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ASSESSMENT OF COASTAL BIRD POPULATIONS AND HABITATS ON THE FINNISH COAST OF THE BALTIC SEA: Implications for Monitoring and Management

by

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Contents

ABSTRACT

Coastal birds are an integral part of coastal ecosystems, which nowadays are subject to severe environmental pressures. Effective measures for the management and conservation of seabirds and their habitats call for insight into their population processes and the factors affecting their distribution and abundance. Central to national and international management and conservation measures is the availability of accurate data and information on bird populations, as well as on environmental trends and on measures taken to solve environmental problems.

In this thesis I address different aspects of the occurrence, abundance, population trends and breeding success of waterbirds breeding on the Finnish coast of the Baltic Sea, and discuss the implications of the results for seabird monitoring, management and conservation. In addition, I assess the position and prospects of coastal bird monitoring data, in the processing and dissemination of biodiversity data and information in accordance with the Convention on Biological Diversity (CBD) and other national and international commitments.

I show that important factors for seabird habitat selection are island area and elevation, water depth, shore openness, and the composition of island cover habitats. Habitat preferences are species-specific, with certain similarities within species groups. The occurrence of the colonial Arctic Tern (*Sterna paradisaea*) is partly affected by different habitat characteristics than its abundance. Using long-term bird monitoring data, I show that eutrophication and winter severity have reduced the populations of several Finnish seabird species.

A major demographic factor through which environmental changes influence bird populations is breeding success. Breeding success can function as a more rapid indicator of sublethal environmental impacts than population trends, particularly for long-lived and slow-breeding species, and should therefore be included in coastal bird monitoring schemes. Among my target species, local breeding success can be shown to affect the populations of the Mallard (*Anas platyrhynchos*), the Eider (*Somateria mollissima*) and the Goosander (*Mergus merganser*) after a time lag corresponding to their species-specific recruitment age. For some of the target species, the number of individuals in late summer can be used as an easier and more cost-effective indicator of breeding success than brood counts.

My results highlight that the interpretation and application of habitat and population studies require solid background knowledge of the ecology of the target species. In addition, the special characteristics of coastal birds, their habitats, and coastal bird monitoring data have to be considered in the assessment of their distribution and population trends.

According to the results, the relationships between the occurrence, abundance and population trends of coastal birds and environmental factors can be quantitatively assessed using multivariate modelling and model selection. Spatial data sets widely available in Finland can be utilised in the calculation of several variables that are relevant to the habitat selection of Finnish coastal species. Concerning some habitat characteristics field work is still required, due to a lack of remotely sensed data or the low resolution of readily available data in relation to the fine scale of the habitat patches in the archipelago. While long-term data sets exist for water quality and weather, the lack of data concerning for instance the food resources of birds hampers more detailed studies of environmental effects on bird populations. Intensive studies of coastal bird species in different archipelago areas should be encouraged.

The provision and free delivery of high-quality coastal data concerning bird populations and their habitats would greatly increase the capability of ecological modelling, as well as the management and conservation of coastal environments and communities. International initiatives that promote open spatial data infrastructures and sharing are therefore highly regarded. To function effectively, international information networks, such as the biodiversity Clearing House Mechanism (CHM) under the CBD, need to be rooted at regional and local levels. Attention should also be paid to the processing of data for higher levels of the information hierarchy, so that data are synthesized and developed into high-quality knowledge applicable to management and conservation.

1. INTRODUCTION

1.1. Why study environmental effects on coastal birds and ecosystems?

Seabirds and coastal birds are an integral part of marine and coastal ecosystems, usually as predators at the top of the food chain. They link into ecosystems at a number of trophic levels (Tasker and Reid 1997). For instance gulls, ducks and waders play an important role in the mass and energy fluxes of food webs, as well as in food web control (Moreira 1997; Eybert *et al*. 2003).

Birds are considered to be useful biological indicators because they are conspicuous, their ecology is versatile and well-known, and census methods for them are highly developed (Koskimies and Väisänen 1991; Bibby *et al.* 2000; Burger and Gochfeld 2001; Carignan and Villard 2002; Gregory *et al*. 2005; Sutherland 2006; O'Connell *et al.* 2007). Various long-term bird monitoring data are available and are constantly augmented by volunteers (Greenwood 2007). Seabirds have been regarded as good indicators of contaminants (e.g. Becker 1989), but they may also be potential indicators of other aspects of the marine environment (Furness and Camphuysen 1997; Article III). In addition, seabirds and coastal birds may provide means to monitor changes at lower trophic levels.

Over the past fifty years humans have changed the Earth's ecosystems extensively, resulting in a rapid global species decline and a loss of ecosystem functioning (Millennium Ecosystem Assessment 2005). The pursuit of economic growth has led to the use of technology to expand the human niche, and has thus acted as a limiting factor for wildlife conservation (Czech 2000, 2006; Huettmann and Czech 2006). Today, environmental changes are threatening the populations, range and diversity of European birds (Tucker and Heath 1994). Globally, 85 % of threatened bird species are at risk as a result of habitat loss and degradation (BirdLife International 2000).

In accordance with general biodiversity loss, the populations of many seabirds have recently declined (BirdLife International 2004a; BirdLife International 2008). Several studies have reported crashes in their reproductive success (Croxall 2004; Wanless *et al*. 2005). Seabirds are becoming more threatened and have deteriorated in status faster than many other species groups between 1988 and 2008 (BirdLife International 2008). There are particularly high proportions of threatened species for instance among albatrosses (BirdLife International 2008). In addition, 44 % of the waterbird populations for which data are available have declined or become extinct, while 34 % have remained constant and 17 % have increased (Wetlands International 2006). The populations of even many common seabird and waterbird species are currently declining (BirdLife International 2008).

Coastal habitats are crucial for a wide diversity of nesting, migrating and wintering birds because of their abundant nesting habitats and food resources (Burger 1991). Even species that spend most of the year in open sea need coastal habitats for nesting. The distribution of many bird species is either concentrated on or limited to the coasts, which also harbour a wide variety of other fauna and flora.

Today coastal areas are exposed to a variety of environmental pressures due to high population densities and rapid economic development. They are subject to several possibly conflicting interests, including settlement, transportation, industry, natural resource extraction and recreation, as well as the management and conservation of biodiversity and ecosystem functions (McCabe 1994; Eglington *et al.* 1998). In addition, coastal ecosystems are affected by climate change, alien species, and other environmental and community changes.

In recent years, growing attention has been paid to ecosystem functioning and the dependence of human societies on the provision of ecosystem goods and services (Millennium Ecosystem Assessment 2005). In Sweden, more than forty categories of goods and services provided by coastal ecosystems have been identified (Rönnbäck *et al*. 2007). Globally, research on the ecosystem services of coastal areas has to a great extent focused on tropical ecosystems, and there is a need for more studies dealing with the functioning of coastal ecosystems in temperate regions (Rönnbäck *et al*. 2007), as well as in Arctic and Antarctic regions (McCabe 1994; Eglington *et al*. 1998).

As an integral part of coastal ecosystems, coastal birds are an important provider of ecosystem goods and services, including provisioning services, such as food and fertilizers; regulating services, such as direct and indirect pest control provided by raptors and scavengers; supporting services, such as nutrient deposition and soil formation; and cultural services, including aesthetic, recreational, educational and scientific values (Şekercioğlu *et al*. 2004; Millennium Ecosystem Assessment 2005; Şekercioğlu 2006).

Acting as resource linkers by transporting minerals and nutrients between marine and terrestrial ecosystems as well as between terrestrial and wetland ones (Post *et al*. 1998; Lundberg and Moberg 2003; Croll *et al*. 2005; Şekercioğlu 2006), seabirds and waterfowl may have direct or cascading effects on plant and animal populations (Norton *et al*. 1997; Stapp *et al*. 1999), may influence the life histories of species (Iason *et al*. 1986; Wolfe *et al*. 2004), and may sometimes shape entire ecosystems (Croll *et al*. 2005).

While the concept and classification of ecosystem services are quite recent, the value of seabirds and waterfowl was recognised already in the 18th century. In 1769, Gadd and Gummerus published a study of the economic value of waterfowl in terms of meat, eggs, skin and feathers, and stressed the management and conservation of these resources, as well as the need for adequate knowledge as a basis of their utilisation (Gadd and Gummerus 1769).

Improved knowledge of coastal habitats is urgently needed, as the increasing use of coastal landscapes is reducing the availability and degrading the quality of coastal habitats, thus compromising ecosystem functioning and the maintenance of ecosystem goods and services (Dayton *et al*. 2000; Rönnbäck *et al*. 2007). Seabirds and coastal birds may help to fill part of the gap in our knowledge of marine and coastal ecosystems under stress, and provide valuable early warnings for unforeseen environmental impacts.

1.2. Habitat selection and population limitation

The use an animal makes of its environment is central to ecology (Johnson 1980; Hirzel *et al*. 2002; Manly *et al*. 2002). Birds select an environment that meets their ecological requirements (von Haartman 1945; Hildén 1965; Cody 1985). The distribution of bird species is in general influenced by resources, such as food, shelter, and sites for nesting, courtship and perching, as well as by structural and functional species characteristics, physiognomic environmental characteristics and land cover (Hildén 1965; Cody 1985; von Numers 1995).

The presence of conspecifics and other species can further affect breeding site selection in the form of sociality and conspecific attraction (Hildén 1965; von Numers 1995; Campomizzi *et al*. 2008), competition (Hildén 1965; Cody 1985), or predation (Forsman *et al*. 2001; Nordström *et al*. 2003; Nordström and Korpimäki 2004). Coloniality (Allainé 1991; Berg 1996; Arroyo *et al*. 2001; Hernández-Matías and Ruiz 2003) or protective nesting associations (Durango 1954; Hildén 1964; Brearey and Hildén 1985; Blanco and Tella 1997; Quinn *et al*. 2003; Quinn and Ueta 2008) may provide shelter from predation. In addition, migrant birds may use residents as cues to good quality habitats (Mönkkönen *et al*. 1999; Thomson *et al*. 2003).

According to Hildén (1965), a bird selects its breeding site on the basis of a sum of positive and negative stimuli that exceeds the threshold for the release of the reaction. The relative importance of habitat characteristics depends on the ecology of each species, adding to the value of comparisons within and between species groups.

Birds, including seabirds and coastal birds, have been widely used in habitat selection studies. Up till now, however, there have been only few studies that have modelled the breeding distribution and abundance of colonial seabirds. For colonial species, conspecific attraction and prospective behaviour, i.e. searching for future breeding sites (Boulinier *et al*. 1996; Falk and Møller 1997), are central to breeding site selection. Only the first pair occupying a site chooses the location independent of conspecifics; the next pairs prospect the abundance and breeding success of conspecifics, and are attracted to existing colonies. If breeding success is good, resources are sufficient and the colony is not disturbed, more birds will join the colony; birds are more likely to attach themselves to existing colonies than to establish new ones (Matthiopoulos *et al.* 2005; Szczys *et al.* 2005). In many respects a colony can function as a unit and may e.g. move to another site if disturbed (Väisänen 1973).

For many seabird species, site fidelity is also central to the habitat selection process. Colony-site tenacity commonly reflects the stability of nesting habitats (Sanchez *et al.* 2004). However, site fidelity may result in the colony or the individual pair remaining in a location even after conditions deteriorate and breeding success declines. Species that show strong site fidelity are likely to occupy only part of the available habitat (Matthiopoulos *et al.* 2005).

The process of habitat selection is closely tied to population limitation. Bird populations are limited by external (environmental) factors that affect intrinsic (demographic) features (Newton 1998). Environmental factors include both biotic and abiotic resources, intraspecific and interspecific competition, predation, and disease, such as parasites and other pathogens. Demographic features include fertility and mortality, as well as immigration and emigration, the net effects of which mediate the impact of environmental factors and determine local population trends. Environmental features can thus be considered ultimate factors and demographic features proximate factors leading to population change (Newton 1998).

Different species and populations may be limited by different factors, or more likely by different combinations of factors. As populations may be limited by different factors at different times and in different areas, population studies that have to be confined to specific study areas and time periods may not allow of generalisations to other areas and periods. In addition, the factors causing year-to-year fluctuations may not be the same as those that cause long-term population trends (Newton 1998). In order to distinguish local effects from large-scale environmental impacts, the importance of local environmental factors for the occurrence and abundance of birds needs to be recognised.

Historically and especially in modern times, humans have affected bird populations either directly by hunting and other human-induced mortality, or indirectly by modifying natural environmental factors (BirdLife International 2004b; Şekercioğlu *et al*. 2004). Human activities have reduced the resources available to birds by habitat degeneration, destruction and fragmentation, or they may have favoured the predators or competitors of a given species (Gaston *et al*. 2003; BirdLife International 2004b; Şekercioğlu *et al*. 2004).

The direct and indirect effects of human activities have played a major role in the loss of bird diversity (Newton 1998; Gaston *et al*. 2003) and are closely related to the extinction risks of numerous species (Kerr and Currie 1995). In total, 1.3 % of 9 916 historic bird species (species that survived since before A.D. 1500) are now extinct (Şekercioğlu *et al*. 2004), and the global number of individual birds has been estimated to have experienced a 20–25 % reduction since the 16th century (Gaston *et al*. 2003). According to Şekercioğlu *et al*. (2004), 19 % of current bird species are extinction-prone.

1.3. The northern Baltic archipelago as a breeding habitat of coastal birds

1.3.1. Characteristics of the Baltic Sea

The Baltic Sea is unique among the seas of the world. It is one of the world's largest brackish water bodies, consisting of saline ocean water and fresh river runoff. The mean depth of the Baltic Sea is 55 meters, the maximum depth being 450 meters. The Baltic Sea is relatively small: its area is 415 000 km^2 and its volume 21 700 km^3 (BACC Author Team 2008). The sea is bordered by Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The catchment area covers 1 700 000 km^2, including parts of 14 states and a population of 90 million people. Most of the population lives close to the coast.

The Baltic Sea is a young sea, with a history characterised by constant and drastic changes (Eronen 2005). The shores of the Baltic Sea change along with the glacio-isostatic land uplift. In the Bothnian Bay land uplift is now about 90 cm/100 years (Björck and Svensson 1994), and it lowers increasingly to the south, being about zero on the Blekinge coast (Frisén *et al*. 2005).

The Baltic Sea is strongly influenced by large-scale atmospheric circulation and hydrological processes in the catchment area. The Baltic Sea has a positive water balance, which is composed of inflows and outflows at the Danish straits, of river runoff and precipitation, as well as to a minor extent of groundwater inflow, thermal expansion, salt contraction, land uplift and ice export (BACC Author Team 2008). The water exchange is very slow: the water residence time is about 33 years (BACC Author Team 2008).

The Baltic Sea is a large transition area between limnic and marine conditions. The current salt balance is maintained by an outflow of low-salinity water in the surface layer and a variable inflow of higher-salinity water at depth. This pattern leads to a stratification of the water body of the central Baltic Sea, consisting of an upper layer of brackish water with a salinity of about 6–8 ‰ and a deep layer with a salinity of about 10–14 ‰. The long term mean salinity of the Baltic Sea is 7.7 ‰ (BACC Author Team 2008).

The Baltic Sea also differs from most other seas by having no real tides. Changes in the water level from 1.7 m in the Archipelago Sea (Granö and Roto 1989) up to 3.2 m in the Bothnian Bay (Frisén *et al*. 2005) are caused by wind conditions and changes in atmospheric pressure. Sea ice is formed every year, with a long-term average maximum coverage of about half of the surface area (BACC Author Team 2008).

The physical properties of the Baltic Sea affect the composition of its flora and fauna, which are rather species-poor in comparison to oceans. In addition to the physical barrier between the Baltic Sea and the ocean, there is also an ecological barrier consisting of low water salinity and temperature, as well as strong seasonality (Leppäkoski *et al*. 2002). The salinity is too low for most marine organisms, but too high for most fresh water organisms. As the Baltic Sea is geologically young, only few species have been able to adapt to live there. Especially the benthic fauna is species-poor. The biota is a mixture of marine, brackish and freshwater indigenous and non-indigenous species. Practically all the current marine fauna and flora have settled in the area during the past 10 000 years, and it is obvious that this immigration still continues (Leppäkoski 1991).

1.3.2. Influence of human-induced environmental changes on coastal birds

The history of the Baltic Sea is a history of change, both geological and – especially during the past decades – human-induced. Due to its small water volume, relatively enclosed basin and strong environmental pressures, the Baltic Sea is among the most polluted seas in the world. The most important environmental pressures on the Baltic Sea include eutrophication, climate change, invasive species, oil hazards, as well as organic and inorganic pollutants.

Since the 1960s one of the main threats to the Baltic Sea has been eutrophication, which is also recognised as one of the major threats to coastal marine ecosystems on a global scale (Nixon 1990). Eutrophication has been defined as the effect of an increase in the supply of organic matter to an ecosystem (Nixon 1990). In the Baltic Sea the increase in organic matter is largely caused by an increase in nutrient input followed by an increase in primary and secondary production (HELCOM 1993; Bonsdorff *et al*. 1997b). The nutrient input originates from agriculture, forestry, industry, habitation, shipping, and aquaculture (HELCOM 1993).

In Finland eutrophication is threatening especially the Archipelago Sea and the Gulf of Finland, partly due to their hydrographic features (Kauppila *et al*. 2004). The Gulf of Finland is regarded as one of the most polluted areas of the Baltic Sea (HELCOM 1990). Due to the anticlockwise circulation of the water in the Gulf of Finland, the Finnish coast is most exposed to nutrients transported from local sources around the entire Gulf (Rönnberg and Bonsdorff 2004). In the Archipelago Sea eutrophication began in the coastal waters and river estuaries, but has nowadays reached as far as the open sea (Bonsdorff *et al*. 1997b). The agricultural runoff into the Archipelago Sea is among the hotspots of the Helsinki Commission (HELCOM), i.e. the Baltic Marine Environment Protection Commission (HELCOM 1993).

The eutrophication of Finnish coastal waters has continued since the beginning of the 1990s, despite a decline in the external nutrient load (Kauppila *et al*. 2004). Nitrogen concentrations have slowly decreased, but concentrations of phosphorus increased during the 1990s, especially in the Gulf of Finland and in the Archipelago Sea. This is due to internal loading, that is the release of phosphorus from sediments as a result of reduced conditions at the sediment-water interface (Kauppila *et al*. 2004).

The effects of eutrophication can be seen in the form of increases in phytoplankton biomass, changes in community structure, increased cyanobacterial blooms, a decrease in water transparency, and mass occurrences of filamentous algae in the littoral zone. In addition, extensive areas of the coastal sea bottom have become devoid of macrofauna due to oxygen depletion (Kauppila *et al*. 2004; BACC Author Team 2008).

Eutrophication affects birds mainly indirectly, by increasing primary production in the sea (Beukema and Cadée 1991; Pitkänen 1994; Bonsdorff *et al*. 1997a). If eutrophication leads to an increase in birds' food resources it may allow their populations to increase, which can lead to their spread into new habitats (von Haartman 1982, 1984). However, eutrophication may also change the species composition and function of aquatic animal communities (Leppäkoski 1975; Viitasalo *et al*. 1990; Bonsdorff 1992; Rumohr *et al*. 1996) in a way detrimental to birds. The effects of eutrophication on vegetation structure may be beneficial, for instance for birds nesting or feeding in reeds, but at least in lakes the accumulation of organic matter, resulting in anaerobic conditions in the substrate, may also impede reed growth (Weisner 1991). Eutrophication also affects birds through toxic algal blooms (Pitkänen *et al*. 1990; Kauppi 1993). Thus eutrophication may diminish the numbers (Article III) and distribution of birds and modify interactions between species.

Along with eutrophication, a major recent environmental change is climate change (IPCC 2001; BACC Author Team 2008), which the United Nation's Framework Convention on Climate Change (UNFCCC) has defined as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and that is in addition to natural climate variability over comparable time periods".

During the period 1871–2004, there were significant positive trends in the mean air temperatures for the northern and southern Baltic Sea Basin, being on the average 0.10 °C/decade north of 60° N and 0.07 °C/decade south of 60° N (BACC Author Team 2008). With the increase in mean and extreme air temperatures the annual extent of sea ice cover has diminished and the ice season has been shortened. Over the latter part of the 20th century northern Europe has become on average more rainy, the largest increases in precipitation occurring in winter and spring. At the same time, summers in the southern parts of the Baltic Sea Basin have become drier. There are indications of an increasing impact of extreme wind events, but storminess indices reveal no clear long-term trend. There are also indications of a sea-level rise in the 20th century compared to the 19th. There is no long-term trend in mean water salinity for the 20th century, but during the 1980s and 1990s mean salinity fell substantially (BACC Author Team 2008). Since the mid-1970s the frequency and intensity of major inflows from the North Sea has decreased, causing a long-lasting stagnation period in the 1980s and 1990s, which together with the simultaneous increase in run-off caused the salinity decline (HELCOM 2007).

Knowledge of the ecological implications of ongoing and future climate change in the Baltic Sea basin is still incomplete and uncertain, but increasing efforts are being put into its assessment. BALTEX (Baltic Sea Experiment) aims at providing better understanding of the mechanisms and processes determining the water and energy cycles between and within the components of our climate system. It was launched in 1992 as a Continental-scale Experiment (CSE) of the Global Energy and Water Cycle Experiment (GEWEX) within the World Climate Research Program (WCRP). To assemble, integrate and assess available knowledge of past, current, and expected future climate change and its impacts on ecosystems in the Baltic Sea basin, BALTEX and HELCOM established the BALTEX Assessment of Climate Change for the Baltic Sea Basin (BACC) Project (BACC Author Team 2008).

The most important implications of climate change for marine ecosystems are its effects on water salinity, temperatures and the eutrophication process (BACC Author Team 2008). The biodiversity of the Baltic Sea is probably particularly sensitive to changes in salinity, the decrease in which may lead to a decrease in marine species and an increase in freshwater species (Möllmann *et al*. 2005; Mackenzie *et al*. 2007). A change in salinity can have a cascading effect on food webs and thus affect the whole pelagic ecosystem (Hänninen *et al*. 2003). The marine ecosystem is also sensitive to temperature variations, which affect both the planktic community and fish reproduction and survival. Eutrophication may be promoted by climatic factors, such as runoff and precipitation, and the resulting nutrient leakage.

In recent years there has been an increasing effort to study the effects of climate change on seabirds (Aebischer *et al*. 1990; Montevecchi and Myers 1997; Thompson and Ollason 2001; Croxall *et al*. 2002; Barbraud and Weimerskirch 2003). Climate change has been shown to affect the populations of oceanic seabirds by diminishing their food resources (Montevecchi and Myers 1997; Barbraud and Weimerskirch 2003). Low energy values of fish have been considered as the cause of major seabird breeding failure in the North Sea (Wanless *et al*. 2005).

In the Baltic Sea area, climate change may affect the breeding performance of seabirds by altering weather conditions during the breeding season or by affecting the condition of the birds after the winter (Hildén 1964; Milne 1976; Lehikoinen *et al*. 2006). Weather, especially temperature, rainfall and wind, is important for the breeding success of the Eider (*Somateria mollissima*), the Velvet Scoter (*Melanitta fusca*), the Mute Swan (*Cygnus olor*) and the Tufted Duck (*Aythya fuligula*) (Koskimies 1955, 1957; Hildén 1964; Koskimies and Lahti 1964; Koskinen *et al*. 2003). Many Baltic waterfowl migrate only as far as the western or southern Baltic Sea or the North Sea (Cramp and Simmons 1977; Pihl *et al*. 1995; Gilissen *et al*. 2002). Thus winter severity in western Europe affects the non-breeding survival of several waterfowl species (Nilsson 1984; Koskinen *et al*. 2003; Article III). It may also affect the density-dependence of survival (Barbraud and Weimerskirch 2003).

Climate change affects the arrival and departure times of migrants (Forchhammer *et al*. 2002; Jonzén *et al*. 2002; Hüppop and Hüppop 2003), the timing of breeding, and breeding performance (Forchhammer *et al*. 1998; Both and Visser 2001; Møller 2002; Sanz 2002). E.g. the Pied Flycatcher (*Ficedula hypoleuca*) may suffer from climate change, since the timing of its migration can become disconnected from the climate at its breeding grounds (Both and Visser 2001). There is also a potential for a mismatch between hatching phenology and resource phenology in ducks (Oja and Pöysä 2007). Furthermore, climate change may bring about changes in migratory routes, stopover sites, and migratory tendencies within species and populations (BACC Author Team 2008). As climate change affects bird population sizes (Tryjanowski and Sparks 2001; Lemoine and Böhning-Gaese 2003) and distributions during breeding and non-breeding seasons (Böhning-Gaese and Bauer 1996; Thomas and Lennon 1999), it alters the composition of bird communities (Lemoine and Böhning-Gaese 2003).

Climate change and its effects on water salinity and temperature can also affect species invasions, as it enables freshwater species to expand their distributions in the Baltic Sea and exotics from warmer regions to be established (BACC Author Team 2008). The Baltic Sea is subject to an intense invasion by non-indigenous species (Paavola *et al*. 2005; Javidpour *et al*. 2006). During the last two centuries some 100 alien aquatic species (fish, macrozoobenthos and zooplankton) have been recorded in the Baltic Sea, and some 60 species have established reproductive populations (Leppäkoski *et al*. 2002). Invasive species have induced major changes in near-shore ecosystems, also causing economic damage to fisheries, shipping and industry (Leppäkoski *et al*. 2002).

In addition to the implications of shipping in terms of nitrogen emissions and the spread of alien species, collisions and groundings of tankers carrying oil and liquid bulk chemicals form a substantial risk for Baltic Sea ecosystems (Hänninen and Rytkönen 2006). There are also numerous illegal oil discharges. The accident risk is especially high in the Baltic Sea, where shipping routes are mainly narrow and shallow. As traffic volumes continue to rise, the risk of accidents increases. Oil and chemical spills are especially deleterious in the Baltic Sea, particularly during the winter, as compounds decompose slowly in the cold water. The annual ice cover further slows down the decomposition process and may hamper salvage operations.

Substantial amounts of harmful substances are also introduced to the Baltic Sea by run-offs from the catchment area and by air deposition. The effects of heavy metals and organochlorines are nowadays widely known, but new threats are constantly emerging, the recent ones including organotin compounds, ftalates used to soften plastics, perfluorcarbons occurring e.g. in teflon, and polybrominated diphenyl ethers used as flame retardants.

Pollution and other environmental factors usually have the severest effects on the early stages in the development of eggs and chicks (Ohlendorf *et al*. 1978). However, toxic algal blooms, oil hazards and persistent chemical pollutants can cause mass mortalities of adult seabirds (Grenquist 1956; Lemmetyinen 1966; Duinker and Koeman 1978; Kauppi 1993). Other important factors for non-breeding survival include environmental hazards at wintering grounds and hunting along migration routes (Jønsen and Hansen 1977; Jønsen 1978).

1.3.3. Finnish coastal bird communities

Finnish coastal bird communities include species of coastal estuaries and mainland wetlands, but no pelagic species. The brackish water and sheltered bays of the Finnish coast also allow many inland species to nest there. Thus many Finnish coastal species may not be considered seabirds outside the Baltic Sea. In this thesis, most of the target species of the Articles I–V are called coastal birds, except for the more marine ducks, alcids and larids that are considered as seabirds also outside the Baltic.

Finnish coastal bird populations have mainly increased in the period during which they have been systematically monitored (Hildén and Hario 1993). The population trends of species may, however, be different in different parts of the Finnish coast (Hario 1998). An alarming recent trend is the population decline of some anatids, particularly the Eider (Hario and Rintala 2008). Due to the decline of the Eider, the total pair number of Finnish coastal bird populations has started to diminish for the first time since the 1940s (Hario and Rintala 2008). A further example of decreasing species is the Caspian Tern (*Sterna caspia*) that has decreased since the 1970s (Väisänen *et al*. 1998).

In the Archipelago Sea the breeding bird communities have changed considerably during the past few decades (von Haartman 1984; Hildén and Hario 1993; von Numers 1995; Väisänen *et al*. 1998; Lehikoinen, Gustafsson *et al*. 2003; Article III). Some coastal birds have declined, some have increased and new species have invaded the area (Tenovuo 1976; von Haartman 1984; von Numers 1999). Many species that are now regarded as among the most characteristic species of the archipelago may have been close to disappearing from the area a few decades ago, or may only have inhabited it for a few decades.

In the 1990s, many bird species in the Archipelago Sea sustained larger populations than at any time since the Second World War (von Numers 1995). For instance, the Greylag Goose (*Anser anser*) populations were at their lowest in the 1940s due to excessive hunting and disturbance, after which they increased (Väisänen *et al*. 1998). The first colonies of the Herring Gull (*Larus argentatus*) appeared in the Archipelago Sea in the 1960s (Väisänen *et al*. 1998), and the population increased until the year 1997 (Hario and Rintala 2008). The current decline of the Herring Gull is probably mediated by the recent culling campaigns on refuse tips (Nummelin *et al*. 1997; Hario and Rintala 2008).

The most recent settlers in the Archipelago Sea include the Mute Swan, the Canada Goose (*Branta canadensis*), the Barnacle Goose (*Branta leucopsis*), and the Cormorant (*Phalacrocorax carbo sinensis*) (Hildén and Hario 1993; Väisänen *et al*. 1998; Lehikoinen, Gustafsson *et al*. 2003). The Mute Swan started to breed in the Archipelago Sea in 1958, the Canada Goose in the 1970s, and the Barnacle Goose, originally an Arctic breeder, in 1984 (Lehikoinen, Gustafsson *et al*. 2003). The Cormorant settled on the Finnish coast in

1996 (Ympäristöministeriö 2005). In the Archipelago Sea empty Cormorant nests were found in 1997, and nesting was verified in 1998 (Lehikoinen, Gustafsson *et al*. 2003).

The Finnish populations of the Canada Goose originated from introduced birds (Lehikoinen, Gustafsson *et al*. 2003). The Barnacle Goose populations in the Baltic Sea probably originated mainly from individuals that started to breed in their spring migration staging areas, but also from birds released from zoos in Sweden and Finland (Larsson *et al*. 1988; Forslund and Larsson 1991). The first Barnacle Geese that settled in the Archipelago Sea area originated from the Skansen park in Sweden (Laine 1996; Lehikoinen, Gustafsson *et al*. 2003). The early history of the Mute Swan in the Baltic Sea is still unclear, but it has been kept in parks and gardens in Europe for centuries (Lehikoinen, Gustafsson *et al*. 2003).

The Cormorant spread to the Archipelago Sea unaided, as part of its recent general population increase in Central Europe and Southern Baltic leading to northward dispersal. Cormorants bred in the Baltic Sea already during prehistoric times, and were hunted for instance in Finland, Sweden and Estonia (Mannermaa and Lõugas 2005). A comparison of skeletal measurements of present-day and prehistoric Cormorants indicates that these individuals belonged to the nominate *Phalacrocorax carbo carbo* (Ericson and Carrasquilla 1997). The subspecies *sinensis* probably immigrated into the Baltic between 1500 and 1800 AD (Ericson and Carrasquilla 1997; Ericson and Tyrberg 2004). According to the ornithological literature, the Cormorant bred in the Åland islands and the Archipelago Sea in the 18th century, and the species may therefore merely be returning to its former breeding grounds, where it was probably eradicated by humans (Lehikoinen, Gustafsson *et al*. 2003).

1.4. Assessment of seabird and coastal bird habitats

Following earlier descriptive studies of the breeding site preferences of seabirds and coastal birds (e.g. Hildén 1964), several studies have addressed large-scale habitat associations in terrestrial and marine environments, based either on field observations (Gunnarsson *et al*. 2006) or on *ex situ* techniques (Huettmann and Diamond 2001; Zharikov *et al*. 2005, 2006). Few studies, except for von Numers (1995) and Articles I and II, have quantitatively analysed the relationship between a range of breeding site characteristics and bird distribution on the Baltic Sea coasts.

A comprehensive overview of coastal bird habitats, as well as many ecological applications, require data on a range of environmental variables and covering large areas that are beyond field-based capabilities (Kerr and Ostrovsky 2003). Geographical information systems (GISs) offer powerful and cost-effective tools for the quantitative analysis and visualisation of a wide range of environmental variables over large areas.

GIS and digital maps have been used to assess the ranges and habitat preferences of landbirds (Fuller *et al*. 2005; Hawkins *et al*. 2005). Studies of seabird and shorebird habitats have largely focused on their foraging distribution (Jones *et al*. 2002; Davoren *et al*. 2003; Yen *et al*. 2004; Pinaud *et al*. 2005; Vlietstra 2005) and stop-over or wintering habitats (Vaitkus and Bubinas 2001; Durell *et al*. 2006; McKinney *et al*. 2006; Yasué 2006). As to the breeding habitats of seabirds and shorebirds, earlier studies have assessed the effect of food resources on breeding habitat selection (Robertson *et al*. 2001), habitat use by long-ranging pelagic species (Pinaud *et al*. 2005) and habitat selection by colonial birds (Kokko *et al*. 2004; Serrano *et al*. 2005).

Together with existing environmental data archives that include spatially explicit information with uniform spatial coverage, detail and accuracy, GISs also provide new possibilities to quantify the physical characteristics of the breeding habitats of birds on fragmented archipelago coasts (Articles I and II). Environmental databases containing shoreline, bathymetry and elevation data can be used to calculate various parameters for islands and their surroundings.

Once environmental factors have been characterised in a GIS, their importance for bird abundance can be analysed inferentially using multivariate statistical models. A widely used method for distribution modelling are generalised additive models (GAMs) (Suárez-Seoane *et al*. 2002; Virkkala *et al*. 2005; Wintle *et al*. 2005; Whittaker *et al*. 2007). Multifaceted habitat requirements are likely to yield several competing hypotheses and models (Article I). Model selection approaches provide a way to draw inferences from a set of multiple hypotheses (Burnham and Anderson 1998; Manly *et al*. 2002; Burnham and Anderson 2004; Johnson and Omland 2004).

Species occurrence data have been widely used for species distribution models and habitat selection studies (Keating and Cherry 2004; Barry and Elith 2006; Elith *et al*. 2006; Leathwick *et al*. 2006; Articles I and II). In recent years, species-distribution modelling has become increasingly important for habitat selection and biodiversity research, as well as for conservation biology. Distribution modelling is used in several fields of ecology, and a number of studies have compared different predictive methods and their performance (Guisan and Zimmermann 2000; Segurado and Araújo 2004; Hirzel *et al*. 2006). In spite of the wealth of research on the distribution of different bird species, there have been only few studies addressing the distribution and abundance of colonial birds, except for Article II.

Where coastal birds have been monitored over a longer period, population trends can be used to assess changes in their habitats (Article III). If bird population trends and demographic processes reflect environmental changes, bird monitoring can be used as a biological early-warning system for complex and unexpected environmental changes.

Knowledge of habitat preferences and the relevance of the local environment may also help to conduct ecological studies. According to Møller and Jennions (2002), a hypothesised relationship (e.g. the main effect of a fixed treatment) generally explains little of the variation in the factor of interest in ecological studies, even experimental ones, and the amounts of variance explained by the predictor (r^2) is usually relatively small. This is to a great extent due to the randomness and noise caused by environmental properties.

1.5. Management and conservation of the Baltic Sea

The management and conservation of the Baltic Sea and its biota and habitats, including the coastal areas of Finland, are based on international treaties, legislation and other processes, and on their implementation at the national level.

The most important international convention concerning the protection of the Baltic Sea is the 1992 Helsinki Convention (Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992) with the later amendments to its Annexes (HELCOM 2004). The 1992 Convention followed the first Helsinki Convention signed in 1974. The United Nations Convention on the Law of the Sea, adopted in 1982, lays down a regime of law for the world's seas, establishing rules governing all uses of oceans. Other conventions related to the Baltic Sea and its bird communities are the Convention on Biological Diversity (CBD), the Convention on the Conservation of European Wildlife and Natural Habitats (the Berne Convention), the Convention on the Conservation of Migratory Species of Wild Animals (CMS or the Bonn Convention), and the Ramsar Convention on Wetlands.

Within the European Union (EU), the requirements of the CBD and other most important international biodiversity conventions are implemented mainly through the Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora) and the Birds Directive (Council Directive of 2 April 1979 on the conservation of wild birds (79/409/EEC)). The main objective of conservation efforts within the EU is the maintenance or achievement of favourable conservation status of both species and habitats of the Community interest. This objective is partially fulfilled by the establishment of the Natura 2000 conservation area network (Mehtälä and Vuorisalo 2007). The Natura 2000 network of nature protection areas, which is regarded as the centrepiece of EU nature and biodiversity policy, is based on the Habitats Directive. The purpose of the network is to assure the favourable conservation status of Europe's most valuable and threatened species and habitats. It comprises Special Areas of Conservation (SACs), designated by Member States under the Habitats Directive, and also incorporates Special Protection Areas (SPAs) designated under the Birds Directive.

A central directive for the management of water bodies is the EU Water Framework Directive (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy). With regard to surface waters, the general aim set forth in the directive is to reach a “good” ecological and chemical status by the year 2015. Due to ecological variability, no absolute standards for biological quality can be set which would apply across the Community. Control conditions are therefore specified that allow only a slight departure from the biological community that would be expected in case of minimal anthropogenic impact. Fundamental to the EU Water Framework Directive is the river-basin approach, implemented through river-basin management plans. The goal is for that all relevant parties to be involved in the preparation of these management plans.

Consistent with the EU Water Framework Directive is the Marine Strategy Framework Directive (Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy). Its aim is to achieve a “good” environmental status of the EU’s marine waters by 2021 and to protect the resource base upon which marine-related economic and social activities depend. The Marine Strategy Framework Directive will establish European Marine Regions on the basis of geographical and environmental criteria. The member states will be required to develop Marine Strategies for their marine waters.

Directives applicable to the protection of the marine environment also include the Urban Waste Water Directive (Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment) and the Nitrates Directive (Council Directive of 12 December 1991 concerning the protection of waters agains pollution caused by nitrates from agricultural sources (91/676/EEC)). Furthermore, the European Parliament and Council have adopted a recommendation concerning the implementation of Integrated Coastal Zone Management (ICZM) (Recommendation of the European Parliament and of the Council of 30 May 2002 concerning the implementation of Integrated Coastal Zone Management in Europe (2002/413/EC)).

Several international organizations have been formed and processes launched for the management and conservation of the Baltic Sea. HELCOM works to protect the marine environment of the Baltic Sea from all sources of pollution through bilateral and multilateral intergovernmental co-operation between the European Community, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. HELCOM administers the Helsinki Convention. One of the duties of the Helsinki Commission is to recommend measures addressing certain pollution sources or areas of concern. These

Recommendations are to be implemented by the Contracting Parties through their national legislation. HELCOM has also outlined the HELCOM Baltic Sea Action Plan (BSAP), which aims at restoring the good ecological status of the Baltic marine environment by 2021.

The International Maritime Organization (IMO) aims at developing and maintaining a comprehensive regulatory framework for shipping. In 2005, it designated the Baltic Sea (without Russian waters) as a Particularly Sensitive Sea Area (PSSA). When an area is officially defined as a particularly sensitive sea area, specific measures can be used to control maritime activities in that area, such as routing measures and strict discharge and equipment requirements for ships.

Baltic 21 is a regional multi-stakeholder process for sustainable development, initiated in 1996 by the Prime Ministers from the eleven member states of the Council of the Baltic Sea States (CBSS). Baltic 21 provides a regional network to implement the activities of the globally agreed Agenda 21 and the World Summit on Sustainable Development. Baltic 21 members include the CBSS member states, the European Commission, intergovernmental organizations and international financial institutions, as well as international urban and business community networks.

There are also a number of international and national non-governmental organizations involved in the protection of the Baltic Sea or bird communities. The WWF International has adopted a Baltic Marine Rescue Programme, supported in Finland by the 'Operaatio Merenneito' (Operation Mermaid) campaign. Further organizations promoting the protection of the Baltic Sea environment include the Coalition Clean Baltic (CCB) and Greenpeace. For the identification and protection of valuable sites for birds, BirdLife International is coordinating a worldwide Important Bird Areas (IBA) project. As a Finnish national extension to the IBA project, the Finnish Environmental Institute and BirdLife Finland have identified 411 Finnish Important Bird Areas (FINIBA), among which wetlands, islands and open sea areas are well represented (Leivo *et al*. 2002). The Finnish Association for Nature Conservation also emphasizes Baltic Sea protection.

Finnish national legislation impacting on coastal birds and their habitats includes the Nature Conservation Act, the Land Use and Building Act, and the Hunting Act. In addition, in 2002 the Finnish Government made a decision-in-principle on steps to be taken to protect the Baltic, i.e. Finland's programme for the protection of the Baltic Sea (Ministry of the Environment 2002). In order to achieve a good ecological state in the Baltic Sea, steps will be taken in six main areas: combating eutrophication, reducing the risks of hazardous substances, curbing the risks caused by various uses of the Baltic Sea, preserving and increasing biodiversity and increasing environmental awareness, and supporting and carrying out research and follow-up.

1.6. Monitoring of coastal ecosystems

1.6.1. Environmental and biodiversity monitoring

The importance of monitoring the environment and investigating the causes of population changes are recognised in most monitoring schemes (e.g. Koskimies and Väisänen 1991; Anker-Nilssen *et al*. 2006; Mavor *et al*. 2008). Hydrological, meteorological and phenological monitoring, and faunistic censuses have a long tradition in Finland. Regular hydrological monitoring of lakes and coastal areas was started in Finland in the 1960s (Niemi 2006).

Environmental monitoring in Finland is partly based on international treaties and other obligations, such as EU directives (Niemi 2006). Biodiversity monitoring can also be regarded as part of environmental monitoring (see e.g. Niemi 2006). With regard to the monitoring of water bodies an important international guideline is the EU Water Framework Directive. Furthermore, the Marine Strategies required by the Marine Strategy Framework Directive will include an assessment of the state of the environment and a definition of 'good' environmental status at the regional level, and will establish environmental targets. According to the Marine Strategy Framework Directive, EU member states shall establish coordinated monitoring programmes for the assessment of the environmental status of their marine waters, including the population dynamics, range and status of seabirds. Finland also participates in the monitoring of the Baltic Sea through the work of HELCOM.

Further international obligations to biodiversity monitoring are set by the Birds Directive and the Habitats Directive. In addition, the CBD requires the contracting parties to monitor the components of biological diversity, including genes and genomes, species and communities, as well as ecosystems and habitats (Glowka *et al*. 1994). The Convention stresses the importance of monitoring components characterised by distinctiveness, richness and representativeness, as well as by economic and cultural importance or potential. The list of examples of such components includes indicator species and the habitats of migratory species. Special attention is to be paid to components requiring urgent conservation measures and those which offer the greatest potential for sustainable use. All these criteria apply remarkably well to coastal habitats and birds.

Biodiversity monitoring is often closely intertwined with the monitoring of threats to biodiversity. The CBD requires the contracting parties to monitor processes and activities which may have significant adverse impacts on the conservation and sustainable use of biological diversity (Glowka *et al*. 1994). In addition, the Birds Directive obliges EU member states to determine the role of certain species as indicators of pollution and to study the adverse effect of chemical pollution on bird populations.

In addition to the CBD and the EU directives, there are other national and international obligations involving the monitoring of biological diversity, e.g. the Berne Convention, the Bonn Convention, and the Ramsar Convention on Wetlands (Research, Monitoring and Data Systems Expert Group 2001). Finnish national legislation related to biodiversity monitoring includes the Nature Conservation Act (20.12.1996/1096), the Land Use and Building Act (5.2.1999/132), and the Hunting Act (28.6.1993/615).

In the Archipelago Sea, biodiversity data have been collected in connection with both floristic and faunistic censuses (Eklund 1958; Hinneri 1972; von Haartman 1984; von Numers 1995) as well as in studies testing major ecological hypotheses (Saccheri *et al*. 1998) since the 1910s (von Numers 1995; Article V). Most of the inventory and monitoring data are spatially and temporally extensive but fragmentary; they also include unpublished data. In addition, substantial amounts of data are being collected in the area by various other stakeholders, such as industrial enterprises, consultants, educational establishments, municipalities and amateurs, for instance ornithologists. These information sources are varyingly available (Article V).

1.6.2. Bird monitoring schemes

Even though the need for biodiversity monitoring and bird monitoring is widely recognised and stressed, treaties and legislative statutes usually contain neither precise instructions on the methods to be used nor criteria for the quantity and quality of the data to be collected.

The focus is rather on the uses of monitoring, including maintaining the conservation status of bird species and the management and sustainable use of populations.

In order to detect bird population changes, understand their causes and predict future changes, a coherent monitoring system is needed. The measurement of regional population dynamics should be as thorough as possible, and the aim should be to identify the population processes that are affected by environmental changes. An ideal monitoring system would thus address population size, reproductive success and mortality (Järvinen 1983; Kilpi 1985; O'Connor 1985; Tiainen 1985; Elmberg *et al*. 2006; Sutherland 2006). The methods applied should be as simple as possible, but reliable and efficient (Koskimies and Pöysä 1989).

Birds are usually monitored by counting pair numbers and densities of breeding populations (O'Connor 1985). However, data on population sizes and densities do not reveal the causes of population trends, neither help to predict future population changes (Elmberg *et al*. 2006). Furthermore, the effect of environmental changes on a breeding population may not be immediate (Article III). This applies in particular to those seabirds that are long-lived, do not easily change their breeding sites (Grenquist 1965; Minton 1968) or may have delayed recruitment. Breeding success is a more rapid and direct indicator of environmental impact than pair numbers. Changes in breeding success may also provide clues to the factors affecting bird populations. Breeding success should therefore be included in seabird and coastal bird monitoring schemes and used in the assessment of environmental changes. For instance the intensive monitoring programme of the Eider in the Söderskär area in the Gulf of Finland (Paavolainen 1950; Grenquist 1965; Hario *et al*. 1986) has been an excellent example of an approach covering several population parameters.

Breeding success is already covered by some monitoring programmes. Several seabird species are being monitored by a Norwegian monitoring programme in the Lofoten and Barents Sea (Anker-Nilssen *et al*. 2006). In the United Kingdom, the Joint Nature Conservation Committee hosts an annual monitoring programme of 26 seabird species, and the Integrated Waterbird Monitoring programme of the Wildfowl and Wetlands Trust covers for instance geese and swans. The Wing Survey conducted by the National Environmental Research Institute in Denmark provides estimates of the breeding success of certain game birds; the yearly age distributions of the game species are estimated on the basis of wings received from hunters.

There are a few other examples of the monitoring of factors related to the breeding success of birds, such as wildlife triangle censuses that combine monitoring of adults and breeding success (Lindén *et al*. 1996), and the Constant Effort Sites (CES) ringing programme for passerines (Peach *et al*. 1996). The CES programme that was started in Great Britain in 1981 has been adopted to several European countries, including Finland, where the SSP (Sisämaan SeurantaPyynti) programme was launched in 1986 (Haapala *et al*. 2008). In North America, a parallel to the CES programme is the Monitoring Avian Productivity and Survivorship (MAPS) programme, established in 1989 (DeSante *et al*. 1995).

In Finland breeding success has been ignored in most census schemes for waterfowl and coastal birds. The breeding success of waterfowl, however, has been monitored on Finnish lakes by brood counts since 1989 (see Oja and Pöysä 2007). The comprehensive archipelago bird census scheme that was launched in Finland in 1984 covers only breeding pair numbers (Hildén 1987; Koskimies and Väisänen 1991). There is an urgent need for reliable data on for instance the recruitment and mortality of migratory European ducks, which are important quarry species in several countries (Elmberg *et al*. 2006).

There are several methods for the measurement of the breeding success of waterfowl, based on nest records and estimation of the adult-juvenile ratio after the breeding season, that could be developed for coastal birds and included in existing monitoring schemes. Traditional methods of monitoring fledgling production are laborious and time-consuming, and are most suitable for short-term studies or studies conducted at key sites. Because of the laboriousness of the monitoring and the expertise required, the monitoring has to be conducted by personnel trained for and assigned to the task. Considerably more spatially comprehensive long-term data could be attained if the methods allowed the estimation of breeding success in a simple and cost-effective way applicable to birdwatchers' activities (Greenwood 2007). For voluntary birdwatchers, rapid single-visit census methods are more suitable than time-consuming multi-visit ones (Koskimies and Pöysä 1989).

1.7. Dissemination of biodiversity data

Actions concerning global environmental changes and the management and conservation of migratory species and species with wide geographical ranges require international cooperation. What is central to common action is that information has to be available on the national environmental situation and on measures taken to solve environmental problems (Glowka *et al*. 1994). In addition, joint collection and sharing of data and information is needed in order to gain a complete view of bird populations, as well as of their habitats both at their breeding and wintering grounds and along their migratory flyways.

A provision on data and information exchange has become a standard addition to international environmental and conservation agreements (Glowka *et al*. 1994). The Ramsar Convention on Wetlands requires its contracting parties to encourage research and the exchange of data and publications regarding wetlands and their flora and fauna, while the Convention on Migratory Species requires the exchange of information on the migratory species concerned, with particular regard to the exchange of the results of research and of relevant statistics.

In the CBD, information exchange is a major focus. The Convention obligates its parties to facilitate the exchange of information relevant to the conservation and sustainable use of biological diversity. The CBD also stipulates the establishment of a Clearing House Mechanism (CHM) to promote and facilitate technical and scientific cooperation. The CHMs aim at establishing a worldwide biodiversity information system, based on local databases connected to a global network through national focal points. As of October 2008, CHM web sites have been established by 87 parties to the CBD according to the CBD web site (http://www.cbd.int/chm/network/). Another major component of the CBD is the improvement of decision-makers' access to biodiversity information (Juma 1997). Thus there is an increasing demand for methods of information processing and sharing.

Efficient biodiversity information sharing implies consideration of all geographical dimensions, from global to local. Worldwide attempts, such as the Global Biodiversity Information Facility (GBIF), are being made to construct information systems integrating national efforts at information production (Edwards *et al*. 2000). To support this, an efficient CHM for sharing deeply-processed high-quality biodiversity information needs roots at the regional level to ensure the inclusion of regionally-focused data as well as better processing and sharing of spatial information (Carling and Harrison 1996; Bisby 2000).

In addition to the CHM and GFIB processes, there are thematic information infrastructure initiatives including e.g. the Global Monitoring for Environment and Security (GMES) (EC 2005), the Global Ocean Observing System (GOOS) (IOC 2005) and the Global Terrestrial Observing System (GTOS) (ENRS 2005). The Biological Collection

Access Service for Europe (BioCASE) enables access to European collection and observational databases using open-source, system-independent software and open data standards and protocols (Berendsohn 2002).

The framework closest to Finnish data policy is the INSPIRE directive of the European Union (Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)), while the global spatial data infrastructure (GSDI) acts as an umbrella organization that provides guidelines for spatial data infrastructure implementation (Nebert 2004). The Finnish national geographic information strategy (Finnish National Council for Geographic Information 2004) mandates free access to geographic metadata, but allows public sector data producers to charge for spatial data sets.

There have been several in-depth descriptions of the preconditions and actions for establishing biodiversity information systems (Olivieri *et al*. 1995; Busby 1997; Stein 1997; Bisby 2000; Edwards *et al*. 2000). However, there has been little discussion of the practical issues related to initiating biodiversity information networks (Xu *et al*. 2000), or of the implications of the new resources for biodiversity information production offered by modern information technology (Article V).

1.8. Aims of the thesis

This thesis addresses the relationships between environmental factors and coastal bird distribution and population trends. In addition to increasing our knowledge of habitat selection by coastal birds and the effect of environmental factors on their population changes, the aim was to identify and test the applicability of different methods for the assessment of coastal bird habitats and population changes, as well as for coastal bird monitoring. The importance of breeding success as a component of bird population trends is also addressed. One prominent focus is on the monitoring, management and conservation of coastal birds and their environment, as well as on the processing and dissemination of data and information.

The following questions are addressed (Roman numerals refer to the original articles presented as annexes):

1. What are the factors that affect habitat selection by Finnish coastal birds? (I, II)
2. Are the occurrence and abundance of a colonial species affected by different factors? (II)
3. Are Finnish coastal bird populations affected by eutrophication and climatic factors? (III)
4. How do habitat selection and responses to environmental changes differ between species and species groups (I–III)
5. What is the relationship between breeding success and population trends? (IV)
6. What methods can be used in the assessment of coastal bird habitats? (I–IV)
7. What methods are available for the monitoring of breeding success? (IV)
8. What is the applicability and interoperability of bird monitoring data? (IV, V)
9. How can bird monitoring data and other local biodiversity data be processed to higher levels of the information hierarchy and made available to target audiences? (V)

2. SETTING OF THE STUDY

2.1. Study areas

2.1.1. General characteristics

The target areas of this thesis are situated in the Archipelago Sea and the Söderskär island group in the Gulf of Finland, on the Finnish coast of the northern Baltic Sea (Fig. 1). The areas belong to the hemi-boreal vegetation zone (Ahti *et al*. 1968), and are characterised by strong seasonality; most birds leave them for the winter (Haila 1983; Hildén and Hario 1993; von Numers 1995). In the Archipelago Sea, the annual ice cover lasts for 60 to 120 days (Seinä and Peltola 1991; Kauppila *et al*. 2004), although the average annual ice cover period has shortened during the past decades (Haapala and Leppäranta 1997). In the Gulf of Finland, the annual ice cover lasts for 30 to 120 days (Kauppila *et al*. 2004).

The average water depth in the Gulf of Finland is 38 m (Perttilä *et al*. 1995) and that in the Archipelago Sea 23 m. Littoral shallow areas are very important for ecosystem functioning (Bonsdorff and Blomqvist 1993), and are particularly vulnerable (Cederwall and Elmgren 1990). The salinity of the Gulf of Finland is approximately 5.5 ‰ (Perttilä *et al*. 1995). In the Archipelago Sea, salinity varies between 3.5 and 7.0 ‰ (Viitasalo *et al*. 1990).

The Archipelago Sea provides excellent opportunities to study the breeding habitats of Finnish coastal birds. It is one of the world's most island-rich archipelagoes, consisting of over 22 000 islands (Granö *et al*. 1999). It is characterised by a fragmented mosaic of different biotopes and a network of environmental gradients (von Numers 1995). The islands range from small skerries, consisting almost entirely of bare rock, to large forested islands.

The Archipelago Sea can be divided into different zones, and different criteria have been applied to characterise the gradual transition from mainland to open sea (Häyrén 1900; Bergman 1939; Andersson and Staav 1980; Granö 1981; von Numers 1995; Korvenpää *et al*. 2003; Tolvanen and Suominen 2004). The inner archipelago zone is dominated by land, in the middle zone approximately half of the area is covered by the sea, and the outer zone is dominated by the sea. The flora and fauna of the Archipelago Sea are changing gradually as a result of post-glacial land upheaval, 3–5 mma^{-1} (Kakkuri 1987), as a consequence of which the zones are constantly shifting outwards.

In the Archipelago Sea and the Söderskär island group, the coastal birds mainly breed on small treeless islets. The Archipelago Sea is a suitable breeding area for most of the Finnish coastal species. It forms the breeding grounds of many gulls, terns, ducks and waders. It is one of the most important breeding areas in Finland for the Eider, the Velvet Scoter and the Caspian Tern (Leivo *et al*. 2002). It is also one of the few breeding grounds of some of the rarest coastal birds in Finland, such as the Common Shelduck (*Tadorna tadorna*), the Dunlin (*Calidris alpina schinzii*) and the Little Tern (*Sterna albifrons*) (Leivo *et al*. 2002). Several breeding bird species are red-listed. The Söderskär area harbours a large Eider population as well as many other duck species and gulls, including Herring Gulls, Lesser Black-backed Gulls (*Larus fuscus*), Mew Gulls (*Larus canus*), and Great Black-backed Gulls (*Larus marinus*).

Both study areas are popular for leisure boating, and some of the islands have summer houses or other buildings. Part of the Archipelago Sea is designated as a Biosphere Reserve, the core of which is the Archipelago Sea National Park. On the basis of the Habitats Directive and Birds Directive, 60 000 ha of the Archipelago Sea have been assigned as Natura 2000 SPA. The area includes four IBAs (Heath *et al*. 2000) and nine FINIBAs (Leivo *et al*. 2002). Some of the islands are protected by landing prohibition. The Archipelago Sea is also important for the implementation of the CMS and the Agreement on the Conservation of African-Eurasian Migratory Waterbirds. The island group of Söderskär is part of the Söderskär and Långören Archipelago, which is a Ramsar site, a Natura 2000 SPA, a Baltic Sea Protected Area, and a Protected Area for the Grey Seal (*Halichoerus grypus*). Landing on the islands is prohibited from May 1 to August 15.

2.1.2. Definition of study areas

Within the Archipelago Sea and Söderskär island group, altogether five study areas were defined: Seksmiilari (A), Trollö-Gullkrona (B), Northern Archipelago Sea (C), Aasla (D) and Söderskär (E) (Fig. 1). The data used in Article I dealt with areas A and B, in Article II area C, in Article III area D, and in Article IV areas D and E. In Article V, the case study dealt with areas A and D.

The study areas of Seksmiilari, Trollö-Gullkrona, the Northern Archipelago Sea and Söderskär consist of island groups. In Articles I and V different island sets were used within the Seksmiilari area, with data on 18 islands being used in Article I and 52 in Article V. The Trollö-Gullkrona area comprises 53 islands, the Northern Archipelago Sea 625 islands and Söderskär 27 islands. The study islands mainly have bedrock shores and thin soil cover. Most of the islands are small and treeless; only a few have forest cover, and very few are inhabited. The study area of Aasla consists of a single larger island, Aasla (60˚18’N, 21˚57’E), and its surrounding sea areas. Seksmiilari and Söderskär belong to the outer archipelago zone, Trollö-Gullkrona and the Northern Archipelago Sea to the middle and outer zones, and Aasla to the inner and middle zone.

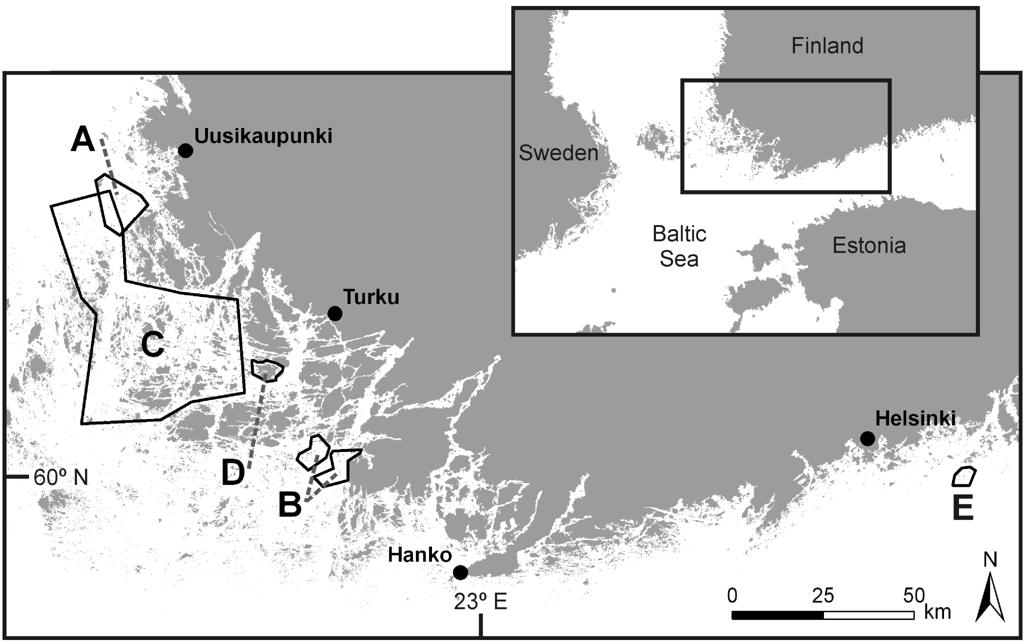

Fig. 1. Map of the study areas: Seksmiilari (A), Trollö-Gullkrona (B), Northern Archipelago Sea (C), Aasla (D) and Söderskär (E).

Many of the study islands belong to long-term bird monitoring areas. Breeding bird populations have been monitored in Seksmiilari during 1963–1992 and 2001–2006, in Trollö during 1957–2006 (with some gaps), in Gullkrona from 1967 to the present, in Aasla from 1975 to the present, and in Söderskär from 1949 to the present (Paavolainen 1950; Grenquist 1965; Hario *et al*. 1986; Articles I and III–V). The Northern Archipelago Sea area at its widest has been censused once (Article II), but parts of it belong to long-term census areas.

2.2. Study species

The target species are characteristic of the southern coast of Finland. They include ducks, gulls, terns and waders, as well as a grebe, a rallid and an alcid (Table 1). The study species groups differ in the different articles, ranging from one species (Article II) to fifteen (Article I). Article V has a wider focus on biodiversity data, but presents two species as a case study. Altogether, twenty species are represented.

The target species represent a wide range of breeding and feeding ecologies. Many aspects of their ecology are well-known, and they are sufficiently abundant in the study areas. The gulls and the Arctic Tern are important to several other species, especially ducks and waders, as they provide protection from predators (Hildén 1965; Brearey and Hildén 1985; von Numers 1995; Valle and Scarton 1999; Nguyen *et al*. 2006).

Table 1. Species covered by the thesis and the target species of each article.

Species		**Article**				
Common name	**Latin name**	**I**	**II**	**III**	**IV**	**V**
Great Crested Grebe	*Podiceps cristatus*			x	x	
Mute Swan	*Cygnus olor*	x		x	x	
Greylag Goose	*Anser anser*	x				
Mallard	*Anas platyrhynchos*	x		x	x	
Tufted Duck	*Aythya fuligula*	x		x		
Eider	*Somateria mollissima*			x	x	x
Velvet Scoter	*Melanitta fusca*	x		x		x
Goldeneye	*Bucephala clangula*			x	x	
Goosander	*Mergus merganser*	x		x	x	
Red-breasted Merganser	*Mergus serrator*			x		
Coot	*Fulica atra*			x	x	
Oystercatcher	*Haematopus ostralegus*	x				
Ringed Plover	*Charadrius hiaticula*	x				
Turnstone	*Arenaria interpres*	x				
Redshank	*Tringa totanus*	x				
Herring Gull	*Larus argentatus*	x				
Lesser Black-backed Gull	*Larus fuscus*	x				
Great Black-backed Gull	*Larus marinus*	x				
Arctic Tern	*Sterna paradisaea*	x	x			
Black Guillemot	*Cepphus grylle*	x				
Species number		**15**	**1**	**10**	**7**	**2**

The Lesser Black-backed Gull and the Black Guillemot are red-listed (Rassi *et al*. 2001). The Lesser Black-backed Gull (the nominate subspecies *Larus fuscus fuscus*), Tufted Duck, Eider, Velvet Scoter, Goldeneye, Goosander, Red-breasted Merganser, Turnstone, and Black Guillemot (the Baltic population) are listed as responsibility species of Finland, as the country holds over 15 % of their European populations (Rassi *et al*. 2001).

In the FINIBA assessment, the Great Crested Grebe, Mute Swan, Greylag Goose, Tufted Duck, Goldeneye, Coot, Oystercatcher, Ringed Plover, Redshank, Turnstone, Herring Gull, Great Black-backed Gull, and Arctic Tern have been used as criteria species for congregation sites. The Eider, Velvet Scoter, Goosander, Red-breasted Merganser, Lesser Black-backed Gull, and Black Guillemot have been regarded as criteria species for both breeding and congregation sites (Leivo *et al*. 2002).

The Tufted Duck, Redshank, Turnstone, Herring Gull, Great Black-backed Gull, Lesser Black-backed Gull, Arctic Tern, and Black Guillemot have been used in the description of the habitat type of "Boreal Baltic islets and islands in outer archipelago and open sea zones" in the Natura 2000 habitat type description (Karttunen and Airaksinen 1998). In addition, the Redshank is included in the description of the habitat type of "Boreal Baltic coastal meadows", and the Great Crested Grebe, Mute Swan, and Mallard in the description of the habitat type of "Boreal Baltic narrow inlets" (Karttunen and Airaksinen 1998).

2.3. Study period

As a whole, this thesis focuses on the forty-year period from the 1960s till the present. The time periods covered by the articles are 2001–2005 in Article I and 1987–1994 in Article II; in Article III, the times covered are 1984–2001 in the statistical analysis and 1975–2003 in the population trend analysis. In Article IV, the data from Aasla cover the years 1975–2007 and the data from Söderskär the years 1967–2007. Different aspects of Article V cover various periods from the 1920s to 2001, but the two bird data sets used as a case study cover the years 1963–1992 (Seksmiilari) and 1975–2000 (Aasla).

3. DATA

3.1. Bird data

3.1.1. Archipelago bird censuses

Archipelago bird counts (as described by Koskimies and Väisänen 1991) were used in Articles I, II and V. In Articles I and II they were used in the analyses of bird habitat selection and in Article V as examples of bird monitoring data and biodiversity data.

In the areas of Seksmiilari and Trollö-Gullkrona (Article I), the bird censuses were conducted by M. Rönkä, M. Rautkari and H. Tolvanen, as well as several assistants, and in the area of the Northern Archipelago Sea (Article II) by M. von Numers. The longer time series of archipelago bird counts in the Seksmiilari area (Article V) was collected by R. Tenovuo.

The censuses were conducted using the standard methods of the Finnish archipelago census scheme (Kilpi 1985; Hildén 1987; Koskimies and Väisänen 1991). We used data on breeding birds. Pair numbers were based on observed individuals or nests (Koskimies and Väisänen 1991). In Article I and in part of the analyses in Article II the pair numbers were transformed into binary data, since the aim was to study habitat selection and occurrence of the target species.

3.1.2. Waterfowl censuses

In Aasla, (Articles III–V) the waterfowl censuses were conducted by L. Saari. The census method was a combination of point and round counts (Koskimies and Väisänen 1991). The sea areas were censused by walking standard routes along the shore around the island and stopping at standard sites. The census route was chosen so that all breeding birds in the area could be counted.

We used data on breeding birds. The pair numbers were based on counted pairs (or equivalents; see Koskimies and Väisänen 1991), since searching for nests was impractical for most of the species due to the habitat structure. The numbers of individuals were converted into pair numbers according to the recommendations by Linkola (1959) either by dividing the individual number by two or by using the number of males or females as the pair number.

3.1.3. Eider censuses

The Eider censuses in Söderskär were conducted by M. Hario, R. Komu, J.T. Lehtonen, P. Muuronen, H. Selin and K. Selin (Hario and Selin 1986; Hario *et al.* 1986) in 1967–2007. The data cover 27 islands or islets.

We used female numbers obtained in nest counts at the end of the brooding period in May and June. Female Eiders and ducklings were ringed and females controlled at the nest, which provided data on the rate of recruitment (proportion of first-breeders out of the breeding population), the age distribution of first-breeders, and mortality (Hario and Selin 1987, 2002).

3.1.4. Brood counts

Breeding success at Aasla was assessed by brood counts in July. We used data on the Mallard, Goldeneye, Mute Swan, Coot, Goosander, Great Crested Grebe and Eider. The age class of the chicks was estimated according to Pirkola and Högmander (1974). We used age classes IIa–III (small half-grown – almost fully-grown). Duckling mortality is largely concentrated during their first weeks (Hildén 1964; Hario and Selin 1991; Paasivaara and Pöysä 2007); the ducklings in age classes IIa–III have passed the most critical phases of development as to cold sensitivity and gull predation (Koskimies and Lahti 1964; Hario and Selin 1989; Mikola *et al.* 1994). For the Mute Swan we used yearly fledgling counts from September, as the fledgling counts in July were too early to quantify the final fledgling production of this species.

In addition to chick numbers, we collected data on the number of individuals in July (autumn population size). The data were collected as described for pair numbers, and covered all observed adults and juveniles. The autumn population size reflects breeding success but also breeding population size, and is affected by reproductive success, natal dispersal of potential recruits, and the number of adults staying in the breeding area after breeding (for many duck species mainly females). We chose to use the autumn population size from July because later the birds are less likely to belong to the local population due to the species-specific patterns of post-breeding movements of females, males and young.

The brood counts in Söderskär were carried out by censusing the feeding areas by boat in the early morning every second or third week (Hario and Selin 1989). The fledgling number obtained in the brood count carried out 70 days after the median hatching date of the population was regarded as the total fledgling number. The yearly timing of breeding was taken into account in the timing of the brood counts. We imputed four annual missing fledgling number values by calculating the average of two neighbouring values before and after the missing ones.

3.2. Environmental data

3.2.1. Island characteristics

Data on island characteristics were used in Articles I and II to study habitat selection by the target species, as well as differences in habitat selection mechanisms affecting the occurrence and abundance of a colonial species (Article II).

For Article I the data were derived mainly from digital data archives, and were supplemented by field observations only when the digital data did not provide sufficient information. This was the case with regard to a few small and low skerries, for which the digital elevation model (DEM) did not provide enough data. For Article II the data were collected in the field or measured from a topographical map or digital elevation model.

Article I covered physical island characteristics. We used shoreline data, elevation model and bathymetric data to calculate five variables for each island: land area (ha), maximum elevation (m), total land area of adjacent islands within 200 m (ha), average water depth within 200 m (m), and mean fetch, i.e. shoreline openness (km).

In Article II we used fourteen abiotic and biotic variables, in three groups: 1) shore habitat, 2) cover habitat and 3) physiognomic characteristics. Shore habitat variables included the proportions (%) of rock, boulder, sand, meadow and reed shore out of the total shore length of the island. Cover habitat variables included the proportions (%) of shrub, meadow or heath, boulder or gravel, rock, and forest cover out of the land area of the island. Physiognomic characteristics described the morphology of the islands, including island area (ha), maximum elevation (m), proportion of land area with a slope less than 5º (%) and exposure (degree).

3.2.2. Water quality and salinity

Water quality data were used in Article III. The data were collected and analysed by the Southwest Finland Regional Environment Centre and the Water Protection Association of Southwest Finland (Kirkkala *et al.* 1998; Suomela 2001). We chose ten monitoring stations within a radius of 15 km from the target area, Aasla. As measures of water quality we used surface water concentrations of total phosphorus ($\mu g\ l^{-1}$) and chlorophyll α ($\mu g\ l^{-1}$), as well as water transparency (Secchi depth, m) (Kirkkala *et al.* 1998). We calculated means for the water quality measures for each station and each summer, and combined the variables into a single variable using the principal component analysis (PCA) software in the SAS statistical package (McCune and Grace 2002). We identified the principal component as a variable indicating eutrophication.

Water salinity data were collected by the Finnish Institute of Marine Research at the Päiväluoto monitoring station (60˚15’N, 21˚58’E) in Nauvo, ca. 2 kilometres south of the study area. The samples were taken at a depth of 20 metres at intervals of ten days.

3.2.3. Weather

Weather data were used in Article III. As an indicator of winter severity we used the yearly maximum sea ice coverage (km^2) of the Baltic Sea, available at the Finnish Institute of Marine Research (Seinä and Peltola 1991). Maximum ice coverage is strongly correlated with regional November–February temperatures and the North Atlantic Oscillation (NAO) index, but has the benefit of being directly and functionally connected with the wintering habits of several of our target species; it was thus selected as the winter severity variable.

We calculated the yearly mean temperature for the five first weeks of the breeding season for each species. In order to estimate the start of breeding for each species in each year we used the yearly mean arrival time of each species, as recorded at the Jurmo ornithological station (59˚50’N, 21˚37’E), ca. 50 kilometres south of the study area.

3.3. Biodiversity data and bibliographic information

The categories of original data considered for the regional CHM in Article V were descriptive biodiversity data, synthetic information and metadata. Data sources included public bibliographical databases and primary databases maintained by biologists. We used geocoded biodiversity information, i.e. biodiversity information that is linked to a geographical location with a spatial label, either directly by map coordinates or indirectly by place and area names.

Holders of georeferenced data in Southwest Finland were reviewed and a spatial information index of Southwest Finland was introduced, comprising a total of 144 databases from 12 fields. Biologists known as database custodians were contacted and their biodiversity databases reviewed. We also reviewed the published biodiversity literature concerning the target area using the major national and international bibliographical databases, including ASFA, BIOSIS PREVIEWS and the HELCOM bibliography.

To examine the challenges arising from joint exploitation of multiple sources of descriptive data, bird censuses in Seksmiilari and Aasla were used as a test case.

4. METHODS OF ANALYSIS

4.1. Environmental factors influencing occurrence and abundance

In Article I we analysed the occurrence (in terms of presence or absence) of 15 bird species on each island in Seksmiilari and Trollö-Gullkrona, in relation to the island characteristics, by means of a generalised linear model (GLM) using the GENMOD procedure of the SAS statistical package, version 8.2 (SAS Institute Inc. 2001). The dependent variable indicated whether a species had accepted an island as its breeding site in at least one year during our study period 2001–2005.

We used model comparison to identify models with good fit, according to Burnham and Anderson (1998, 2004) and Johnson and Omland (2004). For each species we created 31 models, covering all the combinations of independent variables. We compared the models with the second-order Akaike Information Criterion (AICc) (Burnham and Anderson 1998, 2004; Johnson and Omland 2004), which is a parsimonious approach that covers both model fit and number of parameters. The smallest AICc value identified the model that best fit the data. In our final set of models we also included models whose AICc value differed from that of the best model by two units or less, and had thus substantial support (Burnham and Anderson 1998, p. 48).

We used the sets of models in two ways. First, we used the frequencies of the independent variables in the models for each species as an estimate of the importance of the independent variables for the species. Secondly, we chose for each species one model that best fitted the data according to the AICc value, the estimate values, and the principles of parsimony.

In Article II we created predictive distribution models for the Arctic Tern, using 14 environmental variables calculated for 525 islands in the Northern Archipelago Sea. Occurrence was modelled using GAMs and abundance using hurdle models fitted with GAM (Hastie and Tibshirani 1990; Potts and Elith 2006). These models were chosen using stepwise backward selection on the basis of the Akaike Information Criterion (AIC) (Burnham and Anderson 1998; Johnson and Omland 2004). We tested for spatial autocorrelation in model residuals and evaluated the models on independent data for 100 islands. The analyses were conducted using the R language and environment (Venables *et al.* 2007). All models were fitted using the R package "gam" and tested for spatial autocorrelation using the package "spdep".

4.2. Population trends

The long-term bird census data used in Articles III–V allow the assessment of population trends of the target species; the habitat selection studies presented in Articles I and II, in contrast, do not include a temporal aspect.

In Article III we studied the breeding population trends of the Mallard, Tufted Duck, Goldeneye, Mute Swan, Coot, Red-breasted Merganser, Great Crested Grebe, Eider, Velvet Scoter and Goosander in Aasla during 1975–2003. On the basis of the data used in Article IV, a comparison can be drawn between the population trends of the Eider in Aasla during 1975–2007 and in Söderskär during 1967–2007. Article V adds a third study area, Seksmiilari, to the comparison regarding the Eider and the Velvet Scoter during 1963–1992.

In order to assess between-year changes in the population sizes of the species in Article III, we used the program TRIM (Trends & Indices for Monitoring Data) (Pannekoek and van Strien 2003). TRIM, which is based on log-linear models, can be used to analyse time series and to estimate indices and trends (Hario 1998; Tiainen *et al.* 2001; Pannekoek and van Strien 2003). For each species we chose the census areas where the species had been observed in at least one year. TRIM used the data from the different areas to calculate the overall population trend for each species. We used corrections for overdispersion and serial correlation, which are taken into account in TRIM using a Generalised Estimating Equations (GEE) approach (Liang and Zeger 1986).

4.3. Environmental effects on population trends

In Article III we analysed the relationship between bird population sizes and environmental variables using the GENMOD procedure in the SAS statistical package, version 8.2 (SAS Institute Inc. 2001). The GENMOD procedure fits generalised linear models to correlated responses using the GEE method (SAS Institute Inc. 2001).

We modelled the impact of eutrophication, winter severity, temperature of the early breeding period and water salinity on the breeding populations of ten waterfowl species in Aasla. As the dependent variable we used the yearly pair numbers of each species. Since some environmental factors may affect bird populations with a lag, or a lag may result from delayed recruitment, we also used the independent variables with a time lag. We formed the lagged variables by calculating for each year the average of the values of the two preceding years. We used the variable as an indicator of the circumstances in the past years in order to reduce the number of variables and to avoid overparameterisation (using too many independent variables in the model in relation to the numbers of replicates in the data). For the same reason, we built parallel models for effects with and without the time lag. We used year as a repeated subject to control for correlation in the variables between subsequent years.

As we were mainly interested in linear relationships between the dependent and independent variables and wanted to avoid overparameterisation, we did not include non-linear relationships into the models. This approach was further validated by the fact that the squares of the eutrophication values did not show any statistically significant effect on the breeding populations of any of the species.

4.4. Relationship between breeding success and population trends

In Article IV we studied the relationship for seven waterfowl species in Aasla between breeding population trends and breeding success, measured either as chick numbers or individual numbers in the late summer. We also analysed the relationship between numbers of chicks or recruits and breeding population size of the Eider in Söderskär in order to compare the applicability to breeding success monitoring of two types of data: the census data in Aasla and the data collected in the intensive study in Söderskär, where the broods were closely monitored.

As time series on bird populations and breeding success have an autocorrelated structure, regression analyses may result in ineffectual or incorrect models (Box and Newbold 1971). We therefore used transfer functions (TF), which merge the basic concepts of the general regression model with those of the autoregressive integrated moving average (ARIMA) models (Box and Jenkins 1976; Yaffee and McGee 2000; Liu 2006). TFs are able to connect a given time series not only with its own past values but also with past and present values of other time series. Time lags between the modelled time series and the originator time series can also be included in the models (Hänninen *et al*. 2000; Hänninen *et al*. 2003; Vuorinen *et al*. 2003).

As the response variable we used the breeding pair numbers of our target species and as input variables either chick numbers or individual numbers in late summer. For the Eider in Söderskär, we also built a model including the breeding pair number as the response variable and the number of recruits as the input variable. We evaluated the models on the basis of their coefficients of determination (r^2), residual standard errors, and parsimony. The analyses were conducted using the SCA Statistical System, version 8.0 (Liu 2006).

4.5. Assessment of monitoring method

In Article IV we developed and assessed an extension of traditional methods of monitoring breeding success: a combination of point and round counts of broods and full-grown birds in late summer. The census method was developed by L. Saari in accordance with the instructions given in Koskimies and Väisänen (1991), and Linkola (1959).

To assess the strength of the relationship between chick numbers and autumn population sizes for the target species, we calculated the correlations between these variables using the residuals derived from the ARIMA models for both variables. The ARIMA modelling was done using the SCA Statistical System, version 8.0 (Liu 2006), and the correlations were calculated using the procedure CORR of the SAS statistical package, version 9.1 (SAS Institute Inc. 2004).

4.6. Bird censuses as part of a regional biodiversity clearing-house

In the assessment of geospatially structured biodiversity data and information in Article V, the main methods were the testing of the usability of coastal bird census data as an example of descriptive biodiversity data, and the creation of a regional CHM on the basis of bibliographical information and descriptive data. The aim was to address the pathway in the biodiversity information hierarchy from real world observations to information, knowledge and wisdom (Article V; Tolvanen 2006).

In the assessment of the applicability of descriptive bird data, we used the coastal bird censuses conducted in Seksmiilari and Aasla, with the Eider and the Velvet Scoter as target species. We addressed the temporal coverage, structure and geocodability of the data, together with the census methods used, and recorded the data to a digital database. In addition, we produced a metadata description of the database, including e.g. a report of the interpretation principles used for the field data, and a list of records excluded from the database.

As the first step towards the construction of the regional CHM, we created a new database in order to systematise the management of bibliographical data. Redundant records and non-relevant articles were removed, and the filtered records were classified, labelled according to thematic criteria, and geocoded. The second step included the building of the CHM with a freeware server and database software. The CHM used conventional database tools and applied structured query language (SQL) for information retrieval. The information system was later included in a regional spatial data portal called Lounaispaikka, which is part of the GI (geographical information) cooperation in Southwest Finland coordinated by the GI Centre of Southwest Finland.

5. RESULTS AND DISCUSSION

5.1. Relationship between environmental factors and bird populations

5.1.1. Population trends

The Mallard, Tufted Duck, Eider, Goldeneye and Red-breasted Merganser populations in Aasla had been declining since the beginning or middle of the 1990s (Article III). For the Great Crested Grebe and the Coot the population decline had levelled off in the mid-1980s, and populations were more or less stable but smaller than during 1975–1984. The Mute Swan was the only species that was maintaining a larger population at the end of the study period than at the beginning. The pair numbers of the Goosander indicate that the population had been declining since 1994, when it was at its largest. The Velvet Scoter population had crashed from 41 pairs in 1975 to 0–4 pairs from 1993 onward. The Eider population started to decline in Söderskär in 1986–1987, but in Aasla in the mid-1990s (Hario *et al*. 2005; Hario and Rintala 2006; Article IV). In Seksmiilari the Eider and the Velvet Scoter showed a decreasing trend during 1963–1992 (Article V).

The population trends of our target species in Aasla were similar to the general population trends in the SW Finnish archipelago with regard to the Mute Swan, Eider (Väisänen *et al*. 1998; Hario and Rintala 2004) and Goosander (Tiainen *et al*. 2001). For the Eider in Söderskär the trend was similar to the general trend in the Gulf of Finland (Väisänen *et al*. 1998; Hario and Rintala 2004). In Seksmiilari the decline of the Eider seems to have begun earlier than in the SW Finnish archipelago in general.

The population trends of the Velvet Scoter in Aasla and Seksmiilari corresponded to the trend for the SW Finnish archipelago (Tiainen *et al*. 2001). The Velvet Scoter population in Aasla, however, does not show the same recovery after the extreme population low of 1993–1994 that was evident in the general population trend in the SW Finnish archipelago.

The decline of the Great Crested Grebe in Aasla corresponds to its general decrease in the 1990s in Finland (Väisänen *et al*. 1998). Species that showed a decline in Aasla but not generally in the SW Finnish archipelago (Tiainen *et al*. 2001) or in Finland as a whole (Väisänen *et al*. 1998) were the Mallard, Tufted Duck, Goldeneye, Red-breasted Merganser and Coot.

5.1.2. Local breeding site characteristics

Breeding site selection by birds in coastal archipelagoes is affected by features of island topography and cover habitats, as well as the landscape (Hildén 1964; von Numers 1995; Articles I and II) and seabed (Article I) around the islands. Different combinations of island area, water depth, mean fetch and island elevation affected the occurrence of the Mute Swan, Greylag Goose, Mallard, Velvet Scoter, Goosander, Oystercatcher, Ringed Plover, Redshank, Turnstone, Lesser Black-backed Gull, Herring Gull, Great Black-backed Gull, Arctic Tern and Black Guillemot (Article I).

There are differences in habitat preferences between and within species groups (Article I). The most uniform group in this study were the gulls, which preferred large islands and deep waters. The Arctic Tern differed from the other larids in that it preferred large and low islands. Among waders, three species out of four preferred large islands and shallow waters. In contrast, the most important factor for the Turnstone was shoreline openness. The ducks preferred large islands, but in addition, Greylag Goose preferred low islands. The Mallard differed from the other ducks in that it preferred high islands and shallow waters. The Black Guillemot had a combination of preferences distinct from all other species: deep water and open shoreline.

When the analysis was extended to island cover habitats, the probability of the presence of the Arctic Tern increased with increasing proportion of boulder or gravel, decreasing proportion of forest, decreasing island height and increasing island area (Article II). With regard to island area and height, the results are in accordance with Article I. Arctic Tern abundance increased with increasing proportion of boulder or gravel, increasing exposure, increasing proportion of bare rock and increasing area.

Large islands generally provide a more diverse environment than small islets, and are thus better able to meet the birds' habitat requirements regarding nest sites, food and shelter against predators and adverse weather (Hildén 1965; Lack 1969, 1976). In island biogeography studies it has been widely discussed whether island area is important as such, or whether big islands harbour more species than small islands only because of their greater habitat diversity (Begon *et al*. 1996). Furthermore, it has been found that habitat diversity is important along with lake area to the species richness of waterfowl (Elmberg *et al*. 1994). Island size probably also correlates with biotic factors, such as vegetation and the presence of other species. Cover habitats function as nesting substrates, providing shelter from predators and weather, or harbour possible predators (Hildén 1964, 1965; Lemmetyinen *et al*. 1974; von Numers 1995). Large islands are often covered by trees and bushes; thus they favour crows and minks, which are important nest predators in the archipelago (Lemmetyinen 1971). In particular larids and their associates avoid islets with trees (Hildén 1964; von Numers 1995; Article II).

The mechanism through which island area affects habitat choice is species-specific. In general, islands have to be large or high enough to protect nests from the waves but small or low enough to lack bushes and trees that favour predators. In the Archipelago Sea the positive aspects of large islands still seem to outweigh negative ones (Articles I and II). Most of the islands in the study areas are indeed rather small and open and may thus be below the optimum size for birds (see e.g. von Numers 1995). The smallest islets are mere rocks, on which few birds nest, and even many of the larger islands lack trees. Accordingly, the number of species that bred on the islands increased with island area (Article I). As most of the target species of this thesis mainly breed on small treeless islets, the whole range of island areas in the Archipelago Sea is not covered by our data. The range that we used sufficed, however, to reveal the effect of island area on the habitat selection of several of our target species on the relatively small open islets in the study areas.

Island topography is connected with nest site preferences and locomotory capabilities (Hildén 1964, 1965). The preference of the Greylag Goose, Ringed Plover, and Arctic Tern for low islands may indicate that a low profile correlates with a favourable vegetation and shore structure (Article I). In turn, it is easier for ducks and waders to feed in shallow waters, and our depth variable probably also reflects conditions on the shore (Article I). On lakes it has been shown that breeding Mallards prefer lakes with relatively rich, wide and high zones of emergent vegetation and shallow shores (Nummi and Pöysä 1993; Pöysä 2001).

Shoreline openness affects the potential wave exposure of the littoral zone, which is a major physical stress (Coops *et al*. 1991; von Numers 1995; Kiirikki 1996; Ruuskanen *et al*. 1999) affecting the ecological and geomorphological processes in the littoral zone (Tolvanen and Suominen 2005). The preference of the Turnstone and the Black Guillemot for open waters reflects their maritime character (Article I). The Lesser Black-backed Gull has earlier been shown to select less exposed islands than the Herring Gull (von Numers

1995), and its preference for open shorelines found in Article I may indicate that the earlier state is being reversed due for instance to competition or a change in food resources.

When interpreting the habitat preferences of coastal birds, the differences in the sizes of the home ranges or feeding ranges between species have to be taken into account. Whereas gulls and terns utilise feeding areas further away from the nests and transport food to their chicks, waders choose nest sites in the vicinity of which their precocial young can find food. The broods of many duck species also depend on food resources close to the nest site at least in the first days after leaving the nest. For instance Eider females with broods often stay close to their nesting islands (Öst and Kilpi 2000), even though older broods sometimes move longer distances (Cramp and Simmons 1977; Hario and Selin 1989). The Goosander may also lead its brood long distances to rearing areas (Cramp and Simmons 1977). The importance of food resources may therefore be visible on an island-specific or local scale for waders and ducks, but on a wider scale for gulls and terns.

Concerning adults in the early breeding season, the location of feeding areas within a suitable range from the nest site is more important for income breeders than for capital breeders. Income breeders, such as many smaller migratory ducks, acquire the energy needed for reproduction locally in the breeding environment, whereas capital breeders, such as some larger-bodied ducks and many geese, rely on body reserves stored before breeding (Drent and Daan 1980; Jonsson 1997; Arzel *et al*. 2006; Guillemain *et al*. 2007). Capital and income breeding are, however, two extremes of a continuum of strategies rather than mutually exclusive alternatives (Meijer and Drent 1999). Guillemain *et al*. (2007) found that late winter body condition relates to the breeding success of the Common Teal (*Anas crecca*), an income breeder, and some capital breeders have been found to complement their endogenous reserves with food acquired in the breeding area (Arzel *et al*. 2006). In addition, there can be individual and seasonal variation in the strategy even within species (Gaulthier *et al*. 2003; Klaassen *et al*. 2006).

The differences in the feeding and breeding ecology of coastal birds are likely to affect their priorities concerning nest site characteristics. A lower risk of nest predation may take a higher priority in the nest site selection of gulls and terns than that of waders and ducks, for which food resources may be relatively more important. Furthermore, if gulls and terns first select an area with good food resources and then search for a nest site within that area, the size of their home range probably allows a choice between several potential nest sites. Gulls and terns may therefore have an option for a more careful selection of island properties, while waders may have to compromise on the quality of less important island features in favour of good food resources. For secondary cavity-nesting coastal bird species, such as the Goldeneye, the shortage of nest sites may be a limiting factor (Pöysä and Pöysä 2002).

In addition to the species-specific priorities, there are differences in habitat requirements during different phases of breeding within species (Nummi and Pöysä 1993). Nesting birds may be able to forecast the suitability of the habitat to a subsequent phase of breeding (Pöysä *et al*. 2000). Food limitation at the brood stage has been found to affect the habitat selection of nesting Mallards, which indicates that they anticipate the quality of habitats for brood-rearing (Pöysä *et al*. 2000).

As many coastal bird species are colonial, the habitat selection process of the first pair on a site may differ from that of subsequent pairs. The abundance of the colonial Arctic Tern seems to be driven to some extent by a different process than its occurrence, with regard not only to intraspecific relationships but also to abiotic and biotic factors (Article II). It seems probable that large colonies are found on the most suitable islands, as colony size depends among other things on reproductive success, which can be regarded as a measure of habitat quality (Serrano *et al*. 2001). Small colonies and solitary pairs may merely attempt to breed on a site, for instance in their first breeding season.

Colony size is also affected by other factors than those assessed in Article II, such as food resources and behavioural characteristics related to prospecting behaviour (Chastel *et al*. 1993; Boulinier *et al*. 1996; Dittmann *et al*. 2005), site tenacity (Chastel *et al*. 1993; Sanchez *et al*. 2004; Matthiopoulos *et al*. 2005; Szczys *et al*. 2005), and kinship. In addition, nest defence behaviour may be less costly for colony breeders, as for instance terns nesting solitarily have been shown to be more aggressive towards nest predators than those nesting in colonies (Bergman 1939; Lind 1963; Lemmetyinen 1971). In larger colonies individuals may be able to lower their own investment in nest defence (Allainé 1991) and still maintain a higher total of nest defence than smaller colonies or individual pairs, gaining better shelter from predators (Allainé 1991; Berg 1996; Arroyo *et al*. 2001; Hernández-Matías and Ruiz 2003).

On the other hand, Lemmetyinen (1971) showed that solitary Arctic Tern and Common Tern (*Sterna hirundo*) pairs were able to defend their nests from nest predators as efficiently as pairs nesting in colonies. In some cases colonial pairs have been shown to be subject to on the average heavier nest losses than solitary pairs (Lemmetyinen 1971), and predation rate has increased with colony size (Weidinger 1998), which may be due to some predators being more attracted to large colonies than to small colonies or solitary nests.

5.1.3. Regional environmental factors

In addition to local island-specific factors, there are also regional and global environmental factors which influence the habitats and population processes of birds. In the Baltic Sea area, important environmental impacts are eutrophication and climate change.

According to our results, the population sizes of the Goldeneye, Coot and Velvet Scoter decreased with the increase in eutrophication in Aasla (Article III). For the Coot and Velvet Scoter the effects were also evident in time lag models. This may indicate that eutrophication not only increases emigration but also reduces breeding success and/or the winter survival of juveniles.

As primary production increases along with eutrophication, the food resources of birds feeding on fish or benthos may likewise increase (Cederwall and Elmgren 1990; Hario and Selin 1986; Laurila and Hario 1988; Elmgren 1989; Bonsdorff *et al.* 1997a). Eutrophication may also affect the abundance of some species of plants (Tenovuo 1975; Bonsdorff *et al.* 1997a; Salovius *et al*. 2005; von Numers and Korvenpää 2007) and insects (von Haartman 1982). By increasing the food resources, eutrophication has been assumed to benefit the Eider, Mute Swan, Great Crested Grebe and Coot. Furthermore, the Great Crested Grebe and Coot may profit from changes in shore vegetation (von Numers 1995). Eutrophication is supposed to affect bird distribution, in that inland species may start to nest in the archipelago (von Haartman 1984) or inner archipelago species in the outer archipelago (Tenovuo 1976).

In the long run, eutrophication may hamper birds by modifying the structure of the food web (Bonsdorff 1992; Rumohr *et al.* 1996). Enrichment leads to increasing oxygen-consuming drift-algal mats (Salovius *et al*. 2005), which cause anoxy at the sea bottom (Bonsdorff *et al.* 1997a). Oxygen depletion and anoxy at the sea bottom reduce the diversity of benthic fauna (Rumohr *et al.* 1996; Norkko 1997) and may lead to a change in fish communities and a decrease in fish stocks (Rajasilta *et al.* 1989; Hansson and Rudstam 1990). Benthic animals may also be damaged by algal blooms and overgrowth (Bonsdorff 1992).

As the eutrophication process continues the response of the benthic fauna changes from a structural response in terms of increased abundance to a functional response in terms of reduced complexity (Leppäkoski 1975; Pearson and Rosenberg 1978; Bonsdorff *et al.* 1991; O'Brien *et al.* 2003). Eutrophication contributes to a shift in the benthic fauna from suspension feeders to deposit feeders (Bonsdorff *et al.* 1997b; O'Brien *et al.* 2003), and changes the functions and processes at the sea bottom (Sandberg 1994).

Little is still known about the effects of light regime changes on coastal communities (Okey *et al*. 2004). A decrease in water transparency (Sandén and Håkansson 1996) through shading by phytoplankton may harm benthic fauna and fish (Okey *et al*. 2004). Light limitation by phytoplankton, epiphytes and filamentous macroalgae may also lead to a decline of marine macrophytes (Hauxwell *et al*. 2003). In addition to affecting the food resources of birds, decreasing water transparency makes it more difficult to catch fish and find other prey.

The abundance of waterbirds has been found to correlate with water transparency at lakes (Boshoff *et al*. 1991). Water transparency may be more important for "pursuit divers", e.g. divers and mergansers, that search for food while swimming with their eyes below the water surface and then dive after the prey, than for "surface plungers", such as terns, that search for prey while flying and only exploit the volume of water closest to the surface (Eriksson 1985).

It must be noted, however, that the effects of water transparency may be difficult to distinguish from those of other hydrological features. For instance, Garthe (1997) showed that in the North Sea, the summer distribution of the Northern Fulmars (*Fulmarus glacialis*) and Guillemots (*Uria aalge*) correlated with highly saline, thermally stratified water with high water clarity, which should exhibit high concentrations of their prey. In contrast, several gull and tern species frequented turbid waters of low salinity, which was not as easy to interpret on the basis of their feeding ecology.

Of the study species in Article III, particularly the Goosander, Red-breasted Merganser and Great Crested Grebe feed on fish (Cramp and Simmons 1977). Even if increasing eutrophication increases their food resources, it may make feeding more difficult. It may be due to these mutually contradictory effects that we did not find any statistically significant impact of eutrophication on these species.

It is interesting that eutrophication had a statistically significant effect on the Goldeneye, Velvet Scoter and Coot, which seem to be ecologically quite different species. However, there are also similarities in the habitat requirements, diet and feeding habits of these species. All the three species obtain at least a part of their food by diving and feed on Molluscs, although the Coot and the Goldeneye also utilise other feeding methods and food items (Cramp and Simmons 1977, 1980). It is also possible that increasing eutrophication changes the habitats of these species in some other way, to which the species respond in a similar manner.

Our results suggest that the effects of eutrophication on birds are probably more complex than has been assumed. Furthermore, the effects of eutrophication may only become visible after a time lag because many coastal bird species are long-lived and do not readily change their breeding grounds but can relatively easily switch feeding areas (Hildén 1964; Grenquist 1965).

Each bird species responds to increasing eutrophication on the basis of its feeding and breeding ecology. Some species may initially benefit from eutrophication, but at a species-specific stage the effect turns negative. Non-linear relationships between eutrophication and the population sizes of our target species could have implied that there had been a phase of eutrophication optimal to the species during our study period. As eutrophication increased during the study period whereas most of the target species decreased, it is possible that in the inner archipelago eutrophication had already passed the phases optimal for these species.

Indeed, the water quality in the Archipelago Sea declined during the 1980s and 1990s (Jumppanen and Mattila 1994; Suomela 2001). Increasing areas were subjected to hypoxia in near-bottom water (Jumppanen and Mattila 1994). Furthermore, the biomasses of benthic animals in the Aasla area declined during 1980–1993 (Rönkä *et al*., unpubl.). During 1997–2001 there was also a decline in the numbers of the benthic amphipod *Monoporeia affinis*, which is regarded as an indicator of a healthy sea bottom (Räisänen 2003).

The concept of ecological thresholds, which is nowadays a matter for growing concern (Lyytimäki *et al*. 2008), may also apply to eutrophication (Richardson *et al*. 2007; Wazniak *et al*. 2007). According to the concept of ecological thresholds, abrupt non-linear shifts to dramatically different regimes can be triggered by even small differences in gradually changing conditions if a threshold value is exceeded (Muradian 2001; Scheffer and Carpenter 2003; Burkett *et al*. 2005). Once the regime shift has incurred and the system has flipped from one stable state to another, the shift may be difficult to reverse (Scheffer and Carpenter 2003). Further study is required to find out if the relationship that was found in Article III between eutrophication and bird population trends indicates that the eutrophication process has passed an ecological threshold. In order to verify the existence of an ecological threshold, non-linear ecological phenomena have to be distinguished from changes that vary stochastically around a mean, which requires a consideration of temporal and spatial scales (Muradian 2001; Burkett *et al*. 2005).

In addition to eutrophication, winter severity reduced our study populations (Article III). After severe winters the breeding populations of the Mute Swan, Mallard, Eider, Goldeneye and Coot declined, and the Red-breasted Merganser and Goosander populations expressed the same tendency. This was to be expected because of the wintering distribution of these species. The severity of the previous two winters seemed to diminish the breeding populations of the Tufted Duck, Coot and Eider, and the same trend was seen in the Red-breasted Merganser and Goosander populations. This indicates that the effects of prolonged periods of cold winters may be additive, and it may take time for these species to recover from hard winters.

Most of the study species overwinter primarily in the Southern Baltic Sea, the Danish Sound or Kattegat (Cramp and Simmons 1977; Pihl *et al.* 1995; Gilissen *et al.* 2002); a small part of the Finnish population of some waterfowl winters in Finland (Gilissen *et al.* 2002). Thus winter severity and ice conditions in the Baltic Sea are crucial for most Finnish waterfowl. In addition to mortality due to starvation and cold, severe winters may force birds to migrate further than normal, which carries extra costs. Furthermore, if the Baltic Sea is largely covered by ice birds have to feed in small areas, which leads to increased competition for food and possibly elevated risk of disease (Grenquist 1965; but see Hario *et al.* 1995). Winter severity in the Baltic Sea also reflects winter severity in the North Sea and further off the coast of Western Europe, as well as in Central Europe (Hurrell 1995).

Severe winters have been suggested to influence the populations of the Great Crested Grebe and Coot (von Haartman 1945), Tufted Duck (Hildén 1966) and Mute Swan (Minton 1968; Koskinen *et al.* 2003). The crash of many Finnish coastal bird populations in the 1940s was largely due to a sequence of extremely hard winters, during which the Baltic Sea was entirely covered by ice. During the Second World War coastal bird populations also suffered from illegal hunting and egg collecting, as well as from oil discharges from shipwrecks, but high winter mortality has been assumed to be the main reason behind the decline of for instance the Razorbill (*Alca torda*), Greater Scaup (*Aythya marila*) and

Tufted Duck (Hildén and Hario 1993). The difficulties of the Mute Swans during the hard winter of 1838 were illustratively described by Nilsson (1858).

Weather, especially temperature, rainfall and wind, is important for the breeding success of the Eider, the Velvet Scoter and the Mute Swan (Koskimies 1955; Koskimies and Lahti 1964; Koskinen *et al.* 2003). Its effects on population sizes, however, are not self-evident: the survival of adult birds is rarely affected by poor weather, and even a severe crash in fledgling production may not be carried over to the size of the future local breeding population. In Aasla, high temperatures during the breeding season seemed to have on average a slight negative impact on the breeding population sizes (Article III). The negative effects, however, may be an artefact due to the easier detectability of birds during cold springs, as they gather or remain longer in larger flocks during the prebreeding and early breeding period. The importance of weather may also be better reflected for instance in the relationship between windiness and breeding success.

Along with weather, an important implication of climate change is its possible effect on water salinity (HELCOM 2007; BACC Author Team 2008). In the Baltic Sea a change in water salinity can profoundly affect marine food webs and pelagic ecosystems (Hänninen *et al*. 2003). However, we did not find any relationship between water salinity and bird populations in Aasla (Article III); this may indicate either that the resolution of our data is insufficient for the detection of such an effect, or that the effects can only be seen after a longer time period.

In addition to the environmental factors analysed in Articles I–III, there are several other factors that may affect the distribution and population trends of coastal birds. More attention should be paid for instance to food resources, disturbance (Rassi *et al*. 1985; Laurila 1989; Åhlund and Götmark 1989; Mikola *et al*. 1994), predation (Grenquist 1959; Hildén 1964; Nordström *et al*. 2002) and the availability of nesting sites. The effects of many environmental factors, however, are difficult to analyse because of the lack of quantitative data. It should also be noted that the effects of some of the factors driving population changes are felt in wintering areas or along migration routes.

5.2. Relationship between breeding success and population trends

The relationship between reproductive success and breeding population trends depends on juvenile mortality, species-specific natal dispersal and recruitment age. The local autumn population size may differ significantly from that of the early breeding period, depending on the movements of the birds into feeding, moulting and flocking areas (Cramp and Simmons 1977; Hario and Selin 1989; Koskimies and Väisänen 1991; Haig *et al*. 1998; Fransson and Pettersson 2001).

In Aasla, the breeding populations of the Mallard, Goosander and Eider followed their chick numbers with a time lag that corresponds closely to their recruitment ages (Article IV). For the Mallard and Eider the relationship between autumn and breeding population sizes was similar to the relationship between chick number and breeding population size, with time lags that corresponded to their recruitment ages. The breeding population size of the Goldeneye followed its autumn population size with a lag of three years.

Our results imply that Mallard, Goosander and Eider chicks in Aasla are recruited to the local population to an extent sufficient to influence the local population trend. These species show natal site fidelity (Cramp and Simmons 1977; Fransson and Pettersson 2001; Hario and Rintala 2006). Especially among anatids, females return to their birth areas and former nesting sites to breed, and males follow the females from the wintering areas

(Mathiasson 1987; Clarke *et al*. 1997; Fransson and Pettersson 2001). Thus the site choice of females may affect local population trends more than that of males.

In Söderskär the pair number of the Eider followed the recruit number with a lag of 0 to 3 years. The effect of the recruit number on the pair numbers of the same and the following year probably reflects the importance of recruits for breeding population size in the year of recruitment, lasting to the following year. The effects with lags of two and three years, corresponding to the recruitment age of the species, probably reflect the effect of new recruitment on breeding population size. We did not find an interpretable relationship either between fledgling and recruit numbers or between fledgling and pair numbers.

The Eider population in Söderskär seems to be highly dependent on yearly recruitment to the breeding population (Hario *et al*. 2005; Hario and Rintala 2006; Article IV). The fact that Eider fledgling numbers were coupled with breeding population sizes in Aasla but not Söderskär is consistent with the results of earlier studies, according to which reproductive success in Söderskär is not sufficient to sustain the population (Hario and Selin 1991). The Eider population started to decline in Söderskär in 1986–1987 (Hario *et al*. 2005; Hario and Rintala 2006), but in Aasla only in the mid-1990s (Article III). It may therefore be that the populations are in different phases of decline, the population of Söderskär being more dependent on immigration than that of Aasla. A comprehensive analysis of the annual recruitment of Eiders to the Söderskär population would require capture-mark-recapture modelling, but this was outside the scope of our study.

5.3. Bird censuses as part of biodiversity and environmental monitoring

5.3.1. Regional and spatial properties of biodiversity information

The concept of biodiversity is tied to a certain area by definition. Biodiversity data and information lacking geographical dimensions often have little value for end-users. The experimental work on a regional CHM in Article V demonstrates that the geocodability of many biodiversity reports was poor, indicating an urgent need to reconsider the geographical properties of the biodiversity information being produced.

To geocode data and information accurately and to use them efficiently in GISs, special attention should be paid to exploiting the geospatial properties of biodiversity data and information. Geographical descriptions in publications should be improved, and tools should be developed to facilitate geocoding. Geocoding will in turn enhance information retrieval based on geographic position.

Transparency facilitates the interpretation of data and the estimation of its applicability. It is therefore recommended that all data sets used in the CHM be available in the same format and that the same kind of metadata be provided about them (Kalliola 2000; Article V). Furthermore, metadata should be created simultaneously with the data itself, or as soon as possible thereafter, since in many cases it cannot be done later without consulting the collector of the data. Once the metadata and data to be included in the information system have been selected and labelled, procedures for storing, updating and sharing it need to be developed.

In constructing a CHM, co-ordinated information is produced from different sources. In particular the filtering, classifying and labelling of metadata and data, and the assessment of the compatibility and interoperability of the material, need to be done by experts (Article V). In order to function effectively and include the necessary regional human expertise, a CHM needs to be rooted at the regional and local level. The process can be facilitated by encouraging the stakeholders of regional data and information to form networks linked to national biodiversity focal points (see also Olivieri *et al*. 1995). Facilities for producing precise data are good at the regional level, because the network is established and maintained through persons with a good local orientation. The persons and organisations maintaining the network are highly motivated, ensuring its continuity. Furthermore, the use of geospatial data and metadata with GIS tools is effective, since being familiar with the geography of the area users can easily orientate to map-based data retrieval.

At present, information technology has been used particularly at the bottom levels of the information hierarchy to process data and mediate information for end-users. However, promoting biodiversity conservation through increasing biodiversity knowledge and 'wisdom' – i.e. producing insight and understanding out of information – would require more (Article V). The 'human dimension' of the process, which is challenging to replace by information technology, increases towards the top of the information pyramid. Information is transformed into knowledge through a cognitive process in the human brain, where units of information are connected into larger entities. In addition, one essential factor separating knowledge from information is the inclusion of wider connections, such as theory. New building blocks of information can improve existing knowledge or create entirely new knowledge items (Stein 1997). To produce wisdom out of knowledge, accumulated experience at the individual or community level is also needed.

Against this background, the regional and spatial properties of information as the main components of biodiversity information networks become crucial (Article V). A regional approach, combined with the exploitation of georeferenced information through modern information technology, can offer opportunities lacking at the coarse-grained national level CHMs (Xu *et al.* 2000; Article V). In the further development of mechanisms for biodiversity information sharing, such approaches should be seen as a resource enhancing our knowledge and wisdom with regard to biodiversity at the national and global level.

5.3.2. Monitoring for early warnings

Early warning of potential environmental hazards is the prerequisite for the most cost-effective and realistic measures (Järvinen 1983). Bird population trends and demographic processes that reflect environmental changes can be used as a biological indicator system with regard to complex and unexpected environmental changes (Articles III and IV). In order to obtain valuable early warnings of potentially adverse changes, bird monitoring should include the demographic parameters that react most rapidly to changes. As monitoring schemes are resource-limited, the most cost-efficient monitoring methods should be identified and adopted.

In Article IV we develop and assess an extension to the traditional methods of monitoring breeding success: a combination of point and round counts of broods and adults in July. The resulting autumn population indices correlated with chick numbers for all our target species. This indicates that breeding success is carried over to the autumn population size to an extent that allows the assessment of breeding success on the basis on autumn population size. This monitoring method is cost-effective and systematic, but also simple and rapid, making it applicable to bird-watchers' activities. In addition, no extensive experience is needed other than good species identification skills. The method is thus a good alternative to more laborious and time-consuming brood counts.

The applicability of bird monitoring data depends on their quantity and quality (Tiainen *et al*. 2001). To ensure the spatial representativeness of the data, there should be several monitoring areas. With multiple monitoring areas, annual differences between the areas can be taken into account and used to identify factors that influence population status and breeding performance (Sutherland *et al*. 2004). In addition, as for any single-visit census, annual differences in phenology have to be carefully accounted for (Sutherland 2006). The reliability and accuracy of the monitoring method presented here in different surroundings and with different species, requires further study.

The information on breeding success provided by the monitoring of autumn population sizes allows a better understanding of bird population trends and the relationship between breeding success and breeding populations. In order to interpret the monitoring results and infer causalities between environmental factors and bird populations, however, further species-specific population studies are needed on the mortality of waterfowl and seabirds, as well as on their movements during and after the breeding season (see e.g. Haig *et al*. 1998). Furthermore, to improve our knowledge of bird population trends, integrated approaches can be created that combine different long-term data sets (Wernham *et al*. 2002) or extract common signals from a number of intercorrelated time series (Frederiksen *et al*. 2007).

In environmental and population monitoring, continuous long-term data sets are of the utmost importance. Frequent monitoring and long enough time series are needed to detect potential ecological thresholds (Lyytimäki *et al*. 2008) and to capture stochastic extreme environmental events. For time series analyses, yearly data should cover 30 and preferably 50–60 years (Yaffee and McGee 2000), and missing values should be imputed (Yaffee and McGee 2000; Article IV). Particularly when sampling errors are involved, the power of statistical tests performed with the data increases along with the length of the time series (Hatfield *et al*. 1996). A lack of suitable environmental data may hamper comprehensive analysis of the factors driving bird population changes or distribution. There are for instance no spatially comprehensive data available on the food resources of coastal birds in Finland.

In addition to the methodological issues involved in the collection of data on breeding success, there are also challenges in interpreting the data. Breeding success varies considerably due for instance to weather (Hildén *et al*. 1982). Furthermore, in order to use data on breeding success in bird monitoring and environmental research, the correlation between breeding success and population trends has to be known. It must also be taken into account that breeding success may merely reflect local and transient conditions.

A prerequisite of timely and effective management and conservation measures is efficient and accurate processing of the data into entities applicable to decision-making and their dissemination through functional information networks (Article V). Public alert systems for trends in population size and breeding success have already been developed for instance by the British Trust for Ornithology (Baillie *et al.* 2007). Attention should also be paid to the applicability and interoperability of descriptive biodiversity data, since differences in monitoring methods, time scales and data properties may restrict the comparison and interpretation of different data sets (Article V).

5.4. Special features related to environmental studies on archipelago birds

In studying the population dynamics of archipelago birds and environmental impacts on their occurrence and abundance, there are several factors relating to the characteristics of the target systems, the data sets and the mechanisms of the effects that have to be considered.

A fragmented archipelago coast provides excellent opportunities for the study of sea bird breeding habitats. Islands can be regarded as naturally restricted study plots, for which it is easy to define environmental variables. The fine scale of the coastline and habitat features, on the other hand, makes it challenging to use environmental data gained by remote sensing, as a given islet or habitat patch may be represented by only a couple of pixels. In addition, there may be spatial autocorrelation between the features of adjacent islands, which can inflate the statistical significance of the analyses (Segurado *et al.* 2006). Spatial autocorrelation in model residuals may be tested for using the Monte Carlo simulation of Moran's I (Article II).

In a spatially fragmented and dynamic environment, such as a land upheaval archipelago, the spatial and temporal scales of environmental factors and population dynamics also have to be considered. The issue of scale has to be considered with regard to both the scale of the environmental data in relation to that of the bird monitoring data (Article III) and the scales of environmental properties and changes, since different phenomena can have an impact on a local, regional or global scale. In the context of a Baltic archipelago, scales can be specified by assigning phenomena for instance to certain islands or archipelago zones or to the Baltic Sea as a whole.

In addition to the features of the archipelago environment, the ecology of seabirds has to be taken into account in the study of their population trends and habitat preferences. Many seabird species show site fidelity and are thus likely to occupy only part of the available breeding habitats (Matthiopoulos *et al.* 2005). Site fidelity may also result in a colony remaining in a location even when conditions deteriorate. The study and interpretation of the habitat requirements of coastal birds and seabirds is also affected by the fact that the home range size differs considerably between species, some of which are particularly long-ranging.

Furthermore, the abundance of a colonial species may be affected by different factors than its occurrence (Article II). On the one hand, individuals are more likely to join existing colonies than establish new ones (Matthiopoulos *et al*. 2005; Szczys *et al*. 2005), and the effects of habitat characteristics may thus be overridden. On the other hand, prospecting birds searching for future nesting sites (Boulinier *et al.* 1996; Falk and Møller 1997) may merely attempt to breed on sites that they abandon later if unsuccessful. The effects of sociality can be excluded by using occurrence instead of abundance (Article I). Comparisons between occurrence and abundance can be made using hurdle models that allow choosing different variables for the occurrence and abundance parts of the model (Potts and Elith 2006; Article II). More accurate models may be obtained by excluding islands with only a few breeding pairs from the data (Article II).

Further issues affecting the use and intepretation of bird monitoring data are detection probabilities and count errors concerning censuses (Elphick 2008). When studying bird distribution, it has to be taken into account that detection probabilities may be affected by some of the same ecological factors that influence habitat selection. Therefore, a species can appear to avoid a habitat only because it is difficult to detect there. Similarly, observation errors and sampling variability in time series may complicate statistical inference for stochastic population models (Lele 2006) by for instance increasing the noise in the population growth rates (Dennis *et al*. 2006).

Methods have been developed and tested for the analyses of data affected by detection probabilities and count errors (Hatfield *et al.* 1996; Dennis *et al.* 2006; Lele 2006). A need may also rise to validate and further develop census methods that in their current format are prone to detection probability aspects (Alldredge *et al.* 2008). Concerning line transect counts, the proportion of main belt observations (Järvinen 1978) can be used in estimating if the detection probabilities are equivalent to the average ones.

The habitat modelling results presented in Articles I and II in this thesis are probably not biased by detection probability issues, as the counts of many species are based on nests, which at least for larids do not go undetected. Furthermore, the habitats of each species do not vary between islands to an extent that would make it easier to detect the species on one island than another. Concerning the waterfowl counts in Aasla, used in Articles III and IV, the detection probability is probably under 1 but varies in a random manner within species. As the population trends are not compared between species, the results are not biased by the possibility of the detection probabilities not being equal.

Analyses of bird population trends and environmental changes are complicated by autocorrelations within the time series (Articles III and IV). In GLMs the problem can be partly overcome using GEE analysis (Liang and Zeger 1986) (Article III). Autocorrelated time series and the relationships between them can also be analysed using TFs (Article IV). TF analysis may be hampered by feedback from output to input series (Liu and Hudak 1992), e.g. in the case of density-dependence in breeding success (see e.g. Pöysä and Pöysä 2002; Nummi and Saari 2003). However, in many cases where the assumption of a unidirectional relationship between the input and output variables is not strictly true, TF models can still be used effectively (Liu and Hudak 1992).

In addition to correlations within time series, there are often correlations between environmental variables (Article III) or habitat characteristics (Articles I and II), preventing their use in the same model. The problem can be overcome either by choosing among the variables a set within which the correlations remain below a chosen threshold value (Articles I–III) or by combining the intercorrelated variables using PCA (Article III). By summarising the data on the independent variables, it is also possible to avoid overparameterisation.

When the occurrence and abundance of coastal birds are modelled in relation to habitat characteristics, their multifaceted habitat requirements are likely to yield several competing models and hypotheses (Articles I and II). Model selection approaches using for instance the AIC provide a way to summarise and draw inferences from a set of multiple hypotheses and simultaneous models (Burnham and Anderson 1998; Manly *et al*. 2002; Burnham and Anderson 2004; Johnson and Omland 2004). Comparing all possible models (Article I) can be impractical or irrelevant to the study hypotheses, if the number of models is high or the models are not ecologically interpretable. When the relationships are unknown, automatic selection can be useful (Hosmer and Lemeshow 2000; Article II). Earlier automatic selection methods, however, have been criticised because they can result in models with no logical interpretation (James and McCulloch 1990). Whether or not automatic selection methods are used, it is certainly important to also consider the ecological interpretations of the resulting models (Articles I and II).

When using correlative data, such as data on bird numbers and environmental variables, it is important to cover as many factors as possible. This will facilitate assessment of the relationships between different factors. Direct causality, however, is difficult to prove. Correlations between independent and dependent variables may also be due to unknown factors related to the independent variables. Furthermore, environmental changes in breeding grounds and changes in breeding success may not immediately affect population sizes, since many seabird species are long-lived (Holmes *et al*. 2001) and do not easily change their breeding sites (Grenquist 1965; Minton 1968; Blums *et al*. 2002). Environmental changes may also affect birds indirectly, via their predators, competitors or food resources (e.g. Morrison 1986).

5.5. Implications for management and conservation

Efficient management and conservation of coastal birds and their habitats call for insight into the population processes of the target species, as well as the factors affecting their distribution, abundance and population trends. A crucial population component affecting population trends is breeding success (Hario *et al*. 2005; Hario and Rintala 2006; Article IV). Special attention should therefore be paid to the management of the breeding environment of coastal birds, as well as to mapping and protecting their brood-rearing areas.

The relationships between the local environment and bird distribution, as well as the effects of local, regional and global environmental changes on bird populations, have important implications for species and habitat management and environmental assessment. Knowledge of the role played by island characteristics in breeding site selection by coastal birds (Articles I and II) is a prerequisite for understanding their breeding time habitat ecology, mapping and protecting their habitats, and predicting their distribution. Information on resource selection by birds helps to understand how they meet their requirements for survival, thus enhancing the preservation of endangered species and the management of exploited populations (Johnson 1980; Manly *et al*. 2002; Braun 2005). Furthermore, seabirds may have potential as indicators of other aspects of the marine environment (Furness and Camphuysen 1997), such as eutrophication (Article III).

Management and conservation efforts are practically always tied to certain locations. Multivariate, spatially explicit models are nowadays essential tools for conservation ecology (Hirzel *et al*. 2002). Whether working with sampling point data or modelling environment-ecology relationships, GISs provide versatile means for spatial data management and analysis. If implemented correctly, habitat modelling is a repeatable and transparent technique for describing and mapping environmental and biodiversity values (Wintle *et al*. 2005). At their simplest, ecological models can use a small range of high-quality spatial data to produce diverse habitat information.

GISs and environmental data archives enable quantitative modelling of the physical characteristics of coastal bird habitats without field data (Article I). This assessment is spatially explicit and uniform as well as cost-effective, and provides reliable predictions of the structure of bird communities. The models can be further developed by including field-based data on habitat structure and vegetation composition (Article II).

In the target areas of this thesis in the Archipelago Sea, relatively large islands are important for coastal birds (Articles I and II). These islands provide an environment diverse enough to harbour many species but still consist of relatively open habitats. However, they are also subject to changes caused by natural factors, such as land uplift, or by land use changes. In these areas attention should be paid especially to the preservation of large and low islands with open habitats and to the restoration of open habitats. It must be noted, though, that even the largest islands in the study areas are relatively small.

The results of habitat modelling can be applied to the assessment of habitat availability and conservation area suitability (Hirzel and Guisan 2002; Hirzel *et al*. 2006). Generalised habitat maps may also be utilised to extrapolate local or sample-based bird observations, or to plan bird monitoring or management measures. Basic GIS suites provide sufficient tools for most spatial modelling tasks. In some cases, more advanced software packages are needed. In addition, advanced spatial modelling methods often require high levels of expertise in statistics and spatial techniques, lack of which can be a serious handicap in conservation and management initiatives.

Monitoring bird populations is a cost-effective way to take the pulse of the marine ecosystem. In addition, reliable data on population changes and demographic parameters are needed for the sustainable management of coastal birds and waterfowl, not least of quarry species. The need for more wide-scaled, standardised long-term monitoring schemes has been recognised concerning for instance migratory European ducks (Elmberg *et al*. 2006), and the same need is evident regarding many other waterfowl and coastal bird species groups.

The interpretation and application of habitat analyses and population trends requires solid background knowledge of the ecology of the target species. Breeding site preferences are species-specific (Article I), and the occurrence and abundance of colonial species may be affected by different factors (Article II). The habitat preferences of some waterfowl and seabird species may be to some extent overridden by site fidelity and coloniality. For these species, the protection of existing nest sites and colonies is especially important (Matthiopoulos *et al*. 2005; Szczys *et al*. 2005). A further challenge facing the management and conservation of coastal birds and habitats is the variation in the home range sizes among coastal bird species. For long-ranging species, distant feeding areas are crucial along with local nest site characteristics. For species with small home ranges, in turn, all the resources needed have to be available in the close vicinity of the nest site.

Like the habitat selection process, the effects of environmental changes are also species-specific. However, all the detectable effects of eutrophication on the bird populations of Aasla were negative (Article III). This implies that at least in the inner archipelago the eutrophication process may have passed the stage at which its effects become negative for some bird species. With regard to the mitigation of the consequences of eutrophication, it is also worth noting that the predation by certain coastal bird species, such as the Cormorant, on roach and other cyprinids, which have increased due to eutrophication, may help to alleviate its effects (Gere and Andrikovics 1992).

For the assessment and mitigation of the effects of climate change on coastal bird populations, further studies are needed. While some bird species wintering in the Baltic Sea seem to benefit from the milder winters (Article III), the changes in wintering conditions are only one aspect of the multiple and profound ecosystem effects that are likely to be imposed by climate change (BACC Author Team 2008).

In biodiversity management and conservation, special emphasis must be placed on those biodiversity components that require urgent conservation measures and that offer the greatest potential for sustainable use (Glowka *et al*. 1994). In the case of environmental changes that may cause irreversible effects, such as eutrophication and climate change, the potential for sustainable use is compromised if management and conservation measures are delayed. A recent international survey shows a wide concern among experts and stakeholders that current management structures do not suffice to prevent the passing of many ecological thresholds, particularly concerning climate change, but also regarding eutrophication (Lyytimäki *et al*. 2008). There is indeed a need for a proactive approach and for the monitoring of phenomena with potentially adverse effects (Glowka *et al*. 1994).

5.6. Generality of results

Enclosed seas such as the Baltic have specific environmental characteristics and distinctive bird communities. The environmental problems of the Baltic Sea, however, are also widely faced by other seas, and many of the target species of this study also inhabit other sea areas.

As a breeding environment for birds, the archipelagoes of the Finnish coast can be compared with other fragmented archipelagoes for instance on the North Pacific coast of

North America (Cook *et al*. 2006; Article I). The Chesapeake Bay, a large brackish body of water on the mid-Atlantic coast of the United States, offers an interesting counterpart to the Baltic Sea, with similarities in the bird communities and population trends of the two areas (Costanzo and Hindman 2007). Chesapeake Bay also faces similar environmental problems as the Baltic Sea, including eutrophication (Paerl 1993; Diaz and Rosenberg 1995; Boynton *et al*. 1996), climate change (Najjar *et al*. 2000), pollutants (Rattner *et al*. 2007), invasive species (Phelps 1994), and overfishing (Jackson *et al*. 2001), leading to changes in communities and trophic interactions (Viverette *et al*. 2007). The Baltic Sea and Chesapeake Bay also show corresponding advances in environmental status (Rattner and McGowan 2007), as well as management and conservation initiatives (Weber 2004). Chesapeake Bay and the Baltic Sea have been compared in many studies dealing for instance with eutrophication (Paerl 1993; Diaz and Rosenberg 1995; Boynton *et al*. 1996; Cloern 2001) and ecosystem ecology (Baird *et al*. 1991), and new comparative approaches have been encouraged (Ulanowicz 2004).

While the Baltic Sea and its Finnish coast share a number of characteristics with other locations, the large, geologically young, fragmented, seasonal, brackish, non-tidal land upheaval archipelago of SW Finland in particular can be considered unique (Tolvanen 2006). In many other seas, tides are an important coastal process affecting bird habitats. In Chesapeake Bay, for instance, tidal marshes form an important habitat for birds (Wilson *et al*. 2007), and coastal erosion and sea level rise pose a significant threat to the habitats (Erwin *et al*. 1993; Najjar *et al*. 2000).

In considering seabird habitats in fragmented and dynamic coastal areas, especially in land upheaval archipelagoes, special attention should be paid to the scale of the data and the results. The smallest islets in the study areas of this thesis form relatively uniform patches surrounded by water. In areas with larger islands, on the other hand, habitats such as boulder and gravel beaches, rocky spits or vegetation spots may form patches among other land habitats and water.

Furthermore, in land upheaval archipelagoes temporal aspects have to be considered along with spatial ones. The habitats of coastal birds change with land upheaval, which may be reflected in their distribution. As the islands in the inner archipelago become less favourable for species preferring open habitats, new bare islets rise from the sea in the outer archipelago. Sounds and bays in turn develop into flad bays and glo lakes (Numminen 1999).

In spite of differences in habitat characteristics and bird communities, many aspects of the habitat selection processes, demographic factors and environmental effects presented in this thesis, as well as their monitoring and management implications, apply to other marine and coastal environments. The methods used in this study for the assessment of coastal bird habitats and environmental effects also apply to any other location, as long as suitable data and software are available.

The development of international biodiversity information systems is by definition a global issue. Regardless of local and regional differences in the particular ecosystems monitored, the volume and characteristics of the data, the technical capacity for information production and delivery, or the culture affecting data processing and sharing, the objectives set forth in international agreements and legislation are common to a number of states. The principle of the hierarchy of biodiversity information discussed in this thesis is similarly universal, as is the method for the review process of biodiversity information for the regional CHM.

5.7. Future perspectives

5.7.1. Coastal populations and habitats

At present, considerable effort is being put into the assessment and management of Baltic ecosystems. However, there still are many uncertainties concerning the effects of the large-scale environmental changes, such as eutrophication and climate change, affecting the Baltic Sea (HELCOM 2007; BACC Author Team 2008).

Environmental changes, including eutrophication and climate change, affect ecological patterns and processes (Bjørnstad and Grenfell 2001; Stenseth *et al*. 2002) and may induce profound ecosystem changes. Effects on the breeding and feeding ecology of different seabird species may first be visible near the limits of their ranges (Barrett and Krasnov 1996; Montevecchi and Myers 1997), and may therefore also emerge relatively early in Baltic ecosystems, which can be considered marginal because of the distinctive features of the Baltic Sea in comparison to other seas.

According to projections for future climate, the mean annual temperature in the Baltic Sea Basin will rise by 3–5 °C by the end of the 21st century. Most of this warming is likely to occur in the northern areas during the winters and in the southern areas during the summers. Mean annual sea surface temperatures could increase by 2–4 °C. Increased winter precipitation may emerge over the entire catchment area, while in the southern part summers may become drier. The average salinity of the Baltic Sea is projected to decline by 8–50 %. An increase in windiness is more likely than a decrease (BACC Author Team 2008). The various aspects of climate change can be expected to influence biological processes and the biota in the Baltic Sea (HELCOM 2007; BACC Author Team 2008).

With regard to eutrophication, drastic measures are needed to reduce nutrient levels in the Baltic Sea. However, the effects of internal loading (Kauppila *et al*. 2004) and climate change (BACC Author Team 2008) may at least in the short run obscure or offset the effects of reductions in external loading. The effects of nutrient load reductions are unlikely to appear immediately, and sustainable impacts may be seen first after several decades (Bonsdorff *et al*. 1997b; Stigebrandt and Gustafsson 2007). This, however, cannot be an excuse for inaction. In recent years there has also arisen a discussion on ecological engineering methods that could potentially speed up the recovery of the Baltic Sea (Stigebrandt and Gustafsson 2007). The applicability of these methods and the possible ecological and economical consequences of their implementation require yet rigorous investigation.

The current actions for Baltic Sea management have been regarded as insufficient and poorly integrated (WWF Baltic Ecoregion Programme 2008). For efficient management and conservation of Baltic coastal birds and habitats, an important step would be the compilation of an integrated sea use management plan. The EU encourages a more integrated approach to the management of seas in its Integrated Maritime Policy (European Commission 2007), which is supported by the Marine Strategy Directive. Integrated sea use management is also supported by the Water Framework Directive, and the BSAP by HELCOM. Furthermore, the European Commission is preparing an EU Strategy for the Baltic Sea Region on the request of the European Council. The strategy will be presented to the European Council in June 2009.

What is crucial to the maintenance of current bird communities is how fast and to which extent environmental pressures can be abated and whether birds will be able to adapt to changes in their habitats, by for instance utilising prey species that increase with recent environmental changes. In spite of the accumulation of studies of environmental impacts on coastal bird communities, there still are gaps in our knowledge of even some basic ecological aspects of coastal bird species. For instance, it would be interesting to assess the effects of decreasing water transparency on the food resources and feeding habits of coastal birds.

Identifying the areas that will remain suitable for each species during a given period of time is an extremely challenging task. Changes in air temperatures and precipitation may cause a shift in breeding habitats, altering the distribution and thus the populations of European birds (Huntley *et al*. 2007). On Baltic coasts, an inevitable force forming coastal habitats is land uplift, which will probably continue for several thousands of years, although gradually slowing down (Ekman and Mäkinen 1996). In the Quark area between Sweden and Finland the sea bottom will be dry within 3500 years with the present pace of shoreline displacement, which includes the effects of land uplift and sea level rise (Norrman 1992).

The effects of land upheaval on coastal bird habitats may be offset by the rise in sea level caused by climate change (HELCOM 2007). Different scenarios for climate change yield different projections for sea level rise. According to the Intergovernmental Panel on Climate Change (IPCC), the sea level in the oceans can be projected to rise 18–59 cm relative to the period 1980–1999 by the year 2100 (IPCC 2007), whereas Rahmstorf (2007) projects a rise of 50–140 cm above the 1990 level by the year 2100. Whichever scenario will be realised, it is obvious that many Baltic Sea regions currently experiencing a relative fall in sea level can instead face a relative rise (HELCOM 2007). In Finland there can be a relative sea level rise in the southern parts of the coast, whereas in northern Finland the land uplift may still outweigh sea level rise (Myrberg *et al*. 2006).

5.7.2. Gathering and dissemination of data

In order to fully understand changes in seabird populations and their habitats, we need to know more about the dynamics of marine ecosystems and about interactions between birds, their food resources and the environment. Therefore, high-quality data need to be collected both through long-term monitoring schemes and through intensive studies. Access to high-quality spatial data sets is in most cases limited, and sometimes the desired data do not exist. In general, data availability has been a major constraint on successful spatial modelling (Gottschalk *et al*. 2005).

Concerning coastal birds, the monitoring of populations should be secured by a spatially and temporally comprehensive scheme that is also representative of different coastal zones and habitats (see e.g. Hurlbert 1984). In addition, there is a need for spatially comprehensive long-term data on for instance the vital rates and food resources of different species, as well as for remotely sensed habitat data with a resolution sufficient for fragmented archipelago surroundings.

The provision and free delivery of high quality coastal habitat data would greatly increase the capability of ecological modelling and conservation. Especially in the face of climate change and rising sea levels, it would be vital to further increase the availability of coastal data, in particular data on underwater habitats, for example by providing them freely online. Initiatives that promote open spatial data infrastructures and sharing are thus highly regarded (Tolvanen and Kalliola 2008).

Efficient sharing of biodiversity information implies consideration of all scales, from local to global. With the development of new communication technologies, the demand for accurate site-specific data and information will increase and new opportunities will also open up for CHMs. In addition, advanced biodiversity CHMs will probably start to use new powerful map production methods that will facilitate the production of new cartographic presentations by combining data from different sources. Developing automatic or semiautomatic software for data processing would also be highly useful for future CHMs. Special attention should be paid to the synthesising of data and information, and their dissemination to decision-makers and other end-users.

6. SUMMARY

In this thesis, I address the occurrence, abundance, population trends and reproductive success of seabirds breeding on the Finnish coast of the northern Baltic Sea. The distribution and population trends of the target species are analysed in relation to environmental factors ranging from island-specific habitat characteristics to wide-scale environmental changes. I also assess the position and prospects of coastal bird monitoring data as part of biodiversity data and information.

My results highlight the following aspects:

1. Important factors for the habitat selection of coastal birds are island area and elevation, water depth, shore openness and the composition of island cover habitats (Article I). The occurrence of the colonial Arctic Tern is partly affected by different habitat characteristics than its abundance (Article II). The habitat selection process of coastal birds is affected by their species-specific breeding and feeding ecology. Through habitat selection, a number of abiotic and biotic factors influence the distribution of coastal birds.

2. Eutrophication and winter severity have reduced the populations of several Finnish coastal bird species (Article III). Among the most important environmental pressures affecting coastal and marine ecosystems worldwide are climate change and eutrophication, which influence water quality and weather conditions in the Baltic Sea as well. Winters are projected to become milder in the Baltic Sea with climate change. It is impossible to predict, however, what the impact will be of the other profound changes which can be expected to occur in the Baltic ecosystems and communities.

3. A major demographic factor through which environmental changes influence bird populations is breeding success. This affects the populations of the Mallard, Eider and Goosander after a time lag that corresponds to their species-specific recruitment ages (Article IV). To effectively assess the status of bird populations and possible environmental impacts, breeding success should be included in bird monitoring schemes. For some of the target species of this thesis, the number of individuals in the late summer can be used as an easier and more cost-effective indicator of breeding success than brood counts (Article IV).

4. The current development of GISs, digital data archives and open access information infrastructures provide new tools applicable to the assessment and management of coastal bird habitats (Articles I and II), as well as the dissemination of data and information (Article V). Spatial data sets widely available in Finland can be utilised in the calculation of several variables that are relevant to the habitat selection of coastal birds. However, the interpretation and application of GIS analyses require solid background knowledge of the ecology of the target species. Attention should also be paid to the processing of data into higher levels of the information hierarchy, so that data are synthesised and developed into high-quality knowledge applicable to management and conservation (Article V).

5. The relationships between bird populations and their environment can be quantitatively assessed using multivariate ecological modelling and model selection procedures (Articles I–IV). In analysing seabird populations and the environmental characteristics of a fragmented archipelago, the implications of features of the target areas and species must be taken into account, as well as for instance spatial autocorrelation and trends in the data.

6. The study of environmental impacts on birds, as well as the capturing of stochastic extreme environmental events and the detection of ecological thresholds, requires intensive long-term monitoring of bird populations and environmental factors; at present many data sets are too short or sparse for this purpose. Spatio-temporally comprehensive monitoring

of coastal birds and their environment, and the production of applicable and interoperable data, should thus be secured in the future.

The results can be applied to the monitoring, management and conservation of coastal birds and their habitats, as well as to the processing and dissemination of data and information related to biodiversity and environmental factors.

The Baltic Sea is a suitable and relevant target area for studies of environmental changes. In the geologically young Baltic Sea in particular, the history of coastal ecosystems and bird communities is a history of change. The coastal landscape has been formed by land uplift and other coastal processes, climate and water salinity have varied, and species communities have changed. Humans have been present on the Finnish coast of the Baltic Sea since the first skerries rose from the sea: first as hunters, then as year-round settlement, and nowadays increasingly as recreational users. In addition to the concrete presence of people, the coastal areas are nowadays affected by human-induced environmental changes. The scale of the environmental effects of human activities has widened from local to regional and global.

In the future of the Baltic Sea, too, the only certainty seems to be constant change. The coasts of the Baltic Sea include dynamic ecosystems that in many areas have been affected by humans ever since the first islands rose from the sea. It is therefore often challenging to define an ‘optimal’ state of the environment and biotic communities. During the history of the Baltic Sea, much that once was has been lost, and the same applies on a briefer time scale to the succession of every island that rises from the sea. Still, something new has and always will come instead. But with regard to anoxic sea bottoms caused by eutrophication, or toxic substances accumulating in the food-webs, it is clear that unless these processes are abated, there will be nothing to gain. The future of the Baltic Sea, as well as the coexistence of seabirds and humans on its coasts, will depend on the ability to mitigate or adapt to current and coming environmental changes.

LIST OF ABBREVIATIONS

AIC	Akaike Information Criterion
AICc	Second-order Akaike Information Criterion
ARIMA	Autoregressive Integrated Moving Average
BACC	BALTEX Assessment of Climate change for the Baltic Sea Basin
BALTEX	Baltic Sea Experiment
BioCASE	Biological Collection Access Service for Europe
BSAP	Baltic Sea Action Plan
CBD	Convention on Biological Diversity
CBSS	Council of the Baltic Sea States
CCB	Coalition Clean Baltic
CES	Constant Effort Sites
CHM	Clearing House Mechanism
CMS	Convention on the Conservation of Migratory Species of Wild Animals, i.e. Bonn Convention
CSE	Continental-scale Experiment
DEM	Digital Elevation Model
EC	European Commission
EEC	European Economic Community
EU	European Union
FINIBA	Finnish Important Bird Area
GAM	Generalized Additive Model
GBIF	Global Biodiversity Information Facility
GEE	Generalized Estimating Equation
GEWEX	Global Energy and Water Cycle Experiment
GI	Geographical Information
GIS	Geographical Information System
GLM	Generalized Linear Model
GMES	Global Monitoring for Environment and Security
GOOS	Global Ocean Observing System
GSDI	Global Spatial Data Infrastructure
GTOS	Global Terrestrial Observing System
HELCOM	Helsinki Commission, i.e. Baltic Marine Environment Protection Commission
IBA	Important Bird Area
ICZM	Integrated Coastal Zone Management
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
MAPS	Monitoring Avian Productivity and Survivorship
NAO	North Atlantic Oscillation
PCA	Principal Component Analysis
PSSA	Particularly Sensitive Sea Area
SAC	Special Area of Conservation
SPA	Special Protection Area
SQL	Structured Query Language
SSP	Sisämaan SeurantaPyynti
TF	Transfer Function
TRIM	Trends & Indices for Monitoring Data
UNFCCC	United Nation's Framework Convention on Climate Change
WCRP	World Climate Research Program
WWF	World Wildlife Fund

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REFERENCES

Aebischer, N.J., Coulson, J.C. and Colebrookl, J.M. 1990. Parallel long-term trends across four marine trophic levels and weather. *Nature* 347(6295): 753–755.

Ahti, T.L., Hämet-Ahti, L. and Jalas, J. 1968. Vegetation zones and their sections in northwestern Europe. *Annales Botanici Fennici* 5(3): 169–211.

Alldredge, M.W., Pacifici, K., Simons, T.R. and Pollock, K.H. 2008. A novel field evaluation of the effectiveness of distance and independent observer sampling to estimate aural avian detection probabilities. *Journal of Applied Ecology* 45(5): 1349–1356.

Allainé, D. 1991. The effects of colony size and breeding stage on colony defense pattern in the black-headed gull. *Acta Oecologica* 12(3): 385–396.

Andersson, Å. and Staav, R. 1980. *Den häckande kustfågelfaunan i Stockholms län 1974–75*. Natur i Stockholms län 4.

Anker-Nilssen, T., Barrett, R.T., Bustnes, J.O., Erikstad, K.E., Fauchald, P., Lorentsen, S.-H., Steen, H., Strøm, H., Systad, G.H. and Tveraa, T. 2006. *SEAPOP studies in the Lofoten and Barents Sea area in 2005*. NINA Report 127.

Arroyo, B., Mougeot, F. and Bretagnolle, V. 2001. Colonial breeding and nest defence in Montagu's harrier (*Circus pygargus*). *Behavioral Ecology and Sociobiology* 50(2): 109–115.

Arzel, C., Elmberg, J. and Guillemain, M. 2006. Ecology of spring-migrating Anatidae: a review. *Journal of Ornithology* 147(2): 167–184.

The BACC Author Team 2008. *Assessment of Climate Change for the Baltic Sea Basin*. Regional Climate Studies, Springer.

Baillie, S.R., Marchant, J.H., Crick, H.Q.P., Noble, D.G., Balmer, D.E., Barimore, C., Coombes, R.H., Downie, I.S., Freeman, S.N., Joys, A.C., Leech, D.I., Raven, M.J., Robinson, R.A. and Thewlis, R.M. 2007. *Breeding Birds in the Wider Countryside: their conservation status 2007*. BTO Research Report No. 487. BTO, Thetford (http://www.bto.org/birdtrends).

Baird, D., McGlade, J.M. and Ulanowicz R.E. 1991. The comparative ecology of 6 marine ecosystems. *Philosophical Transactions of the Royal Society of London Series B - Biological Sciences* 333(1266): 15–29.

Barbraud, C. and Weimerskirch, H. 2003. Climate and density shape population dynamics of a marine top predator. *Proceeding of the Royal Society of London B - Biological Sciences* 270(1529): 2111–2116.

Barrett, R.T. and Krasnov, Y.V. 1996. Recent responses to changes in stocks of prey species by seabirds breeding in the southern Barents Sea. *ICES Journal of Marine Science* 53(4): 713–722.

Barry, S. and Elith, J. 2006. Error and uncertainty in habitat models. *Journal of Applied Ecology* 43(3): 413–423.

Becker, P.H. 1989. Seabirds as monitor organisms of contaminants along the German North Sea coast. *Helgoländer Meeresuntersuchungen* 43(3–4): 395–403.

Begon, M., Harper, J.L. and Townsend, C.R. 1996. *Ecology. Individuals, Populations and Communities. Third Edition*. Blackwell Science, Oxford.

Berendsohn, W.G. 2002. BioCASE – a biological collection access service for Europe. *Alliance News* 29(6): 6–7.

Berg, Å. 1996. Predation on artificial, solitary and aggregated wader nests on farmland. *Oecologia* 107(3): 343–346.

Bergman, G. 1939. Untersuchungen über die Nistvogelfauna in einem Schärengebiet westlich von Helsingfors. *Acta Zoologica Fennica* 29: 1–134.

Beukema, J.J. and Cadée, G.C. 1991. Growth rates of the bivalve *Macoma balthica* in the Wadden Sea during a period of eutrophication: relationships with concentrations of pelagic diatoms and flagellates. *Marine Ecology Progress Series* 68: 249–256.

Bibby, C.J., Burgess, N.D., Hill, D.A. and Mustoe, S.H. 2000. *Bird Census Techniques*, *2nd edn*. Academic Press, London.

BirdLife International 2000. *Threatened birds of the world*. Lynx Edicions and BirdLife International, Barcelona and Cambridge.

BirdLife International 2004a. *Birds in the European Union: A status assessment*. BirdLife International, Wageningen.

BirdLife International 2004b. *State of the World's Birds 2004: Indicators for Our Changing World*. BirdLife International, Cambridge.

BirdLife International 2008. *State of the world's birds: indicators for our changing world*. BirdLife International, Cambridge.

Bisby, F.A. 2000. The Quiet Revolution: Biodiversity Informatics and the Internet. *Science* 289(5488): 2309–2312.

Björck, S. and Svensson, N.-O. 1994. Development of the Baltic Sea and the Skagerrak/Kattegat. In: *Geology*, pp. 138–142. National Atlas of Sweden, Stockholm.

Bjørnstad, O.N. and Grenfell, B.T. 2001. Noisy clockwork: time series analysis of population fluctuations in animals. *Science* 293(5530): 638–643.

Blanco, G. and Tella, J.L. 1997. Protective association and breeding advantages of choughs nesting in lesser kestrel colonies. *Animal Behaviour* 54(2): 335–342.

Blums, P., Nichols, J.D., Hines, J.E. and Mednis, A. 2002. Sources of variation in survival and breeding site fidelity in three species of European ducks. *Journal of Animal Ecology* 71(3): 438–450.

Bonsdorff, E. 1992. Drifting algae and zoobenthos – effects on settling and community structure. *Netherlands Journal of Sea Research* 30: 57–62.

Bonsdorff, E. and Blomqvist, E.M. 1993. Biotic couplings on shallow water soft bottoms – examples from the northern Baltic Sea. *Oceanography and Marine Biology: an Annual Review* 31: 153–176.

Bonsdorff, E., Aarnio, K. and Sandberg, E. 1991. Temporal and spatial variability of zoobenthic communities in the archipelago waters of the Northern Baltic Sea – consequences of eutrophication? *Internationale Revue der Gesamten Hydrobiologie* 76(3): 433–449.

Bonsdorff, E., Blomqvist, E.M., Mattila, J. and Norkko, A. 1997a. Long-term changes and coastal eutrophication. Examples from the Åland Islands and the Archipelago Sea, northern Baltic Sea. *Oceanologica Acta* 20(1): 319–329.

Bonsdorff, E., Blomqvist, E.M., Mattila, J. and Norkko, A. 1997b. Coastal eutrophication: causes, consequences and perspectives in the archipelago areas of the Northern Baltic Sea. *Estuarine, Coastal and Shelf Science* 44(Supplement A): 63–72.

Boshoff, A.F., Palmer, N.G. and Piper, S.E. 1991. Spatial and temporal abundance patterns of waterbirds in the southern Cape Province. 1. Diving and surface predators. *Ostrich* 62(3–4): 156–177.

Both, C. and Visser, M.E. 2001. Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. *Nature* 411(6835): 296–298.

Boulinier, T., Danchin, E., Monnat, J.-Y., Doutrelant, C. and Cadiou, B. 1996. Timing of prospecting and the value of information in a colonial breeding bird. *Journal of Avian Biology* 27(3): 252–256.

Box, G.E.P. and Jenkins, G.M. 1976. *Time series: analysis, forecasting and control*. Holden-Day, San Francisco.

Box, G.E.P. and Newbold, P. 1971. Some comments on a paper of Coen, Gomme and Kendall. *Journal of Royal Statistical Society* A 134(2): 229–240.

Boynton, W.R., Hagy, J.D., Murray, L., Stokes, C. and Kemp, W.M. 1996. A comparative analysis of eutrophication patterns in a temperate coastal lagoon. *Estuaries* 19(2B): 408–421.

Braun, C.E. (ed.) 2005. *Techniques for Wildlife Investigations and Management, sixth edn*. The Wildlife Society, Bethesda.

Brearey, D. and Hildén, O. 1985. Nesting and egg-predation by Turnstones (*Arenaria interpres*) in larid colonies. *Ornis Scandinavica* 16(4): 283–292.

Burger, J. 1991. Coastal landscapes, coastal colonies, and seabirds. *Reviews in Aquatic Sciences* 4(1): 23–43.

Burger J. and Gochfeld, M. 2001. On developing bioindicators for human and ecological health. *Environmental Monitoring and Assessment* 66(1): 23–46.

Burkett, V.R., Wilcox, D.A., Stottlemyer, R., Barrow, W., Fagre, D., Baron, J., Price, J., Nielsen, J.L., Allen, C.D., Peterson, D.L., Ruggerone, G. and Doyle, T. 2005. Nonlinear dynamics in ecosystem response to climatic change: Case studies and policy implications. *Ecological Complexity* 2(4): 357–394.

Burnham, K.P. and Anderson, D.R. 1998. *Model Selection and Inference*. Springer, New York.

Burnham, K.P. and Anderson, D.R. 2004. Multimodel inference. Understanding AIC and BIC in model selection. *Sociological Methods and Research* 33(2): 261–304.

Busby, J.R. 1997. Management of Information to Support Conservation Decision Making. In: Hawksworth, D.L., Kirk, P.M. and Dextre Clarke, S. (eds.). *Biodiversity Information – Needs and Options*, pp. 105–114. Cab International, Wallingford.

Böhning-Gaese, K. and Bauer, H.-G. 1996. Changes in species abundance, distribution, and diversity in a central European bird community. *Conservation Biology* 10(1): 175–187.

Campomizzi, A.J., Butcher, J.A., Farrell, S.L., Snelgrove, A.G., Collier, B.A., Gutzwiller, K.J., Morrison, M.L. and Wilkins, R.N. 2008. Conspecific attraction is a missing component in wildlife habitat modeling. *Journal of Wildlife Management* 72(1): 331–336.

Carignan, V. and Villard, M.A. 2002. Selecting indicator species to monitor ecological integrity: a review. *Environmental Monitoring and Assessment* 78(1): 45–61.

Carling, R.C.J. and Harrison, J. 1996. Biodiversity information on the Internet: cornucopia or confusion? *Biodiversity Letters* 3(4–5): 125–135.

Cederwall, H. and Elmgren, R. 1990. Biological effects of eutrophication in the Baltic Sea, particularly the coastal zone. *Ambio* 19(3): 109–112.

Chastel, O., Weimerskirch, H. and Jouventin, P. 1993. High annual variability in reproductive success and survival of an Antarctic seabird, the snow petrel *Pagodroma nivea*. A 27-year study. *Oecologia* 94(2): 278–285.

Clarke, A.L., Sæther, B.-E. and Røskaft, E. 1997. Sex biases in avian dispersal: a reappraisal. *Oikos* 79(3): 429–438.

Cloern, J.E. 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series* 210: 223–253.

Cody, M. (ed.) 1985. *Habitat selection in birds*. Academic Press, Orlando.

Cook, J.A., Dawson, N.G. and McDonald, S.O. 2006. Conservation of highly fragmented systems: The north temperate Alexander Archipelago. *Biological Conservation* 133(1): 1–15.

Coops, H., Boeters, R. and Smit, H. 1991. Direct and indirect effects of wave attack on helophytes. *Aquatic Botany* 41(4): 333–352.

Costanzo, G.R. and Hindman, L.J. 2007. Chesapeake Bay breeding waterfowl populations. In: Erwin, R.M., Watts, B.D., Haramis, G.M., Perry, M.C. Dobson, and K.A. (eds.). *Waterbirds of the Chesapeake Bay and vicinity: harbingers of change?*, pp. 17–24. Waterbirds 30 (Special Publication 1).

Cramp, S. and Simmons, K.E.L. 1977. *Handbook of the Birds of Europe, the Middle East and North Africa. The Birds of the Western Palearctic. Volume I. Ostrich to Ducks*. Oxford University Press, Oxford.

Cramp, S. and Simmons, K.E.L. 1980. *Handbook of the Birds of Europe, the Middle East and North Africa. The Birds of the Western Palearctic. Volume II. Hawks to Bustards*. Oxford University Press, Oxford.

Croll, D.A., Maron, J.L., Estes, J.A., Danner, E.M. and Byrd G.V. 2005. Introduced predators transform subarctic islands from grassland to tundra. *Science* 307(5717): 1959–1961.

Croxall, J.P. 2004. The potential effects of marine habitat change on Antarctic seabirds. *Ibis* 146(Supplement 1): 90–91.

Croxall, J.P., Trathan, P.N. and Murphy, E.J. 2002. Environmental change and Antarctic seabird populations. *Science* 297(5586): 1510–1514.

Czech, B. 2000. Economic growth as the limiting factor for wildlife conservation. *Wildlife Society Bulletin* 28(1): 4–15.

Czech, B. 2006. If Rome is burning, why are we fiddling? *Conservation Biology* 20(6): 1563–1565.

Davoren, G.K., Montevecchi, W.A. and Anderson, J.T. 2003. Distributional patterns of a marine bird and its prey: habitat selection based on prey and conspecific behaviour. *Marine Ecology Progress Series* 256: 229–242.

Dayton, P.K., Sala, E., Tegner, M.J. and Thrush, S. 2000. Marine reserves: Parks, baselines, and fishery enhancement. *Bulletin of Marine Science* 66(3): 617–634.

Dennis, B., Ponciano, J.M., Lele, S.R., Taper, M.L. and Staples, D.F. 2006. Estimating density dependence, process noise, and observation error. *Ecological Monographs* 76(3): 323–341.

DeSante, D.F., Burton, K.M., Saracco, J.F., and Walker, B.L. 1995. Productivity indices and survival rate estimates from MAPS, a continent-wide programme of constant-effort mist netting in North America. *Journal of Applied Statistics* 22(5–6): 935–947.

Diaz, R.J. and Rosenberg, R. 1995. Marine benthic hypoxia: a review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology – an Annual Review* 33: 245–303.

Dittmann, T., Zinsmeister, D. and Becker, P.H. 2005. Dispersal decisions: common terns, *Sterna hirundo*, choose between colonies during prospecting. *Animal Behaviour* 70(1): 13–20.

Drent, R.H. and Daan, S. 1980. The prudent parent: energetic adjustments in avian breeding? *Ardea* 68(1–4): 225–252.

Duinker, J.C. and Koeman, J.H. 1978. Summary report on the distribution and effects of toxic pollutants (metals and chlorinated hydrocarbons) in the Wadden Sea. In: Essink, K. and Wolff, W.J. (eds.). *Pollution of the Wadden Sea area*, pp. 45–54. Report 8. Wadden Sea Working Group, Balkema, Rotterdam.

Durango, S. 1954. The tufted duck as a breeder in colonies of gulls and terns. *Ornis Fennica* 31(1): 1–18 (in Swedish with English summary).

Durell, S.E.A. le V. dit, Stillman, R.A., Caldow, R.W.G., McGrorty, S., West, A.D. and Humphreys, J. 2006. Modelling the effect of environmental change on shorebirds: a case study on Poole Harbour, UK. *Biological Conservation* 131(3): 459–473.

EC 2005. *Communications from the Commission to the Council and the European Parliament – Global Monitoring for Environment and Security (GMES): From Concept to Reality*. Commission of the European Communities, COM(2005) 565 Final, 2005/1432, Brussels.

Edwards, J.L., Lane, M.A. and Nielsen, E.S. 2000. Interoperability of biodiversity databases: biodiversity information on every desktop. *Science* 289(5488): 2312–2314.

Eglington, A., Israel, R. and Vartanov, R. 1998. Towards sustainable development for the Murmansk region. *Ocean & Coastal Management* 41(2–3): 257–271.

Eklund, O. 1958. Die Gefässpflanzenflora beiderseits Skiftet im Schärenarchipel Südwestfinnlands. *Bidrag till kännedom af Finlands natur och folk* 101: 1–342.

Ekman, M. and Mäkinen, J. 1996. Recent post-glacial rebound, gravity change and mantle flow in Fennoscandia. *Geophysical Journal International* 126(1): 229–234.

Elith, J., Graham, C.H., Anderson, R.P., Dudic, M., Ferrier, S., Guisan, A., Hijmans, R.J., Huettmann, F., Leathwick, J.R., Lehmann, A., Li, J., Lohmann, L.G., Loiselle, B.A., Manion, G., Moritz, C., Nakamura, M., Nakazawa, Y., Overton, J.M., Peterson, A.T., Phillips, S.J., Richardson, K., Scachetti-Pereira, R., Schapire, R.E., Soverton, J., Williams, S., Wisz, M.S. and Zimmermann, N.E. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29(2): 129–151.

Elmberg, J., Nummi, P., Pöysä, H. and Sjöberg, K. 1994. Relationships between species number, lake size and resource diversity in assemblages of breeding waterfowl. *Journal of Biogeography* 21(1): 75–84.

Elmberg, J., Nummi, P., Pöysä, H., Sjöberg, K., Gunnarsson, G., Clausen, P., Guillemain, M., Rodrigues, D. and Väänänen, V.-M. 2006. The scientific basis for new and sustainable management of migratory European ducks. *Wildlife Biology* 12(2): 121–127.

Elmgren, R. 1989. Man's impact on the ecosystem of the Baltic Sea: energy flows today and at the turn of the century. *Ambio* 18(6): 326–332.

Elphick, C.S. 2008. How you count counts: the importance of methods research in applied ecology. *Journal of Applied Ecology* 45(5): 1313–1320.

ENRS 2005. *Coastal GTOS strategic design and phase 1 implementation plan*. GTOS Report 36. Environment and Natural Resources Service, FAO, Rome.

Ericson, P.G.P. and Carrasquilla, F.H. 1997. Subspecies identity of prehistoric Baltic cormorants *Phalacrocorax carbo*. *Ardea* 85(1): 1–7.

Ericson, P.G.P. and Tyrberg, T. 2004. *The early history of the Swedish avifauna. A review of the subfossil record and early written sources.* Kungl. Vitterhets Historie och Antikvitets Akademiens Handlingar, Aktikvariska serien 45.

Eriksson, M.O.G. 1985. Prey detectability for fish-eating birds in relation to fish density and water transparency. *Ornis Scandinavica* 16(1): 1–7.

Eronen, M. 2005. Land uplift: virgin land from the sea. In: Seppälä, M. (ed.). *The Physical Geography of Fennoscandia*, pp. 17–34. The Oxford Regional Environments Series, Oxford University Press, Oxford.

Erwin, R.M., Haramis, G.M., Krementz, D.G. and Funderburk, S.L. 1993. Resource protection for waterbirds in Chesapeake Bay. *Environmental Management* 17(5): 613–619.

European Commission 2007. *An Integrated Maritime Policy for the European Union*. Office for Official Publications of the European Communities, Luxembourg.

Eybert, M.-C., Geslin, T., Questiau, S. and Feunteun, E. 2003. Shorebird community variations indicative of a general perturbation in the Mont Saint-Michel bay (France). *Comptes Rendus Biologies* 326(Supplement 1): 140–147.

Falk, K. and Møller, S. 1997. Breeding ecology of the Fulmar *Fulmarus glacialis* and the Kittiwake *Rissa tridactyla* in high-arctic northeastern Greenland, 1993. *Ibis* 139(2): 270–281.

Finnish National Council for Geographic Information 2004. *National geographic information strategy 2005–2010*. Publications of the Ministry of Agriculture and Forestry 10a/2004.

Forchhammer, M.C., Post, E. and Stenseth, N.C. 1998. Breeding phenology and climate. *Nature* 391(6662): 29–30.

Forchhammer, M.C., Post, E. and Stenseth, N.C. 2002. North Atlantic Oscillation timing of long- and short-distance migration. *Journal of Animal Ecology* 71(6): 1002–1014.

Forslund, P. and Larsson, K. 1991. Breeding range expansion of the Barnacle Goose *Branta leucopsis* in the Baltic area. *Ardea* 79(2): 343–346.

Forsman, J.T., Mönkkönen, M. and Hukkanen, M. 2001. Effects of predation on community assembly and spatial dispersion of breeding forest birds. *Ecology* 82(1): 232–244.

Fransson, T. and Pettersson, J. 2001. *Svensk ringmärkningsatlas, Vol 1*. Stockholm.

Frederiksen, M., Mavor, R.A. and Wanless, S. 2007. Seabirds as environmental indicators: the advantages of combining data sets. *Marine Ecology Progress Series* 352: 205–211.

Frisén, R., Johansson, C.E. and Suominen, V. 2005. Archipelagos in the Baltic Sea. In: Seppälä, M. (ed.). *The Physical Geography of Fennoscandia*, pp. 267–281. The Oxford Regional Environments Series, Oxford University Press, Oxford.

Fuller, R.M., Devereux, B.J., Gillings, S., Amable, G. and Hill, R. 2005. Indices of bird-habitat preference from field surveys of birds and remote sensing of land cover: a study of south-eastern England with wider implications for conservation and biodiversity assessment. *Global Ecology and Biogeography* 14(3): 223–239.

Furness, R.W. and Camphuysen, C.J. 1997. Seabirds as monitors of the marine environment. *ICES Journal of Marine Science* 54(4): 726–737.

Gadd, P.A. and Gummerus, J. 1769. *Oceonomisk Afhandling om sjöfogels wård och ans i Finska skärgården*. Disp. 4:o, Aboae.

Garthe, S. 1997. Influence of hydrography, fishing activity, and colony location on summer seabird distribution in the south-eastern North Sea. *ICES Journal of Marine Science* 54(4): 566–577.

Gaston, K.J., Blackburn, T.M. and Goldewijk, K.K. 2003. Habitat conversion and global avian biodiversity loss. *Proceedings of the Royal Society of London Series B* 270(1521): 1293–1300.

Gaulthier, G., Bety, J. and Hobson K.A. 2003. Are greater show geese capital breeders? New evidence from a stable-isotope model. *Ecology* 84(12): 3250–3264.

Gere, G. and Andrikovics, S. 1992. Effects of waterfowl on water quality. *Hydrobiologia* 243/244: 445–448.

Gilissen, N., Haanstra, L., Delany, S., Boere, G. and Hagemeijer, W. 2002. *Numbers and distribution of wintering waterbirds in the Western Palearctic and Southwest Asia in 1997, 1998 and 1999. Results from the International Waterbird Census*. Wetlands International Global Series No. 11.

Glowka, L., Burhenne-Guilmin, F., Synge, H., McNeely, J. and Gündling, L. 1994. *A Guide to the Convention on Biological Diversity*. IUCN Gland and Cambridge, Cambridge.

Gottschalk, T., Huettmann, F. and Ehlers, M. 2005. Thirty years of analysing and modelling avian habitat relationships using satellite imagery data: a review. *International Journal of Remote Sensing* 26(12): 2631–2656.

Granö, O. 1981. The zone concept applied to the Finnish coast in the light of scientific traditions. *Fennia* 159(1): 63–68.

Granö, O. and Roto, M. 1989. The duration of shore exposure along the emerging Finnish coast. *Journal of Coastal Research* 5(1): 49–55.

Granö, O., Roto, M. and Laurila, L. 1999. *Environment and land use in the shore zone of the coast of Finland*. Publicationes institute geographici universitatis Turkuensis 160.

Greenwood, J.J.D. 2007. Citizens, science and bird conservation. *Journal of Ornithology* 148(Supplement 1): S77–S124.

Gregory, R.D., van Strien, A., Vorisek, P., Gmelig Meyling A.W., Noble, D.G., Foppen, R.P.B. and Gibbons, D.W. 2005. Developing indicators for European birds. *Philosophical Transactions of the Royal Society B - Biological Sciences* 360(1454): 269–288.

Grenquist, P. 1956. Öljytuhoista Suomen aluevesillä v. 1948–1955. *Suomen Riista* 10: 105–116.

Grenquist, P. 1959. Variksen aiheuttamasta tuhosta Söderskärin lintusuojelualueen haahkakannalle 1953–1959. *Suomen Riista* 13: 156–163.

Grenquist, P. 1965. Changes in abundance of some duck and sea-bird populations off the coast of Finland 1949–1963. *Finnish Game Research* 27: 1–114.

Guillemain, M., Elmberg, J., Arzel, C., Johnson, A.R. and Simon, G. 2007. The income-capital breeding dichotomy revisited: late winter body condition is related to breeding success in an income breeder. *Ibis* 150(1): 172–176.

Guisan, A. and Zimmermann, N.E. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling* 135(2–3): 147–186.

Gunnarsson, T.G., Gill, J.A., Appleton, G.F., Gíslason, H., Gardarsson, A., Watkinson, A.R. and Sutherland, W.J. 2006. Large-scale habitat associations of birds in lowland Iceland: Implications for conservation. *Biological Conservation* 128(2): 265–275.

Haapala, J. and Leppäranta, M. 1997. The Baltic Sea ice season and the changing climate. *Boreal Environment Research* 2(1): 93–108.

Haapala, J., Heikinheimo, M. and Valkama, J. 2008. Constant Effort Ringing in Finland in 2007. In: *Linnut-vuosikirja (The yearbook of the Linnut magazine) 2007*, pp. 80–85. BirdLife Finland, Helsinki (in Finnish with English summary).

von Haartman, L. 1945. Zur Biologie der Wasser- und Ufervögel im Schärenmeer Südwest-Finnlands. *Acta Zoologica Fennica* 44: 1–120.

von Haartman, L. 1982. The Arctic Tern *Sterna paradisaea* – a new inhabitant of the inshore archipelago. *Ornis Fennica* 59(2–3): 63–76.

von Haartman, L. 1984. New archipelago birds in the era of water eutrophication. *Annales Zoologici Fennici* 21(3): 427–430.

Haig, S.M., Mehlman, D.W. and Oring, L.W. 1998. Avian movements and wetland connectivity in landscape conservation. *Conservation Biology* 12(4): 749–758.

Haila, Y. 1983. *Ecology of Island Colonization by Northern Land Birds: A Quantitative Approach*. University of Helsinki, Helsinki.

Hansson, S. and Rudstam, L.G. 1990. Eutrophication and Baltic Fish Communities. *Ambio* 19(3): 123–125.

Hario, M. 1998. Recent trends and research results for four archipelago bird species – common eider, velvet scoter, herring gull and lesser black-backed gull. In: *Linnut-vuosikirja (The yearbook of the Linnut magazine) 1997*, pp. 12–24. BirdLife Finland, Helsinki (in Finnish with English summary).

Hario, M. and Rintala, J. 2004. Population trends of the Mute Swan, the Common Eider and three species of goose on the Finnish coasts in 1986–2003. In: *Linnut-vuosikirja (The yearbook of the Linnut magazine) 2003*, pp. 49–57. BirdLife Finland, Helsinki (in Finnish with English summary).

Hario, M. and Rintala, J. 2006. Fledgling production and population trends in Finnish common eiders (*Somateria mollissima mollissima*) – evidence for density dependence. *Canadian Journal of Zoology* 84(7): 1038–1046.

Hario, M. and Rintala, J. 2008. Population trends of the Common Eider and four gull species in Finnish coastal areas in 1986–2007. In: *Linnut-vuosikirja (The yearbook of the Linnut magazine) 2007*, pp. 52–59. BirdLife Finland, Helsinki (in Finnish with English summary).

Hario, M. and Selin, K. 1986. A 30 year change in the breeding time of the common eider in the Gulf of Finland. *Suomen Riista* 33: 19–25 (in Finnish with English summary).

Hario, M. and Selin, K. 1987. The variation in clutch size and egg volume in different age classes of the common eider. *Suomen Riista* 34: 59–65 (in Finnish with English summary).

Hario, M. and Selin, K. 1989. Mortality in and the impact of gull predation on eider ducklings in the Gulf of Finland. *Suomen Riista* 35: 17–25 (in Finnish with English summary).

Hario, M. and Selin, K. 1991. Where have all the eider ducklings gone? *Suomen Riista* 37: 35–43 (in Finnish with English summary).

Hario, M. and Selin, K. 2002. Cohort-specific differences in reproductive output in a declining common eider *Somateria mollissima* population. *Danish Review of Game Biology* 16(1): 33–45.

Hario, M., Lehtonen, J.T. and Hollmén, T. 1995. Role, if any, of the acanthocephalan worm *Polymorphus minutus* in common eider mortality. *Suomen Riista* 41: 21–26 (in Finnish with English summary).

Hario, M., Rintala, J. and Selin, K. 2005. Fledgling production as the factor regulating the population of the common eider. *Suomen Riista* 51: 16–26 (in Finnish with English summary).

Hario, M., Komu, R., Muuronen, P. and Selin, K. 1986. Population trends among archipelago birds in Söderskär bird sanctuary 1963–86. *Suomen Riista* 33: 79–90 (in Finnish with English summary).

Hastie, T. and Tibshirani, R. 1990. *Generalized additive models*. Chapman & Hall, London.

Hatfield, J.S., Gould, W.R., Hoover, B.A., Fuller, M.R. and Lindquist, E.L. 1996. Detecting trends in raptor counts: Power and Type I error rates of various statistical tests. *Wildlife Society Bulletin* 24(3): 505–515.

Hauxwell, J., Cebrián, J. and Valiela, I. 2003. Eelgrass *Zostera marina* loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. *Marine Ecology Progress Series* 247: 59–73.

Hawkins, B.A., Diniz-Filho, J.A.F. and Soeller, S.A. 2005. Water links the historical and contemporary components of the Australian bird diversity gradient. *Journal of Biogeography* 32(6): 1035–1042.

Heath, M.F., Evans, M.I., Hoccom, D.G., Payne, A.J. and Peet, N.B. (eds.) 2000. *Important Bird Areas in Europe: Priority Sites for Conservation: 2 volume set*. BirdLife Conservation Series No. 8. BirdLife International, Cambridge.

HELCOM 1990. *Second periodic assessment of the state of the marine environment of the Baltic Sea, 1984–1988; background document*. Baltic Sea Environment Proceedings 35B.

HELCOM 1993. *First assessment of the state of the coastal waters of the Baltic Sea.* Baltic Sea Environment Proceedings 54.

HELCOM 2004. *Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992 (Helsinki Convention)*. Helsinki Commission, Helsinki.

HELCOM 2007. *Climate Change in the Baltic Sea Area – HELCOM Thematic Assessment in 2007*. Baltic Sea Environment Proceedings No. 111.

Hernández-Matías, A. and Ruiz, X. 2003. Predation on common tern eggs by the yellow-legged gull at the Ebro Delta. *Scientia Marina* 67(Supplement 2): 95–101.

Hildén, O. 1964. Ecology of duck populations in the island group of Valassaaret, Gulf of Bothnia. *Annales Zoologici Fennici* 1(3): 153–279.

Hildén, O. 1965. Habitat selection in birds. A review. *Annales Zoologici Fennici* 2(1): 53–75.

Hildén, O. 1966. Changes in the bird fauna of Valassaaret, Gulf of Bothnia, during recent decades. *Annales Zoologici Fennici* 3(4): 245–269.

Hildén, O. 1987. A new seabird monitoring scheme in Finland. *Lintumies* 22(2): 62–67 (in Finnish with English summary).

Hildén, O. and Hario, M. 1993. *Muuttuva saaristolinnusto*. Forssan kirjapaino, Forssa.

Hildén, O., Järvinen, A., Lehtonen, L. and Soikkeli, M. 1982. Breeding success of Finnish birds in the bad summer of 1981. *Ornis Fennica* 59(1): 20–31.

Hinneri, S. 1972. *An ecological monograph on eutrophic deciduous woods in the SW archipelago of Finland*. Annales Universitatis Turkuensis Series A 50.

Hirzel, A. and Guisan, A. 2002. Which is the optimal sampling strategy for habitat suitability modelling. *Ecological Modelling* 157(2–3): 331–341.

Hirzel, A.H., Hausser, J., Chessel, D. and Perrin, N. 2002. Ecological niche factor analysis: how to compute habitat-suitability maps without absence data? *Ecology* 83(7): 2027–2036.

Hirzel, A.H., Le Lay, G., Helfer, V., Randin, C. and Guisan, A. 2006. Evaluating the ability of habitat suitability models to predict species presences. *Ecological Modelling* 199(2): 142–152.

Holmes, D.J., Flückiger, R. and Austad, S.N. 2001. Comparative biology of aging in birds: an update. *Experimental Gerontology* 36(4–6): 869–883.

Hosmer, D.W. and Lemeshow, S. 2000. *Applied logistic regression. 2nd edn*. John Wiley & Sons, inc., New York.

Huettmann, F. and Czech, B. 2006. The steady state economy for global shorebird and habitat conservation. *Endangered Species Research* 2: 89–92.

Huettmann, F. and Diamond, A.W. 2001. Seabird colony locations and environmental determination of seabird distribution: a spatially explicit breeding seabird model for the Northwest Atlantic. *Ecological Modelling* 141(1–3): 261–298.

Huntley, B., Green, R.E., Collingham, Y.C. and Willis, S.G. 2007. A *Climatic Atlas of European Breeding Birds*. Lynx Edicions, Barcelona.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54(2): 187–211.

Hurrell, J.W. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. *Science* 269(5224): 676–679.

Hüppop, O. and Hüppop, K. 2003. North Atlantic Oscillation and timing of spring migration in birds. *Proceeding of the Royal Society of London B - Biological Sciences* 270(1512): 233–240.

Hänninen, S. and Rytkönen, J. 2006. *Transportation of liquid bulk chemicals by tankers in the Baltic Sea*. VTT Publications 595.

Hänninen, J., Vuorinen, I. and Hjelt, P. 2000. Climatic factors in the Atlantic control the oceanographic and ecological changes in the Baltic Sea. *Limnology and Oceanography* 45(3): 703–710.

Hänninen, J., Vuorinen, I. and Kornilovs, G. 2003. Atlantic climatic factors control decadal dynamics of a Baltic Sea copepod *Temora longicornis*. *Ecography* 26(5): 672–678.

Häyrén, E. 1900. Längs-zonerna i Ekenäs skärgård. *Geografiska Föreningens Tidskrift* 12: 222–234.

Iason, G.R., Duck, C.D. and Clutton-Brock, T.H. 1986. Grazing and reproductive success of red deer: the effect of local enrichment by gull colonies. *Journal of Animal Ecology* 55(2): 507–515.

IOC 2005. *An implementation strategy for the coastal module of GOOS*. GOOS Report 148. Intergovernmental Oceanographic Commission, UNESCO, Paris.

IPCC 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge.

IPCC 2007. *Climate Change 2007. A Synthesis Report. An Assessment of the Intergovernmental Panel on Climate Change*.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Earlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J. and Warner, R.R. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293(5530): 629–638.

James, F.C. and McCulloch, C.E. 1990. Multivariate analysis in ecology and systematics: panacea or Pandora's box. *Annual Review of Ecology and Systematics* 21: 129–166.

Javidpour, J., Sommer, U. and Shiganova, T.A. 2006. First record of *Mnemiopsis leidyi* A. Agassiz 1985 in the Baltic Sea. *Aquatic Invasions* 1(4): 299–302.

Johnson, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61(1): 65–71.

Johnson, J.B. and Omland, K.S. 2004. Model selection in ecology and evolution. *Trends in Ecology and Evolution* 19(2): 101–108.

Jones, I.L., Rowe, S., Carr, S.M., Fraser, G. and Taylor, P. 2002. Different patterns of parental effort during chick-rearing by female and male Thick-Billed Murres (*Uria lomvia*) at a low-arctic colony. *Auk* 119(4): 1064–1074.

Jonsson, K.I. 1997. Capital and income breeding as alternative tactics of resource use in reproduction. *Oikos* 78(1): 57–66.

Jonzén, N., Hedenström, A., Hjort, C., Lindström, Å., Lundberg, P. and Andersson, A. 2002. Climate patterns and the stochastic dynamics of migratory birds. *Oikos* 97(3): 329–336.

Juma, C. 1997. The Role of Information in the Operation of the Convention of Biological Diversity. In: Hawksworth, D.L., Kirk, P.M. and Dextre Clarke, S. (eds.). *Biodiversity Information – Needs and Options*, pp. 125–128. Cab International, Wallingford.

Jumppanen, K. and Mattila, J. 1994. *The development of the state of the Archipelago Sea and environmental factors*. Lounais-Suomen vesiensuojeluyhdistys r.y., Turku.

Järvinen, O. 1978. Species-specific census efficiency in line transects. *Ornis Scandinavica* 9(2): 164–167.

Järvinen, O. 1983. How should a Finnish monitoring system of bird populations be implemented? *Ornis Fennica* 60(4): 126–128 (in Finnish with English abstract).

Jønsen, A.H. 1978. *Statistics of duck hunting in Denmark 1966–1976*. Danish Review of Game Biology 10(7).

Jønsen, A.H. and Hansen, E.B. 1977. *Oil pollution and seabirds in Denmark 1971–1976*. Danish Review of Game Biology 10(5).

Kakkuri, J. 1987. Character of the Fennoscandian land uplift in the 20th century. *Geological Survey of Finland, Special Paper* 2: 15–20.

Kalliola, R. 2000. Quality, information and maps in the information age. *Foresight* 2: 223–229.

Karttunen, K. and Airaksinen, O. 1998. *Natura 2000 – habitats manual*. Finnish Environment Institute, Helsinki (in Finnish with English abstract).

Kauppi, L. (ed.) 1993. *Mass mortalities of seabirds in the eastern Gulf on Finland in spring 1992*. Publications of the Water and Environment Administration, Series A 142.

Kauppila, P., Pitkänen, H., Räike, A., Kiirikki, M., Bäck, S. and Kangas, P. 2004. The Baltic waters around Finland: Eutrophicaton continues despite decreased nutrient loading. In: Eloranta, P. (ed.) 2004. *Inland and Coastal Waters of Finland*, pp. 41–62**.** University of Helsinki / Palmenia Centre for Continuing Education / Palmenia Publishing, Saarijärvi.

Keating, K.A. and Cherry, S. 2004. Use and interpretation of logistic regression in habitat-selection studies. *Journal of Wildlife Management* 68(4): 774–789.

Kerr, J.T. and Currie, D.J. 1995. Effects of human activity on global extinction risk. *Conservation Biology* 9(5): 1528–1538.

Kerr, J.T. and Ostrovsky, M. 2003. From space to species: ecological applications for remote sensing. *Trends in Ecology and Evolution* 18(6): 299–305.

Kiirikki, M. 1996. Mechanisms affecting macroalgal zonation in the northern Baltic Sea. *European Journal of Phycology* 31(3): 225–232.

Kilpi, M. 1985. Archipelago bird populations in Finland: monitoring and recent changes. *Ornis Fennica* 62(2): 42–46.

Kirkkala, T., Helminen, H. and Erkkilä, A. 1998. Variability of nutrient limitation in the Archipelago Sea, SW Finland. *Hydrobiologia* 363(1–3): 117–126.

Klaassen, M., Abraham, K.F., Jefferies, R.L. and Vrtiska, M. 2006. Factors affecting the site of investment, and the reliance on savings for arctic breeders: the capital-income dichotomy revisited. *Ardea* 94(3) (Special Issue): 371–384.

Kokko, H., Harris, M.P. and Wanless, S. 2004. Competition for breeding sites and site-dependent population regulation in a highly colonial seabird, the common guillemot *Uria aalge*. *Journal of Animal Ecology* 73(2): 367–376.

Korvenpää, T., von Numers, M. and Hinneri, S. 2003. A mesoscale analysis of floristic patterns in the South-West Finnish archipelago. *Journal of Biogeography* 30(7): 1019–1031.

Koskimies, J. 1955. Juvenile mortality and population balance in the velvet scoter (*Melanitta fusca*) in maritime conditions. *Acta XI Congr. Int. Orn. Basel 1954*: 476–479.

Koskimies, J. 1957. Verhalten und Ökologie der Jungen und der Jungen-führenden Weibchen der Samtente. Zur Fortpflanzungsbiologie der Samtente, *Melanitta f. fusca* (L.) II. *Annales Zoologici Societatis Zoologicae-Botanicae Fennicae 'Vanamo'* 18(9): 1–69.

Koskimies, J. and Lahti, L. 1964. Cold hardiness of the newly hatched young in relation to ecology and distribution in ten species of European ducks. *Auk* 81(3): 281–307.

Koskimies, P. and Pöysä, H. 1989. Waterfowl censusing in environmental monitoring: a comparison between point and round counts. *Annales Zoologici Fennici* 26(3): 201–206.

Koskimies, P. and Väisänen, R.A. 1991. *Monitoring bird populations*. Zoological Museum, Finnish Museum of Natural History, Helsinki.

Koskinen, P., Saari, L., Nummi, P. and Pellikka, J. 2003. Population density and weather affect the breeding success of mute swan in southern Finland. *Suomen Riista* 49: 17–24 (in Finnish with English summary).

Lack, D. 1969. The numbers of bird species on islands. *Bird Study* 16(4): 193–209.

Lack, D. 1976. *Island Birds*. Blackwell Scientific Publications, Oxford.

Laine, J. 1996. Breeding of the Barnacle Goose in Finland. *Linnut* 31(2): 24–27 (in Finnish with English summary).

Larsson, K., Forslund, P., Gustafsson, L. and Ebbinge, B.S. 1988. From the high Arctic to the Baltic: the successful establishment of a Barnacle Goose *Branta leucopsis* population on Gotland, Sweden. *Ornis Scandinavica* 19(3): 182–189.

Laurila, T. 1989. Nest site selection in the Common Eider *Somateria mollissima*: differences between the archipelago zones. *Ornis Fennica* 66(2): 100–111.

Laurila, T. and Hario, M. 1988. Environmental and genetic factors influencing clutch size, egg volume, date of laying and female weight in the common eider *Somateria mollissima*. *Finnish Game Research* 45: 19–30.

Leathwick, J.R., Elith, J. and Hastie, T. 2006. Comparative performance of generalized additive models and multivariate adaptive regression splines for statistical modelling of species distributions. *Ecological Modelling* 199(2): 188–196.

Lehikoinen, A., Kilpi, M. and Öst, M. 2006. Winter climate affects subsequent breeding success of common eiders. *Global Change Biology* 12(7): 1355–1365.

Lehikoinen, E., Gustafsson, E., Aalto, T., Alho, P., Klemola, H., Laine, J., Normaja, J., Numminen, T. and Rainio, K. 2003. *Varsinais-Suomen linnut*. Turun Lintutieteellinen Yhdistys ry, Turku.

Leivo, M., Asanti, T., Koskimies, P., Lammi, E., Lampolahti, J., Mikkola-Roos, M. and Virolainen, E. 2002. *Suomen tärkeät lintualueet FINIBA*. BirdLife Suomen julkaisuja nro 4 (in Finnish with English summary).

Lele, S.R. 2006. Sampling variability and estimates of density dependence: a composite-likelihood approach. *Ecology* 87(1): 189–202.

Lemmetyinen, R. 1966. Damage to waterfowl in the Baltic area caused by waste oil. *Suomen Riista* 19: 63–71 (in Finnish with English summary).

Lemmetyinen, R. 1971. Nest defence behaviour of Common and Arctic Terns and its effects on the success achieved by predators. *Ornis Fennica* 48(1): 13–24.

Lemmetyinen, R., Portin, P. and Vuolanto, S. 1974. Polymorphism in relation to the substrate in chicks of *Sterna paradisaea Pontopp*. *Annales Zoologici Fennici* 11(4): 265–270.

Lemoine, N. and Böhning-Gaese, K. 2003. Potential impact of global climate change on species richness of long-distance migrants. *Conservation Biology* 17(2): 577–586.

Leppäkoski, E. 1975. *Assessment of degree of pollution on the basis of macrozoobenthos in marine and brackish-water environments*. Acta Academiae Aboensis Ser. B 30.

Leppäkoski, E. 1991. Introduced species – resource of threat in brackish-water seas? Examples from the Baltic and the Black Sea. *Marine Pollution Bulletin* 23: 219–223.

Leppäkoski, E., Gollasch, S., Gruszka, P., Ojaveer, H., Olenin, S. and Panov, V. 2002. The Baltic – a sea of invaders. *Canadian Journal of Fisheries and Aquatic Sciences* 59(7): 1175–1188.

Liang, K.-Y. and Zeger, S.L. 1986. Longitudinal Data Analysis using Generalized Linear Models. *Biometrika* 73(1): 13–22.

Lind, H. 1963. Nogle sociale reaktioner hos terner. *Dansk Ornithologisk Forenings Tidskrift* 57: 155–175.

Lindén, H., Helle, E., Helle, P. and Wikman, M. 1996. Wildlife triangle scheme in Finland: methods and aims for monitoring wildlife populations. *Finnish Game Research* 49: 4–11.

Linkola, P. 1959. Zur Methodik der quantitativen Vogelforschung in den Binnengewässern. *Ornis Fennica* 36(3–4): 66–78.

Liu, L.-M. 2006. *Time Series Analysis and Forecasting*. Scientific Computing Associates Corp., Illinois.

Liu, L.-M. and Hudak, G.B. 1992. *Forecasting and time series analysis using the SCA Statistical System. Vol. 1*. Scientific Computing Associates Corp., Illinois.

Lundberg, J. and Moberg F. 2003. Mobile link organisms and ecosystem functioning: implications for ecosystem resilience and management. *Ecosystems* 6(1): 87–98.

Lyytimäki, J., Hildén, M., Aberra, Z. and Lindholm, M. 2008. *The significance of ecological thresholds in coastal areas. Results of an international web survey*. Reports of Finnish Environment Institute 21.

Mackenzie, B.R., Gíslason, H., Mollmann, C. and Koster, F.W. 2007. Impact of 21st century climate change on the Baltic Sea fish community and fisheries. *Global Change Biology* 13(7): 1348–1367.

Manly, B.F.J., McDonald, L.L., Thomas, D.L., McDonald, T.L. and Erickson, W.P. 2002. *Resource selection by animals: Statistical design and analysis for field studies, second edn*. Kluwer Academic Publishers, Dordrecht.

Mannermaa, K. and Lõugas, L. 2005. Birds in the subsistence and cultures on four major Baltic Islands in the Neolithic (Gotland, Åland, Hiiumaa and Saaremaa). In: Grupe, G. and Peters, J. (eds.). Feathers, Grit and Symbolism. Birds and Humans in the Ancient Old and New Worlds. *Documenta Archaeobiologiae* 3: 179–198.

Mathiasson, S. 1987. Parents, children and grandchildren – maturity process, reproduction strategy and migratory behaviour of three generations and two year-classes of Mute Swans *Cygnus olor*. *Acta Regiae Societatis Scientiarum et Litterarum Gothoburgensis, Zoologica* 14: 60–70.

Matthiopoulos, J., Harwood, J. and Thomas, L. 2005. Metapopulation consequences of site fidelity for colonially breeding mammals and birds. *Journal of Animal Ecology* 74(4): 716–727.

Mavor, R.A., Heubeck, M., Schmitt, S. and Parsons, M. 2008. *Seabird numbers and breeding success in Britain and Ireland, 2006*. UK Nature Conservation, No. 31. Joint Nature Conservation Committee, Peterborough.

McCabe, T.R. 1994. Assessing value of Arctic wildlife and habitat subject to potential petroleum development. *Landscape and Urban Planning* 28(1): 33–45.

McCune, B. and Grace, J.B. 2002. Principal Component Analysis. In: McCune, B. and Grace, J.B., *Analysis of Ecological Communities*, pp. 114–121. MjM Software Design, Gleneden Beach.

McKinney, R.A., McWilliams, S.R. and Charpentier, M.A. 2006. Waterfowl-habitat associations during winter in an urban North Atlantic estuary. *Biological Conservation* 132(2): 239–249.

Mehtälä, J. and Vuorisalo, T. 2007. Conservation policy and the EU Habitats Directive: favourable conservation status as a measure of conservation success. *European Environment* 17(6): 363–375.

Meijer, T. and Drent, R. 1999. Re-examination of the capital and income dichotomy in breeding birds. *Ibis* 141(3): 399–414.

Mikola, J., Miettinen, M., Lehikoinen, E. and Lehtilä, K. 1994. The effects of disturbance caused by boating on survival and behaviour of velvet scoter *Melanitta fusca* ducklings. *Biological Conservation* 67(2): 119–124.

Millennium Ecosystem Assessment 2005. *Ecosystems and human well-being: Synthesis*. Springer, Berlin.

Milne, H. 1976. Body weight and carcass composition of the Common Eider. *Wildfowl* 27: 115–122.

Ministry of the Environment 2002. *Finland's Programme for the Protection of the Baltic Sea. The Finnish Government's decision-in-principle*. The Finnish Environment 570.

Minton, C.D.T. 1968. Pairing and breeding in mute swans. *Wildfowl* 19: 41–60.

Montevecchi, W.A. and Myers, R.A. 1997. Centurial and decadal oceanographic influences on changes in northern gannet populations and diets in the north-west Atlantic: implications for climate change. *ICES Journal of Marine Science* 54(4): 608–614.

Moreira, F. 1997. The importance of shorebirds to energy fluxes in a food web of a south European estuary. *Estuarine, Coastal and Shelf Science* 44(1): 67–78.

Morrison, M.L. 1986. Bird populations as indicators of environmental change. In: Johnston, R.F. (ed.). *Current Ornithology 3*, pp. 429–451. Plenum Press, New York.

Muradian, R. 2001. Ecological thresholds: a survey. *Ecological Economics* 38(1): 7–24.

Myrberg, K., Leppäranta, M. and Kuosa, H. 2006. *Itämeren fysiikka, tila ja tulevaisuus*. Yliopistopaino, Helsinki.

Møller, A.P. 2002. North Atlantic Oscillation (NAO) effects of climate on the relative importance of first and second clutches in a migratory passerine bird. *Journal of Animal Ecology* 71(2): 201–210.

Møller, A.P. and Jennions, M.D. 2002. How much variance can be explained by ecologists and evolutionary biologists? *Oecologia* 132(4): 492–500.

Möllmann, C., Kornilovs, G., Fetter, M. and Köster, F.W. 2005. Climate, Zooplankton, and pelagic fish growth in the central Baltic Sea. *ICES Journal of Marine Science* 62(7): 1270–1280.

Mönkkönen, M., Hardling, R., Forsman, J.T. and Tuomi, J. 1999. Evolution of heterospecific attraction: using other species as cues in habitat selection. *Evolutionary Ecology* 13(1): 91–104.

Najjar, R.G., Walker, H.A., Anderson, P.J., Barron, E.J., Bord, R.J., Gibson, J.R., Kennedy, V.S., Knight, C.G., Megonigal, J.P., O'Connor, R.E., Polsky, C.D., Psuty, N.P., Richards, B.A., Sorenson, L.G., Steele, E.M. and Swanson, R.S. 2000. The potential impacts of climate change on the mid-Atlantic coastal region. *Climate Research* 14(3): 219–233.

Nebert, D. (ed.) 2004. *Developing spatial data infrastructures: the SDI cookbook*. Global Spatial Data Infrastructure Association, Reston.

Newton, I. 1998. *Population limitation in birds*. Academic Press, San Diego.

Nguyen, L.P., Abraham, K.F. and Nol, E. 2006. Influence of Arctic Terns on survival of artificial and natural Semipalmated Plover nests. *Waterbird*s 29(1): 100–104.

Niemi, J. (ed.) 2006. *Environmental monitoring in Finland 2006–2008*. The Finnish Environment 26/2006. Finnish Environment Institute, Vammala.

Nilsson, L. 1984. The impact of hard winters on waterfowl populations of south Sweden. *Wildfowl* 35: 71–80.

Nilsson, S. 1858. Tam Svan. In: Nilsson, S. *Skandinavisk fauna. Foglarna. Andra Bandet. Tredje Upplagan*, pp. 386–390. Berlingska Boktryckeriet, Lund.

Nixon, S.W. 1990. Marine eutrophication: A growing international problem. *Ambio* 19(3): 101.

Nordström, M. and Korpimäki, E. 2004. Effects of island isolation and feral mink removal on bird communities on small islands in the Baltic Sea. *Journal of Animal Ecology* 73(3): 424–433.

Nordström, M., Högmander, J., Laine, J., Nummelin, J., Laanetu, N. and Korpimäki, E. 2003. Effects of feral mink removal on seabirds, waders and passerines on small islands in the Baltic Sea. *Biological Conservation* 109(3): 359–368.

Nordström, M., Högmander, J., Nummelin, J., Laine, J., Laanetu, N. and Korpimäki, E. 2002. Variable responses of waterfowl breeding populations to long-term removal of introduced American mink. *Ecography* 25(4): 385–394.

Norkko, A. 1997. *The role of drifting macroalgal mats in structuring coastal zoobenthos. Ph. D. Thesis*. Åbo Akademi University, Finland.

Norrman, J.O. 1992. Coast and Shore. In: Sjöberg, B. (ed.). *Sea and Coast*, pp. 38–43. National Atlas of Sweden, Stockholm.

Norton, D.A., Delange, P.J., Garnock-Jones, P.J. and Given, D.R. 1997. The role of seabirds and seals in the survival of coastal plants: lessons from New Zealand *Lepidium* (Brassicaceae). *Biodiversity and Conservation* 6(6): 765–785.

von Numers, M. 1995. Distribution, numbers and ecological gradients of birds breeding on small islands in the Archipelago Sea, SW Finland. *Acta Zoologica Fennica* 197: 1–127.

von Numers, M. 1999. Vår skärgårdsfågelfauna förändras. *Skärgård* 2/1999: 9–14.

von Numers, M. and Korvenpää, T. 2007. 20th century vegetation changes in as island archipelago, SW Finland. *Ecography* 30(6): 789–800.

Nummelin, J., Laine, J. and Jokinen, M. 1997. Harmaalokin kaatopaikkapyynti ja sen vaikutus lajin kannan kehitykseen. *Ympäristö ja Terveys* 5/1997: 46–49.

Nummi, P. and Pöysä, H. 1993. Habitat associations of ducks during different phases of the breeding season. *Ecography* 16(4): 319–328.

Nummi, P. and Saari, L. 2003. Density-dependent decline of breeding success in an introduced, increasing mute swan *Cygnus olor* population. *Journal of Avian Biology* 34(1): 105–111.

Numminen, S. 1999. *Flads and glo-lakes in the Archipelago Sea*. The Finnish Environment 339, Southwest Finland Regional Environment Centre, Turku (in Finnish with English abstract).

O'Brien, K., Hänninen, J., Kanerva, T., Metsärinne, L. and Vuorinen, I. 2003. Macrozoobenthic zonation in relation to major environmental factors across the Archipelago Sea, northern Baltic Sea. *Boreal Environment Research* 8(2): 159–170.

O'Connell, T.J., Bishop, J.A. and Brooks, R.P. 2007. Sub-sampling data from the North American Breeding Bird Survey for application to the Bird Community Index, an indicator of ecological condition. *Ecological Indicators* 7(3): 679–691.

O'Connor, R.J. 1985. Long-term monitoring of British bird populations. *Ornis Fennica* 62(2): 73–79.

Ohlendorf, H.M., Risebrough, R.W. and Vermeer, K. 1978. Exposure of marine birds to environmental pollutants. *Wildlife Research Report* 9: 1–40.

Oja, H. and Pöysä, H. 2007. Spring phenology, latitude, and the timing of breeding in two migratory ducks: implications of climate change impacts. *Annales Zoologici Fennici* 44(6): 475–485.

Okey, T.A., Vargo, G.A., Mackinson, S., Vasconcellos, M., Mahmoudi, B. and Meyer, C.A. 2004. Simulating community effects of sea floor shading by plankton blooms over the West Florida Shelf. *Ecological Modelling* 172(2–4): 339–359.

Olivieri, S.T., Harrison, J. and Busby, J.R. 1995. Data and information management and communication. In: Heywood, V.H. and Watson, R.T. (eds.), *Global Biodiversity Assessment*. Cambridge University Press, Cambridge.

Paasivaara, A. and Pöysä, H. 2007. Survival of common goldeneye *Bucephala clangula* ducklings in relation to weather, timing of breeding, brood size, and female condition. *Journal of Avian Biology* 38(2): 144–152.

Paavola, M., Olenin, S. and Leppäkoski, E. 2005. Are invasive species most successful in habitats of low native species richness across European brackish water seas? *Estuarine, Coastal and Shelf Science* 64(4): 738–750.

Paavolainen, E.-P. 1950. On the bird fauna of the western archipelago of Porvoo. *Suomen Riista* 5: 28–59 (in Finnish with English summary).

Paerl, H.W. 1993. Emerging role of atmospheric nitrogen deposition in coastal eutrophication – biogeochemical and trophic perspectives. *Canadian Journal of Fisheries and Aquatic Sciences* 50(10): 2254–2269.

Pannekoek, J. and van Strien, A. 2003. *TRIM 3 Manual (Trends & Indices for Monitoring data)*. Statistics Netherlands, Voorburg.

Peach, W.J., Buckland, S.T. and Baillie, S.R. 1996. The use of constant effort mist-netting to measure between-year changes in the abundance and productivity of common passerines. *Bird Study* 43(2): 142–156.

Pearson, T.H. and Rosenberg, R. 1978. Macrobenthos succession in relation to organic enrichment and pollution on the marine environment. *Oceanography and Marine Biology: an Annual Review* 16: 229–311.

Perttilä, M., Niemistö, L. and Mäkelä, K. 1995. Distribution, development and total amounts of nutrients in the Gulf of Finland. *Estuarine, Coastal and Shelf Science* 41(3): 345–360.

Phelps, H.L. 1994. The Asiatic clam (*Corbicula fluminea*) invasion and system-level ecological change in the Potomac River estuary near Washington, DC. *Estuaries* 17(3): 614–621.

Pihl, S., Durinck, J. and Skov, H. 1995. Midwinter waterbird counts in the Baltic Sea, 1993. *Suomen Riista* 41: 27–34 (in Finnish with English summary).

Pinaud, D., Cherel, Y. and Weimerskirch, H. 2005. Effect of environmental variability on habitat selection, diet, provisioning behaviour and chick growth in yellow-nosed albatrosses. *Marine Ecology Progress Series* 298: 295–304.

Pirkola, M.K. and Högmander, J. 1974. The age determination of duck broods in the field. *Suomen Riista* 25: 50–55 (in Finnish with English summary).

Pitkänen, H. 1994. *Eutrophication of the Finnish Coastal Waters: Origin, fate and effects of riverine nutrient fluxes*. Publications of the Water and Environment Research Institute, National Board of Waters and the Environment 18.

Pitkänen, H., Kangas, P., Sarkkula, J., Lepistö, L., Hällfors, G. and Kauppila, P. 1990. *Veden laatu ja rehevyys itäisellä Suomenlahdella*. Vesi- ja ympäristöhallinnon julkaisuja, sarja A 50.

Post, D.M., Taylor, J.P., Kitchell, J.F., Olson, M.H., Schindler, D.E. and Herwig, B.R. 1998. The role of migratory waterfowl as nutrient vectors in a managed wetland. *Conservation Biology* 12(4): 910–920.

Potts, J.M. and Elith, J. 2006. Comparing species abundance models. *Ecological Modelling* 199(2): 153–163.

Pöysä, H. 2001. Dynamics of habitat distribution in breeding mallards: assessing the applicability of current habitat selection models. *Oikos* 94(2): 365–373.

Pöysä, H. and Pöysä, S. 2002. Nest-site limitation and density dependence of reproductive output in the common goldeneye *Bucephala clangula*: implications for the management of cavity-nesting birds. *Journal of Applied Ecology* 39(3): 502–510.

Pöysä, H., Elmberg, J., Sjöberg, K. and Nummi, P. 2000. Nesting mallards (*Anas platyrhynchos*) forecast brood-stage food limitation when selecting habitat: experimental evidence. *Oecologia* 122(4): 582–586.

Quinn, J.L. and Ueta, M. 2008. Protective nesting associations in birds. *Ibis* 150(Supplement 1): 146–167.

Quinn, J.L., Prop, J., Kokorev, Y. and Black, J.M. 2003. Predator protection or similar habitat selection in red-breasted goose nesting associations: extremes along a continuum. *Animal Behaviour* 65(2): 297–307.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315(5810): 368–370.

Rajasilta, M., Eklund, J., Kääriä, J. and Ranta-aho, K. 1989. The deposition and mortality of the eggs of the Baltic herring, *Clupea harengus membras* L., on different substrates in the south-west archipelago of Finland. *Journal of Fish Biology* 34(3): 417–427.

Rassi, P., Alanen, A., Kanerva, T. and Mannerkoski, I. (eds.) 2001. *The 2000 Red List of Finnish Species*. Ministry of the Environment, Finnish Environment Institute, Helsinki (in Finnish with English abstract).

Rassi, P., Alanen, A., Kemppainen, E., Vickholm, M. and Väisänen, R. 1985. *Uhanalaisten eläinten ja kasvien suojelutoimikunnan mietintö. Osa II. Suomen uhanalaiset eläimet*. Komiteanmietintö 1985:43. Valtion painatuskeskus.

Rattner, B.A. and McGowan, P.C. 2007. Potential hazards of environmental contaminants to avifauna residing in the Chesapeake Bay estuary. *Waterbirds* 30(Special Issue 1): 63–81.

Research, monitoring and data systems expert group 2001. *Proposal for a national monitoring system of biological diversity; report by a research, monitoring and data systems expert group*. The Finnish Environment 532. Ministry of the Environment, Helsinki. (In Finnish with English abstract.)

Richardson, C.J., King, R.S., Qian, S.S., Vaithiyanathan, P., Qualls, R.G. and Stow, C.A. 2007. Estimating ecological thresholds for phosphorus in the Everglades. *Environmental Science & Technology* 41(23): 8084–8091.

Robertson, G.J., Fifield, D., Massaro, M. and Chardine, J. 2001. Changes in nesting-habitat use of large gulls breeding in Witless Bay, Newfoundland. *Canadian Journal of Zoology – Revue Canadienne de Zoologie* 79(12): 2159–2167.

Rumohr, H., Bonsdorff, E. and Pearson, T.H. 1996. Zoobenthic succession in Baltic sedimentary habitats. *Archive of Fishery and Marine Research* 44(3): 179–214.

Ruuskanen, A., Bäck, S. and Reitalu, T. 1999. A comparison of two cartographic exposure methods using *Fucus vesiculosus* as an indicator. *Marine Biology* 134(1): 139–145.

Räisänen, R. 2003. *Rymättylän ja Velkuan kalankasvatuslaitosten vedenlaatu- ja pohjaeläintutkimus vuonna 2001. Vuosiyhteenveto.* Tutkimusseloste 204. Lounais-Suomen vesi- ja ympäristötutkimus Oy.

Rönnberg, C. and Bonsdorff, E. 2004. Baltic Sea eutrophication: area-specific ecological consequences. In: Kautsky, H. and Snoeijs, P. (eds.). *Biology of the Baltic Sea*, pp. 227–241. Kluwer Academic Publishers, Dordrecht.

Rönnbäck, P., Kautsky, N., Pihl, L., Troell, M., Söderqvist, T. and Wennhage, H. 2007. Ecosystem goods and services from Swedish coastal habitats: identification, valuation, and implications on ecosystem shifts. *Ambio* 36(7): 534–544.

Saccheri, I., Kuussaari, M., Kankare, M., Vikman, P., Fortelius, W. and Hanski, I. 1998. Inbreeding and extinction in a butterfly metapopulation. *Nature* 392(6675): 491–494.

Salovius, S., Nyqvist, M. and Bonsdorff, E. 2005. Life in the fast lane: macrobenthos uses temporary drifting algal habitats. *Journal of Sea Research* 53(3): 169–180.

Sanchez, J.M., Corbacho, C., del Viejo, A.M. and Parejo, D. 2004. Colony-site tenacity and egg color crypsis in the Gull-billed Tern. *Waterbirds* 27(1): 21–30.

Sandberg, E. 1994. Does short-term oxygen depletion affect predator-prey relationships in zoobenthos? Experiments with the isopod *Saduria entomon*. *Marine Ecology Progress Series* 103: 73–80.

Sandén, P. and Håkansson, B. 1996. Long-term trends in Secchi depth in the Baltic Sea. *Limnology and Oceanography* 41(2): 346–351.

Sanz, J.J. 2002. Climate change and breeding parameters of great and blue tits throughout the western Palaearctic. *Global Change Biology* 8(5): 409–422.

SAS Institute Inc. 2001. The GENMOD Procedure. In: *SAS/STAT® User's Guide, Version 8*, pp. 1363–1464. SAS Institute Inc., Cary.

SAS Institute Inc. 2004. *Base SAS® 9.1 Procedures Guide*. SAS Institute Inc., Cary.

Scheffer, M. and Carpenter, S.R. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. *Trends in Ecology and Evolution* 18(12): 648–656.

Segurado, P. and Araújo, M.B. 2004. An evaluation of methods for modelling species distributions. *Journal of Biogeography* 31(10): 1555–1568.

Segurado, P., Araújo, M.B. and Kunin, W.E. 2006. Consequence of spatial autocorrelation for niche-based models. *Journal of Applied Ecology* 43(3): 433–444.

Seinä, A. and Peltola, J. 1991. Duration of the ice seasons and statistics of fast ice thickness along the Finnish coast 1961–1990. *Finnish Marine Research* 258: 1–46.

Şekercioğlu, Ç,H. 2006. Increasing awareness of avian ecological function. *TRENDS in Ecology and Evolution* 21(8): 464–471.

Şekercioğlu, Ç,H., Daily, G.C. and Ehrlich, P.R. 2004. Ecosystem consequences of bird declines. *Proceedings of the National Academy of Sciences* 101(52): 18042–18047.

Serrano, D., Oro, D., Esperanza, U. and Tella, J. 2005. Colony size selection determines adult survival and dispersal preferences: Allee effects in a colonial bird. *American Naturalist* 166(2): E22–E31.

Serrano, D., Tella, J.L., Forero, M.G. and Donázar, J. A. 2001. Factors affecting breeding dispersal in the facultatively colonial lesser kestrel: individual experience vs. conspecific cues. *Journal of Animal Ecology* 70(4): 568–578.

Stapp, P., Polls, G.A. and Sánchez Piñero, F. 1999. Stable isotopes reveal strong marine and El Niño effects on island food webs. *Nature* 401(6752): 467–469.

Stein, B. 1997. Designing Information Systems to Support Biodiversity Conservation. In: Hawksworth, D.L., Kirk, P.M. and Dextre Clarke, S. (eds.). *Biodiversity Information – Needs and Options*, pp. 129–146. Cab International, Wallingford.

Stenseth, N.C., Mysterud, A., Ottersen, G., Hurrell, J.W., Chan, K.-S. and Lima, M. 2002. Ecological effects of climate fluctuations. *Science* 297(5585): 1292–1296.

Stigebrandt, A. and Gustafsson, B.G. 2007. Improvement of Baltic Proper water quality using large-scale ecological engineering. *Ambio* 36(2–3): 280–286.

Suárez-Seoane, S., Osborne, P.E. and Alonso, J.C. 2002. Large-scale habitat selection by agricultural steppe birds in Spain: identifying species-habitat responses using generalized additive models. *Journal of Applied Ecology* 39(5): 755–771.

Suomela, J. 2001. *Saaristomeren tila vuosituhannen vaihteessa*. Lounais-Suomen ympäristökeskuksen moniste 20/2001.

Sutherland, W.J. (ed.) 2006. *Ecological Census Techniques, a Handbook, 2nd edn*. Cambridge University Press, Cambridge.

Sutherland, W.J., Newton, I. and Green, R.E. 2004. *Bird Ecology and Conservation. A Handbook of Techniques*. Oxford University Press, New York.

Szczys, P., Hughes, C.R. and Kesseli, R.V. 2005. Novel microsatellite markers used to determine the population genetic structure of the endangered Roseate Tern, *Sterna dougallii*, in Northwest Atlantic and Western Australia. *Conservation Genetics* 6(3): 461–466.

Tasker, M.L. and Reid, J.B. 1997. Seabirds in the marine environment. Introduction. *ICES Journal of Marine Science* 54(4): 505–506.

Tenovuo, R. 1975. The Mute Swan (*Cygnus olor*) population in southwestern Finland. *Suomen Riista* 26: 5–13 (in Finnish with English summary).

Tenovuo, R. 1976. Mute Swan in Finland. *Ornis Fennica* 53(4): 147–149.

Thomas, C.D. and Lennon, J.J. 1999. Birds extend their ranges northwards. *Nature* 399(6733): 213.

Thompson, P.M. and Ollason, J.C. 2001. Lagged effects of ocean climate change on fulmar population dynamics. *Nature* 413(6864): 417–420.

Thomson, R.L., Forsman, J.T. and Mönkkönen, M. 2003. Positive interactions between migrant and resident birds: testing the heterospecific attraction hypothesis. *Oecologia* 134(3): 431–438.

Tiainen, J. 1985. Monitoring bird populations in Finland. *Ornis Fennica* 62(2): 80–89.

Tiainen, J., Hario, M. and Rintala, J. 2001. Monitoring ducks in Finnish Baltic archipelagoes: comparison of two census methods and recent trends. In: *Linnut-vuosikirja (The yearbook of the Linnut magazine) 2000*, pp. 149–158. BirdLife Finland, Helsinki (in Finnish with English summary).

Tolvanen, H. 2006. *Spatial Information in Coastal Geography: Studies of Processes, Landforms, Ecosystems and Management*. Annales Universitatis Turkuensis Ser. AII, Biologica – Geographica – Geologica Tom. 197. Turun yliopisto, Turku.

Tolvanen, H. and Kalliola, R. 2008. A structured approach to geographical information in coastal research and management. *Ocean & Coastal Management* 51(6): 485–494.

Tolvanen, H. and Suominen, T. 2004. Classification of transitional archipelago environments based on shoreline dimensions. In: *Proceedings of the Littoral 2004 Conference, Aberdeen* 19.–22.9.2004, pp. 136–137.

Tolvanen, H. and Suominen, T. 2005. Quantification of openness and wave activity in archipelago environments. *Estuarine, Coastal and Shelf Science* 64(2–3): 436–446.

Tryjanovski, P. and Sparks, T.H. 2001. Is the detection of the first arrival date of migrating birds influenced by population size? A case study of the red-backed shrike *Lanius collurio*. *International Journal of Biometeorology* 45(4): 217–219.

Tucker, G.M. and Heath, M.F. 1994. *Birds in Europe: their conservation status.* BirdLife Conservation Series no. 3.

Ulanowicz, R.E. 2004. New perspectives through brackish water ecology. *Hydrobiologia* 514(1–3): 3–12.

Vaitkus, G. and Bubinas, A. 2001. Modelling of sea duck spatial distribution in relation to food resources in Lithuanian offshore waters under the gradient of winter climatic conditions. *Acta Zoologica Lituanica* 11(3): 288–302.

Valle, R. and Scarton, F. 1999. The presence of conspicuous associates protects nesting Redshank *Tringa totanus* from aerial predators. *Ornis Fennica* 76(3): 145–148.

Venables, W.N., Smith, D.M. and the R Development Core Team 2007. *An Introduction to R. Notes on R: A Programming Environment for Data Analysis and Graphics Version 2.5.0*. (available at: http://www.r-project.org/index.html).

Viitasalo, M., Vuorinen, I. and Ranta, E. 1990. Changes in Crustacean mesozooplankton and some environmental parameters in the Archipelago Sea (Northern Baltic) in 1976–1984. *Ophelia* 31(3): 207–217.

Virkkala, R., Luoto, M., Heikkinen, R.K. and Leikola, N. 2005. Distribution patterns of boreal marshland birds: modelling the relationships to land cover and climate. *Journal of Biogeography* 32(11): 1957–1970.

Viverette, C.B., Garman, G.C., McIninch, S.P., Markham, A.C., Watts, B.D. and Macko, S.A. 2007. Finfish-waterbird trophic interactions in tidal freshwater tributaries of the Chesapeake Bay. *Waterbirds* 30(Special Issue 1): 50–62.

Vlietstra, L.S. 2005. Spatial associations between seabirds and prey: effects of large-scale prey abundance on small-scale seabird distribution. *Marine Ecology Progress Series* 291: 275–287.

Vuorinen, I., Hänninen, J. and Kornilovs, G. 2003. Transfer-function modelling between environmental variation and mesozooplankton in the Baltic Sea. *Progress in Oceanography* 59(4): 339–356.

Väisänen, R.A. 1973. Establishment of colonies of Caspian Tern *Hydroprogne caspia* by deserting flights in the northern Gulf of Bothnia. *Ornis Scandinavica* 4(1): 47–53.

Väisänen, R.A, Lammi, E. and Koskimies, P. 1998. *Muuttuva pesimälinnusto*. Otava, Keuruu.

Wanless, S., Harris, M.P., Redman, P. and Speakman, J.R. 2005. Low energy values of fish as a probable cause of a major seabird breeding failure in the North Sea. *Marine Ecology Progress Series* 294: 1–8.

Wazniak, C.E., Hall, M.R., Carruthers, T.J.B., Sturgis, B., Dennison, W.C. and Orth, R.J. 2007. Linking water quality to living resources in a mid-Atlantic lagoon system, USA. *Ecological Applications* 17(5): S64–S78.

Weber, T. 2004. Landscape ecological assessment of the Chesapeake Bay Watershed. *Environmental Monitoring and Assessment* 94(1–3): 39–53.

Weidinger, K. 1998. Effect of predation by skuas on breeding success of the Cape petrel *Daption capense* at Nelson Island, Antarctica. *Polar Biology* 20(3): 170–177.

Weisner, S.E.B. 1991. Within-lake patterns in depth penetration of emergent vegetation. *Freshwater Biology* 26(1): 133–142.

Wernham, C.V., Toms, M.P., Marchant, J.H., Clark, J.A., Siriwardena, G.M. and Baillie, S.R. (eds.) 2002. *The Migration Atlas: movements of the birds of Britain and Ireland*. T. & A.D. Poyser, London.

Wetlands International 2006. *Waterbird Population Estimates – Fourth Edition*. Wetlands International, Wageningen.

Whittaker, R.J., Nogués-Bravo, D. and Araújo, M.B. 2007. Geographical gradients of species richness: as test of the water-energy conjecture of Hawkins *et al.* (2003) using European data for five taxa. *Global Ecology and Biogeograph*y 16(1): 76–89.

Wilson, M.D., Watts, B.D. and Brinker, D.F. 2007. Status review of Chesapeake Bay marsh lands and breeding marsh birds. *Waterbirds* 30(Special Issue 1): 122–137.

Wintle, B.A. Elith, J. and Potts, J.M. 2005. Fauna habitat modelling and mapping: A review and case study in the Lower Hunter Central Coast region of NSW. *Austral Ecology* 30(7): 719–738.

Wolfe, K.M., Mills, H.R., Garkaklis, M.J. and Bencini, R. 2004. Post-mating survival in a small marsupial is associated with nutrient inputs from seabirds. *Ecology* 85(6): 1740–1746.

WWF Baltic Ecoregion Programme 2008. *2008 Baltic Sea Scorecard*. (available at: http://www.wwf.fi/wwf/www/uploads/pdf/balticseascorecard2008.pdf).

Xu, H., Wang, D. and Sun, X. 2000. Biodiversity Clearing House Mechanism in China: present status and future needs. *Biodiversity and Conservation* 9(3): 361–378.

Yaffee, R.A. and McGee, M. 2000. *Introduction to Time Series Analysis and Forecasting with Applications of SAS and SPSS*. Academic Press, San Diego.

Yasué, M. 2006. Environmental factors and spatial scale influence shorebirds' responses to human disturbance. *Biological Conservation* 128(1): 47–54.

Yen, P.P.W., Huettmann, F. and Cooke, F. 2004. A large-scale model for the at-sea distribution and abundance of Marbled Murrelets (*Brachyramphus marmoratus*) during the breeding season in coastal British Columbia, Canada. *Ecological modelling* 171(4): 395–413.

Ympäristöministeriö 2005. *Merimetson kannanhoitosuunnitelma*. Ympäristöministeriön moniste 161. Ympäristöministeriö, Helsinki.

Zharikov, Y., Skilleter, G.A., Loneragan, N.R., Taranto, T. and Cameron, B.E. 2005. Mapping and characterizing subtropical estuarine landscapes using aerial photography and GIS for potential application in wildlife conservation and management. *Biological Conservation* 125(1): 87–100.

Zharikov, Y., Lank, D.B., Huettmann, F., Bradley, R.W., Parker, N., Yen, P.P.W., Mcfarlane-Tranquilla, L.A. and Cooke, F. 2006. Habitat selection and breeding success in a forest-nesting Alcid, the marbled murrelet, in two landscapes with different degrees of forest fragmentation. *Landscape Ecology* 21(1): 107–120.

Åhlund, M. and Götmark, F. 1989. Gull predation on Eider ducklings *Somateria mollissima*: Effects of human disturbance. *Biological Conservation* 48(2): 115–127.

Öst, M. and Kilpi, M. 2000. Eider females and broods from neighboring colonies use segregated local feeding areas. *Waterbirds* 23(1): 24–32.