspects that warrant further development (Wikenros et al. 2014). Within this context, we will develop a design for spatial monitoring with different levels of sampling to provide the most precise and accurate measurement of group size. Particularly important will be to document variations in group size according to primiparous status or inbreeding and to calculate the number of territories to sample to reach a good statistical power. We will then use individual based population models to quantify – with uncertainty properly accounted for – a conversion factor from the number of reproductions to total population size, the latter remaining the currency used to make management decisions. Moreover, as a population grow larger there is need for a more cost effective monitoring. By using information on wolf movements and demography it is possible to model how field efforts during censuses can be optimized.

1.b Modelling the effects of harvest strategies, including genetics
With the Scandinavian wolf population continuously growing, controlling the population through harvest has become a central management option. Earlier research has provided models that have targeted the demographic effects of different harvest strategies (Liberg et al. 2009, 2011, 2012). But because the Scandinavian wolf population is relatively small, semi-isolated, and suffer from low genetic variation the effects of different harvest strategies also need to incorporate genetic aspects. There is a need for management to have a robust modelling framework that can be used to predict both the demographic and genetic consequences of future harvest size and strategies. Our objective is use available data on demography and genetics to construct this type of model that can be used in active management.

2. Multispecies - interactions with prey and other predators in the ecosystem
Interaction between predators is an important factor affecting population dynamics of carnivores (Linnell and Strand 2000). The effect of interactions between species such as interference and exploitation competition differs between species, habitats, and densities of competitors or geographical location (Creel 2001). In multi-predator communities, competition or predation may limit the abundance of other predators because many individuals suffer a reduction in fecundity, survivorship, or growth as a result of intra- or interspecific resource competition or direct interference competition (Watts and Holekamp 2008). The re-colonization of wolves into Scandinavia has in some parts occurred in parallel with an expansion of other large carnivores such as lynx (*Lynx lynx*) (Liberg and Andrén 2006), brown bears (*Ursus arctos*) (Kindberg et al. 2011), and more recently wolverines (*Gulo gulo*) (van Dijk et al. 2008). We have previously studied the potential interactions between overlapping populations of wolves and lynx (Wikenros et al. 2010) and are currently studying interactions between wolves and brown bears (Milleret 2012), studies of potential interactions between wolves and wolverines will be initiated.

2.a Wolf-brown bear-moose-human interaction
We aim to intensify a cooperative research project with the Scandinavian Brown Bear Research Project to further investigate interactions between brown bears and wolves and their combined effect on moose. We intend to study habitat selection on various spatio-temporal scales, direct and indirect interactions, the propensity for these species to visit, use and possibly monopolize carcasses killed by the other species, and test if the presence of brown bears affects the foraging behavior of wolves (i.e. kill rate). Especially relevant is to study the combined effect of wolf and brown bear predation on the moose population and its consequences for harvest yield (Jonzén et al. 2013). We will combine data on both harvest yield (moose shot per area), hunter effort (hours spent hunting), and moose density (moose

observations) to study the temporal development of human harvest in wolf-bear and predator-free areas, to better evaluate the impact of wolves and brown bears on the moose-harvest system. Our working hypothesis is that brown bear presence leads to an increased kill rate on common prey species (moose) for wolves due to carcass utilization by brown bears. These studies rely on already agreed collaboration between the wolf and the brown bear research projects in Scandinavia. We also aim, to compare our data on wolf-bear-prey interactions in Scandinavia with similar data from Yellowstone National Park, USA, contributing to the general understanding of the co-existence of large carnivores in different systems.

2.b Wolf-wolverine interactions

The recent colonization by wolverines into the southern boreal forest system of Scandinavia has led to overlapping distributions of wolves and wolverine. A central question is to study the symmetry of their interactions and in particular test the hypothesis that wolf occupation may facilitate wolverine establishment by providing carcasses (van Dijk et al. 2008). Studies at the home-range level will provide information on to the extent that wolverines utilize wolf-killed prey as the source of food and how this may affect their movement ecology and fitness. This will contribute to our understanding on if and how this smallest large predator will benefit from wolf presence by utilizing carcasses of wolf killed prey.

2.c Wolf-multiple wild prey interactions

Large predators such as wolves and brown bears may severely affect the abundance and structure of prey populations (NRC 1997, Eberhardt et al. 2003). Much work on wolf-ungulate dynamics has focused to study wolf predation and its characteristics in relation to their primary prey species (Messier 1994, Vucetich et al. 2002). Wolf research in Scandinavia has so far mainly targeted wolf-moose interactions (Sand et al. 2005, 2006, 2008, 2012, Gervasi et al. 2013, Zimmermann et al. 2014a) and its impact on human sustainable yield harvest (Wikenros 2011, Jonzén et al. 2013). With the recent expansion of the wolf population into more southern areas in Scandinavia, there is a need to include studies on wolf predation in a multi-prey community which includes much higher densities of alternative prey species such as roe deer (*Capreolus capreolus*), fallow deer (*Dama dama*), red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*). Our objective is to obtain a more complete set of estimates of wolf predation at variable deer densities (mainly roe deer) by quantifying prey selection and kill rate as a function of both moose and deer density.

2.d Wolf-domestic prey

Some areas also include a significantly higher density of livestock such as sheep and cattle that results in an increased risk for wolf depredation events on domestic animals. Specifically we will study wolf behavior near cattle in relation to density of wild prey species by performing intense predation studies.

2.e Wolf-reindeer interactions

Another area of strong relevance to management is to study the effects of wolves and their predation in the reindeer (*Rangifer rangifer*) husbandry area of Scandinavia. This area of Scandinavia has clear restrictions against wolf presence by the political and management authorities, but have a continuous influx of wolves from both the Scandinavian population in the south and from individuals immigrating from the north and east (Liberg and Sand 2009). Because the Scandinavian population is highly dependent on immigration from the Finnish/Russian population and because these individuals must traverse the reindeer husbandry area there is a strong conflict for having wolves in this area. The possibilities for having genetically important wolves present in the reindeer area is dependent on the extent of

damage they cause for the reindeer herding. Thus, there is a need to more closely study the effects and damage caused by wolves when disperse through or establish within this area. Moreover, dispersing wolves at first usually have a search image on moose (their main food), but when moving into the reindeer husbandry area, how short or long this search image may last before prey switching towards semi-domestic reindeer is unknown, and should be studied.

2.f Linking demography to habitat suitability

At a broad scale, habitat suitability models have been provided by identifying the factors determining the presence of a given species at a given location (Basille et al. 2008, Martin et al. 2012a). Few studies have focused on individual performance and population dynamics, especially because of the difficulties to collect long-term spatial data of recognizable individuals and to link the right proxy of performance to the right spatial metric (Gaillard et al. 2010). Because population development, size and composition has been and will continue to be a central part of wolf ecology in Scandinavia, studies of demographic parameters will be important as will studies on how these are mechanistically linked to environmental structures. We will test what spatial structuring factors that affect population dynamics and individual performance. This includes 1) prey density, vegetation and topography, 2) human impact (e.g. human density, infrastructure), 3) climate (e.g. winter conditions) and 4) brown bear distribution. We will work on several spatio-temporal scales, from the establishment of wolf packs in a given area, to the effect of natal dispersal behavior on dispersal success including the effect of fine scale movements on resource acquisition. Causes and rates of mortality including the extent of poaching (Liberg et al. 2012) being a limiting factor of population growth warrants further focus as are the factors influencing establishment, persistence (mortality) and performance (reproductive success) of wolf packs in the population (part of ongoing PhD-study at HUC, Evenstad).

2.g Linking genetics and ecology

Past research on wolf ecology in Scandinavia integrated research on genetics to ecological parameters including genetic rescue (Vila et al. 2003), effects of inbreeding depression on fitness traits (Liberg et al. 2005, Bensch et al. 2006), and information on population origin and connectivity with source populations (Forslund 2009, Åkesson and Bensch 2009, Liberg and Sand 2009, 2012a,b). In Sweden, the genetic status of the population is currently a major issue for whether the Scandinavian population has obtained favorable conservation status (FCS) according to the article 17 in the habitat directive of the European Union (SOU 2011:37, SOU 2013:60, Prop. 2012/13:191). In foreseeable future, continued integration of estimates of population development, ecological, and genetic data will be of strong scientific interest and of high relevance for wolf management in Scandinavia. For the next three years we will investigate 1) how the genetic constitution in the population is affected by harvest and 2) the mechanisms causing inbreeding depression in the population. We will test the hypothesis that recent immigration of un-related wolves has resulted in positive demographic effects at the population level i.e., genetic rescue and analyze how individual genetic constitution is linked to early survival, pair formation, breeding success, morphological traits, body condition and malformations.

3. Integrating human dimension with wolf ecology

Recent studies on public attitudes towards large carnivores have shown large geographical differences as well as significant differences on the national level in Norway and Sweden (Gangås et al. 2013). As an extension of studies on wolf demography and its spatially structuring factors, it is now possible to initiating an interdisciplinary study by integrating data on spatial variation in public attitudes (data currently collected at HUC, Evenstad) with

data on components of demography. Specifically, we will test if public attitudes towards wolves and poaching may contribute to explain past spatial performance and development of the wolf population.

Time schedule, implementation and collaborations

For the three-year period 2015-2017, to summarize in short, our main objectives is to focus on the following research areas: refining methods for wolf population estimation; examining the effects of human harvest on wolf population size, structure and genetic constitution; wolf interactions with other guild members; predation dynamics in areas with multiple prey; and linking wolf demography to genetics, spatial characteristics and human attitudes.

In addition to the two research groups responsible for this project description and application from the Scandinavian wolf research project - SKANDULV (SLU and HUC), the project will continue and increase the scientific cooperation with several other researcher and institutions. Among these are Øystein Flagstad, John Linnell, John Odden (Rovdata/NINA), Olof Liberg (emeritus, SLU), Staffan Bensch, Niclaes Jonzén (Lund University), Linn Swensson, Jens Karlsson (Wildlife Damage Center, Sweden), Ilpo Kojola (Finnish Game and Fisheries Research Institute), and on bears Jon Swenson, Jonas Kinberg (Norwegian University of Life Sciences, Swedish Hunting Association), and on interactions with wolverines Jens Persson, Malin Aronsson (SLU)

Methods and data

Ten to 15 wolves will be marked annually by darting from helicopter, and equipped with GPS/GSM-collars mainly in areas with overlapping populations of brown bears and wolverines, and in areas with high density of multiple prey. The research project has been evaluated and approved by The Norwegian Agency of Animal Welfare (FOTS ID 7224). Summer litter sizes are determined by direct counts of the number of pups at wolf dens and by DNA-analyses of pup scats collected at den sites. DNA analyses of samples taken from anaesthetized and retrieved dead wolves and non-invasive samples (feces, hair) collected during other field activities are performed at Rovdata/NINA and Grimsö (Åkesson et al. 2013). Predation on ungulates is studied during 6-8 week periods with intensive GPS positioning (1-2 locations/hour) of instrumented wolves in combination with field investigation of GPS-locations (Sand et al. 2005). Population densities and distributions of ungulates are estimated by pellet counts (Månsson et al. 2011, Zimmermann et al. 2014). Modeling of the effects of harvest strategies and viability analyses will be conducted by using individually- and pack-based models and parameterized with demographic data as received from collared wolves (Chapron et al. 2012). For exploring interaction among predator species we will use GPS-collars on multiple species in the same area, snow tracking of individuals, predation studies, camera traps at kill sites, population estimates of other species.

Relevance for management

The strong re-colonization of wolves in Scandinavia is an example of how successful conservation efforts may change negative population trends. However, the successful conservation of wolves has resulted in strong conflicts with humans in a number of aspects.

As a wolf population grows larger there is a need of an active and adaptive management, including many different aspects such as increased efforts of communication, preventive measures and compensation payments, and harvest of the wolf population. Management actions should continuously be evaluated and existing knowledge used to make new qualified predictions on how these actions will affect the wolf population and other species interacting in the system (Walters 1986).

The management of wolves in Sweden is governed by the EU Habitats Directive which puts strict conditions about how to manage the wolf population in Europe. The Habitats Directive and its interpretation guiding documents also put emphasis on the use of best available science in assessing the conservation status of species, such as demography and genetics. Our project is the single largest producer of scientific knowledge on wolves in Scandinavia and is therefore an important support for Swedish authorities in handling this controversial issue. From communication with the Scandinavian management authorities on specific management relevant research questions, we have identified some specific areas that deserve further focus. These include evaluation of the monitoring methods used for estimating population size and structure (for which a part has been funded directly from SEPA), models that consider different types of harvest of wolves and how they may affect population demography (census estimates) and genetics. There is also a need to better understand how a growing wolf population affects and are affected by other species including different types of prey, large carnivores, and human activities. The above mentioned factors should be linked to basic demographic and genetic parameters and processes to receive a better understanding of the mechanisms and overall impact of inbreeding and genetic diversity on population status. Our research will focus on how to improve monitoring methods and the construction of harvest models (Tools for wildlife research), to study how wolves interact with other carnivore and prey species (Multispecies research) and to link human dimension to ecological parameters of the wolf population (Future wildlife management).

Plan for communication

SKANDULV has a developed strategy to communicate results in high-ranked scientific journals and in Swedish/Norwegian popular science articles. The research project is organizing an annual three day conference where results are communicated among researchers, representatives from the ministry of environment, central managing authorities (Miljødirektoratet & SEPA), the regional management on the county level (Rovviltnemnder, County Administrative Boards) and NGOs (conservation and hunting associations). SKANDULV performs educational presentations on a regular basis for managers, stakeholders and the general public. The publications are made available at SKANDULV´s, SLU´s and HUC's websites. Our results will also be published in popular magazines (Hjorteviltet, , Fakta Skog, Svensk Jakt, Våre Rovdyr) and informed through local media. Results will also be orally presented at undergraduate university courses, stakeholder meetings, international congresses, and at annual Large Carnivore Symposiums, usually receiving a large focus from media. The coordinator of the project (Camilla Wikenros) will serve as a communication channel to the public, to other academic environments, and to management authorities at different levels. During the previous three-year-period we produced a total of 40 different publications/reports including 14 scientific, 13 popular, 5 technical reports and 8 student thesis and participated in a number of meetings, workshops, symposia and congresses.

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