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von Numers, Sebastian ; von Numers, Mikael; Öst, Markus

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Population changes in the declining Turnstone (*Arenaria interpres*) and other waders in the northern Baltic Sea based on past and current breeding observations

Sebastian von Numers, Markus Öst & Mikael von Numers*

S. von Numers, Novia University of Applied Sciences, Raseborgsvägen 9, FI-10600 Ekenäs, Finland

*M. von Numers, M. Öst, Åbo Akademi University, Environmental and Marine Biology, FI-20520 Turku/Åbo, Finland. * Corresponding author's e-mail: mnumers@abo.fi*

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Many waders are declining based on winter surveys, but assumed trends need to be validated against changes in breeding numbers. Comparing breeding population changes between threatened and non-threatened closely related species allows assessment of the species-specificity of threats. To identify biogeographical and biological correlates of population trends in declining Ruddy Turnstones (*Arenaria interpres*) and four other waders in the Archipelago Sea, SW Finland, we re-censused 209 islets in 2015–2018 hosting breeding Turnstones in the late 1980s–early 1990s. We used island-specific geographical variables and pair numbers of five gull and three tern species as predictors in species-specific logistic regression models of breeding probability. The number of islands with Turnstones (29) decreased by 86.1%. The proportion of islands with breeding Ringed Plovers (*Charadrius hiaticula*) significantly increased, while there were no trends for Redshanks (*Tringa tetanus*), Oystercatchers (*Haematopus ostralegus*) or Common Sandpipers (*Actitis hypoleucos*). However, the proportion of islands with more than one breeding pair of Oystercatchers increased. Ruddy Turnstone breeding occurrence was positively associated with Arctic (*Sterna paradisaea*) and Caspian Tern (*Hydroprogne caspia*) breeding numbers, island exposure and area, and negatively associated with forest area and Common Tern (*S. hirundo*) breeding numbers. Probable reasons for the decline are the presence of American mink (*Neovison vison*), a significantly declining proportion of islands with breeding Arctic Terns and natural vegetation succession. Our study highlights that population trends vary greatly between waders, but confirms the population decline of the Turnstone, now increasingly confined to exposed thinly scattered islands. Maintaining viable populations of small larids is crucial in improving its conservation status.

1. Introduction

Many waders have experienced a global decline of considerable conservation concern (International Wader Study Group 2003, Catry *et al.* 2011, Studds *et al.* 2017). However, wader population

trends and drivers of change are not uniform between species (e.g., Sutherland *et al.* 2012). Population estimates are mainly based on winter counts, which may show various forms of bias (e.g., Meltote *et al.* 2006). There is, therefore, a need to validate estimated population trends against actual

observed changes in breeding population size, and this need is most urgent for endangered species. Comparing trends in breeding population size of focal endangered species with those of related species sharing the same breeding habitats provides a valuable means to assess whether the causes of the decline are species-specific or shared across species.

To this end, we present data on population changes in the declining Ruddy Turnstone (hereafter Turnstone) *Arenaria interpres* based on systematic censuses during the breeding season in the archipelago of SW Finland over the past thirty years. As a means of comparison, we analyze corresponding changes in breeding population size of four other wader species inhabiting the same study area, to improve the understanding of the extent to which the threats on the Turnstone are unique to this species. The present work also provides valuable insight into the drivers of population change in all five wader species regardless of their conservation status.

The number of turnstones in the northern Baltic increased in the first half of the 20th century (Hildén & Vuolanto 1999), but has decreased in Finland during the last few decades (Valkama *et al.* 2011, Vösa *et al.* 2017). It used to be one of the most common breeding waders on small islands of the Finnish archipelago (e.g., Väisänen *et al.* 1998) and the most common wader of the outer archipelago. Today it is classified as endangered (EN) in Finland (Lehikoinen *et al.* 2019). The reasons for the decline are not known.

von Numers (1995) counted the breeding birds on 1757 islands in the central and northern parts of the archipelago of SW Finland during the late 1980s to early 1990s, well before the decline in the Turnstone population began. The study area then held ca 5% of the Finnish breeding population of Turnstones estimated at ca 4300 pairs (Thorup 2004). In 2015–2018, we resurveyed all islands that had breeding Turnstones in a part of von Numers' (1995) study area, to determine the present number of Turnstones, as well as their distribution pattern and relationship to environmental and biological factors. The four other waders breeding on the islands (Ringed Plover *Charadrius hiaticula*, Redshank *Tringa totanus*, Oystercatcher *Haematopus ostralegus* and Common Sandpiper *Actitis hypoleucos*) were also censused, to deter-

mine if their numbers, distribution patterns and relationship to environmental and biological factors have changed similarly as for the Turnstone.

Island-specific geographical predictors such as island area, forest area, exposure, height and topographical diversity and biological predictors such as larid breeding numbers have been shown to influence the breeding population size of waders and other waterbirds in the same area (Bergman 1946, von Numers 1995, Heinänen & von Numers 2009). The interspecific relationship is particularly strong for the Turnstone and the Arctic Tern (*Sterna paradisaea*) (von Numers 1995).

Turnstones benefit from terns in at least four ways: terns provide an effective guard system, they chase off Crows (*Corvus corone*) and other potential predators, provide food in terms of eggs, and dilute the risk of nest predation by increasing the number of potential target nests (Nyström 1925, Brearey & Hildén 1985, Farraway *et al.* 1986, Valle & Scarton 1999, Brown & Brown 2001). In light of the presumed importance of this particular interspecific relationship in the population dynamics of Turnstones, we separately analyzed whether the number of breeding pairs of Arctic Terns or the availability of islands hosting co-nesting Arctic Terns have changed between the two census periods.

2. Material and methods

2.1. Study area

The present study covers the 209 islands (mean area 11,160 m², SD 17,761) hosting breeding Turnstones in the earlier nest survey of von Numers (1995) conducted in late 1980s–early 1990s (totally 1,757 censused islands). The focal islands are located in the central and northern archipelago of SW Finland, stretching from the inner archipelago near the mainland in NE to the outer archipelago in NW and SW (Fig. 1). The majority of these islands are located in the more exposed and maritime parts of the study area, and characterized by small size, and low forest coverage and height (von Numers 1995). The land uplift is ca. 3.9 mm/year (Johansson *et al.* 2004). The vegetation mainly consists of scattered trees or small stands of trees (usually creeping junipers *Juni-*

Table 1. The initial candidate predictors (and their units) in logistic regression models of breeding probability in five species of waders in the Archipelago Sea. Islet height was dropped from further analyses because of collinearity with island topographical diversity.

Variable	Metric	Definition
Area	m ²	Island area
Height	m	Maximum height of island
Forest area	m ²	Island forest cover, omitting individually growing trees
Exposure	m ²	Water area within a 5 km zone around each island
Topographical diversity		Standard deviation of the 10 × 10 m pixels of the digital elevation model (DEM) inside the shoreline of each island
Common Gull	n	Number of breeding pairs on each island
Black-headed Gull	n	Number of breeding pairs on each island
Lesser Black-backed Gull	n	Number of breeding pairs on each island
Herring Gull	n	Number of breeding pairs on each island
Greater Black-backed Gull	n	Number of breeding pairs on each island
Caspian Tern	n	Number of breeding pairs on each island
Common Tern	n	Number of breeding pairs on each island
Arctic Tern	n	Number of breeding pairs on each island

perus communis, pine *Pinus sylvestris*, black alder *Alnus glutinosa*, silver birch *Betula pendula* and rowan *Sorbus aucuparia*). In the present study, these 209 islands were re-censused in 2015–2018.

2.2. Censuses

The 209 islands were censused in 2015–2018 using the same methods as described in von Numers (1995). In both periods, the breeding census on each island was carried out once and at the same time of the year, in the latter part of May and in June. Each island was investigated by systematically searching through its entire area on foot. Smaller islets were easily censused within minutes, whereas larger islands were censused by either walking in a spiral (if conducted by a single observer) or by walking in parallel lines at a distance of ca 10 m (if two persons were involved) (von Numers 1995). Average census speed was adjusted to the topography and observed breeding densities. Nest-counting was preferred over counts of territorial pairs, and counted nests were marked to avoid double-counting of nests. However, in case of waders that display conspicuous nest defence behaviours, breeding pairs could be easily counted even if the nest was not always found.

The number of breeding pairs of the following

species was recorded: waders (Turnstone, Ringed Plover, Redshank, Oystercatcher and Common Sandpiper), gulls (Common Gull *Larus canus*, Black-Headed Gull *Chroicocephalus ridibundus*, Lesser Black-backed Gull *L. fuscus*, Herring Gull *L. argentatus* and Greater Black-backed Gull *L. marinus*) and terns (Caspian Tern *Hydroprogne caspia*, Common Tern *S. hirundo* and Arctic Tern *S. paradisaea*).

2.3. Island-specific predictors

The initial set of candidate predictors, their units and definitions are given in Table 1. We measured the geographical predictors (Table 1) in a GIS (ArcMap 10.5). The shoreline data, the aerial photographs and the digital elevation model (DEM) (resolution 10 m) were obtained from the National Land Survey of Finland. Topographical diversity of the islands was determined using the Focal Statistics Tool in ArcView. Forest area was measured from the aerial photographs. Island exposure roughly reflects the surrounding archipelago type, with low and high values indicating the sheltered inner and maritime outer archipelago, respectively. The biological predictors include the number of breeding pairs of the five species of gulls and the three species of terns (see ‘Censuses’ and Table 1).

Table 2. Number of breeding pairs and occupied islands, and the percentage of islands hosting more than one breeding pair for the five wader species on the 209 study islands in the Archipelago Sea.

	Number of pairs			Number of islands						% Islands with more than one pair	
	Historical	Present	% change	Extinctions	Pre-served	Colonizations	Historical	Contemporary total	% change	Historical	Change
Turnstone	233	33	−85.8	180	29	–	209	29	−86.1	10.0	6.9
Ringed Plover	14	41	192.9	7	6	31	13	37	184.6	7.7	8.1
Redshank	61	60	−1.6	36	24	35	60	59	−1.7	1.7	1.7
Oystercatcher	80	104	30	31	47	45	78	92	17.9	2.6	12.0
Common Sandpiper	4	10	150	2	2	8	4	10	150	0.0	0.0

2.4. Statistical methods

We analysed time trends in the probability of occurrence for all species except the Turnstone using McNemar's test for correlated proportions based on paired binary data (exact p-values were calculated when expected cell frequencies were below 5). For the Turnstone, we were unable to use this method. This is because all the 209 re-censused islands included in this study had breeding Turnstones in the past, and thus the number of islands hosting breeding pairs of Turnstones is, by definition, lower or unchanged today. Therefore, there is no meaningful statistical method to test for significant changes in the probability of occurrence for this species, and so interpretation of occurred changes is restricted to a descriptive level. For all species, we performed Fisher's exact tests to assess changes in the proportion of sites holding one or more breeding pairs; Fisher's exact tests were used due to low sample sizes.

For each species, the probability of occurrence during 2015–2018, coded as 0 (breeding pairs absent) or 1 (breeding pairs present), was modelled using logistic regression analysis (IBM SPSS 24.0) to determine the geographical and biological determinants (Table 1) of breeding presence. However, the small sample size precluded formal quantitative analysis of Common Sandpiper presence on the islands. A stepwise selection method was used to select the combination of predictor variables that best explained the variation in each response variable. We did not include interactions between the predictors given the lack of *a priori* hypotheses and the desire to avoid overfitting the

models. Entry testing ($p < 0.05$) was based on score statistics, and removal testing ($p < 0.10$) was based on the probability of likelihood-ratio statistics, based on the partial likelihood estimates. The goodness-of-fit of the models was assessed using Hosmer and Lemeshow tests and Nagelkerke R^2 (Hosmer & Lemeshow 2000). The predictors were tested for significance using Wald statistics.

We tested the predictors for collinearity, as strong correlation causes problems in model fitting and interpretation (e.g., Graham 2003). We used SPSS Collinearity diagnostics and found collinearity between island topographical diversity and island height. We chose to exclude island height (variance inflation factor (VIF) = 68.8). This is because variability in height is expected to affect the waders' ability to detect approaching predators (Heinänen & von Numers 2009), and thus island topographical diversity is likely to be a biologically more informative predictor. After the exclusion, no significant collinearity was detected among the remaining predictors (VIF < 2.3).

Finally, in a supplementary statistical analysis reported in the Discussion, we analysed time trends in the presence of breeding Arctic Terns, the most important biotic determinant of the presence of breeding Turnstones (see Introduction and Results). First, we compared the number of breeding pairs of Arctic Terns during the two time periods with a paired t-test on log-transformed pair numbers. Second, to assess temporal changes in the availability of colonies with co-nesting Arctic Terns, we compared the proportion of islands lacking arctic terns in the two periods with a two-way binomial proportion test.

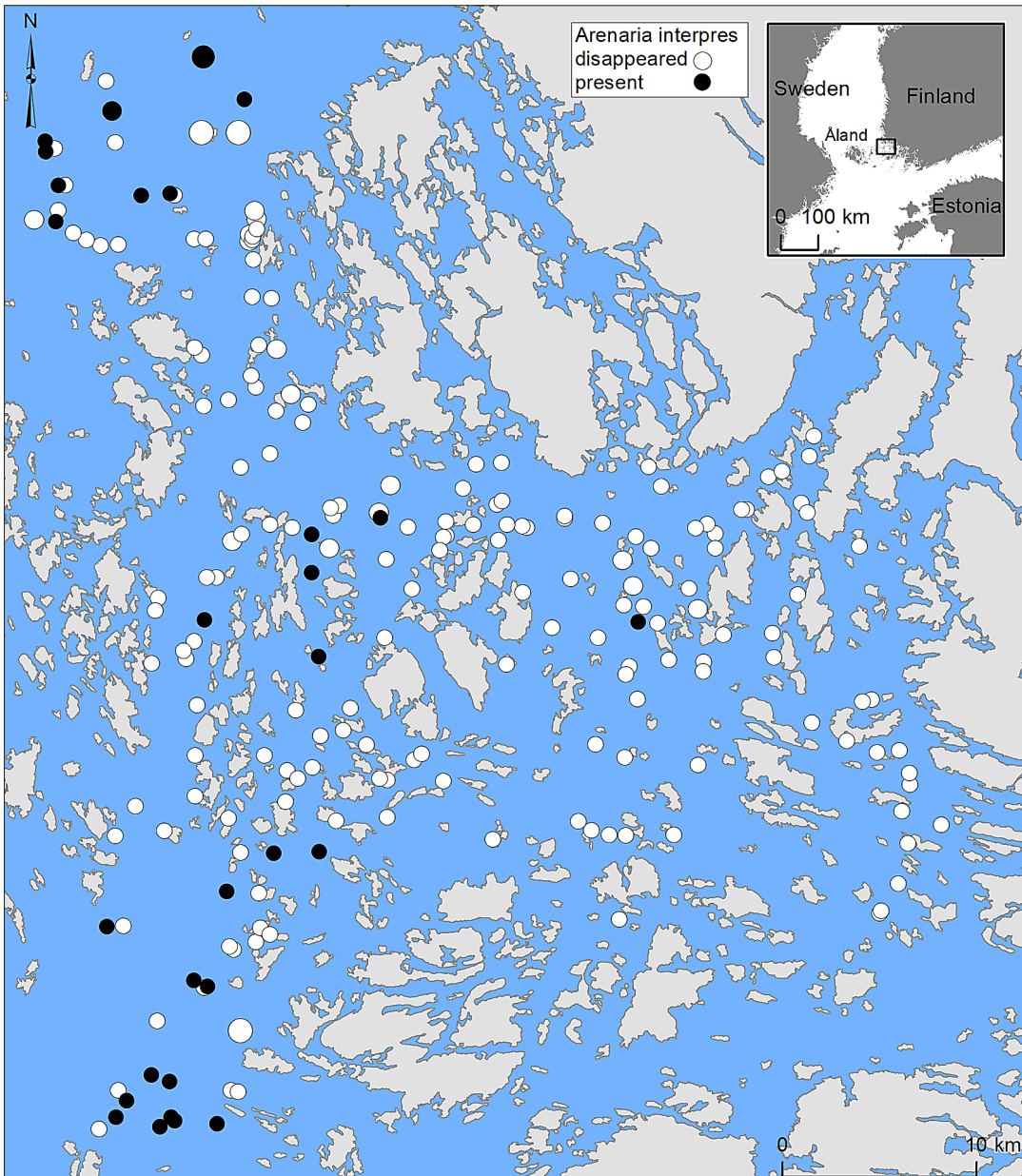


Fig. 1. The breeding distribution of Turnstones on the 209 islands censused during the late 1980s–early 1990s and 2015–2018, respectively. Circles denote absence during the latter survey and filled circles denote presence during both surveys. The symbol size is proportional to the number of breeding pairs, being at most four pairs.

3. Results

3.1. Number of breeding pairs

The change in the number of Turnstones, from 233 pairs (ca 5% of the Finnish breeding population at that time; Thorup 2004) to only 33 pairs (–85.8%),

is convincingly drastic to demonstrate a significant decrease (Table 2). The numbers of Ringed Plovers, Oystercatchers and Common Sandpipers have numerically increased, while the number of Redshanks has remained nearly unchanged (Table 2).

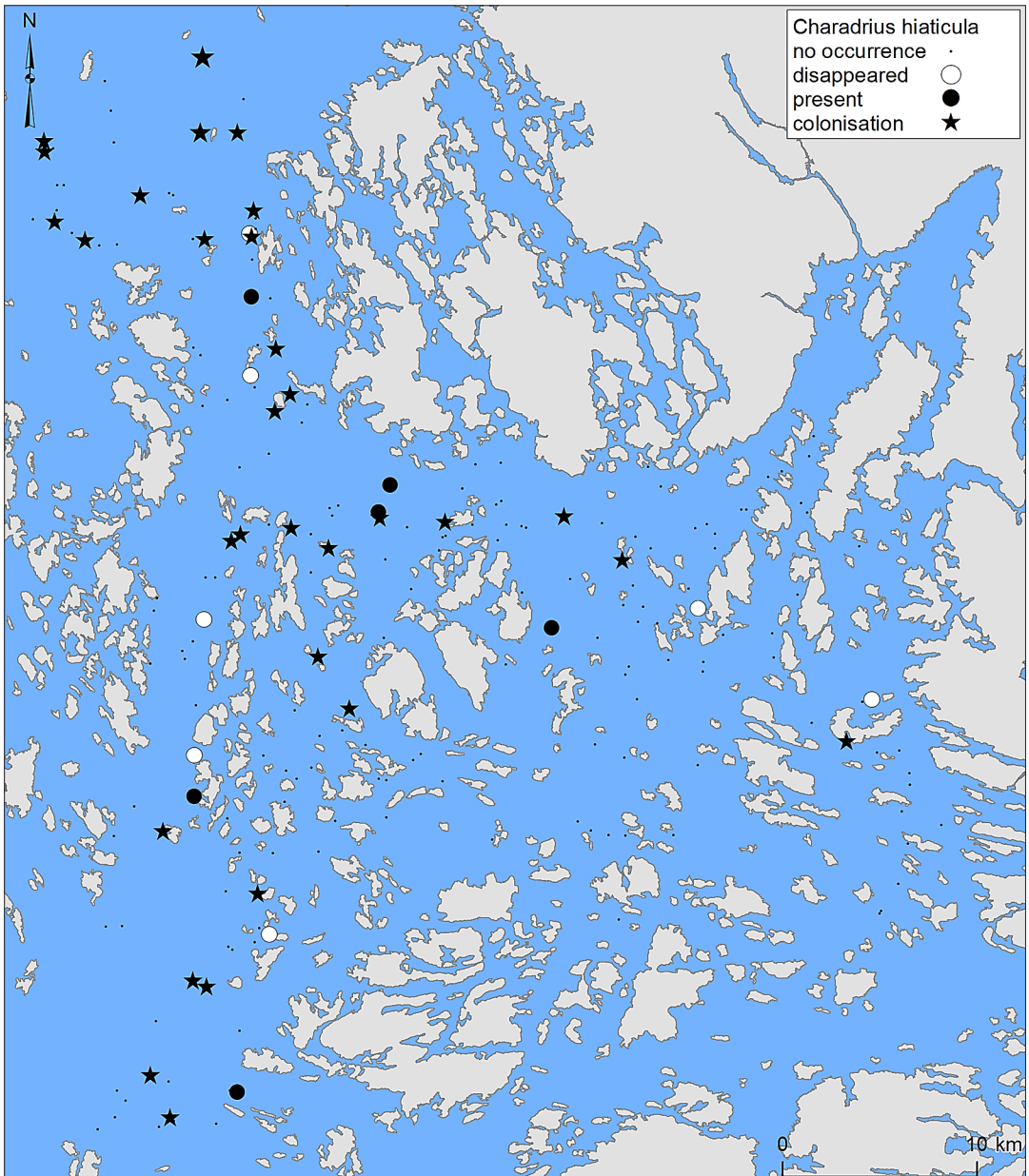


Fig. 2. The breeding distribution of Ringed Plovers on the 209 islands censused during the late 1980s–early 1990s and 2015–2018, respectively. Circles denote absence during the latter survey, filled circles denote presence during both surveys, stars denote colonisations during the latter survey and dots denote no records during either survey.

3.2. Proportion of occupied islands and their geographical distribution

The Turnstone has disappeared from 180 islands and persists on 29 (–86.1%; Table 2). The Turnstone has almost completely disappeared from the

inner eastern and central parts of the study area, but it persists in its maritime SW and NW parts characterized by thinly scattered and exposed islands (Fig. 1). There was a significant increase in the proportion of islands with breeding Ringed Plovers (McNemar test: $X^2 = 13.921$, $p < 0.001$). It

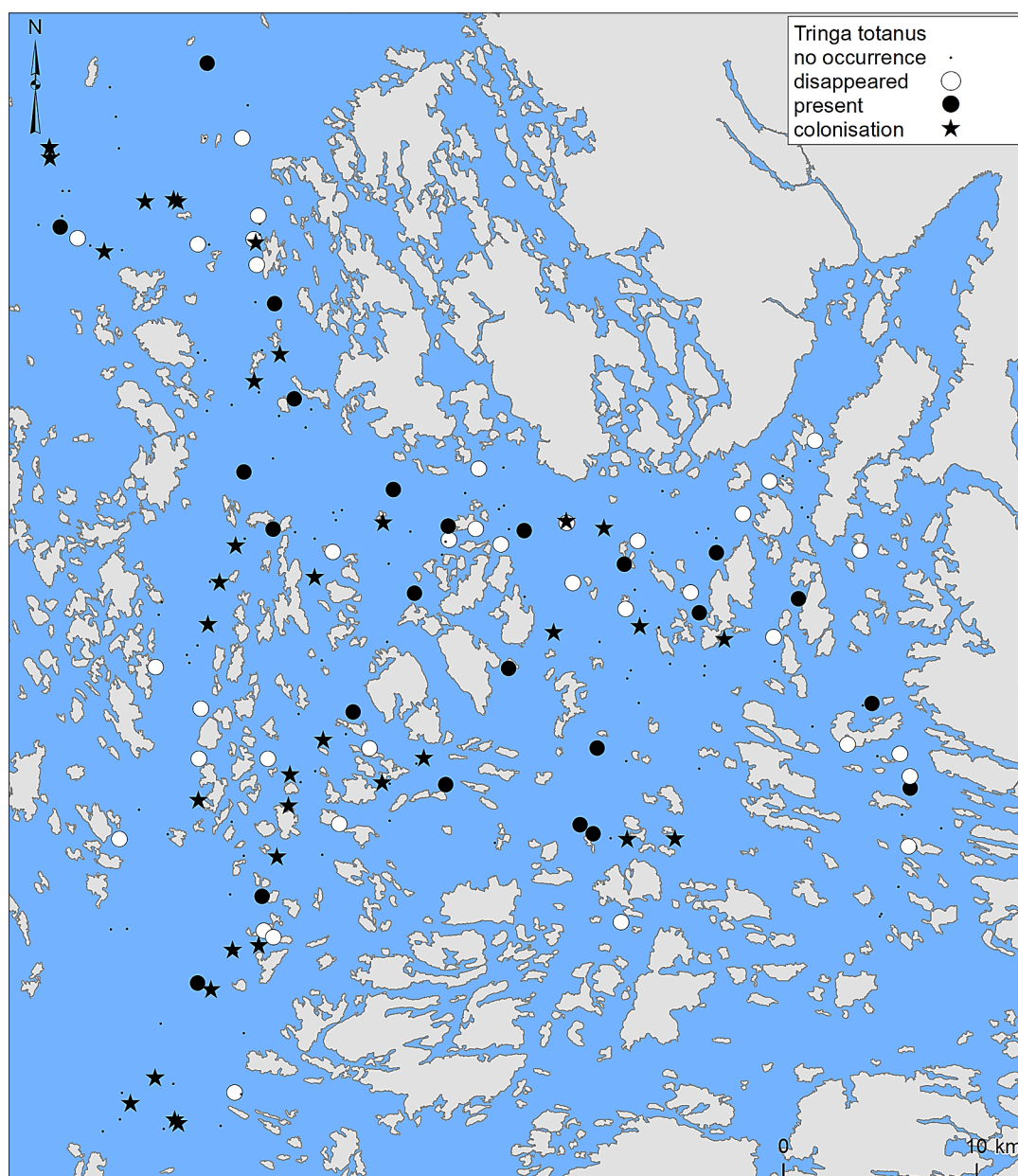


Fig. 3. The breeding distribution of Redshanks on the 209 islands censused during the late 1980s–early 1990s and 2015–2018, respectively. Circles denote absence during the latter survey, filled circles denote presence during both surveys, stars denote colonisations during the latter survey and dots denote no records during either survey.

has shown the strongest numerical increase of the waders (184.6%; Table 2), and most of the pairs breed in the western part of the study area (Fig. 2). There was no significant change in the proportion of islands with breeding Redshanks (McNemar test, $p = 1$). The species is evenly distributed in the

area (Fig. 3) but the turnover is high, with 36 abandoned and 35 colonized islands (Fig. 3, Table 2).

Likewise, there was no significant change in the proportion of islands hosting breeding Oystercatchers (McNemar test, $p = 0.14$). The Oystercatcher is nowadays by far the most common of the

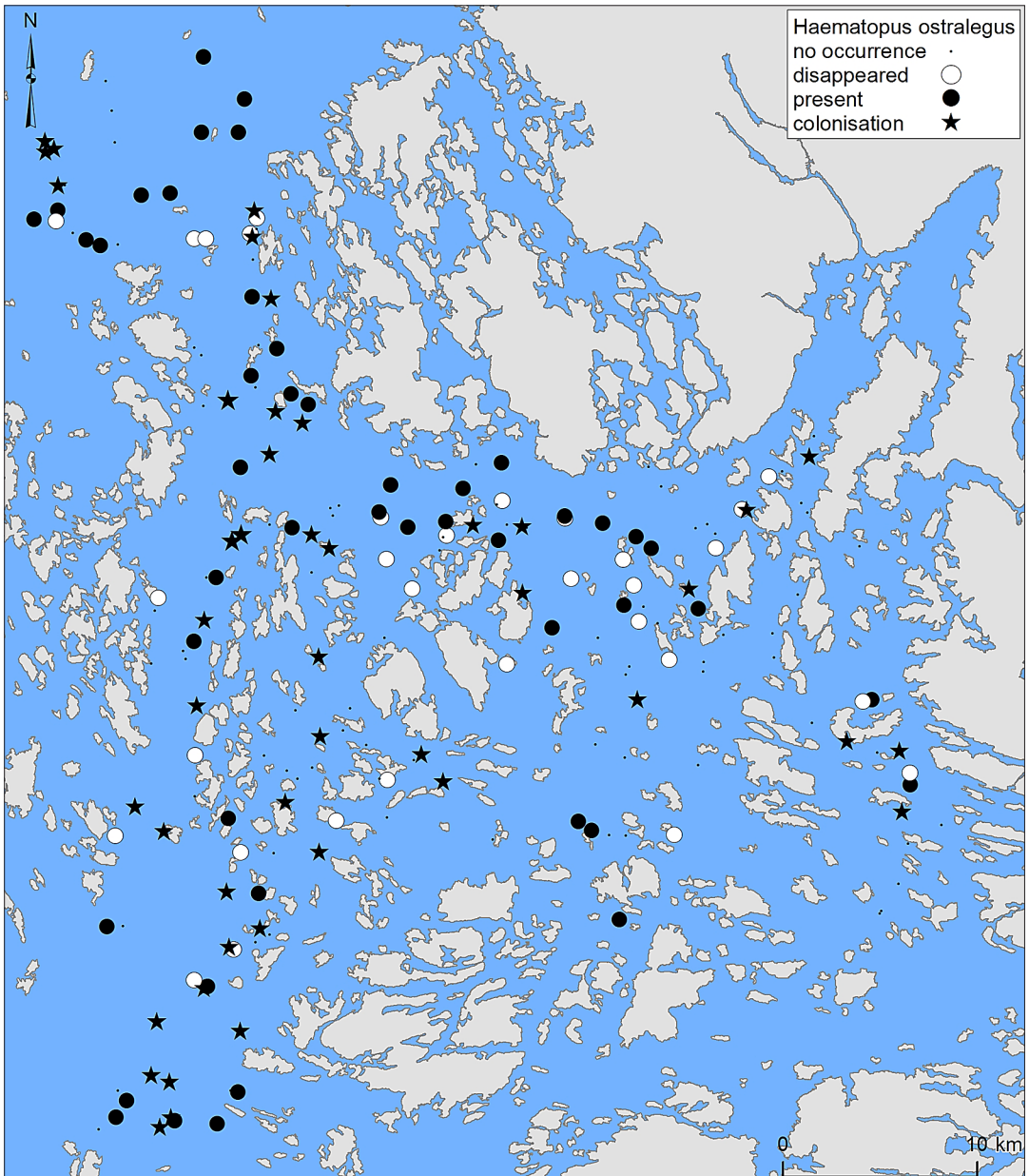


Fig. 4. The breeding distribution of Oystercatchers on the 209 islands censused during the late 1980s–early 1990s and 2015–2018, respectively. Circles denote absence during the latter survey, filled circles denote presence during both surveys, stars denote colonisations during the latter survey and dots denote no records during either survey.

waders (Table 2), occurring in the whole study area, but it is more common in the maritime western parts (Fig. 4). Finally, there was no significant change in the proportion of islands with breeding Common Sandpipers (McNemar tests, $p = 0.11$), although the number of breeding pairs has more

than doubled (Table 2). Our inability to verify any potential increase statistically is most likely due to the limited statistical power. The Common Sandpiper has been, and still is, rare in the study area (Fig. 5), as it mostly occurs on larger forested islands. The proportion of islands with more than

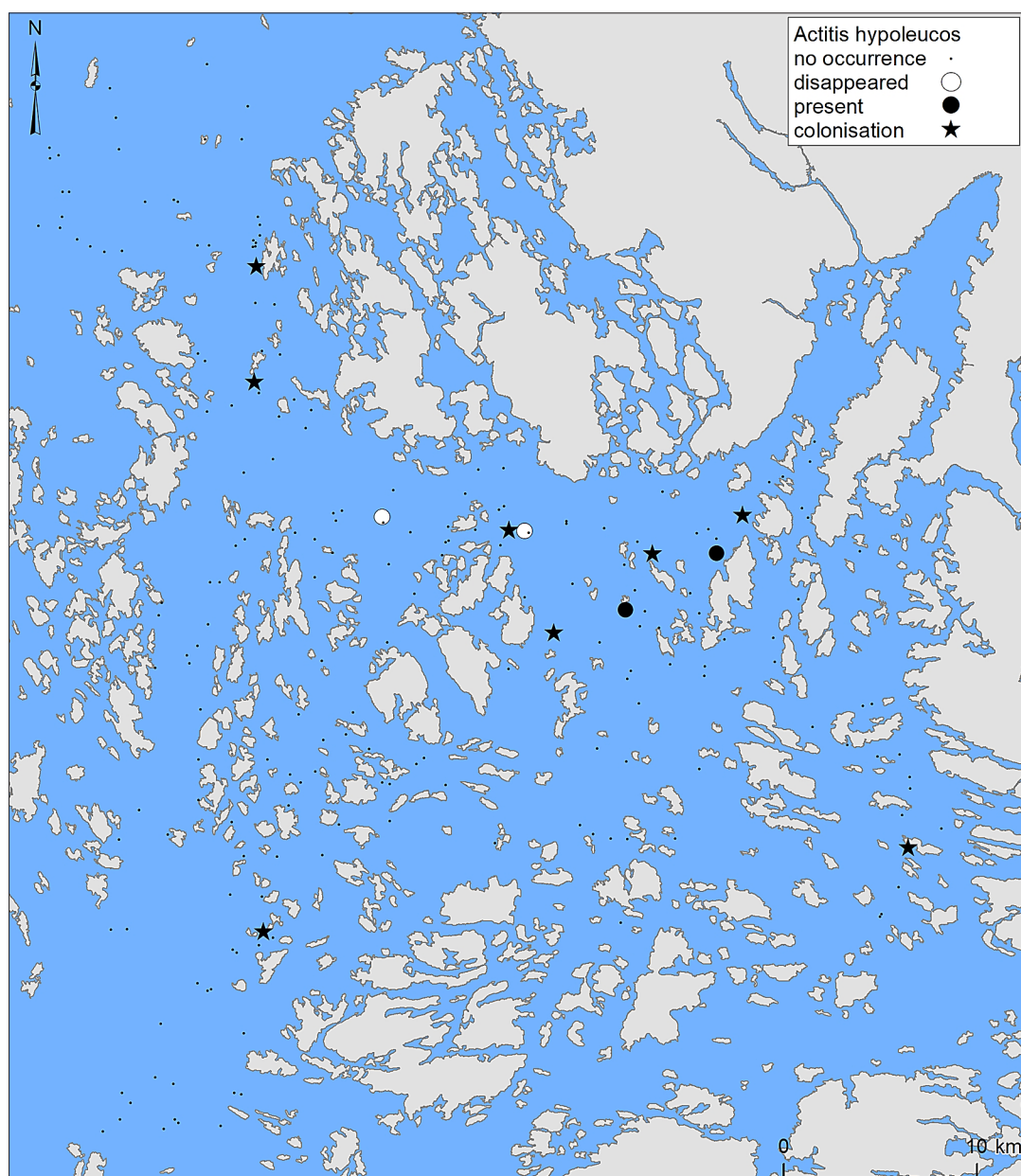


Fig. 5. The breeding distribution of Common Sandpipers on the 209 islands censused during the late 1980s–early 1990s and 2015–2018, respectively. Circles denote absence during the latter survey, filled circles denote presence during both surveys, stars denote colonisations during the latter survey and dots denote no records during either survey.

one breeding pair has significantly increased for the Oystercatcher (from 2.6 to 12.0%, Fisher's exact test, $p = 0.039$, Table 2); no changes in the proportion of one versus multiple breeding pairs was observed for the other four waders (Fisher's exact tests, all p -values = 1).

3.3. Predictors of nest-site occupancy

The final logistic regression model comparing abandoned and still occupied islands showed that higher breeding numbers of Arctic and Caspian Terns as well as increasing island area and expo-

Table 3. Predictors of the probability of occurrence of breeding Turnstones in the final logistic regression model comparing abandoned and still occupied islands based on two consecutive nest surveys (late 1980s–early 1990s and 2015–2018, respectively). Shown are the parameter estimates (β) with their respective standard errors (S.E.), Wald statistics, significance (P), degrees of freedom (df) and estimated odds ratios ($\exp(\beta)$).

	β	S.E.	Wald	df	P	$\exp(\beta)$
Intercept	−1.887	0.617	9.349	1	0.002	0.152
Area	0.333	0.165	4.077	1	0.043	1.395
Exposure	1.606	0.472	11.55	1	0.001	0.201
Forest area	−33.385	8.954	13.901	1	<0.001	0
Common Tern	−0.494	0.151	10.743	1	0.001	0.61
Arctic Tern	0.197	0.046	18.43	1	<0.001	1.218
Caspian Tern	4.145	1.046	15.701	1	<0.001	63.096
Herring Gull	−2.128	1.203	3.128	1	0.077	0.119
Lesser Black-backed Gull	−1.163	0.636	3.345	1	0.067	0.312

Table 4. Predictors of the probability of occurrence of breeding Ringed Plovers in the final logistic regression model comparing islands with and without the species during the nest survey in 2015–2018. Shown are the parameter estimates (β) with their respective standard errors (S.E.), Wald statistics, significance (P), degrees of freedom (df) and estimated odds ratios ($\exp(\beta)$).

	β	S.E.	Wald	df	P	$\exp(\beta)$
Intercept	−1.163	0.456	6.5	1	0.011	0.313
Area	0.439	0.137	10.224	1	0.001	1.551
Exposure	0.43	0.195	4.879	1	0.027	0.65
Arctic Tern	0.024	0.013	3.471	1	0.062	1.024
Greater Black-backed Gull	−1.059	0.362	8.577	1	0.003	0.347

sure were associated with an increased probability of Turnstone occurrence (Table 3). Higher numbers of breeding Common Terns and increasing forest area, on the other hand, were correlated with a decreased probability of Turnstone occurrence. Herring and Lesser Black-backed Gull breeding numbers showed no significant relationship with the probability of Turnstone occurrence (Table 3).

The final logistic regression model of Ringed Plover nest-site occupancy showed that increasing island area and exposure were associated with an increased probability of occurrence, while more nesting Greater Black-backed Gulls had a negative association with the probability of Ringed Plover occurrence (Table 4). The breeding abundance of Arctic Terns had no significant relationship with the probability of occurrence of Ringed Plovers (Table 4).

The final logistic regression model of Redshank nest-site occupancy revealed that presence of more breeding Common Gulls showed a posi-

tive relationship with the probability of occurrence, whereas the number of breeding Greater Black-backed Gulls and topological diversity showed a negative association with Redshank occurrence (Table 5).

The final logistic regression model of Oystercatcher nest-site occupancy showed that increasing breeding numbers of Arctic Terns and increasing island area had a positive relationship with the probability of occurrence (Table 6). The number of breeding Common Gulls and increasing island exposure, while included in the final model (Table 6), had no statistically significant association with Oystercatcher nest-site occupancy.

4. Discussion

Our findings clearly demonstrate that recent population changes may substantially differ between wader species (cf. Sutherland *et al.* 2012), as a

Table 5. Predictors of the probability of occurrence of breeding Redshanks in the final logistic regression model comparing islands with and without the species during the nest survey in 2015–2018. Shown are the parameter estimates (β) with their respective standard errors (S.E.), Wald statistics, significance (P), degrees of freedom (df) and estimated odds ratios ($\exp(\beta)$).

	β	S.E.	Wald	Df	P	Exp(β)
Intercept	−0.453	0.3	2.289	1	0.130	0.635
Arctic Tern	0.019	0.012	2.632	1	0.105	1.019
Common Gull	0.057	0.021	7.497	1	0.006	1.058
Greater Black-backed Gull	−0.901	0.282	10.199	1	0.001	0.406
Topogr. diversity	−0.063	0.027	5.609	1	0.018	0.939

Table 6. Predictors of the probability of occurrence of breeding Oystercatchers in the final logistic regression model comparing islands with and without the species during the nest survey in 2015–2018. Shown are the parameter estimates (β) with their respective standard errors (S.E.), Wald statistics, significance (P), degrees of freedom (df) and estimated odds ratios ($\exp(\beta)$).

	β	S.E.	Wald	df	P	Exp(β)
Intercept	−1.024	0.363	7.941	1	0.005	0.359
Arctic Tern	0.079	0.024	10.493	1	0.001	1.082
Common Gull	0.041	0.021	3.658	1	0.056	1.042
Area	0.395	0.146	7.27	1	0.007	1.484
Exposure	0.225	0.134	2.812	1	0.094	0.798

sharp population decline was exclusively observed in the Turnstone. This population decline coincided with a shift in the breeding distribution of Turnstones towards areas with exposed thinly scattered islands in SW and NW. In the following Discussion, we will first assess to what extent the apparent population decline of the Turnstone may in fact reflect breeding dispersal and range shift. We then examine the population dynamics of the other waders, before scrutinizing the potential causes of the population decline in Turnstones. Finally, we summarize our conclusions as to why breeding population trends may differ between Turnstones and the other waders.

4.1. Turnstone population decline or dispersal: methodological perspectives

Our sampling protocol has some inherent biases that may overestimate the magnitude of the observed population decline of Turnstones. Thus, because we re-censused only the islands having breeding Turnstones during the earlier census period, a decline in the number of breeding islands (and,

consequently, pairs) is expected. A corresponding comparison relating the number of preserved breeding islands to the historical total of occupied islands for the other waders (Table 2) would reveal apparent declines ranging from 39.7% (Oystercatchers) to 60% (Redshank), to be compared with 86.1% for the Turnstone. Notwithstanding, these other species have not suffered any real population decline at the scale of the entire study area.

The question then arises to what extent breeding dispersal to new nesting sites may confound the apparent decline in Turnstone breeding numbers. Although our sampling protocol may slightly overestimate the true population decline due to dispersal processes, we have reasons to believe that this bias is not a significant concern. First, the Turnstone is increasingly confined to the outer parts of the study area, bordering on the open sea. Second, and perhaps more importantly, the interannual fidelity to breeding sites is among the highest recorded among scolopacid waders, estimated at 87% for males and 70% for females in Finland (Bergman 1946). To conclude, breeding dispersal is unlikely to substantially bias the observed decline in Turnstone breeding numbers.

4.2. Population dynamics of the other waders

The pair number of Ringed Plovers has almost trebled and the proportion of islands hosting breeding pairs significantly increased between the two surveys. The increase in the number of pairs is consistent with other similar archipelago areas in the vicinity, where increasing pair numbers have been noted (Vösa *et al.* 2017). In Finland, the Ringed Plover was previously classified as Near Threatened (NT) (Tiainen *et al.* 2015), but the classification has now been changed to LC (Least Concern) (Lehikoinen *et al.* 2019). Probable reasons for the success of the Ringed Plover in our study area include its nest-site preference for open and flat bedrock areas, efficient distraction of nest predators by broken wing display, and an early breeding phenology.

Predator distraction behaviour, which decreases chick mortality (Gómez-Serrano & López-López 2017), is better developed in Ringed Plovers compared to the other waders included in this study. Efficient antipredator behaviours are likely to be positively linked to fecundity given the substantial predation pressure in the study area (see 4.3.). Furthermore, species having an early breeding phenology may be less severely affected by predation by the American mink *Mustela vison* than late-breeding species (Nordström *et al.* 2003).

The Redshank population has remained stable. There was a positive association with co-nesting Common Gulls, and an indicative positive association with co-nesting Arctic Terns. Similar results were obtained by von Numers (1995) and Heinänen & von Numers (2009). von Numers (1995) argued that the presence of colonies of small larids affects the distribution of the Redshank, resulting in a preference for small and open treeless islands. The benefit for the Redshank to breed among small larids is probably protection from predators, e.g., by utilizing the early warning system used by larids (Brearey & Hildén 1985, Valle & Scarton 1999).

Decreasing topographical diversity increased the probability of occurrence, reflecting the Redshank's preference for flat islands with areas reminiscent of shore meadows as breeding

grounds (Heinänen & von Numers 2009). In other parts of the archipelago of SW Finland, the Redshank has generally increased (Vösa *et al.* 2017), concomitant with, and perhaps associated with, an increase in Common Gulls (Hario & Rintala 2014). In contrast, in Finland as a whole, it is classified as Near Threatened (NT) (Lehikoinen *et al.* 2019), as it has decreased on formerly grazed shore meadows.

The Oystercatcher used to be the most common wader in the area (von Numers 1995); it still is, and it has numerically increased, although we were unable to detect a statistically significant increase in the number of occupied islands (McNemar test: $p = 0.14$). It has increased in other parts of the archipelago (Vösa *et al.* 2017) and in Finland in general (Valkama *et al.* 2011). The Oystercatcher breeds on most types of shores (von Numers 1995) explaining the positive association with island area. The positive association with breeding numbers of Arctic Terns and Common Gulls (Table 6), also observed by von Numers (1995) and Heinänen & von Numers (2009), may be a result of similar substrate preferences (gravel and small stones) for nest-site selection.

Interestingly, the proportion of islands with more than one breeding pair has increased significantly. Potentially, this finding could reflect increasing predation pressure in the area (Öst *et al.* 2018), forcing Oystercatchers to breed socially to reduce per capita nest predation risk. Nevertheless, large and early-breeding species such as the Oystercatcher are considered less susceptible to predation by the American mink than small or late-breeding species (Nordström *et al.* 2003). Alternatively, therefore, the increased occurrence of multiple breeders on islands may relate to reduced resource availability, although this possibility is difficult to substantiate in retrospect.

The Common Sandpiper is the rarest of the waders. It is not typical for small sparsely vegetated islands, but rather a bird of forested islands (e.g., von Numers 1995). The observed indicative increase in breeding numbers might point to an increase in the number of pairs on larger forested islands in the vicinity. The number of Common Sandpipers in Finland is generally considered stable (Valkama *et al.* 2011).

4.3. Reasons for the Turnstone's decline

The decrease in the number of breeding Turnstones appears to be a species-specific phenomenon, as the other species have not decreased. With the decline of the breeding population, the remaining breeding pairs are increasingly confined to presumably preferred breeding habitats, situated in the SW and NW parts of the study area (Fig. 1).

Globally, the Turnstone has an extremely large range, and its Red List Category is set to Least Concern (BirdLife International 2018). The general population trend is decreasing, however. Helseth *et al.* (2005) reported a significant decrease in the number of trapped Turnstones at the Ottenby Bird Observatory between the periods 1976–1989 and 1990–2003. The most likely breeding areas for the populations passing Ottenby are Sweden, Finland and the Russian Arctic (Helseth *et al.* 2005). The decrease observed at Ottenby may therefore have been an early sign of the imminent population decline in Finland. Pertinent in this respect is that the decrease (82%) was particularly large for juvenile birds.

The implications of this finding are that a long-term decline in Turnstone reproductive success may have contributed to the population decline, and that the prerequisites of successful reproduction at the Baltic breeding grounds may have been compromised. This conclusion also echoes that of Roodbergen *et al.* (2012), who argued that the recent population declines of several species of waders in western Europe can be attributed primarily to increased chick rather than adult mortality, based on a review of wader demography.

Losses on the wintering grounds are possible. However, this possibility seems unlikely to be a major contributor to the decline in view of the existing evidence. According to Branson *et al.* (1978) and Summers *et al.* (1989), the Fennoscandian and west Russian population of Turnstones mainly winter in West Africa. Simmons *et al.* (2015) report a decline in the wintering population of Turnstones since 1990 at the coast of Namibia. The authors interpreted this decline as a reflection of declining breeding populations, because local conditions in southern Africa's largest wetlands have not changed significantly. In addition, potential environmental changes during migration may also contribute to the population decline. How-

ever, in the absence of long-term data on, e.g., Turnstone body mass dynamics from stopover sites, such potential changes remain a knowledge gap and an exciting area of future study.

The American mink can adversely affect breeding densities of particularly smaller wader species, including the Turnstone (Nordström *et al.* 2003). It sporadically occurs in the whole study area, and it was seen by us on the islands during the censuses twice. Öst *et al.* (2018) reported a significant increase over the past decades in the number of American minks in the Tvärminne archipelago, situated ca. 100 km east of the present study area. An increase in our present study area is thus also likely. Late-breeding, small-sized archipelago birds such as Turnstones and Arctic Terns may be disproportionately affected by mink predation (Nordström *et al.* 2003). Nevertheless, the American Mink is unlikely to be the sole reason for the decline in the number of Turnstones, because the other waders have not shown a similar decline.

We found that the occurrence of Arctic Terns was an important factor positively influencing Turnstone occurrence (Table 3). Our findings thus corroborate those of von Numers (1995), who argued that occurrence of Arctic Terns was the factor that most strongly positively influenced Turnstone occurrence. Of the islands with Turnstones (29) in our current data, all but one (28, 96.6%) had breeding Arctic Terns present, while of the islands without Turnstones (180), only 64 (35.6%) had breeding terns, which is a statistically significant difference (binomial proportion test: $\chi^2_1 = 35.28, p < 0.001$).

von Numers (1995) compared Turnstone islands with (197) and without (86) nesting small larids (Common and Arctic Terns, Black-headed Gulls). In the study by von Numers (1995), only exposure and maritimity (a measure of an island's position in relation to the open sea) had an influence on the probability of occurrence of the Turnstone. The conclusion drawn was that the Turnstone extends its typically maritime distribution towards less maritime areas in the presence of small larids. It is therefore relevant to ask whether changes in the distribution and numbers of Arctic Terns have caused a corresponding change in the distribution of the Turnstone.

There was no statistically significant change in the number of breeding Arctic Terns per island

(pairwise t -test on log-transformed breeding numbers: $t_{208}=1.760$, $p=0.08$). Importantly, however, the proportion of the 209 islands without breeding Arctic Terns has significantly increased over the study period (historical: 43 (20.6%); contemporary: 65 (31.1%); binomial proportion test: $\chi^2_1=5.506$, $p=0.019$). Consequently, Arctic Terns are today distributed over a smaller number of colonies, i.e., Turnstones are provided less opportunities for co-nesting with Arctic Terns. There was also a small shift westwards in the mean center (3.3 km as measured by ArcMap Mean center tool) of Arctic Tern occurrences. As the Turnstone benefits from occurrences of Arctic Terns, the shift in the distribution of Arctic Terns and the smaller number of available colonies with co-nesting terns will probably affect the distribution and breeding numbers of Turnstones. This may partly explain the shift in distribution of the Turnstone and contribute to its general decrease.

Finally, the vegetation of the islands has undergone a natural succession, meaning that on some of the islands low vegetation and trees have emerged during the period. The land uplift of about 11 cm during the 30-year period after accounting for the sea level rise (Johansson *et al.* 2014) that contributes to the succession. This effect is hard to quantify, however, as the changes are too small to be visible on aerial photographs.

Bergman (1946) pointed out that the short-legged Turnstone is not well adapted to agile movement in taller vegetation, unlike the Redshank. Subtle and gradual as these effects are, there may still be an effect of the succession on Turnstone population dynamics, which is probably greater on islands in the inner parts of the archipelago. Perhaps relevant in this respect is the negative effect of increasing forest cover on Turnstone breeding probability (Table 3).

4.4. Conclusions

This study shows that the Turnstone has undergone a strong population decline not found among the other waders nesting in the same area. Our results, coupled with previous findings, suggest that this difference may be due to three different, but partly intertwined, mechanisms. First, the life-history characteristics of the Turnstone may render it

especially susceptible to predation during the breeding season. Thus, small-sized and late-breeding species may be more severely affected by the American Mink (Nordström *et al.* 2003), which has most likely increased in the study area (cf. Öst *et al.* 2018). Second, the Turnstone is more strongly dependent on viable breeding populations of particularly Arctic Terns than are the other wader species. The declining availability of islands hosting breeding colonies of Arctic Terns, possibly linked to increased predation by minks, is therefore likely to have negative consequences for the persistence of Turnstone breeding populations. Third, because the Turnstones actively avoids high vegetation when selecting nest sites, natural succession processes in the area may disproportionately affect the Turnstone.

In conclusion, our study highlights the need to maintain viable populations of especially small gull species, due to their important role in facilitating population persistence of not only waders but also waterfowl (Kurvinen *et al.* 2016), many species of which are currently in a state of decline in the Baltic Sea.

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Populationsförändringar hos roskarlen (*Arenaria interpres*) och andra vadare i norra Östersjön utgående från tidigare och nya inventeringar

Vintertaxeringar har visat att många vadare minskat i antal, men dessa trender bör valideras mot förändringar i antalet häckande par. En jämförelse av förändringar mellan de häckande populationerna av hotade och icke hotade närbesläktade arter ger en möjlighet att artspecifikt bedöma hoten. Vi återinventerade 2015–2018 förekomster av roskarl och fyra andra vadare på 209 skär i Skärgårdshavet, SV Finland, som hyste häckande roskarl under slutet av 1980-talet till början av 1990-talet, för att hitta biogeografiska och biologiska samband

med populationstrenderna. Vi använde skärspedificka geografiska variabler och parantalet av fyra larid- och tre tärnarter som prediktorer i artspecifika logistiska regressionsmodeller för häcknings-sannolikhet.

Antalet skär med roskarl (29) minskade med 86,1 %. Andelen skär med häckande större strandpipare (*Charadrius hiaticula*) ökade signifikant, medan det inte fanns någon trend gällande rödbena (*Tringa totanus*), strandskata (*Haematopus ostralegus*) eller drillsnäppa (*Actitis hypoleucos*). Proportionen skär med flera än ett par häckande strandskata ökade däremot. Roskarlens häckning var positivt associerad med antalet häckande par av silvertärna (*Sterna paradisaea*) och skrântärna (*Hydroprogne caspia*), skärets exponeringsgrad och yta, samt negativt associerad med skogsyta och antalet par av häckande fisktärna (*S. hirundo*). Sannolika orsaker till minskningen är närvaron av mink (*Neovison vison*), en signifikant minskande andel skär med silvertärna och naturlig vegetationssuccession.

Vår studie visar att populationstrenderna varierar stort mellan vadarna, men bekräftar populationsminskningen hos roskarlen, vars förekomst nu i allt högre grad är begränsad till exponerade isolerade skär. Bibehållandet av livskraftiga populationer av små måsfåglar är viktigt för att förbättra artens bevarandestatus.

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