Between devil and (not a very) deep blue sea

Endangered sea shore species in a changing climate

Action 11: Assessment of impacts of climate change on biodiversity in coastal ecosystems and implementation of new policies and conservation strategies

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VACCIA

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Front page: Beef cattle grazing at the low elevation sea shore meadow at Kutukari, Hailuoto Island at the Bothnian Bay. Trampling by cattle decreases the reproductive success of the endangered Southern Dunlin (*Calidris alpina schinzii*). Photo: Marika Niemelä.

1 Foreword

Vulnerability Assessment of ecosystem services for Climate Change Impacts and Adaptation (VACCIA) was a EU LIFE+ project in 2009–2011. VACCIA was coordinated by Finnish Environment Institute and the participating institutes included the Finnish Meteorological Institute and the Universities of Helsinki, Jyväskylä and Oulu.

VACCIA was divided into 13 Action packages. Here we summarize part of the work conducted in Action 11: Assessment of impacts of climate change on biodiversity in coastal ecosystems and implementation of new policies and conservation strategies. This action was led by Marko Hyvärinen, with Kari Koivula, Anna Mari Markkola and Markku Orell each leading their respective research groups. The other parts of Action 11 are (1) The strategy and action plant for *ex situ* conservation of threatened plants in Finland (Marko Hyvärinen) and (2) Spatial population model on passerine birds in fragmented forest a habitats and its implementation in two LT(S)ER-sites with contrasting climate (Markku Orell). These parts of Action 11 are reported separately.

We wish to thank Kirsti Jylhä and Reija Ruuhela of the Finnish Meteorological Institute for providing the sea level data. We are also grateful to Jorma Pessa, Sami Timonen, Johanna Helkimo and numerous field assistants and the cattle owners for co-operation in the study on Southern Dunlin nesting preformance. We are also grateful to late Jouko Siira, who initiated the long-term monitoring of the Arctic pendant grass and Creeping alkali grass, and all the field workers who helped in the continuation of this work.

In addition to VACCIA, parts of this work has been funded by the Finnish Cultural Foundation, the Kone Foundation, the Emil Aaltonen Foundation, the Tauno Tönning Foundation, Oulun luonnonystävät, Societas pro Fauna et Flora Fennica, Maj and Tor Nessling Foundation and NORNET. Wihuri Foundation the Thule Institute at the University of Oulu and the Finnish Environment Centre, the Academy of Finland (projects 128384, 47973, 50451 and 1201996)

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2 Introduction

2.1 Land-uplift shores at Bothnian Bay

The shores of the Bothnian Bay in the northern Baltic Sea are characterised by relatively rapid isostatic land uplift (ca. 6.9 – 9 mm year^{-1}) continuously exposing virgin land for plants to colonise. Autogenic and allogenic changes in soil and plant communities will eventually make these exposed sites unsuitable for the early colonisers. The course of the primary succession in the waterfront is often delayed and shaped by frequent disturbances by ice scouring, water level movements and suffocation of extant vegetation by floating plant debris. Hence, disturbances are the key processes underlying the local short-term dynamics of the plant populations of the seashore meadows

A number of species require the habitat that is kept relatively open by the scouring of shore vegetation by waves and ice and the grazing by cattle and geese, which use this region as important feeding area during their migration. The topography of the area is very flat, which means that even small changes in sea level will result in large horizontal movement of the shore line. This makes the shores frequently subject to the flooding of sea water when air pressure differences and southern winds force the water towards the end of the Bothnian Bay. Annual variation is often ± 1 m relative to the theoretical mean water level, which will either expose large areas of the sea bottom and facilitate the feeding of many waders, or flood to large extents of the coastal meadows that serve as the nesting grounds. Most plant species inhabiting the shores line are relatively tolerant of short duration floods, but these may also be detrimental if they coincide with the time of flowering or another sensitive part of their life-cycle. Flooding sea water will also carry large amounts of debris, such as reed and algae, which will be deposited to the shore when the water recedes after the flood. The resulting mats of debris can prevent the growth of the plants below. A handful of plant species has adapted to such high-disturbance conditions, however, and benefit from the disturbance because their competitors are more adversely affected.

The Red List of Finnish Species (Rassi et al. 2010) reports shores to be the prime habitat for an important proportion (12.5 %) of endangered species. The report stated overgrowth to be the most important threat. Overgrowth results from several different processes and attempts have been made to slow it down with active management. Climate change and its consequences have not been able to take into account and the Red List does not yet consider it to be a significant threat. The following will present the effect of climate change on habitats with examples of endangered species studied at the Bothnian Bay.

2.2 Climate change and the Baltic Sea

Along with the habitat destruction and deterioration, global warming is one of the most important factors threatening the biodiversity on earth. There is already a pile of evidence for changes due to climate change in e.g. phenology and distribution of species representing different taxa (e.g. Walther et al. 2002, Parmesan & Yohe 2003). As the climate change progresses, directional changes (i.e. trends) in the mean climate values will and already have caused changes in ecosystems, for example through shifts in vegetation patterns (Jentsch et al. 2007). It has recently been recognized that also the already emerging intensification of extreme weather events may have serious implications for the ecosystems worldwide (Jentsch et al. 2007). Extreme weather events, such as floods, prolonged frozen spells and droughts, can have catastrophic effects on e.g. bird populations, including long-term effects on whole cohorts (Stenseth et al. 2002, Crick 2004). Probably the most well known regularly occurring major weather event is the El Niño, leading to breeding failure and mortality among seabirds in the Pacific area (Crick 2004).

Climate warming is expected to change the hydrological conditions at low elevation meadows at the northern parts of the Bothnian Bay. At the more southern parts of Finland this process is likely not as extensive. Especially at the Bothnian Bay the rise of sea level will slow the rate of new shore emerging with land uplift and the short term wind-raised floods may become more common. The wind-raised floods are the increase in water level caused by the certain wind directions, leading to sea water being pushed to the end of the Bothnian Bay.

The sea level is already rising because of heat expansion, and it is expected to accelerate in future decades, especially if the glaciers start to melt. When the sea-level rises the vegetation moves upward and inland, but sea walls that prevent this are believed to lead to coastal squeeze and loss of marsh area. An increase in the wind-raised floods at late spring will affect the reproductive output of especially ducks and shore waterfowl and waders. The effects of wind-raised floods on vegetation may be both negative and positive. The concern for the coastal habitats such as saltmarshes and grasslands is global. However, the sea-level rise does not necessarily lead to loss of marsh area because marshes can accrete vertically and maintain their elevation with respect to sea-level (Hughes 2004). The decreasing rate of emergence of new shore will make the low-growth vegetation meadow zone narrower, which diminishes and deteriorates the habitat for the species requiring it.

The amount of habitats for the birds nesting at low elevation sea shores will decrease and, in addition, the reproductive success of the birds may decrease especially due to wind-raised floods. Flood damages affect reproductive success directly as damaged nests, but also by delaying the time of nesting as the proportion of renesting increases. The recruitment value of late nesting is lower in many species.

Different scenarios of global climate models differ widely in the predict increase in ocean levels, ranging from 9 to 88 cm with the median 48 cm (Church et al. 2001). The sea level rise may cause major habitat loss in the long-term. However, in some areas a more pressing threat for the shoreline ecosystems (at least for birds) could be the changes in timing, magnitude and frequency of (spring) floods caused by the changing wind patterns (van de Pol et al. 2010). This is probably the case in the Bothnian Bay area, where the land rises 6–9 mm per year due to the postglacial adjustment. The coastal meadows along the Bothnian Bay seem to be relatively safe from the predicted sea level rise. The adjustment is predicted to continue for 7 000 – 12 000 years, resulting in 100 – 150 meters land rise. This phenomenon constantly creates new areas for colonizing plant species that are poor competitors. This ideal phase of seaside meadows with low vegetation lasts about 80-160 years (Siira & Pessa 1992, Hägg et al. 2006).

3 Sea level variation in Bothnian Bay

The most important factors affecting the water level in the Baltic Sea are air pressure, wind, currents through the Straits of Denmark and ice cover (Finnish Meteorological Institute). The impact of tides on the Finnish coast is only a few centimetres. The sea level variation is influenced by different factors in winter and summer. In winter the westerly winds and in summer precipitation are considered the most important factors affecting the Baltic Sea level variations (Hünicke et al. 2008). Wind piles up water to especially inner bays, and the highest amplitudes of water level can be found in these areas. In the Bothnian Bay area the variation in water levels is very high. The sea level behaves periodically in annual scale. The average sea level is at its highest in December and at its lowest in April-May (Fig. 1). The sea level standard deviation (SD) also has a periodic annual behaviour. The SD is greatest in winter, November-January, and smallest in summer, May-July. The individual years differ greatly from each other, and the annual periodicity is not evident in every year. The maximum observed sea level in Oulu since 1922 is +183 cm (14.1.1929) and the minimum is –131 cm (14.1.1984), with reference to the theoretical mean sea level (Finnish Meteorological Institute).

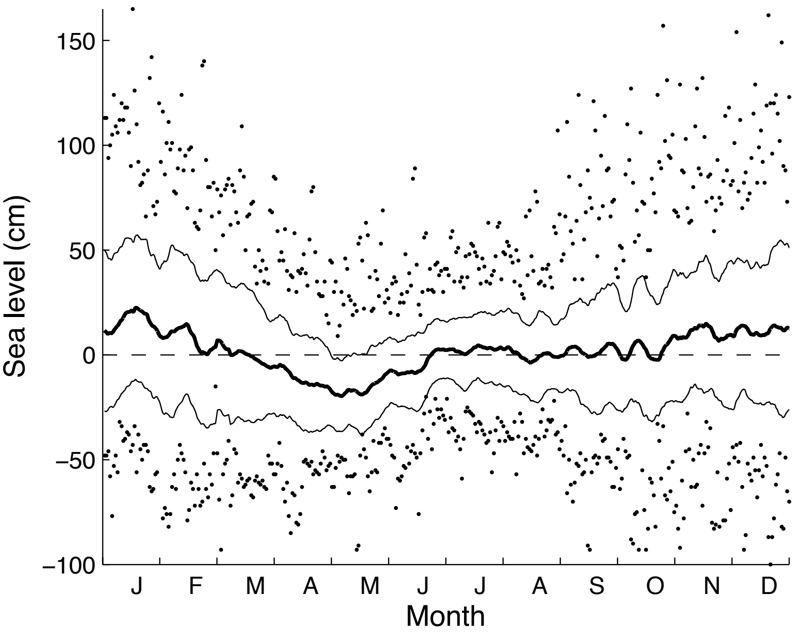

Figure 1. Variation in sea level at Oulu, Bothnian Bay between 1990–2010. The thick and thin lines indicate one-week centered moving average and standard deviation, respectively. Dots indicate highest and lowest daily averages. Sea shore plants, such as the arctic pendant grass (*Arctophila fulva* var. *pendulina*) and creeping alkali grass (*Puccinellia phryganodes*) require the open habitat caused by disturbance, such as fluctuating sea levels and ice scouring. On the other hand, the flooding of sea water to the low elevation shore meadows at May–June is a threat to the nests of the Southern Dunlin (*Calidris alpina schinzii*). Data: The Finnish Meteorological Institute.

The global climate models are too general for predicting the changes in local weather patterns. Therefore, the Finnish Meteorological Institute (FMI) has derived observational climate data and climate change scenarios for the purpose of impacts and adaptation studies of the ecosystem goods and services at nine LTSER (Long-Term Socio-Ecological Research network) areas in Finland. The climate change scenarios for the VACCIA project were mainly based on research performed in the ACCLIM (Climate change survey and expert service for adaptation assessment) project (Jylhä & Laapas 2010). Three different greenhouse gas and aerosol emission scenarios (A1B, A2 and B1) were considered. The aim was to predict the changes in local weather patterns that follow from the global climate models. The scenarios were constructed from the output of global climate model (GCM) simulations that originated from the CMIP3 multi-model dataset (Meehl et al. 2007). The scenarios were calculated relative to the modelled 1971-2000 baseline period (for details, see (Jylhä & Laapas 2010).

We analyze sea level data provided by the Finnish Meteorological Institute that is collected at one hour intervals from 1.1.1990 at 01:00 o'clock to 31.12.2010 at 24:00 o'clock. The mareograph (i.e. sea level measurement station) is situated at the Toppila Straight in Oulu (ca. 65° 02' N, 25° 26' E), about 19 km NE from the nearest Southern Dunlin nesting sites.

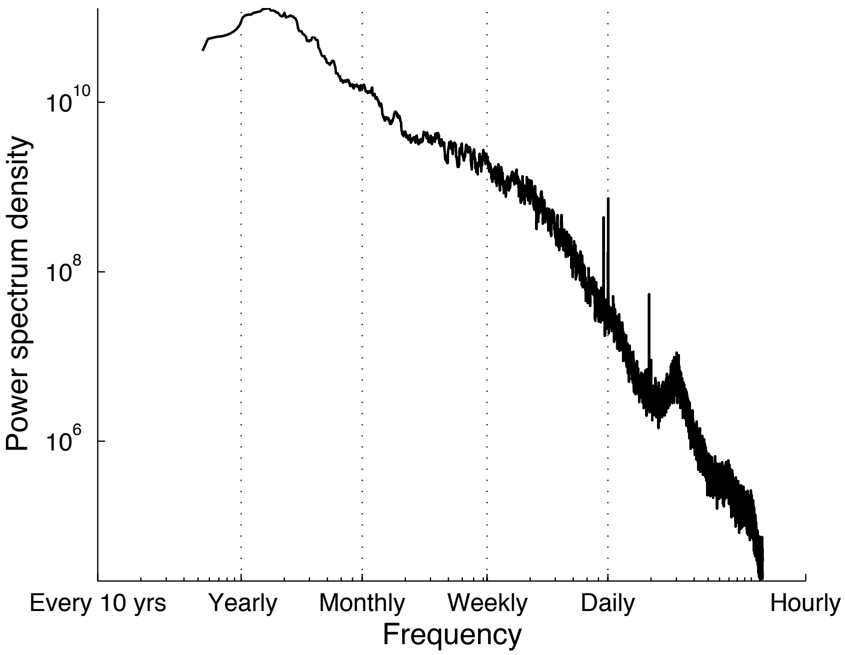

Fig. 2. Power spectrum of the sea level variation at Oulu. The frequencies with high spectral density have the greatest contribution to the overall variability. The peaks at 24 h and 12 h indicate a component of diurnal cyclicity in sea level. Data: The Finnish Meteorological Institute.

We characterized the temporal structure of the sea level variation with a power spectrum analysis, which is based on a Fourier transformation of the original sea level time series to sinusoidal components that each have a specific frequency and magnitude. The distribution of these magnitudes indicates the relative contribution of each frequency to the total variation in the time series. The power spectrum of the sea level variation in Oulu mareograph show that low frequency variation generally has a highest effect on the overall sea level variation. This indicates, that water level tends to change rather slowly (Fig. 2). This general pattern is only broken by the clear sign of diurnal variation, i.e. a daily cycle in the sea level. There is also another peak at yearly variation and also the water level tends to be similar at the same time of the year in different years. Despite large variation there is some predictability in sea level variation, which may affect how species time their vital functions (such as nesting or flowering) during the season.

4 Dynamics and management of endangered Arctic pendant grass

*4.1 Arctic pendant grass (***Arctophila fulva** *var.* **pendulina***)*

The endangered (EN) Arctic pendant grass (*Arctophila fulva* var. *pendulina*, Fig. 3) grows at sea shore meadows of the Bothnian Bay, often occupying the wettest parts of shore near the water line, even growing on bare mud. Recruitment of the species relies on vegetative reproduction, as viable seeds have not been observed at the Bothnian Bay population. The arctic pendant grass is threatened by the overgrowth of meadows and the resulting increase in the competition with other grasses, such as the common reed (*Phragmites australis*) and the creeping bendgrass (*Agrostis stolonifera*). In order to succeed, the species requires disturbances, such as the scouring of vegetation by sea level changes and the movement of ice, which keep the shore habitat open. These disturbances also break loose fragments of vegetation and spread them locally. The success of the creeping alkali grass is further affected by the grazing by geese at the low elevation shore meadows.

Figure 3. Arctic pendant grass (*Arctophila fulva* var. *pendulina*) often grows on bare mud close to the shoreline. Photo: Marko Hyvärinen.

The main threat to this species is the cessation of natural disturbances of the shores. The lack of scouring by ice or grazing by geese and cattle allows the competing plant species, most importantly *Agrostis stolonifera* and *Phragmites australis*, to form dense vegetation that prevents the grow and regeneration of species like *A. fulva* that are relatively tolerant to disturbance but less competitive for space. Our project was to test and quantify the role of disturbance to *A. fulva* using long-term monitoring data in combination with individual based, spatially realistic population model. This model was analyzed for *A. fulva* performance at different scenarios corresponding to anticipated changes in disturbance, as well as for the role of different vital processes (such as growth, reproduction and dispersal) of their life-cycle.

4.2 Arctophila fulva data

We mapped and measured the area of *A. fulva* patches at the Liminka Bay individually at four consecutive growing seasons from 2000 to 2003. A coherent stand of *A. fulva* shoots was considered to be one patch. Patches were considered as separate ones if there was at least one metre wide space without any *A. fulva* shoots between them. The coordinates in the centre of each patch were recorded with a GPS. The patch areas were measured both at the beginning and end of each growing season (except only once in 2000) in order to get a separate estimate of patch size change during the summer and winter seasons. The spring time measurements took place c. 4–5 weeks after ice melting, when *A. fulva* shoots had grown to a size that allowed the patches to be identified. The second measurement was taken at the end of August. Each patch was measured and drawn to a 1:100 scale for size estimation. The smallest patches were measured in the field with the help of a 0.25 m^2 grid frame.

The monitoring of the formation, growth, shrinkage and mortality of the patches allowed the estimation of quality, magnitude and frequency of the wintertime disturbance and the growth during the summer. We constructed a spatially explicit simulation model to predict the future development of the population and find the most important processes during its life-cycle where management actions could improve population performance. The focal processes included the probability distributions for size transitions in the winter and the summer seasons, the frequency of a new patch formation, the size of a new patch, the dispersal distance and the probability of disappearance of the extant patches.

4.3 Spatially explicit model of patch dynamics

A spatially explicit model represents each patch of *A. fulva* as a circle of defined coordinates and area in continuous space. The viable habitat was modelled as a narrow shore region between the sea in the west and the dense vegetation (mainly *Carex* spp. and grasses, Poaceae) in the east (Fig. 4). The borders of the area were determined on the basis of aerial photographs and maps and confirmed with field observations. Sufficient area was given along the shoreline in the north and in the south not to constrain population growth or dispersal.

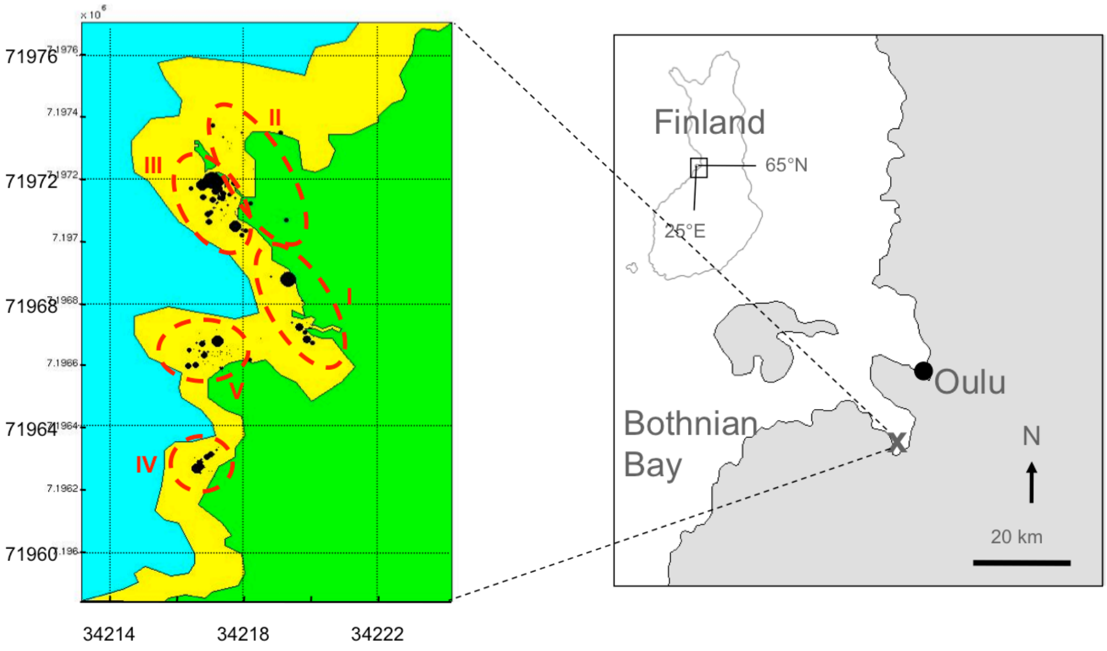

Figure 4. The map of A*rctophila fulva* patches, marked with black dots, on a narrow habitable shore (yellow) near the mouth of River Temmesjoki between dense vegetation (green) and the sea (blue). Dashed lines indicate subpopulations. Redrawn after Rautiainen et al. (2007).

We derived distributions of patch size, growth during summer and decline in winter and the proportion of patch are to be removed in disturbance events (Fig. 5). All these parameters were markedly variable and we therefore incorporated this variation in the model by drawing the simulated growth, decline and disturbance rates from appropriate random distributions. The radial growth rate of the patches did not show size dependency and we therefore modelled it as a normally distributed linear increment in the patch radius, based on the parameters that were estimated from a maximum likelihood fit of a normal distribution on the field data. If the patches that grew into a contact with each other in the simulation, they were merged into a single patch of the size of the constituent patches and location at their midpoint. The change in the patch area during the winter season was mostly due to ice scouring or the suffocation by the ice and we modelled it as stochastic disturbance.

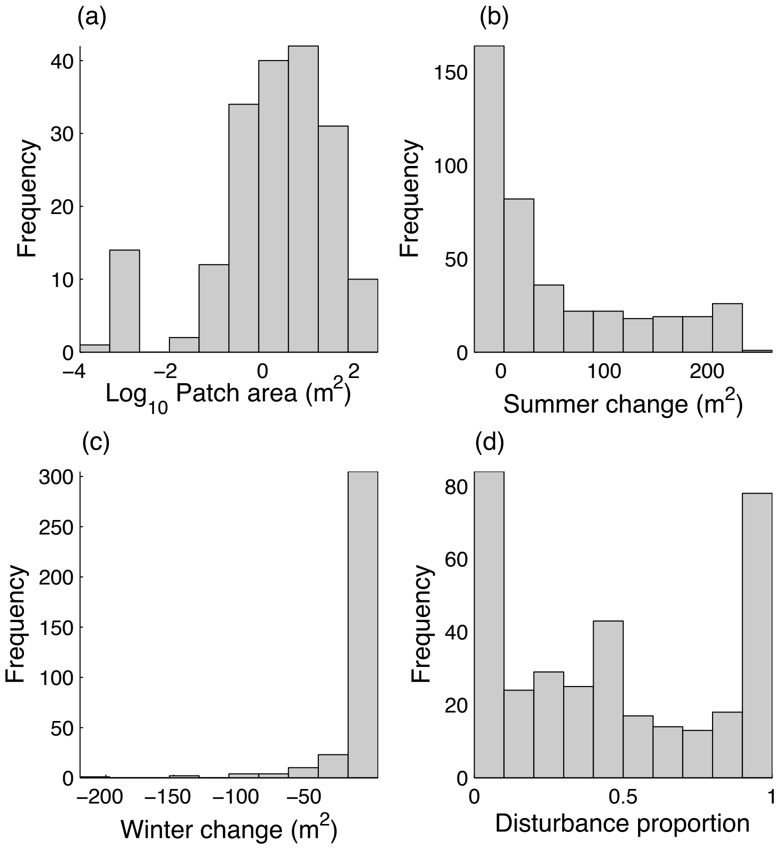

Fig. 5 (a) the distribution of patch size in the end of the growing season 2002, (b) the distribution of changes in patch area during the summers in 2000–2003, (c) the distribution of changes in patch area during the winters in 2000–2003 and (d) the proportion of patch area removed in a disturbance event. Redrawn after Rautiainen et al. (2007).

Fragments of existing patches become loose after ice melting in the spring and are translocated by water movements and may root in new locations. We modelled this process by assuming that new patches are formed near existing patch with a rate estimated from the observed new patch formation. We further assumed that new patches formed from the nearest existing one and used this measure as the dispersal distance, which was modelled as an exponentially distributed random variable. The dispersal of the new patches was modelled equally probable to all directions The new patches were initiated with an exponentially distributed size corresponding to observed areas the new patches.

The winter-time disturbance of the *A. fulva* patches was modelled in two stages. The first stage models the survival probability of patch as function of patch area. The second stage models the loss of area in patches that was not completely destroyed as a uniformly distributed random proportion. Patches less than 50 m^2 in size did not show size dependency in disturbance proportion. Larger patches showed that the maximum disturbance proportion decreased with patch area and this dependency was modelled with a negative exponentially function of patch size.

Many of the parameters in the model have values that are taken from a specified random distribution (growth of patches, new patch formation, initial size of a new patch, dispersal distance and disturbance). All simulations were therefore replicated for 100 times in order to get an estimate of the distribution of the response variable. Each replicate of the simulation was run for 30 time steps (years), which contained both a summer and a winter season. This length of the simulation was considered sufficiently long for the changes in the state of the *A. fulva* population to become clearly detectable.

4.4 Results and discussion

The simulations were initiated with the observed size distribution and location of the patches at the end of the growing season in 2003. The effect of model's parameters on the development of the system was analysed by graphing the total area of the patches at the end of the simulated period (total and subpopulations separately) against different parameter values ranging around the observed ones. The results are presented separately for the total population and each of the five sub- populations, in order to project the general development of the population and the possible differences between sites.

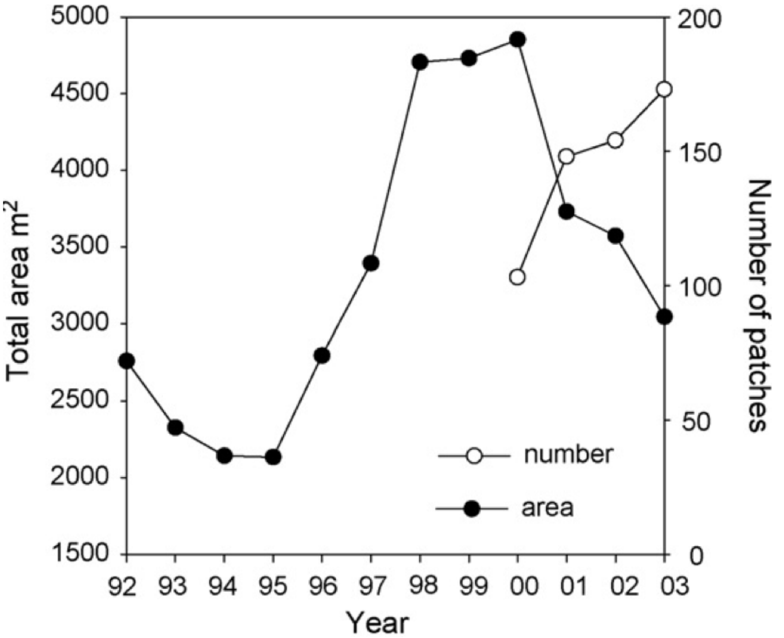

Fig. 6. The total area of *A. fulva* patches at the Liminka Bay in years 1992–2003 and the number of patches in years 2000–2003. Rautiainen et al. (2007).

Simulations with the fitted parameter estimates predicted that the area of *A. fulva* population will considerably decrease and the number of patches increase in the next 30 years, as the recent trend has also been in the monitoring data (Fig. 6). A previous study of the *A. fulva* population at the Liminka Bay based on the patch demography in 1992–1999 did not show immediate danger of extinction (Rautiainen et al. 2004). Unfortunately, according to the present study the situation is less optimistic. There was a considerable decrease of overall cover of *A. fulva* at Liminka Bay over the period of four years of this study. The large number of new patches formed during the study period, especially in the summer 2001, could not reverse this unwanted trend. It appeared that most of the new patches were formed to small bays at the shoreline where the prevailing wind direction moved the rhizome fragments. Unfortunately, these new patches were quite rapidly outcompeted by closing vegetation of the shoreline. In the same time competitive exclusion, ice scouring and suffocation by debris diminished also the area of the older patches, resulting in a decrease in the total area covered by *A. fulva*.

Winter disturbance during the study years has been severe. Many *A. fulva* patches disappeared completely, many lost large proportions from their area and the growth during the summer was not fast enough to compensate the wintertime losses. The summer growth has been restrained by competitive exclusion and suffocation by plant debris. If the current trend continues during the following years the fate of the *A. fulva* population at the Liminka Bay seems poor. However, our study period could naturally present four exceptionally bad years for *A. fulva*. If this is the case our simulations produced too pessimistic predictions about the fate of the study population. This highlights the importance for long term monitoring of studied species in the field of conservation biology in order to produce reliable predictions about population dynamics.

Growth of the initial size of a new patch had a positive effect on the total area of the subpopulations at the end of the simulated 30-year period (Fig. 7). In the analysis of the sensitivity of the model results for the initial patch size we increased the patch size to over seven square metres. However, most of the new patches are initially very small, only few shoots in size. New patches larger than one square metre would have higher survival in the face of the disturbances, but they appear extremely rarely in nature and the removal of such areas would only be possible from some large patches, which would still experience it as a major disturbance. Small patches were very prone to disappear during wintertime. The situation is similar to the sea grasses *Zostera novazelandica* in southern New Zealand and *Z. marina* in southern Norway: according to Ramage & Schiel (1999) and Frederiksen et al. (2004) the lower mortality of larger patches was probably due to improved anchoring and mutual physical protection among shoots.

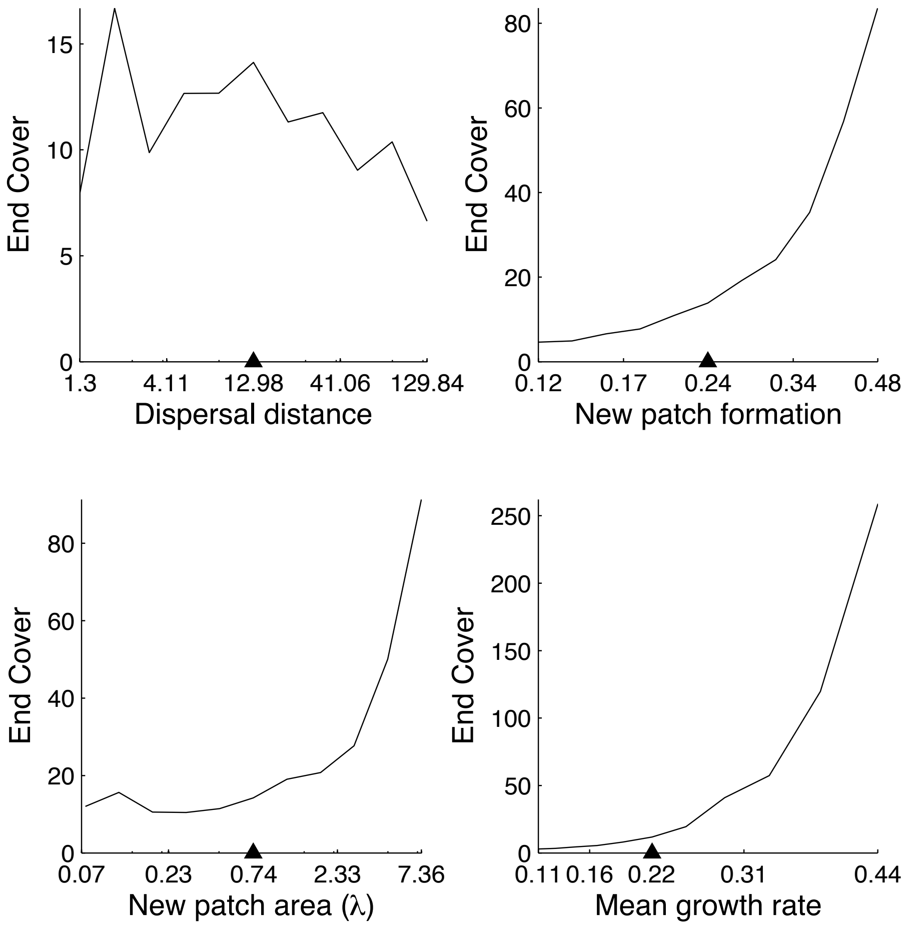

Figure 7. The sensitivity of the area (m^2) covered by *Arctophila fulva* at the end of a 20 year simulated time span to the vital rates of their life-cycle. The lines indicates the total population and the observed rates are indicated by the triangle. Redrawn after Rautiainen et al. (2007).

Results indicate that if we could somehow prevent the disappearance of small patches during winter, or if patches would lose less area, it would have a large effect to the population growth. However, we do not have any means to reduce winter disturbance. Therefore the best way to increase the growth of the *A. fulva* population is to increase new patch formation. The analysis of the sensitivity of the patch area at the end of the simulation to the new patch formation probability showed that if we could double the patch formation probability (from 0.25 to 0.5) it would have a major effect on the population growth. Rooting of rhizome fragments to the open areas further from the shoreline is difficult because wind pushes them towards the shore near dense vegetation. Therefore the rooting of the transplants should be aided and they should be anchored for example with poles. Since a considerable portion of transplants might disappear in disturbances, transplantations should be carried out in large numbers.

5 Natural avian grazing on seashore meadow vegetation dominated by Creeping alkali grass

Populations of several *Anser* and *Branta* goose species have increased during the past decades and become important herbivores in many European coastal areas (e.g. Bakker et al. 1997, Fox et al. 1998, Van Eerden et al. 2005). For example, European Greylag Goose (*Anser anser*) populations increased nearly seven-fold since 1960's by the end of 1980's (Nilsson et al. 1999, Dick et al. 1999). Geese prefer low-growth (usually early successional) meadows, which offer the most favourable forage for a grazer of relatively small size and limited digestive capacity (e.g. Olff et al. 1997, Fox et al. 1998, Huisman et al. 1999, van der Wal et al. 2000a,b). The impact of geese could thus be expected to be stronger in the earlier successional stages than in the later stages. The island of Hailuoto has fairly recently emerged from the sea as a result of a high rate of isostatic land uplift (c. 7 mm year^{-1}, Johansson et al. 2004) and its shores and meadows therefore represent early stages in primary succession. In addition, disturbances caused by short-term changes in sea level in response to variation in wind direction and ice scouring in winter are important drivers in creating open spaces in existing vegetation on the coasts of the Gulf of Bothnia (Ericson 1980). In spite of the dynamic nature of the coastal habitats, overgrowth by taller vegetation, especially by the common reed (*Phragmites australis*), has taken place on the shores of Baltic Sea on a large scale (e.g. Dijkema 1990).

The salt marsh plant community is an early successional stage in the continuum of shore vegetation types and typically experiences intensive herbivory. The small perennial graminoid *P. phryganodes* is an endangered species of the low-growing salt marsh meadows in the Bothnian Bay (Ryttäri et al. 2001). The two creeping alkali grass sites at the Bothnian Bay are the only occurrences of this species within the European Union and the status of the species has recently been classified as critically endangered (CR). We investigated the influence of grazing by the greylag goose (*Anser anser*) on the threatened early successional species, Creeping alkali grass (*Puccinellia phryganodes)* and other coastal meadow plant species was studied in a five-year exclosure experiment on the coast of the Bothnian Bay. Grazing was assumed to benefit low-growth early successional plant species by depressing the invasion and growth of taller graminoids.

The ecological requirements and threats of creeping alkali grass (*Puccinellia phryganodes*) resemble those of the Arctic pendant grass. The main difference is the concentration of P*uccinellia* habitats at soils that are most strongly eroded by ice at the lowest meadow zone (Siira & Merilä 1985, Siira 2011). This is possibly due to the small size and therefore, a poorer competitive ability of *Puccinellia*. The spread of the plant depends on vegetative growth and this can be assisted by multiplied and transplanting plant fragments to new areas. Creeping alkali grass is preferred food of the nesting and moulting greylag geese (*Anser anser*) due to its softness and palatability. The creeping alkali grass is, however, well tolerant to grazing, especially since grazing reduces the density of the competing grass species.

5.1 Material and methods

The study (Niemelä et al. manuscript) was carried out in a coastal meadow on Isomatala, a small island (c. 1 km^2) linked to the southern part of the main island of Hailuoto, Finland (24° 46' N, 64° 56' E), on the east coast of the Bothnian Bay. In spring 1999, 40 experimental quadrats were established on the coastal meadow of Isomatala grazed by greylag geese. The quadrats (0.5 x 0.5 m) were established as pairs in to the main population of *P. phryganodes*.

where it grows along ca. 1 km long narrow (width of ca. 75 m) zone. The experimental area covered ca. 270 x 110 m including *ca* 40 % of the local population of *P. phryganodes*. Quadrat placement on two succession stages of vegetation with a closed canopy and *P. phryganodes* present in each quadrat. Succession stages were characterized either by low-growth or tall-growth plant species (ten quadrat pairs in each stage). A quadrat was considered to represent low-growth vegetation (succession stage 1) if the ground cover of tall-growth *P. australis* and *C. stricta* were together less than 5%. *P. australis* was considered here as a late successional species based on the earlier descriptions of vegetation from the Isomatala (Siira 1984; Siira & Merilä 1997).

Figure 8. An exclosure protects the Creeping alkali grass (*Puccinellia phryganoides*) from grazing by geese in an experiment at Isomatala islet at Hailuoto. Photo: Marika Niemelä.

The quadrats in each pair were assigned to two treatments (grazed, non-grazed) at random. Grazing was prevented using 1 x 1 m (0.5 m high) exclosures (Fig. 8) of metal wire with a mesh size of 2 cm in the margins and 4 cm for the roof. To avoid damage caused by ice during winter, the exclosures were removed each autumn after the geese had left the area and established again at the end of May. The cover of vascular plant species was determined annually (1999 – 2003) in August-September using the point quadrat method. A 0.5 x 0.5 m frame with 100 randomly assigned, fixed point locations was used and the hits were recorded at the intersection with the ground or vegetation. In addition, for three abundant competitors of *P. phryganodes* (*A. stolonifera*, *J. gerardii* and *P. australis*), the maximum height (five highest individuals of the species per quadrat) and the number of flowering shoots were measured.

5.2 Results and discussion

Goose grazing reduced the biomass and height of vegetation as well as suppressed the performance of taller graminoids, especially early in the growing season when they were most abundant in the goose's diet. The grazing of tall graminoids was most pronounced in the earlier successional stage, thus benefiting subordinate species. *P. phryganodes* and small forbs was slightly more abundant in the grazed than non-grazed experimental quadrats, but grazing did not markedly slow down the overall decline of *P. phryganodes* or the increase the taller graminoid cover. *P. phryganodes* performed slightly better in pairwise comparisons in grazed quadrats in both successional stages in some years. While *P. phryganodes* decreased in abundance, several other graminoids (including *Juncus gerardii*, *Calamagrostis stricta* and *Phragmites australis*) increased in abundance during the experiment. The results indicate that primary succession of vegetation driven by isostatic land uplift may progress very rapidly in low-lying Bothnian Bay coastal meadows in spite of relatively intensive grazing by geese.

Although the advantages of grazing for low-growth species were relatively small in closed vegetation, suppression of biomass, height and sexual reproduction of taller graminoids by Greylag Geese may give an important extra time for low-growth species to spread seawards to newly emerged soil created by land uplift and various disturbances (e.g. ice scouring). In addition, visual comparison of the meadow grazed intensively by geese to ungrazed or less intensively grazed nearby areas suggest that goose grazing slows down the invasion of tall-growth graminoids to the lower part of the shore. This kind of result was obtained in the Dutch Wadden Sea where intensive grazing by brent and barnacle geese (*Branta bernicla* L. and *B. leucopsis* Bechstein) during spring migration significantly suppressed performance of *Elymus athericus* (Link) Kerguélen seedlings and hence, reduced invasion of this tall–growth later successional grass especially at young low-productive salt marsh (Kuijper et al. 2004).

6 Parasitism and simulated grazing on Creeping alkali grass

Plant parasitism and herbivory are common in natural grasslands, where they are an important part in the network of plant interactions affecting species abundance and distribution. However, only few studies have examined these two processes at the same time. We conducted a factorial experiment in greenhouse conditions, examining the outcome of competition between two coexisting grass species. The studied graminoids were critically endangered *Puccinellia phryganodes* and *Agrostis stolonifera,* which is a common meadow grass that is considered competitively superior competitor to *P. phryganodes*. (Fig. 9). In addition, we treated the plants by simulated grazing, which is another characteristic processes of grasslands. The salt marsh community is an early successional stage in the continuum of shore vegetation types and typically experiences intensive herbivory and a high density of hemiparasitic plants. The meadow with the largest subpopulation of *Puccinellia* is intensively grazed by greylag geese (*Anser anser*). The annual root hemiparasite *O. litoralis* ssp. *litoralis* is one of the few species not foraged. A hypothesis is that grazing delays succession and enables the persistence of *Puccinellia*.

Figure 9. (Top) Creeping alkali grass (*Puccinellia phryganoides*) spreading vegetatively over wet, sandy soil. (Bottom) Dense *Odontites littoralis* population on *Puccinellia*-dominated meadow on the Isomatala islet in Hailuoto. Photos: Marika Niemelä.

The ecological requirements and threats of creeping alkali grass (*Puccinellia phryganodes*) resemble those of the arctic pendant grass. The main difference is the concentration of *Puccinellia* habitats at soils that are most strongly eroded by ice at the lowest meadow zone. This is possibly due to the small size and therefore, a poorer competitive ability of *Puccinellia*. The spread of the plant depends on vegetative growth and this can be assisted by multiplied and transplanting plant fragments to new areas. Creeping alkali grass is preferred food of the nesting and moulting greylag geese (*Anser anser*) due to its softness and palatability. The creeping alkali grass is, however, well tolerant to grazing, especially since grazing reduces the density of the competing grass species.

5.3 Experimental data

The experiment (Niemelä et al. 2008) was conducted as a factorial greenhouse experiment of interspecific competition (one or two host species present), the hemiparasitic plant being present or absent, and grazing being simulated by clipping the host plant or leaving them untreated. All these treatments were performed on 15 individuals of both *Puccinellia* and *Agrostis*. The experimental plants were collected from a coastal meadow at Isomatala, a low island at the southern tip of the island of Hailuoto. The randomly collected seeds of *Odontites* were collected from the same site and sown into a mixture of mull and sand, stratified at +5°C in the dark during November– March, to induce their germination. *Puccinellia* and *Agrostis* were planted in to pots with peat an sand. Small individuals were assigned to the treatments, with *Odontites* if required by the treatment. The plants were grown in a greenhouse for three months. During the growing, light and tempreature conditions were varied to reflect the conditions at their native site. The plants assigned to the simulated herbivory treatment were clipped so that 2–3 cm of their shoot remained. This corresponded to between 75% and 93% reduction in aboveground biomass. After three months, when the capsules of Odontites had fully ripened, the plants were harvested by separating the shoot from the roots and both parts were weighted dry. The roots were washed clean of soil particles and prepared for microscopical examination of the presence of haustoria of *Odontites* in the roots of the host plants.

5.4 Results and discussion

As expected, *P. phryganodes* was a competitor inferior to *A. stolonifera*, but the two species did not differ as hosts for the hemiparasite. The effect of the hemiparasite was a 59% reduction in the aboveground biomass of *P. phryganodes* and 45% reduction of *A. stolonifera* (Fig. 10). Parasitism was indicated to give an indirect benefit for *P. phryganodes* by decreasing the competitive advantage of *A. stolonifera*; competition decreased the biomass of non-parasitised *P. phryganodes* by 36% while the biomass reduction in parasitised *P. phryganodes* was only 36% (Fig. 10). In addition, in the presence of the hemiparasite a greater proportion of the aboveground biomass of the study system was formed of *P. phryganodes*. Also the simulated grazing led to a greater reduction in the aboveground biomass in *A. stolonifera* than in *P. phryganodes*, which is a further indication of the increased the competitive ability of *P. phryganodes*. The results suggests that both hemiparasitic plants and herbivory may play a significant role in the maintenance of plant species diversity by promoting competitively inferior species.

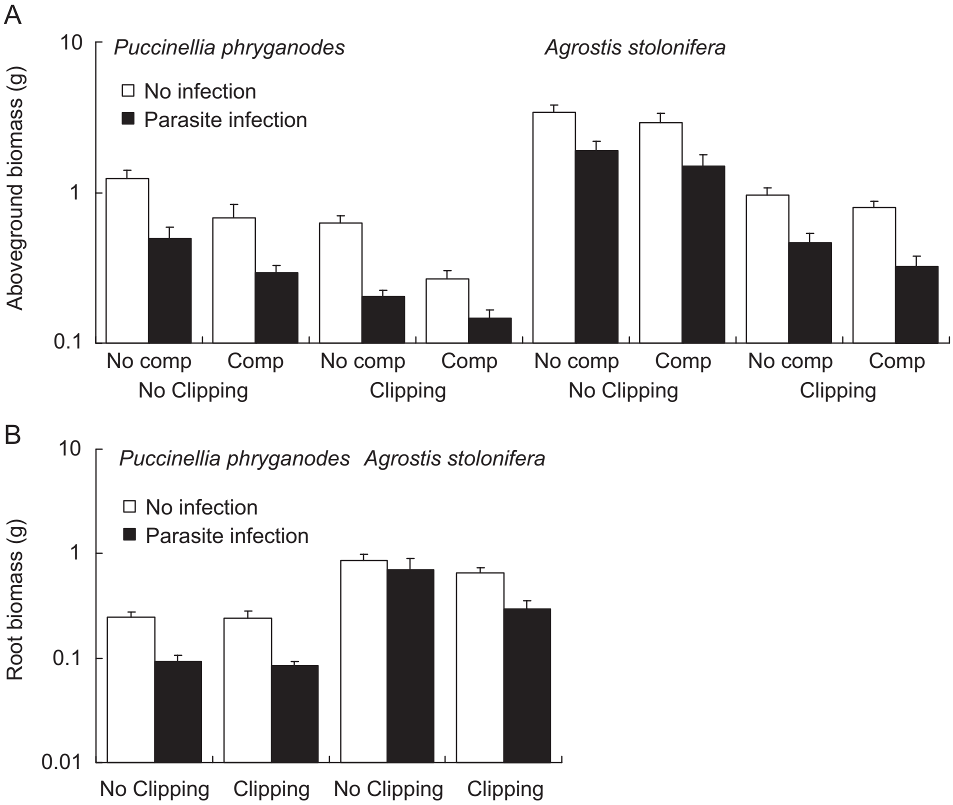

Fig. 10. Aboveground biomass (mean+1 SE; A) of *Puccinellia phryganodes* and *Agrostis stolonifera* in the different treatments of clipping, competition (Comp), and parasitism. (B) Root biomass (mean+1 SE) of *Puccinellia phryganodes* and *Agrostis stolonifera* grown with (parasite infection) or without (no infection) the hemiparasite, *Odontites litoralis*. Reproduced from Niemelä et al. (2008).

The availability of light for the hemiparasitic *Odontites* increases in the presence of geese, as these do not forage on *Odontites* by impose a heavy grazing pressure on other species in the meadows. Combined with the observed ability of *Odontites* successfully reproduce in spite of the experimental removal of the main part of the host shoots can at least partly explain how geese grazing may enable *Odontites* to prevail in the salt marsh plant community. Our results also suggest that *Agrostis* is able to maintain its dominance in aboveground biomass, but yields some of its relative competitive ability to its inferior competitor *Puccinellia*. Grazing by geese may therefore be an important factor to slow down the competitive replacement of *Puccinellia* by *Agrostis* and other stronger competitors of the salt marsh community. The hemiparasitic *Odontites* may also improve the persistence of *Puccinellia* by having a greater adverse effect on its competitor *Agrostis*. However, the abundance of the hemiparasite is highly variable between years (M. Niemelä, personal observation), which may reduce its influence on the host plants. This implies that the hemiparasite alone is not a sufficient explanation for the persistence of *Puccinellia* in competition, but the more regular impact of grazing by goose must also be present. In the long term and at a larger spatial scale, the persistence of *Puccinellia* may be more dependent on abiotic than biotic factors, as the salt marsh requires ability to disperse to the continuously emerging new competition-free environment that is formed by land uplift and occasional scouring of the vegetation by ice.

The results suggest that flooding of *P. phryganodes* during the germination and early seedling growth of its hemiparasite *O. litoralis* can reduce the hemiparasite infection rate resulting to reduced impact on its hosts *P. phryganodes* and *A. stolonifera* during the same growth season. In addition flooding during the flowering time of *O. litoralis*, will reduce seed production and affect also seed bank size of the hemiparasite. Inspired by these results, we have started an investigate whether the occurrence of *P. phryganodes* and *O. litoralis* at their main site of coexistence at the small island of Isomatala (south of Hailuoto) are related to the elevation above the sea level. This study will capitalize on the 20 year time series on the sea level variation at Bothnian Bay, which allows us to assign a probability of flood to different elevations. The actual modelling of the flood probability of *P. phryganodes* will still require a detailed measuring of the topography on the shores of Isomatala island, which is planned to be carried out in 2012The results suggest that flooding of *P. phryganodes* during the germination and early seedling growth of its hemiparasite *O. litoralis* can reduce the hemiparasite infection rate resulting to reduced impact on its hosts *P. phryganodes* and *A. stolonifera* during the same growth season. In addition flooding during the flowering time of *O. litoralis*, will reduce seed production and affect also seed bank size of the hemiparasite. Inspired by these results, we have started an investigate whether the occurrence of *P. phryganodes* and *O. litoralis* at their main site of coexistence at the small island of Isomatala (south of Hailuoto) are related to the elevation above the sea level. This study will capitalize on the 20 year time series on the sea level variation at Bothnian Bay, which allows us to assign a probability of flood to different elevations. The actual modelling of the flood probability of *P. phryganodes* will still require a detailed measuring of the topography on the shores of Isomatala island, which is planned to be carried out in 2012.

6 The risk of floods and predators on Southern Dunlin

*6.1 Southern Dunlin (*Calidris alpina schinzii*)*

Grassland breeding birds, and particularly waders, have declined severely in Europe during the last few decades (Thorup 2006). The Waterbird Index shows that the status of waterbird populations remains poor. Globally, 44% of known populations are decreasing and only 17% are increasing. The sandpipers and their close relatives (snipes, woodcocks, curlews, godwits and phalaropes) are one of the largest waterbird families. With an already poor (and below global average) status in the 1970s, their status has undergone continuing deterioration over the last three decades and currently 70% of their populations are decreasing and only 10% are increasing. One reason for the decline of waders may be the high proportion long-distance migratory species, but a number of non-migratory populations with geographically restricted range are also at risk (Wetlands International 2010).

The main reason for these population declines in Europe is most likely the deterioration and loss of meadows that are the main breeding habitats. Meadows suffer from overgrowth caused by increased eutrophication and the cessation of agricultural practises such as grazing and hay making that have kept these habitats open (Soikkeli & Salo 1979). Additionally, ground nesting birds suffer from high nest predation rates, possibly because of changes in predator communities and increased susceptibility to nest predation due to changes in breeding habitat (e.g. Koivula & Rönkä 1998, MacDonald & Bolton 2008). European Union agri-environment schemes (AES) have been initiated to counteract the species declines. The management actions for coastal meadows include, for example, provision of wet features, management of water levels, mowing and re-establishment of livestock grazing (Wilson et al. 2007). Grazing management has successfully increased suitable wader breeding habitat by altering once overgrown meadows into low vegetation, with a concurrent increase in local wader breeding densities (e.g. Olsen & Schmidt 2004, Ottvall & Smith 2006). However, not all the impacts of livestock grazing are positive. Livestock have been found to reduce avian reproductive success through nest trampling and other disturbance, increasing nest predation and even by cattle consuming eggs themselves (Beintema & Müskens 1987, Hart et al. 2002, Pakanen et al. 2011). Herein lies the potential danger of a management induced trap (Battin 2004). Increased density in managed areas may be erroneously considered to indicate that managed habitats are able to sustain viable populations, but in reality they may work as traps, and may in extreme case lead populations to extinction (Kokko & Sutherland 2001, Pakanen et al. manuscript)

The meadows in Bothnian Bay hold several populations of endangered species, such as the Siberian primrose (*Primula nutans* ssp. *finmarchica*), the Black-tailed Godwit (*Limosa limosa*) and the Southern Dunlin (*Calidris alpina schinzii*, Fig. 11). In the Finnish Red Data Book 2010 (Rassi et al. 2010) the Baltic southern dunlin is classified as a critically endangered (CR) subspecies of the Dunlin (*C. alpina*) based on the criterion C (small and continuously declining population; Rassi et al. 2010). The current population estimate of the Baltic southern dunlin is 1500 – 2000 individuals scattered over Estonia, Sweden, Denmark and Finland. Few pairs are found in Poland, Latvia and Lithuania (Väisänen et al. 1998). The Finnish population size is 50 – 55 pairs. The population decline is evident on the distribution maps: the main range of Southern Baltic dunlin in Finland has retracted almost exclusively to Oulu region after the 1980's (Valkama et al. 2011). However, the decline of Baltic southern dunlin has halted mainly due to conservation measures (Rassi et al. 2010).

The effect of catastrophic floods on the population viability of endangered species becomes more likely when climate changes. The critically endangered (CR) Southern Dunlin (*Calidris alpina schinzii*) is the most endangered of the waders at sea shores. A proportion of the nests of this small wader are destroyed at wind-raised floods, but at this moment predators play a larger role in reproductive success.

Figure 11. The Southern Dunlin (*Calidris alpina schinzii*) is one of the smallest waders in Finland. Practically all individuals at the Bothnian Bay are ring marked and the demography of the whole population is known as a result of long term monitoring. Photo: Veli-Matti Pakanen.

A significant proportion (80 %) of the Southern Dunlins in Finland nest at the grazed sea shore meadows of the Bothnian Bay. In these environments also the trampling of cattle destroys nests. The predator damages can be reduced by covering the nests with a steel netting that is sufficiently dense to prevent attacks of larger predator birds, but loose enough not to prevent the Dunlin female to get to the nest. The effect of wind-raised floods may increase in the future, but the active prevention of damages at the time of floods is difficult. The prevention of damages would require fast reaction to the rising of the sea level, large number of available personnel and knowledge of the location of individual nests at the meadows. At the long run it would be more efficient to concentrate on the flood protection of the meadows that Southern Dunlins use for nesting and favour grazing practices that diminish nesting damages.

6.2 Study species and sites

The Southern Dunlin (*Calidris alpina schinzii*) has very strict breeding habitat demands. Dunlins prefer open and very short-grassed meadows for both incubation and chick rearing (Thorup 1998). Such preference may not be optimal on grazed meadows, because sward height is associated to the stocking rates. This may lead to a trap situation, where the most preferred habitats have the highest trampling mortalities and thus lower reproduction success.

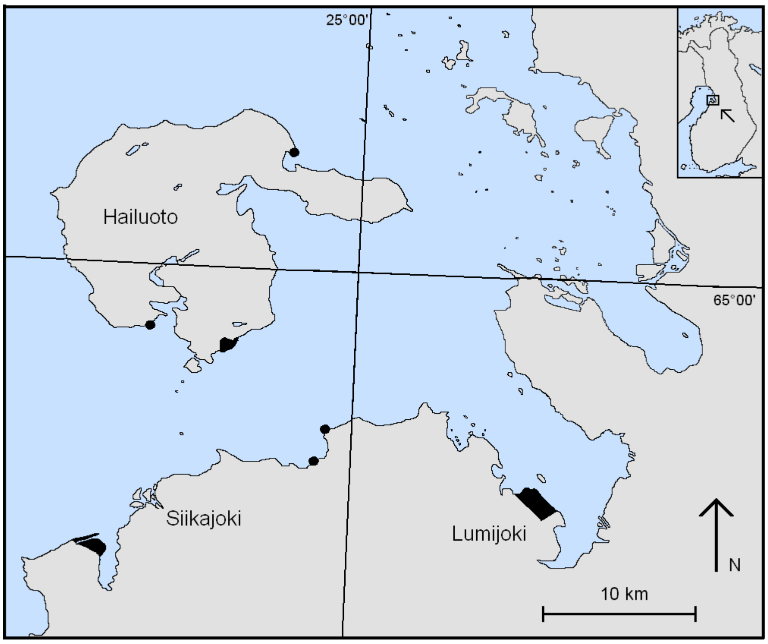

Figure 12. The location of the Southern Dunlin nesting areas (in black) at the Bothnian Bay.

The study area is situated on the northern end of the Baltic Sea, the Bothnian Bay (ca. 64° 50' N, 25° 00' E, Fig. 12). The area currently holds about 45 pairs distributed in three large meadows in Lumijoki, Siikajoki and Hailuoto, and five small meadows (1 to 27 pairs). This area holds about 80% of the Finnish Southern Dunlin population (Thorup 2006) and the large pasture alone, Pitkänokka in Lumijoki, holds ca. 50% of the Finnish Southern Dunlin population. In addition to the studied populations, a few (≤ 6) breeding sites are occasionally inhabited with 0 – 2 breeding pairs in nearby areas. The study site is situated quite far from the other Finnish Southern Dunlin breeding areas. The closest two breeding populations are ca. 100 km SW in Kalajoki (0-2 pairs) and 400 km SW in Pori (4 pairs).

The short-term effects of increased flooding frequencies on birds' nesting success is still mostly an unanswered question (but see van de Pol et al. 2010). Flooding of coastal nesting sites has always occurred (e.g. Becker & Anlauf 1988), but the magnitude and frequency of the floods are expected to change. For example, flooding events have become more frequent in the Wadden Sea (van de Pol et al. 2010, Koffijberg et al. 2006, 2010).

6.3 The model of nesting performance

We modified a recently developed stochastic simulation model of Southern Dunlin nesting performance (Pakanen et al. manuscript) to incorporate the additional mortality caused by flooding of sea water to nesting sites at different elevations. The model calculates the reproductive performance for different climate change scenarios affecting the timing, magnitude and frequency of early summer floods. Hourly sea level data was incorporated to the model to determine the probability of nesting failure due to flooding for the whole breeding season.

A simulation model (Fig. 13) accounting for the birds re-nesting after failure was used to calculate reproductive success (the proportion of successful breeding females, number of hatchlings produced and local recruitment) per female (Beintema & Müskens 1987, Green et al. 1997; Ratcliffe et al. 2005). Models were parameterised with life history data acquired in a previous study (Pakanen et al., unpublished). Temporal variance in parameters during the breeding season were also considered.

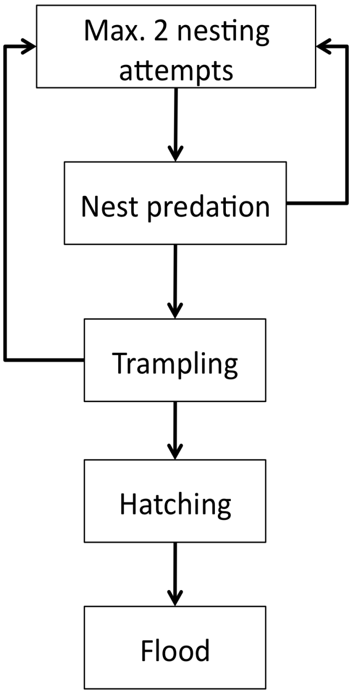

Figure. 13. A simplified representation of the events in the Southern Dunling nesting performance model. The model allows birds to renest if the first nest is destroyed and there is sufficient time left during the nesting season. All events are stochastic with occurrence probabilities based on the long-term monitoring data.

First, each female was assigned a date of nest initiation by randomly drawing from a Poisson distribution centered at the mid-May. The nesting period, including laying and incubation stages, was set with a 26 day duration (Soikkeli 1967). Daily fate of the nest until hatching (next 26 days) was determined by nest age specific survival estimates. The age specific daily survival estimates were used because the average estimate of daily nest survival can result in biased estimates of hatching success if the data is not equally weighed by all ages.

Second, different sources of nest mortality were evaluated by comparing a random number between 0 and 1 against the survival probability, which was time-dependent for trampling and flood, and Beta-distributed random number with time-dependent mean and variance for the probability of nest predation.

At this stage of the model we also evaluated the flood risk as a probability for sea level to rise to nests at 0 to100 cm elevations above mean water level. We assumed that even a short (< 1 hour) flooding is sufficient to destroy a nest by cooling the eggs. The daily probabilities of flood were calculated from the 20 year data at 1 hour intervals of the Oulu mareograph. The flood probabilities were smoothed for the model as 15 day unweighted central moving averages. At each simulated day, the fate of a nest was evaluated by comparing the daily probability of flood was to a random number from a 0 to 1 uniform distribution.

Third, for the nests destroyed at some point before hatching, the female was assigned to renest with a probability that decreased with the time of the nesting season. These nest survival estimates do not include the effect of trampling. The maximum number of possible nesting attempts per individual was set to two. The interval between nest failure and second nest initiation was about five days. The last possible day of nest initiation was considered to be 15th of June.

Fourth, if a nest survived for the 26 days incubation period, the number of chicks hatching was randomized based on the following observed frequencies of nests with different numbers of eggs. Recruitment to the population was calculated by multiplying the number of hatched chicks by an estimate of calendar day specific juvenile survival.

We analyze the model by simulating each climate change scenario and nest elevation in 10 000 runs. We use the average number of recruits across the replications as a measure of Southern Dunlin nesting performance.

6.4 Data

The Bothnian Bay is characterised by low meadows and mudflats constantly created by postglacial adjustment (Mäkinen and Saaranen 1998). However, this development is challenged by increasing overgrowth of meadows, especially by common reed (*Phragmites australis*). Thus, most known Southern dunlin breeding sites are managed with grazing or mowing (Pessa et al. 2006). Two habitat classes used by the Southern Dunlins can be recognised visually: low (LG) and high grazing intensity (HG) habitats. LG is characterised by high (20 – 30 cm) sward height while in HG habitats sward height is low (0 – 10 cm). LG habitats exist on meadows that are either not managed, are managed by mowing, or have low stocking rates (< 1.25 heads/ha). HG habitats exist on pasture with high stocking rate (1.46 – 2.19 head/ha). LG habitat class includes seven meadows with a joint area of about 800 hectares while HG habitat occurs on a single 238 ha meadow. (Pakanen et al. 2011)

Nest site elevation was measured in Pitkänokka meadow with geodetic equipment with 10 cm altitude contours from the shoreline at average sea level. Mean elevation of the meadow was 28.5 cm (SD = 15 cm, range 0 – 60 cm) and the nests were situated on average 547 m

(SD = 214 m, range 275 – 1040 m) from the shoreline at mean water level (Pakanen et al. 2011).

Life history data were collected from 2002 to 2010. Territories and nests were searched for from late April to early July. Nests with eggs were considered active and were visited every 1 to 7 days until hatching to determine the nest fate. When possible the presence of an incubating bird was used to infer an active nest. Cause of nest failure was determined based on nest remains. Nest locations were entered into a GPS device. Some of the nests were protected against trampling of livestock by iron poles that prevent cattle but do not provide shelter against predators. Non-protected nests were marked with small inconspicuous cues such as dung piles, dildos, rubber ducks etc. Estimates of hatching dates were determined by the egg number during laying (assuming a 1.5 day laying interval Soikkeli 1967), by egg floatation during the incubation period or by hatching date (assuming 21.5 day incubation period and 4.5 day laying period; Soikkeli 1967). In general hatching dates could be approximated accurately and recently hatched chicks could be controlled at or in the vicinity of the nest. If the chicks had already left the nest, their size, which closely correlates with age, was used to approximate their hatching date. When a nest had obviously hatched but chicks were not found, the estimated hatching date was used. Date of nest failure was approximated to be the mid day between last two visits if no other information was available.

Adult birds were captured from their nests when incubating or tending newly hatched young with mist-nets or traps. Adults were given one metal ring and 3 UV-resistant darvic colour rings for individually identifiable colour ring combinations. Hatchlings were ringed with a steel ring. Individuals were sexed according to the CHD-gene (Griffiths et al. 1998), sexual behaviour or morphological measurements (own unpublished data). Field work was done with permission from the North-Ostrobothnian regional environment centre (PPO-2004-L-289-254, PPO-2006-L-206-254) and complies with national laws.

We considered the following climate change scenarios in the prediction of changes in the spring flooding probability along the coast of Bothnian Bay due to expected changes in wind patterns. The baseline is the observed sea levels in the last 20 years, with the mean water level being 1.7 cm and standard deviation 28.5 cm. The 9 cm and 48 cm increases are the minimum and median predictions for the global increase in sea levels (Church et al. 2001). We could not find quantitative estimates of the changes in the magnitude of sea level variation, but we consider 20% and 50% increases to be realistic possibilities. We therefore modelled the scenarios where the mean water level increases by either 9 cm or 48 cm or the standard deviation of water level increases by either 20% (5.7 cm) or 50% (14.3 cm). In addition, we modelled the scenarios where the 9 cm increase in water level is associated with a 20% increase in standard deviation and the 48 cm increase in mean is associated with 50% increase in standard deviation.

6.5 Results and discussion

Our studies showed that the most important factor on the nesting success of Southern Dunlins is the reduced grazing by cattle and the delayed onset of grazing at the nesting area. The Baltic Southern Dunlins appear to have adapted to the variable sea level, because their timing of breeding coincides well with the lowest risk of spring floods. Most likely there are also other restrictions to the timing of breeding period, such as arrival from migration and gaining energy for the onset of breeding. Late hatching chicks are less probable to recruit than early hatching chicks (Pakanen et al. manuscript.)

Nest site elevation is also an important predictor of the flooding probability (Fig. 14). Naturally, the higher the nest is situated from the sea level, the safer it is from flooding. The birds probably nest in different places in different meadows, depending on e.g. the predation pressure, seasonal drying of the meadows and sword height, which in turn depends on e. g. age of the meadow, cattle crazing and mowing.

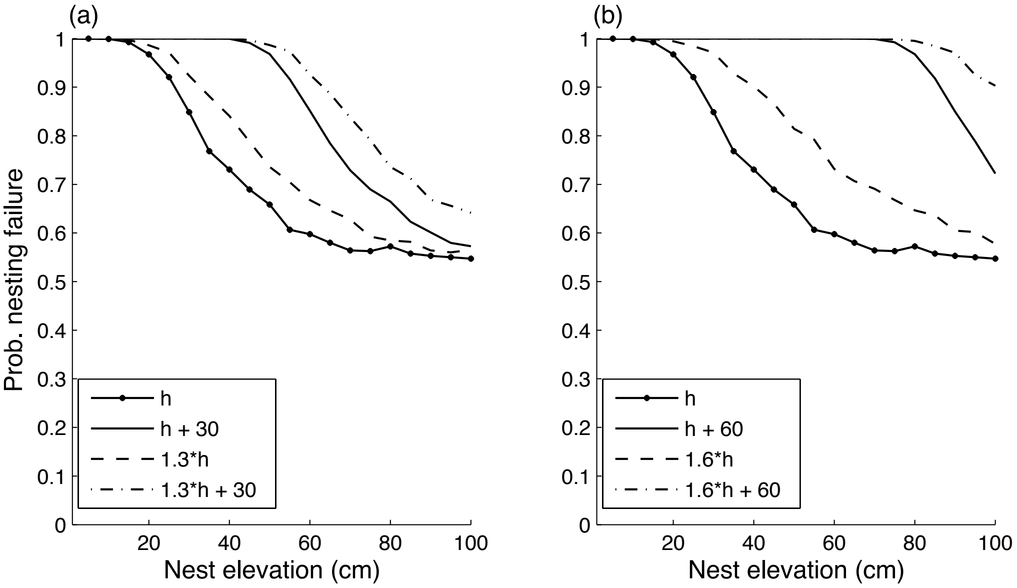

Fig. 14. Probability of nest failure at different elevations above mean water level at different scenarios on the effects of climate change on sea water level. The scenario corresponding to the observed 20 year data set on sea level is denoted by *h*, with mean = 1.7 cm and SD = 28.5 cm. The other scenarios are expressed in relation to *h* as (a) increase of mean sea level by 30 cm, increase of sea level standard deviation by 30% (8.5 cm), (b) increased mean 60 cm, SD = 60% (17.1 cm).

It has been shown that in the Wadden Sea previously rare summer flooding has become more frequent and more extreme, especially during the period when the eggs of most species have just hatched (van de Pol et al. 2010).

Climate models predict that winter storminess and thereby tidal variability will increase in the Wadden Sea (Oost et al. 2005), but there is no information on summer storms (van de Pol et al. 2010). Sea level rise is mainly caused by global warming and therefore saltmarshes and coastal meadows around the world are likely to face similar problems (Bildstein et al. 1991). Along the Atlantic coast of North America sea levels are also rising faster than land accretion can keep up with, causing summer flooding to become more frequent. It is feared that many North American coastal-nesting species will suffer as a consequence (Erwin et al. 2006, van de Pol et al. 2010). However, little is known about southern or Arctic breeding sites. Coastal-nesting birds are generally strict habitat specialists and thus face no other option than to locally adapt to their uncertain future. Van de Pol et al. (2010) showed that waders breeding in coastal meadows would benefit most from choosing higher nest sites. Adjustment of the timing of breeding is less optimal (van de Pol et al. 2010).

Figure 15. The Southern Dunlin nest has been covered with an iron netting to protect it from predators. The nest has been lifted on top of a tussock to prevent it from being flooded in a storm. Photo: Veli-Matti Pakanen.

7 Targeted restoration improves adaptation

Fluctuations in water level and the changes therein have a different effect on the endangered grasses and Southern Dunlins. The success of the sea shore grasses requires disturbances by changes in water level, whereas the floods during the nesting time are detrimental to the offspring production of Southern Dunlins. The *Arctophila fulva* and Dunlins do not occupy the same meadows, which makes it easier to choose a restoration and management practices that take the different requirements of these species into account. The natural disturbance regime of the arctic pendant grass and creeping alkali grass habitats should be preserved by avoiding land use practices and structures that change the movement of currents and ice at the critical areas. The water level changes at the nesting habitats of Southern Dunlins, in turn, should be minimized by, e.g., improving the flood protection of the shores.

7.1 Grazing in the revival of sea shore meadows

Many overgrown sea shore habitat has been brought into management with the special support of agricultural environments by European Union. For example, over 2500 ha of traditional biotopes receive special support at the Bothnian Bay. About 90 % of this area is managed by grazing and rest by mowing. Grazing is mainly by cattle and less than 15 % is grazed by sheep or they are grazed by horse or mixed livestock. Of the area grazed by cattle, about 90 % is used for beef cattle (mostly cows) and the rest for dairy breed heifers. The sea shore management practiced have changed greatly since the early 20th century, when mowing was the other central management practice and nearly all grazing cattle was dairy breed.

Grazing by cattle has led to the desired outcome at the sea shore meadows: the vegetation is significantly lower and low-growing species (such as halophytes) are more common than in unmanaged meadows. The shore meadows grazed by beef cattle is often more completely eaten and has less detritus, making the vegetation more open than the meadows grazed by dairy breed cattle. Mid-sized beef cattle thrive better with the sparse fodder of natural meadows than large-sized beef cattle. The animal material (race, physiological state) and the number of animals could be matched more carefully with the availability of food at the sea shore meadows. Lighter cattle could be more suitable grazers in nature management, if the soil of sea shore meadows becomes more frequently inundated and softened by wind-raised floods. The management of upper shores becomes more important in the future in preservation of sufficiently large open meadows. This could require creation of new meadow environments above the actual sea shore zone.

8 Recommendations

Our results indicated that mowing as management tool was able to slow down the deterioration of suitable habitats for two of the studied species, *A. fulva* and *P. nutans*, and enhance their vegetative and/or sexual reproduction. *P. phryganodes* is apparently more dependent on the narrow competition-free habitat newly emerging from the sea and exposed to intensive ice scouring. Thus, the removal of taller plant species is not effective enough to enable its persistence above the lowest shore.

Instead, grazing and concomitant trampling by cattle provide an effective management tool for preserving and creating suitable habitats (Pykälä 2000, Jutila 2001). Transplantations of the species to non-vegetated habitats, which have recently risen from the sea and are beyond the reach of extant individuals, might help to lower the risk of regional extinction (see e.g. Oostermeijer 2003).

For the management of biodiversity, a moderate density of grazing animals has usually been found to be best as it results in a mosaic of heavily grazed and lightly grazed patches providing suitable habitats for diversity of species (e.g. Andresen et al. 1990). In Finland, the recommended density of suckler cows for coastal meadows is 0.5–1.0 cows/ha (Decree 14.11.2000/106 of the Finnish Ministry of Agriculture and Forestry). The density of animals on the coastal meadows varies between 0.41 and 0.66 adults/ha. A density as low as 0.4 adults/ha seemed to be adequate for a coastal meadow in the maintenance stage keeping the mean sward height at desired low level from the point of view of the biodiversity management. High density of cattle is not favourable for the overall biodiversity (Andresen et al. 1990, Pakanen et al. 2011) and may also result in sward height too low to sustain adequate growth of the cattle (e.g. Spörndly et al. 2000). However, in the restoration phase, higher cattle densities are often required to reduce the dominance of tall-growth species. Also timing of the grazing season may contribute both to biodiversity and the performance of the cattle. Delaying the start of the grazing season from early June till mid-June on the coastal meadows of the Bothnian Bay would probably improve the breeding success of many bird species. Also for cattle this might be a better starting date for grazing as there is more forage available. However, to ensure sufficiently high-forage quality, the grazing season should not start later than in mid-June.

The value of environmental management and especially habitats with restored and maintained by grazing will change, which will also alter financial support for special agricultural environments. The goals of nature management will get more weight in relation to the economic goals in the decision on the way the special environment support in agriculture is targeted. The profitability of the management should be secured so that this practice can continue also in the future. If drier management sites are sought from further away from the shore, questions of land ownership, especially the scarcity of the commons, can make the planning of management projects more difficult. Because of the effects on birds, the grazing season should be shortened in the late spring, which may increase the costs of supplementary feeding.

The probability of a new patch formation is the most important factor for the population persistence of endangered *A. fulva*, whereas changes in the dispersal distance, for example, are less important. The best way to enhance the persistence of the population of this species is to promote the new patch formation. This could be done by transplanting rhizome fragments of the species to the suitable open areas in the shallow water where they are not immediately displaced by the later successional species.

9 The need for further research

The monitoring of endangered plants at low growth sea shores should be continued in order to get a reliable picture of the balance between growth and disturbance under climate change. This would improve the evaluation of climate change on the frequency and intensity on disturbance factors. Climate change may also affect the invertebrates of the sea shore. This can have an impact on the resource availability of birds with consequence on their reproductive success, which is so far completely unstudied. Even the description of organisms inhabiting the shore zone has marked deficiencies. It is likely that low growth meadows will be restored and managed also in the future. There is little knowledge beyond monitoring studies on how different methods of restoration and management affect biodiversity. An impact analysis should be made for the most central endangered species so that their complete life-cycle is considered.

Dairy cattle has largely been replaced by beef cattle in the management of sea shore meadows and better knowledge of its effect on vegetation is needed. Since the changes in grazing can affect, in addition to the sea shore species, also their grazers, the condition of the cattle should also be investigated. The environmental changes caused by climate change present different challenges also to grazing at sea shores. There are needs for further research in both the environmental effects of grazing and animal well-being as well as the profitability of different management practices.

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