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Habitat selection, elevational shift, and population trend in the Norwegian population of the Eurasian Dotterel (*Charadrius morinellus*)

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Preface

This master thesis marks the end of my master's degree within nature management at NMBU (Norwegian University of Life Sciences). This study has a parallel "sister-study" which concerns another bird species. Therefore, the field work has been conducted in cooperation with another master student at NMBU: Oscar Østvold.

During this study I have obtained knowledge about how human activity can affect birds in alpine habitats, as well as how we might mitigate these consequences. I have also acquired an insight in the use of statistical tools and methods that are relevant for bird conservation and monitoring.

I wish to thank my supervisor Svein Dale for participation during the fieldwork and leading me through the statistical analysis as well as the writing process. I also wish to thank the County Governor of Trøndelag and Ola Bekkens fuglevernfond for supporting this study financially, and Roar Økseter for guidance regarding QGIS. For providing accommodation during the field work, I wish to thank Raymond Sørensen at Norsk Villreinsenter Nord. Lastly, I want to thank Oscar Østvold for an excellent cooperation during this study.

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Abstract

Climate change occurs at a faster rate in alpine areas and in northern latitudes compared to other regions. However, we have too little knowledge of the consequences of such changes within alpine areas. Studies regarding this subject have to our knowledge been geographically restricted, mainly to central Europe and the western hemisphere. We conducted a study in Norway during the breeding season regarding the Eurasian Dotterel (*Charadrius morinellus*). We counted territories, registered site variables, and used historical data to address the population trend and to uncover a potential shift in elevation. We found a significant, negative relationship between the number of territories and the density of sheep. Additionally, different levels of bedrock nutrition influenced the number of territories, where areas with intermediate bedrock richness contained the most territories. The mean elevation of a territory was 1429 m a.s.l. (range: 1221-1656 m a.s.l.) We also found that the dotterel had experienced an elevational shift in Norway from 1970 to 2022, equalling an upward shift of 17.4 m a.s.l. for each decade. If this trend continues, the loss of breeding habitat in our study sites may amount to ca 20% during the next 50 years. However, we found no significant shift in elevation for the period 2008-2022 in the same region. The population trend within our study sites was also stable from 2008 to 2022. Even though we found a stable population trend, a continued shift in the elevation will likely lead to future population declines. A potential management tool that we present here, is to limit the density of grazing sheep in alpine breeding areas. It might also be crucial for management to gather more data regarding population trends in alpine birds and the potential drivers for elevational shifts. Such data could then be used to create mitigating efforts to reduce the effects of these drivers.

Table of content

Introduction

Climate change can pose as a threat to biodiversity through changes in habitats and weather patterns (Couet et al., 2022; Pörtner et al., 2022; Sekercioglu et al., 2008), and such changes have been observed to affect alpine ecosystems in northern latitudes at a faster rate than other regions (Brunetti et al., 2009; Ewing et al., 2020; Walther et al., 2002). Although these ecosystems experience rapid changes while containing many specialized species, it is demanding to gather knowledge about these areas due to their vastness, lack of infrastructure and that studies in these environments are often costly (Lindström et al., 2015). Historically, organisms have responded to climatic changes either by evolutionary or phenotypic adaptation, or by shifting their habitat use, and in failing to do so an organism might face extinction (Nogues-Bravo et al., 2018). However, different organisms respond differently to a changing climate; while some species may gain advantages, others might face severe consequences (Buchan et al., 2019; Campana et al., 2020).

Birds in alpine habitats face negative consequences in the early stages of climate change, and consequences such as elevational shifts and population declines have already been observed (Couet et al., 2022; Lehikoinen et al., 2018; Pernollet et al., 2015). The effect of climate change differs across space, but it also differs between species traits which may affect the rapidness of elevational shifts (Couet et al., 2022; Jiguet et al., 2010). Species of birds with smaller climatic envelopes are more likely to experience population declines than birds with a wider niche during climate change (Jiguet et al., 2006; 2010). Generalists also tend to cope better with climate change than specialists (Davey et al., 2012; Jiguet et al., 2007). Traits such as migratory strategy or number of broods might also affect a species ability to cope with climate change (Gilroy et al., 2016; Jiguet et al., 2007; Lindström et al., 2019). Climate change can also result in mismatches in prey and predator relationships, or change the optimal timing for reproduction in long distance migratory species (Both et al., 2006). Additionally, insects within alpine areas has also shown to experience elevational shifts (McCain & Garfinkel, 2021), which also might change the habitat use of alpine birds due to their diet.

Some of these alpine bird species are expected to, or have shown to shift their elevational range upwards within the alpine ecosystems in the western hemisphere (Sekercioglu et al., 2008). However, in Northern Europe studies regarding elevational shifts are to our knowledge few. As the available area within alpine breeding grounds tend to decrease with elevation, constraints in available habitat might occur due to elevational shifts. Additionally, if several species experience an elevational shift in the same period, competition for resources within alpine areas might occur (Couet et al., 2022). Studies have already shown that shifts in elevation is related to the chance of going extinct among alpine birds, and alpine bird populations in Northern Europe have already shown declines, although the main drivers behind these declines remain unclear (Lehikoinen et al., 2014; 2018).

To address how climate change will affect alpine birds in general, is challenging due to potential interactions between climate change and local factors (Davey et al., 2012). Local factors could be topography, where flat and homogenous areas are more susceptible to climate change than heterogenous areas (Peterson, 2003). Factors such as windward and leeward slopes can make alpine habitats heterogenous in microclimatic conditions, and the aspect of a slope can determine which slopes have richer habitats in terms of vegetation (Winkler et al., 2016). Another local factor that can affect the alpine habitats are pastorale agriculture (Wehn et al., 2011). Pastoral agriculture can alter vegetation through grazing, trampling and fertilization, and this form of agriculture has been practiced for centuries in Northern Europe (Devos, 2022). Other grazing species within the alpine ecosystems in Northern Europe, that might influence alpine vegetation are *Reindeer tarandus* and *Ovibos moschatus*. Other factors that can influence alpine areas on local level, is human disturbance and bedrock richness. However, we need a more solid understanding regarding the interactions between the abiotic and the biotic factors in alpine ecosystems (Couet et al., 2022).

Changes in grazing pressure and climatic conditions can cause a shift in the treeline ecotone, and over recent years the ecotone has advanced in elevation or remained stable on a global level (Devos, 2022; Harsch et al., 2009). An advancement of the treeline can introduce competition between endemic and new species, as well as causing potential changes in the microenvironment within alpine habitats (Devos, 2022). The advancement of shrubs and heather may also change the microenvironmental conditions within alpine habitats. However, the treeline ecotone in Northern Europe has shown a deviating pattern compared to the global advancement, where little evidence of advancement has been observed in the southern parts of Norway (Dalen & Hofgaard, 2005; Schei et al., 2015). In the Dovre region large saplings have been observed to make an advancement, possible due to better climatic conditions (Hofgaard et al., 2009; Moen et al., 2008). In Dovre it has also been observed that vegetation in the lower alpine zones has changed over the recent years (Vanneste et al., 2017).

A species belonging to the Charadriiformes that inhabit alpine habitats in Northern Europe, such as the middle alpine zone, is the Eurasian Dotterel (*Charadrius morinellus*) (hereafter dotterel) (Lislevand, 2021; Stenbrenden & Røsæg, 2009). The dotterel was evaluated among other alpine birds for the Norwegian red-list in 2021, where several *Charadriiformes* were enlisted as near threatened (NT), but the dotterel was evaluated in the category of least concern (LC) (Stokke et al., 2021). Despite having shown stable population trends with no significant decline in Norway, management is in need of more data in order to obtain more precise estimates regarding the population trends (Stokke et al., 2021).

The dotterel population in Fennoscandia is to our knowledge stable (Lindström et al., 2015; 2019), and in Sweden the population has even showed an increase (BirdLife-Sverige, 2022). However, the population has experienced declines in both the UK and Finland (Ewing et al., 2020; Hayhow et al., 2015; Saari, 1995). Ewing et al. (2020) found that the potential drivers for the decline of dotterel populations in Scotland was changes in vegetation due to acidic rain, changes in grazing pressure, and through disturbance by backpackers. Regarding changes in climatic conditions, the effect on the dotterel population was not significant (Ewing et al., 2020). Hayhow et al. (2015) also found a strong support for grazing and acidic rain as driving factors, which changed the vegetation cover and availability of insect prey (Hayhow et al., 2015). As for Saari (1995), he found that hunting and the use of pesticides in the North African wintering habitats was the cause of the population decline. He also states that overgrazing by reindeer in Finland might be a driving factor (Saari, 1995). Predation may also be a potential factor, occurring mainly through nest predation, where *Vulpes vulpes*, *Corvus corax* and *Larus canus* act as the most important predators (Byrkjedal, 1987). In the UK, predator generalists such as *Corvus corone* has been occupying higher elevations in alpine areas, and in Norway foxes and ravens are known to be attracted by litter, left by hikers and ski-goers in alpine areas (Byrkjedal, 1980; Watson, 1988). Even though earlier studies have not found climate change to be the main driver of population declines, the dotterel thrives in alpine areas that have, or are expected to experience climatic changes. It is therefore likely that negative effects caused by climate change, have, or will affect the population of dotterel negatively.

A study conducted on Norway's most common waders observed that changes in lichen cover due to less grazing and an extended, yearly snow cover probably were the biggest drivers of population declines among alpine birds (Byrkjedal & Kålås, 2012). Such changes increased the amount of lichen cover and might have replaced original vegetation in important feeding areas. Byrkjedal & Kålås (1984a) found that the dotterel occupied snow free peaks in the early breeding period, but moves to the nesting sites in lower elevations as soon as patches without snow occurs. However, Byrkjedal and Kålås (2012) states that it is uncertain how important changes snow cover are for population trends, and if they are caused by climate change. Byrkjedal & Kålås (2012) also found that some *Charadriiformes* showed a decline in population trends within Norway, however they found no decline in the population of dotterel. They stated however that the sample size for dotterel was quite low (Byrkjedal & Kålås, 2012). A low sample size could be due to the behavior in the dotterel, where it becomes more cryptic later in the breeding season. This change in behavior might affect number of observed individuals while performing transect lines (Kålås & Byrkjedal, 1984b).

To mitigate the potential extinction drivers and improve management strategies, it is important to obtain detailed data and a solid understanding of how human disturbance and climate change affects the biodiversity within the alpine ecosystems (Chamberlain et al., 2012; Jiguet et al., 2007; Sekercioglu et al., 2008). So far, tools such as the red-lists highlight the risks of species going extinct. Small scale monitoring of population trends has also been conducted across various areas, and preferably such monitoring should be conducted on a yearly basis (Byrkjedal & Kålås, 2012). However, large scale monitoring of population trends of waders was not conducted in Northern Europe until 2014, when a joint monitoring program was released in Fennoscandia (Lehikoinen et al., 2014; Lindström et al., 2015).

We conducted field surveys within alpine areas in the Dovre region, to determine which site variables explain the number of dotterel territories, which will provide a better understanding of which variables that are most important. Additionally, through using historical data we explored the population trend of dotterel within our study sites, we also checked for potential elevational shifts in the southern parts of Norway. The Dovre region is an interesting area to conduct such a study, since Dovre has experienced changes in precipitation and length of the growing season, which could be the reason for the observed change in vegetation in the lower alpine habitats (Holten et al., 2008). In this study, we addressed the following research questions: A) How does the site variables affect the distribution of dotterel territories? B) Has the dotterel shifted its elevational distribution within its alpine habitats? C) What trend does the dotterel population show within our study sites? Given that climate change has already affected alpine areas, we expect to find an upward elevational shift in habitat use in the southern parts of Norway, as well as a decrease in the population within our study sites.

Materials and methods

Study area and period

The fieldwork was conducted in the spring of 2022 in Norway, from 23 May until 28 June. Scattered across the municipalities of Dovre, Folldal and Oppdal we defined 45 smaller study sites that were visited during the fieldwork (figure 1). The municipalities are in the county of Innlandet, except Oppdal which belongs to the county of Trøndelag. The area containing the study sites borders to several national parks such as Dovre NP, Dovrefjell-Sunndalsøra NP and Rondane NP. Dovre NP and Dovrefjell-Sunndalsøra NP contained some of our study sites.

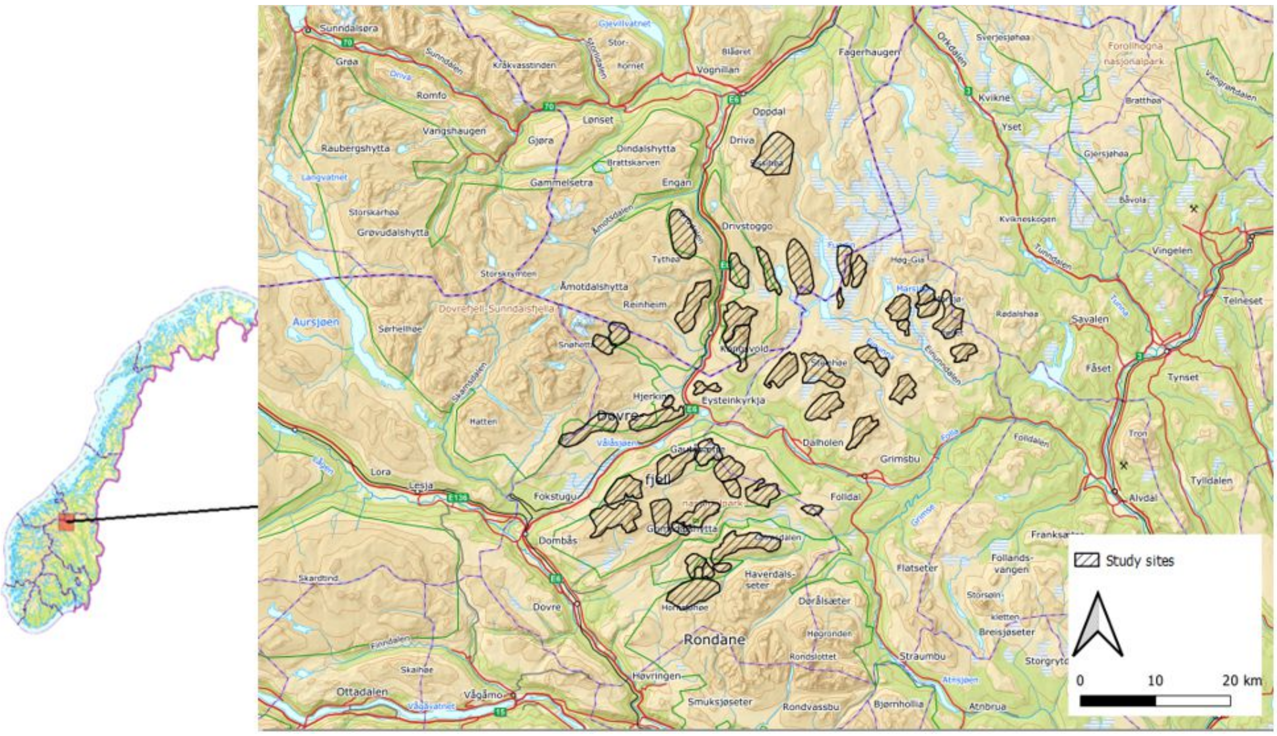


Figure 1: A map showing the study area, with the study sites where we conducted our field surveys regarding the Eurasian Dotterel (*Charadrius morinellus*) (created in QGIS 3.14).

We determined through existing literature and historical observations that alpine areas from the elevation of 1200m a.s.l. and up to the mountain summits were to be used as study sites (Artsobservasjoner, 2022; Haftorn, 1971; Lislevand, 2021). Our study sites cover most of the mountain summits within the Dovre-region since many of these contained historical observations of dotterel. To obtain a more diverse dataset, study sites with no historical observations were also defined. These study sites were then drawn as a polygon layer in QGIS and used as base for the study sites that were to be visited (QGIS, 2023). QGIS is an open-source computer programme which is used to plot maps and analyse geographical data.

According to "Nasjonal Berggrunnsdatabase" the bedrock within the study area differed between the study sites. The southern and eastern parts the study area mainly consisted of "fyllitt" and "glimmerskifer". The western parts around Snøhetta were dominated by "meta-arkose", while the northern part of the study area consisted mainly of "gråvakke" and "tuffitt" (NGU, 2022).

The study sites consisted of intermediate alpine zones with sparse vegetation, as well as some high alpine zones with little to no vegetation. Many of the study sites were influenced by lime-rich bedrock, which can result in a rich alpine vegetation (Miljødirektoratet, 2022b). The vegetation within our study sites was characterized by the lack of shrubs and heather and was dominated by grass, mosses, or lichen species. Additionally, our study sites were characterized by patches of snow in varying sizes during the breeding season, however these patches would shrink as the lateness of the study period grew (figure 2).

Figure 2: Typical terrain within the study sites in the Dovre-region, which still contained large patches of snow in the end of May. (Vålåsjåhøe. Photo: Axel Brevig-Edfeldt)

There was little human influence within our study sites, but the study area is known to be used for different outdoor activities according to "kart.naturbase.no". The Northern parts of the study area contained areas which were classified as very important for outdoor activities. In the southern and eastern parts of the study area there were high elevation sites that were classified as important (Miljødirektoratet, 2022b). Other signs of human activity that were observed in some study sites where a few tourist cabins, fishing huts, gravel roads, stretches of the Nordic pilgrimage trail, traces of military activity and cairns in varying sizes. Books used for registration of visits by hikers at mountain summits, often indicated a low to intermediate number of visitors through the year. Additionally, we observed very few hikers while performing our surveys. The human major influence that seemed to be present within all our study sites were the grazing of livestock such as sheep and cow.

Study species

The dotterel belongs to the *Charadriidae*-family in the Charadriiformes-order, and is a thrush-sized, long distance, migratory bird with a cinnamon, white and chestnut plumage (Cramp, 1983) (figure 3). The dotterel is in Europe most common in Northern Europe and Scotland (Kålås, 1994), but smaller populations can be found in Central and Southern Europe (Cramp, 1983; Haftorn, 1971). In Norway the dotterel has its breeding ground in alpine habitats, but it can also be observed in the lowlands and along the coast during the migration (Kålås, 1994). During the breeding season from May to August the dotterel thrives in the elevation of 1100 to 1400 m a.s.l. (between the heather- and the lichen-fields) and is well adapted to the harsh alpine climate (Haftorn, 1971; Lislevand, 2021). These alpine breeding grounds are rocky and has a sparse vegetation cover, dominated by species belonging to mosses, grass or lichens (Cramp, 1983; Haftorn, 1971).

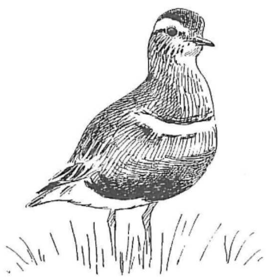
A)  B) 

Figure 3: A) An Eurasian Dotterel (*Charadrius morinellus*) observed in its breeding habitat. (Nørdre Knutshøa, Oppdal, photo: Axel Brevig-Edfeldt) B) An illustration of the dotterel, by John Atle Kålås (Kålås, 1994).

The dotterel migrates to Norway in the middle of May and migrates south during the months of August and September (Haftorn, 1971; Kålås, 1994). During the breeding season the dotterel mainly hunt for insect prey such as the *Coleoptera, Tipulidae* and *Diptera,* but may feed on plant material to some extent (Byrkjedal, 1989; Cramp, 1983). There is to our knowledge no difference between the diet within and outside the breeding season, but the dotterel is known to also feed on earthworms during the migration (Haftorn, 1971). Outside the breeding season the dotterel is found in North-Africa, where it thrives in dry and rocky steppes (Cramp, 1983; Kålås, 1994). The population in Norway is estimated to be 8000 and 13500 pairs (Shimmings & Øien, 2015).

The dotterel is a polyandrous species where the female can produce several clutches with different males during the breeding season (Kålås, 1994). Often the brood consists of three eggs, and if one clutch is lost the male dotterel is known to accept an additional clutch (Hof et al., 2017; Kålås & Byrkjedal, 1984a).

Field surveys

We measured the time spent and distance walked within each study site above the 1200 m a.s.l. border (table A1). The survey route was established in a manner that covered as much variation of topography as possible. Additionally, if possible, the survey route should not cross previous walked distances within the study site (figure 4). We walked a total of 435 km within the study sites, equalling a mean of 9.9 km within each study site. A total of 142 hours and 48 minutes were spent within the study sites, which equals a mean of 3 hours and 14 minutes spent within each site. The mean start time was at 0630 h., with the earliest start at 0430 h. and the latest at 1223 h.

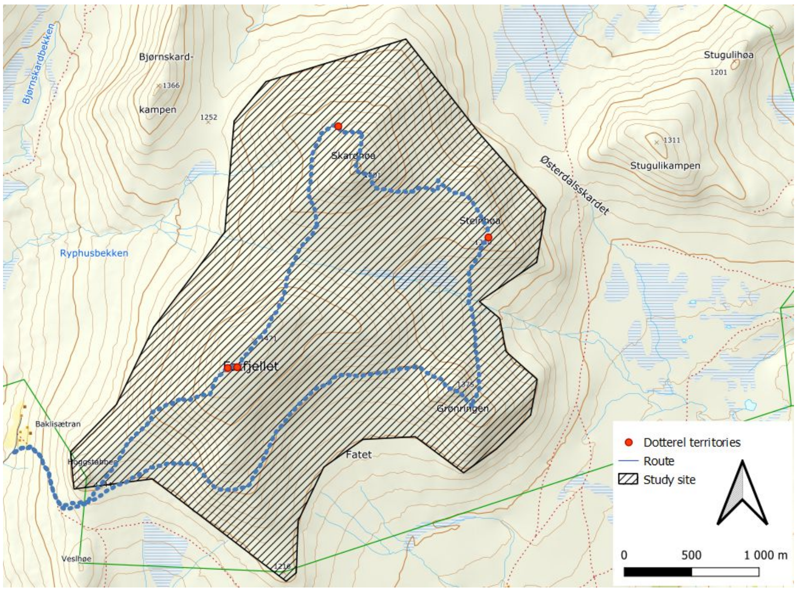


Figure 4: An example of a survey route tracked by the app "Strava" to log movement while counting territories of the Eurasian Dotterel (*Charadrius morinellus*). This survey route was performed within the study site of Fatfjellet in Folldal. (Obtained from the app Strava, using QGIS 3.14)

We used handheld binoculars for spotting dotterel territories, and a handheld GPS for registration of observations. The application "Norgeskart friluftsliv" for mobile telephone was used for the registration of observed territories. The application "Strava" was also used during the field work, to assist in keeping an overview over orientation, time spent, and distance walked. Regarding weather, if unfavourable conditions for observing dotterel occurred, we would postpone the fieldwork for better conditions. Along our routes we registered site variables (see "Site variables") (table A1). To strengthen the chance of observing dotterels we maintained a slow walking pace.

When a dotterel was observed, we registered the GPS-position as well as the sex, if the observation was audible or visual, what activity the dotterel was performing, and how many individuals we observed. If two observations were closer than 300 meters to each other, the observation would count as the same bird, unless two different individuals were seen or heard at the same time. Registrations of observations was in the form of observed territories, two individuals seen together or a parent with chicks would thereby represent one territory. Additionally, we found no effect of lateness of the study period upon the number of observed dotterel territories ($R = -0.19$, $p = 0.24$). The study site of Snøfonnhøa was excluded from the analyses due to bad weather conditions, resulting in that 44 out of 45 study sites was used.

From the starting point towards the study sites up to the 1200 m a.s.l. border, we registered time spent and the distance from 1000 m a.s.l. to 1100 m a.s.l., and 1100 m a.s.l. to 1200 m a.s.l, since observations of dotterel could potentially occur below our defined study sites. Upon exiting the study sites, we noted the time of exit and the time spent and distance walked between the same elevation intervals as the entry route. However, if the same route was used for exiting and entry to and from the border of the study site, we did not register time spent and distance walked back to the starting point (figure 4).

Site variables

Area (km^2) above 1200 m a.s.l. was calculated through using QGIS. This was done by using the "field calculator" function on the polygons representing our study sites. Isolation (km) was calculated as the distance between the highest peak within our study sites and the nearest neighbouring peak above 1200 m a.s.l. This was done using the "measure line" function in QGIS. Maximum elevation (m a.s.l) within our study sites was calculated using a DTM (Digital Terrain Model) in QGIS, which delivers elevation data for a given location.

Data regarding amount of sheep per km^2 was obtained through using the map service of "NIBIO Kilden" (NIBIO, 2023a), which delivers detailed information about landscape within our study area. The data was gathered from 16 different livestock-areas, where all but three study sites belonged to a livestock-area. The three areas without any values for sheep per km^2 were marked as "NA" and not 0, since we observed sheep close to these sites. The livestock areas could contain several of our study sites since each area was not specific for each study site. Of 16 livestock-areas, 14 contained two or more study sites, and per livestock-area there were 2.6 study sites.

The survey duration (hours) was measured as the time used while performing the transect lines within the study sites above the 1200 m a.s.l. border. Bedrock Nutrition within our study sites was determined through using "Økologisk grunnkart" from "artsdatabanken". This map-service contains layers with several variables applicable for nature related studies. Under the "Miljø-variabel" section we used the layer called "Kalkinnhold i berggrunn", which provides a rough estimate over the nutrition level for a given area (Artsdatabanken, 2022). The levels of nutrition that "Artsadatabanken" uses is "very rich", "rich", "intermediate", "poor", and "very poor". However, we only had observations of dotterel in the levels of "rich", intermediate" and "very poor", so these three levels were used in the statistical analyses. Number of grazing species were determined while performing the field survey. This site variable includes the species of reindeer, sheep, cow, and muskox. The grazers were distributed into two groups, where "group 1" represented study sites with one or two species of grazers, and "group 2" represented study sites with three or four species of grazers.

The number of observers within each study site was registered and varies from one to three observers. Additionally, the mean elevation of dotterel territories was calculated for each study site that contained observations. This variable was only created to test for potential interactions between sheep density and the mean elevation of territories. Transect distance (km) was measured as the distance walked within the study sites above 1200 m a.s.l.

Historical data collection

Changes in elevation over time

The historical data containing observations of dotterel was gathered from "artsobservasjoner", which is a web-service where observations of species can be registered by birdwatchers, hikers etc (https://www.artsobservasjoner.no/ViewSighting/SearchSighting). "Artsobservasjoner" provides GPS-locations of a given observation, as well as the date and type of observation. The data for the height analysis was gathered from the period of 1970 to 2022, in the months of June and July, for the whole of Southern Norway. Data was gathered from 900 m a.s.l. and upwards, to rule out observations from the lowlands along the migration routes. The counties chosen was Viken, Vestland, Trøndelag, Vestfold and Telemark, Rogaland, Møre og Romsdal, Innlandet, and Agder. We did not use our own data from the field survey since our behaviour likely differed from the regular user of "Artsobservasjoner". Very few of the registered observations of dotterel in "artsobservasjoner" contained direct information regarding elevation. By using QGIS we extracted the elevation of each geographical point on which the observations in "Artsobservasjoner" were linked with.

Population trend

To calculate the population trends, we also used data from "Artsobservasjoner" (https://www.artsobservasjoner.no/ViewSighting/SearchSighting). We plotted all our study sites in “Artsobservasjoner” and extracted observations of Dotterel. The analysis was conducted on data from 2008-2022. Data was gathered from June and July during this period. Our own observations were excluded from this analysis, for the same reason as the elevation analysis. If there were no observations of other bird species, or very few observations of birds that do not share the same habitat preference as dotterel, the year was marked as “NA”. If bird species that share habitat with the dotterel was observed, such as horned lark (*Eremophila alpestris*), golden plover (*Pluvialis apricaria*) and northern wheatear (*Oenanthe oenanthe*) and there were zero observations of dotterel, the study site would be marked with “0” observations of Dotterel. To cope with years that had no observations, we used “artsobservasjoner.no” to examine if the study site had been visited by observers for the given year.

One observation was chosen to represent one study site for each year, which would be the observation with most registered dotterels for that year. Since observations in “artsobservasjoner.no” is registered for individuals of the dotterel, we altered the observations to represent territories. This means that one or two individuals would represent one territory, and three and four individuals would represent two territories etc.

Statistical analyses

Exploratory analyses

To look at how the different site variables affected the number of observed territories individually, we used the Pearson correlation test in RStudio (Rstudio, 2021). The Pearson correlation test was used for site variables such as area, isolation, maximum elevation, sheep/km^2 and the survey duration within the study sites. The site variable of sheep/km^2 was log10-transformed for the statistical analysis. For categorical variables with two levels such as number of grazing species, we used a two-sided T-test with a confidence interval of 0.95. For the categorical variable “Bedrock Nutrition” and “Observers” with three levels we used ANOVA-analyses. For all these three categorical variables, we used the “as.character” function if RStudio to make them nominal variables. To test if there was a significant preference for aspect of habitat, we used chi-square test in RStudio, and visualized the distribution with the “lubridate” package (https://cran.rproject.org/web/packages/lubridate/index.html).

GLM analysis

Looking at all our site variables together, and which ones that affected the number of observed territories the most, we used GLM analysis (generalized linear model) in RStudio (Rstudio, 2021). The GLM analysis was performed using the "stepAIC" function in the "MASS" package, which delivers the best fitted model according to AIC values (https://cran.r-project.org/package=MASS). However, the site variable "distance walked" was excluded due to high collinearity with the site variable "Survey duration" in the GLM analysis.

The variable that was used as the dependent variable in the GLM analysis was the number of territories within each study site. We used Poisson error distribution to conduct this analysis. The explanatory site variables that were used was area, isolation, maximum elevation, sheep/km^2, survey duration, bedrock nutrition, number of grazing species and observers. Additionally, to compare AIC values with alternative models, we used different combinations of variables (table A2). The variable of sheep/km^2 was log10-transformed for the GLM-analysis.

To further explore if there were any significant interaction between sheep density and the mean elevation of observed dotterel territories, we conducted an additional GLM-analysis. This model contained number of territories as response variable and all the variables from the best fitted model according to the "stepAIC" function, in addition to testing for a potential interaction (*) between sheep density and mean elevation of observed territories. Study sites with zero numbers of territories were excluded from this analysis.

Changes in elevation over time

The analysis was conducted through using linear regression in RStudio (LM-function), choosing elevation (m a.s.l.) for the observations as the dependent variable, while year was used as an explanatory variable and region was included as a random factor (Rstudio, 2021). To establish the regions, we merged counties with few observations together. This method was performed for the whole period, but also the period of 2008 to 2022, to see if there was a difference within a smaller time frame. This period was also used due to a sharp increase in observations of dotterel reported from 2008, due to the release of "artsobservasjoner" the same year. The years before 2008 was characterized by few registered observations.

To strengthen the elevation analysis of dotterel, we conducted an analysis regarding increase in elevation in dotterel observations on region-level. The analysis was conducted on elevation of observations across counties, which were merged into regions due to a low sample size. The regions were used as random factor in the main analysis after this discovery (figure A1) (table A3).

To deal with potential biases in "artsobservasjoner" due to the citizen science nature of the data, we performed analyses of the behaviour and the effort of birdwatchers. The behaviour analysis was conducted using the elevation of observations of *Lagopus muta* and *Plectrophenax nivalis* which has similar habitat preferences, for the period of 1970 to 2022 (figure A2) (table A4). These species thrive in high-alpine areas, which could reveal if birdwatcher has in fact stayed at high elevations through our study period. Since we found no change in behaviour, a potential elevational shift in the dotterel is therefore not a consequence of birdwatchers gradually staying in higher elevations through the period. The effort analysis was conducted using the number of observations of dotterel within each region in southern Norway. The effort analysis was conducted using region as random factor, where counties with few observations were merged (figure A3) (table A5). The analyses indicated that there were regional biases in observer effort in relation to year, which meant that the analyses shown in the main text included region as a covariate.

Population trend

To determine what kind of trend the population of dotterel had within our study sites, we used the package RTRIM in RStudio (Rstudio, 2021) (https://cran.r-project.org/package=rtrim). Model 2 was used, which assumes that the populations varied across our study sites, but the same growth would be shown in all study sites. Additionally, the growth rates were also assumed to be constant during the specified time intervals. This package was used to cope with the uneven input of data regarding observations for each year and study site. Using the Wald function after conducting the analysis, showed if the population trend was significant (Wald Chi-Square test).

Results

Observations of Dotterel

We observed a total of 78 territories during our study period (figure 5). Across our study sites the number of observed territories of dotterel varied from zero to eight territories (figure A4). The mean number of territories across all our study sites were 1.8 territories.

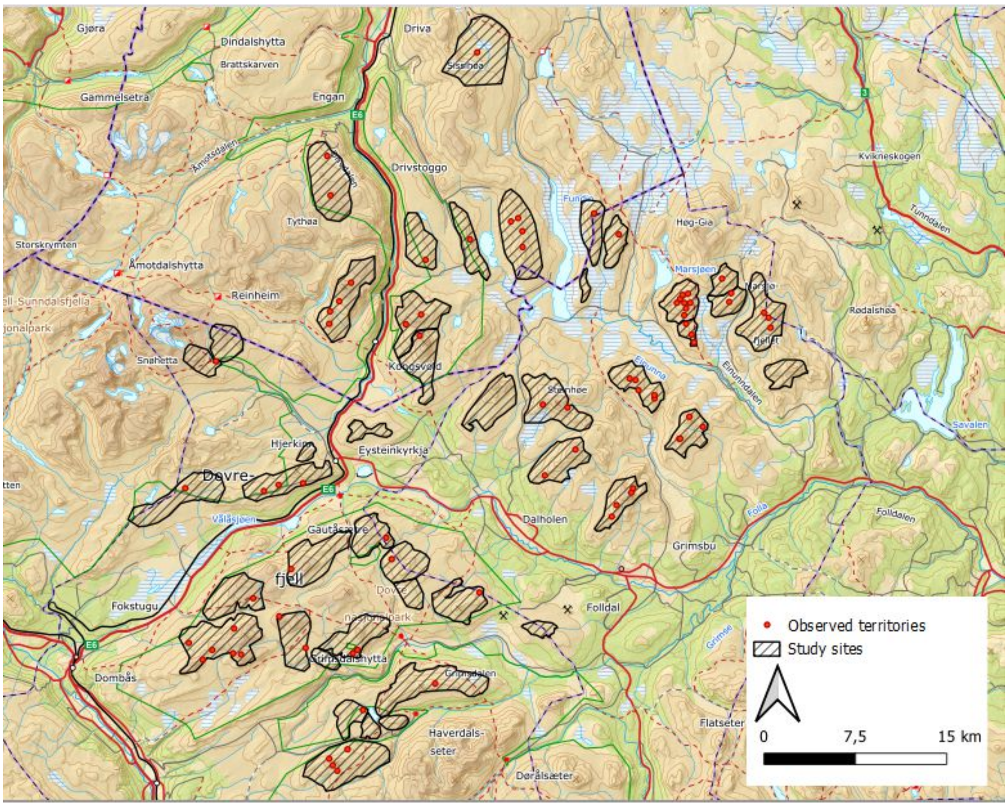
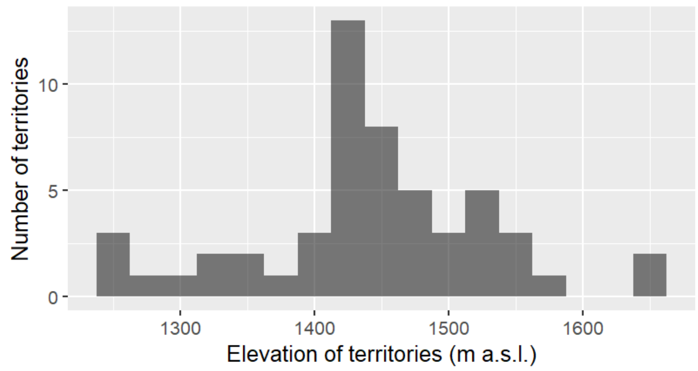


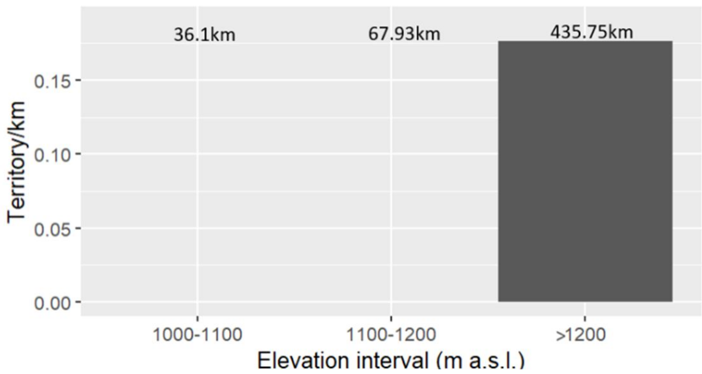
Figure 5: A map over the study sites in the municipalities of Dovre, Folldal and Oppdal. The study sites are represented with shaded polygons, and territories of the Eurasian Dotterel (*Charadrius morinellus*) are marked as red dots.

Habitat selection

The mean elevation of a territory was at 1429 m a.s.l, with a range of 1221 to 1656 m a.s.l. (figure 6A). We observed no territories outside our study sites (<1200 m a.s.l.), even though several kilometres were covered below our study sites (figure 6B). We observed territories of dotterel in all aspects of mountain slopes, but with indications of a preference to northeast and southeast facing slopes ($\chi^2 = 11.83$, df = 3, p = 0.008) (figure 6C). When the difference between the mountain peak and the elevation of the observed territories was measured (figure 6D), we found that the mean of the difference in elevation was 123 m, with a range of 15 to 456 m. We also found that 23 percent of the observed territories was within the difference of 50 m from the mountain summits.



A)



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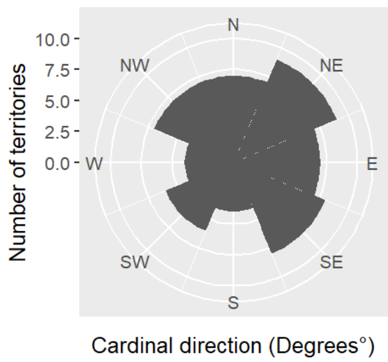

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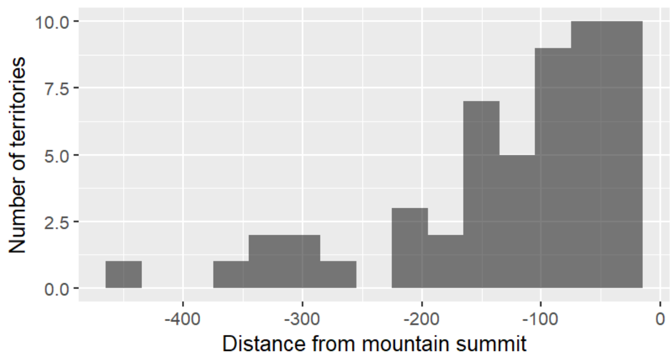


D)

Figure 6**:** A) A histogram showing the distribution of the number of territories of the Eurasian Dotterel (*Charadrius morinellus*) along the elevation-gradient. B) A bar-plot showing number of km walked and the number of territories per kilometre walked within the different elevation intervals. C) A polar plot showing the weight of number of territories across the aspect (cardinal direction) of our study sites. D) The distribution of number of territories when looking at the difference between m a.s.l. of observed territories and the maximum height of a study sites. The distance from the mountain summit is measured in m.

Pearson correlation analyses

Available area, the elevation of the highest peak and survey duration within our study sites all had a significant positive relationship with the number of territories of dotterel (table 1) (figure 7). Isolation of a study site and the density of sheep had a non-significant relationship with the number of observed territories (table 1).

Table 1: Pearson Correlation Analysis conducted on the number of territories of the Eurasian Dotterel (*Charadrius morinellus*), and the variables measured within the study sites (df: 42): Area above 1200 m a.s.l. within a study site (Area), distance to nearest summit above 1200m a.s.l. (Isolation), height of the highest mountain peak within a study site (Maximum elevation), density of sheep within the study sites (Sheep/km2) and time spent within a study site (Survey duration).

Variable	R	P-value
Area (Km^2)	**0.46**	**<0.01**
Isolation (Km)	0.17	0.25
Maximum elevation	**0.38**	**<0.05**
Sheep/km^2 (log)	-0.08	0.62
Survey duration	**0.59**	**<0.001**

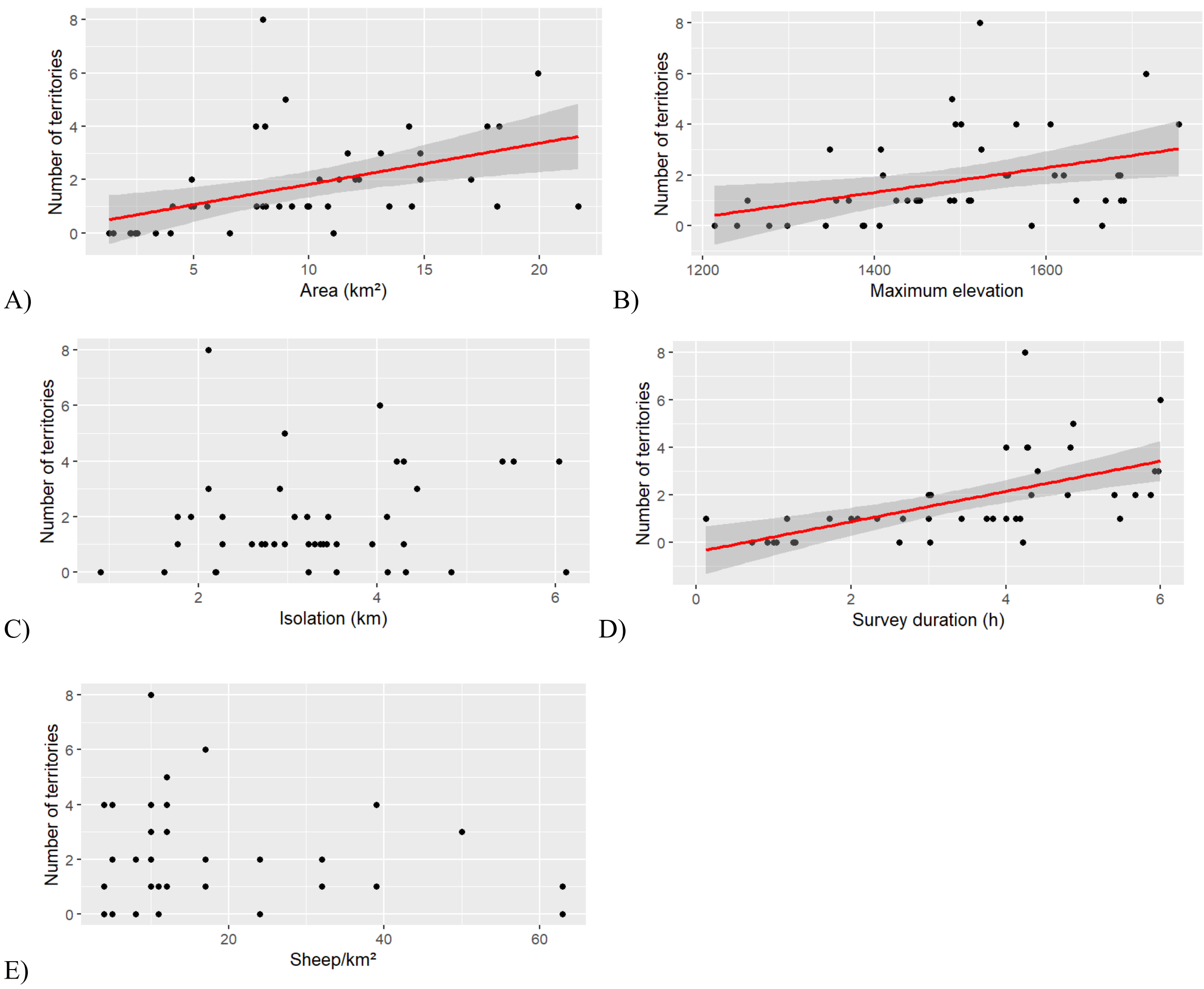


Figure 7: Plots showing the relation between territories of the Eurasian Dotterel (*Charadrius morinellus)* and site variables A) Available area above 1200 m a.s.l. B) Maximum elevation of the mountain peaks within the study sites. C) Isolation of study sites. D) Time (hours) used within the study sites. E) Density of sheep within our study sites.

Anova analysis and T-test

There was a significant difference between study sites with different levels of bedrock nutrition (table 2). Comparing the “intermediate” level of nutrition with the “rich”, there is a significant difference in the number of observed territories (figure 8A). Although having a small sample size, there was no significant difference between study sites with “very poor” bedrock nutrition, compared with “intermediate” and “rich” bedrock nutrition (figure 8A). There was no significant difference between the two categories of grazing animals, and the number of observed territories (table 2) (figure 8B). We found no significant difference between the number of observers and the number of dotterel territories (figure 8C).

Table 2: ANOVA analysis conducted on the site variables “Bedrock nutrition” and “Observers” in relation to territories of the Eurasian Dotterel (*Charadrius morinellus*). A two-sided t-test conducted on the site variable “Number of grazing species” in relation to dotterel territories.

Variable	**F-value/t**	**df**	**P-value**
Bedrock richness	**3.36**	**2**	**0.044**
Number of grazing species	1.23	1	0.24
Observers	0.04	2	0.96

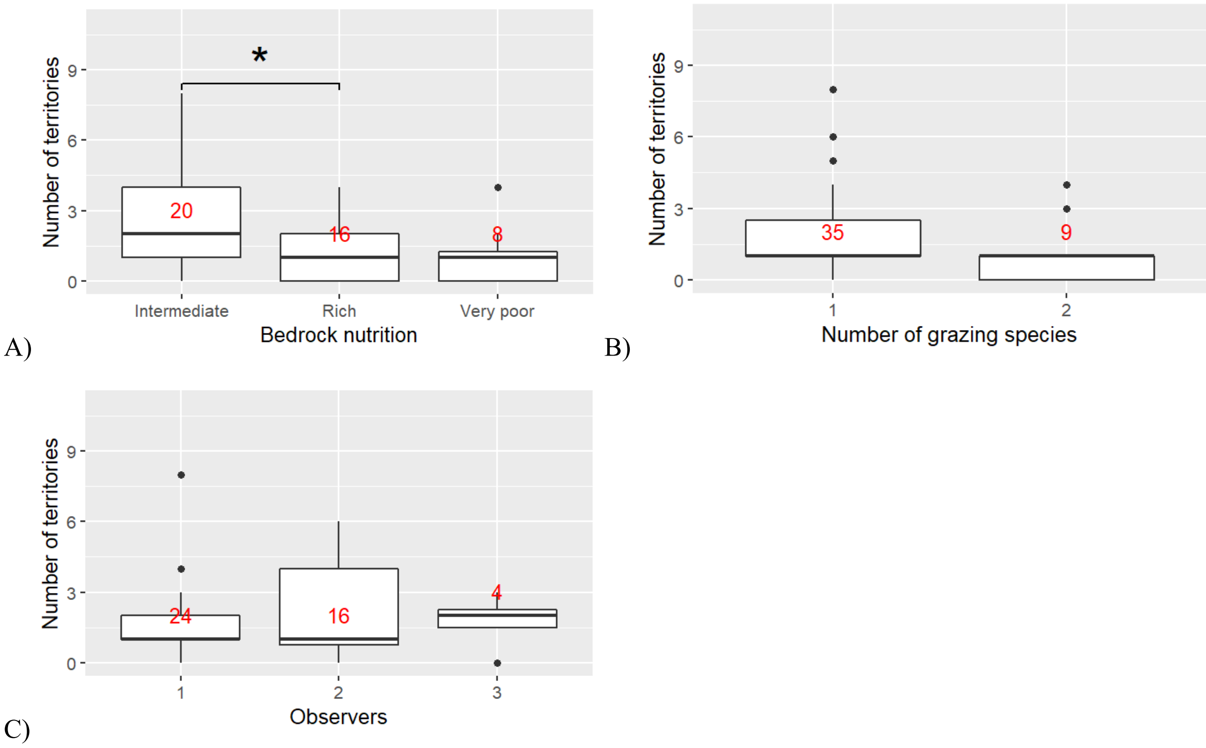


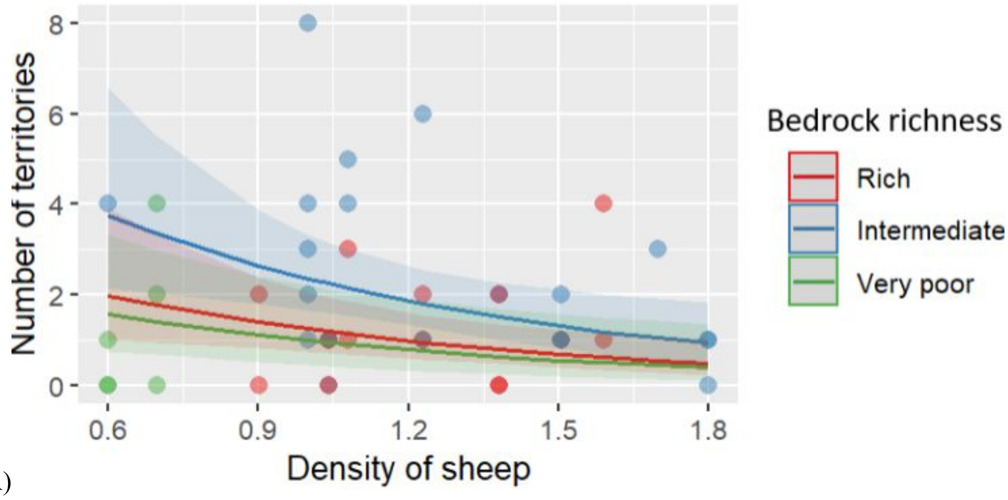
Figure 8: A) Boxplots showing the number of territories of the Eurasian Dotterel (*Charadrius morinellus*) in relation to A) bedrock richness, B) Number of grazing species. and C) number of observers. The number of study sites (n) are shown in red. Significant differences are marked with “*”.

GLM analysis

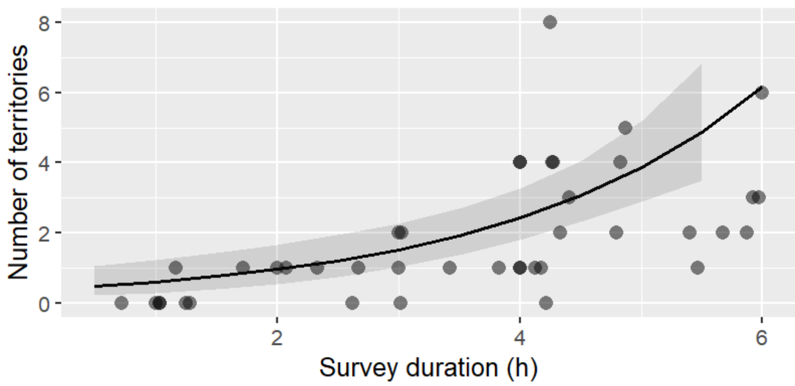
When comparing multiple site variables together in an GLM analysis, time used, bedrock richness and sheep/km^2 within the study sites are expressed in the top model (AIC: 124.32) (table 3) (figure 9 A and B). Survey duration, bedrock richness and sheep/km^2 were all significant. Compared to several other variations of our variables used in the GLM analysis, this model has the lowest AIC value (table A2). When checking for potential interactions between sheep density and the mean hight of dotterel territories within each study site (table 4), we did not observe any significant interaction.

Table 3: General linear model-analysis conducted on all the site variables in relation to the number of territories of the Eurasian Dotterel (*Charadrius morinellus*). This table represents the best fitted model using the StepAIC-method, where intermediate bedrock richness is used as level of reference.

Variable	Estimate	Std. Error	P-value
Intercept	0.37	0.61	0.53
Bedrock rich	**-0.64**	**0.27**	**<0.05**
Bedrock very poor	-0.86	0.45	0.06
Survey duration	**0.47**	**0.97**	**<0.001**
Sheep/km^2	**-1.17**	**0.45**	**<0.01**



A)



B)

Figure 9: Relationships between the number of territories of the Eurasian Dotterel (*Charadrius morinellus*) and: A) Density of sheep (log-transformed), with the three different levels of bedrock. B) The number of hours spent within our study sites.

Table 4: General linear model-analysis conducted on the number of territories of the Eurasian Dotterel (Charadrius morinellus), with the significant variables from table 3, in addition to the mean elevation of territories within each study site, and the interaction (*) between sheep density and mean elevation.

Variable	Estimate	Std. Error	P-value
Intercept	-3.70	5.35	0.49
Bedrock rich	-0.52	0.33	0.12
Bedrock very poor	-0.38	0.44	0.39
Survey duration	**0.36**	**0.16**	**0.02**
Sheep density	0.22	0.24	0.36
Mean elevation	<0.01	<0.01	0.51
Sheep density * Mean elevation	<0.001	<0.001	0.33

Height analysis

The relationship between year and the elevation of observed dotterel across the southern parts of Norway showed a positive significant relationship for the period 1970-2022, with an increase of 1.74 m each year which equals 87 m during the full period (table 5) (figure 10). The period from 2008-2022 only showed a weak positive relationship, with an increase in elevation at 0.13 m each year. However, the relationship for 2008-2022 was not significant (table 5) (figure 10).

Table 5: Table showing relationship between the elevation of observed territories of the Eurasian Dotterel (*Charadrius morinellus*) in southern Norway and the year of observation. The table represents the period from 1970 to 2022 and 2008 to 2022 in the months of June and July.

Period: 1970-2022			
Variable	**Estimate**	**Std. Error**	**P-value**
Intercept	**-2228.56**	**541.87**	**<0.001**
Year	**1.74**	**0.27**	**<0.001**
Period: 2008-2022			
Variable	**Estimate**	**Std. Error**	**P-value**
Intercept	1032.2	1818.3	0.57
Year	0.13	0.9	0.89

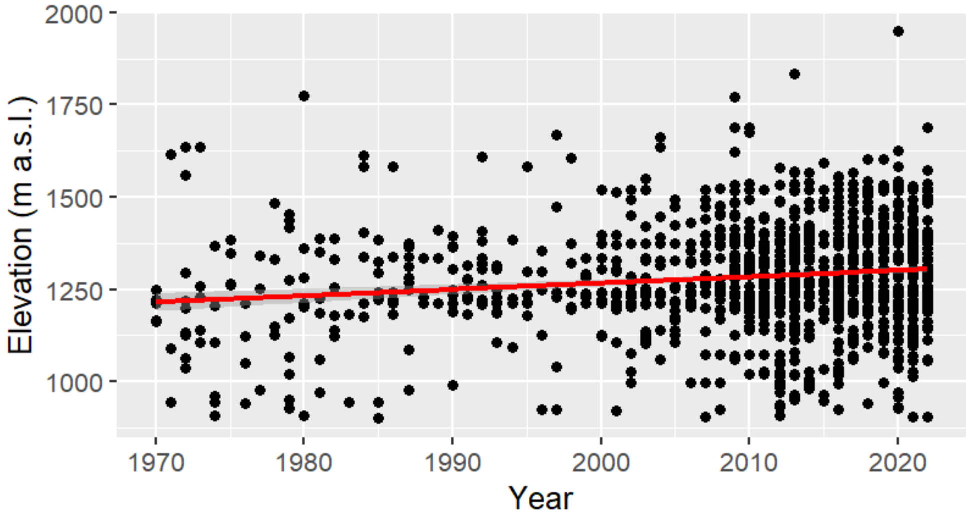


Figure 10: A scatterplot showing the relationship between the elevation of observations of Eurasian Dotterel (*Charadrius morinellus*) in southern Norway and the year of observation. This figure represents the period from 1970 to 2022 in the months of June and July.

Population trend

The population trend of the dotterel in the study area showed a positive but non-significant trend during the period of 2008 to 2022 (figure 11) (Wald = 1.42, df = 1, slope = 0.028. SD = 0.024, p = 0.23). 2013 was a year with many registrations, which causes the sudden peak of registered observations of dotterel.

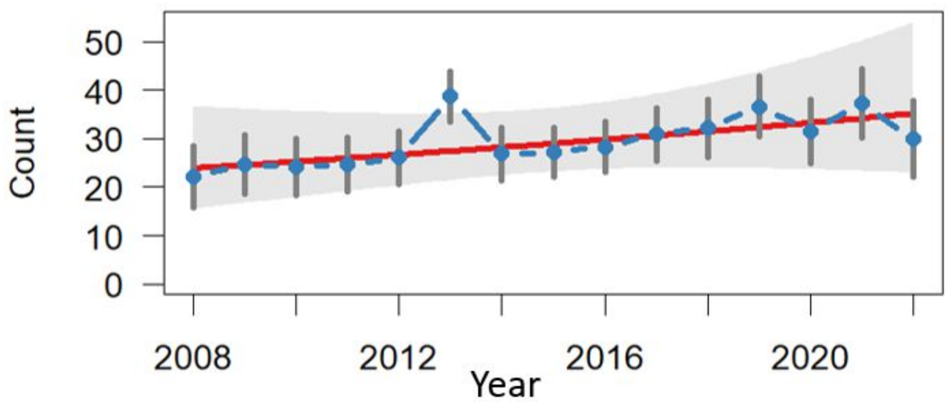


Figure 11: The population trend for the Eurasian Dotterel (*Charadrius morinellus*) across the 44 study sites in Dovre, Folldal and Oppdal. The figure is based on observations of dotterel in the period from 2008 to 2022, in the months of June and July.

Discussion

Habitat selection

When we compared all our site variables together, we found that areas with intermediate richness and low density of sheep contained most territories. We only observed a significant difference in the number of territories between intermediate and rich bedrock nutrition. However, the number of study sites with very poor nutrition was quite low compared to rich and intermediate areas. One possible reason for that intermediate areas contained most territories, is that rich areas might be favourable for grazing species such as sheep. If more sheep is attracted to these areas, consequences such as more fertilization and disturbance through trampling might occur (Devos, 2022; Wehn et al., 2011), which could cause the area to be more dominated by grass and become less optimal as breeding grounds (Smith et al., 2008; van der Wal et al., 2003). Trampling from grazing animals might also lead to absence of dotterel, through destruction of nests, eggs, and changes in the moss-layer which contain important invertebrate prey (Ewing et al., 2020; Smith et al., 2008).

However, grazing by livestock may also decrease the establishment of taller vegetation such as shrubs in the lower alpine zones (Wehn et al., 2011). Additionally, intensity of grazing sheep in alpine areas has proven to increase the abundance of certain alpine bird species in a short term period (Loe et al., 2007). Loe et al. (2007) found that *Anthus pratensis* and *Lagopus lagopus* increased in number when the density of sheep was high. It is however important to note that Loe et al. (2007) conducted their study in the lower parts (1050 m a.s.l. to 1300 m a.s.l.) of the elevation interval preferred by the dotterels. We observed these two species often in lower elevations than the dotterel during our field surveys, which were characterized by having more vegetation such as shrubs and heather.

One could argue that the findings of Loe et al. (2007), Wehn et al. (2011) and our results (table 3) (figure 9A) indicate that livestock grazing might be positive for the dotterel in lower altitudes, since regrowth and changes in vegetation might be kept at bay, and that grazing in higher altitudes might be unfavourable due to trampling, disturbance, and fertilization. However, when exploring this further (table 4), our results indicated that there was no significant interaction between the elevation of dotterel territories and sheep density on number of territories. We cannot fully rule out that the effects of grazing upon alpine birds varies with elevation, and it would have been interesting to test this further in addition to how the different species of livestock alters the vegetation.

Another site variable that did not show a significant relationship, was the number of grazing species. Livestock, reindeer, and muskox might have an overlapping diet to some extent; therefore, the density of grazing species might be a more reliable site variable when addressing the effect upon number of territories. It would have been interesting to determine the density of other grazing species such as cattle, goat, reindeer, and muskox within our study sites. Especially since some of the grazing species affect habitats in different ways, such as goat and cow which may counteract changes in vegetation following a warmer climate (Wehn et al., 2011). Additionally, there is to our knowledge no current evidence of overgrazing from livestock or wild grazers within our study sites. There are however historical records of overgrazing following big reindeer populations in Dovre (Jordhøy et al., 1997). In addition to keeping wild populations low through hunting, or to regulate the density of livestock within one area, another tool that has been presented, is to use certain plant species as indicators of the health of alpine grazing areas (Evju et al., 2006). Evju et al. (2006) conducted their study in the elevation interval of 1050-1300 m a.s.l. regarding sheep grazing and might therefore be applicable for alpine birds such as the dotterel. Such methods could be used to make sure that the grazing pressure is kept at a favourable and sustainable level for alpine birds. It might be beneficial to also determine such indicators among vegetation, following grazing from other grazing species such as goat or cow.

Our findings support the well-known fact that the dotterel is known to thrive in areas with little and low vegetation (Cramp, 1983; Haftorn, 1971). We observed most territories in study sites with intermediate richness, which seemed to contain the type of vegetation described by Cramp (1983) and Haftorn (1971). Fields of grass which might contain too dense vegetation for the dotterel, seemed to be less prominent in areas with intermediate richness, than in rich areas. When considering areas with poor richness, these areas might contain too little vegetation to be suitable breeding sites. The absence of vegetation might also lead to lower density of invertebrate prey compared to intermediate and rich areas. However, it is important to note that the estimated richness of an area provided by "artsdatabanken", were in some study sites in conflict with the richness that we observed. Some areas that seemed poor during the field surveys, were by "artsdatabanken" categorized as rich or intermediate. Therefore, as the service provided by "artsdatabanken" might deliver a rough estimate of bedrock richness, the map-service might be better suited for less fine scale analysis. One alternative solution to cope with this potential bias, is to perform registrations during the field surveys, of the vegetation at each location of an observed dotterel territory. This can be used to compare with any potential map service such as "artsdatabanken", to check for any differences in the outcome of statistical analyses.

The effect of isolation was not significant on the number of observed territories. We observed several pairs of dotterels in flight as they were moving longer distances. Since the dotterel is a long distance migrant (Cramp, 1983; Haftorn, 1971), it is not unlikely that it has the ability to move between remote breeding areas, even within a breeding season. Especially the female is known to visit several distant breeding grounds, within each breeding season (Whitfield, 2010). Isolation of habitats might therefore not be a crucial site variable for the dotterel. However, we measured isolation of habitat as the distance between mountain peaks, but if isolation was measured as the distance between the 1200 m a.s.l. borders of our study sites, the effect of changes in vegetation might be more imminent (Holten et al., 2008; Michelsen et al., 2011). If more vegetation in the lower parts of the breeding areas develops into taller vegetation such as dwarf shrubs, it might increase the isolation between the lower parts of the available breeding areas. But given the dotterels trait to move between breeding sites, the increased isolation itself might not be an imminent threat.

Our observations regarding preference of aspect, indicate that the dotterel thrives in northeast and southeast facing habitats (figure 6C). This is somewhat unexpected since south facing slopes are more productive and richer (Winkler et al., 2016). Although our study was not specifically designed to test the preference of aspect, this result is interesting since the dotterel seems to also thrive in less productive areas, such as intermediate habitats and north facing slopes. A possible explanation for that the dotterel preferred northeast facing slopes, is that these slopes may contain larger patches of snow which contain "insect fallout" (Antor, 1995). We observed that many of these larger snow patches that contained living and dead insects, which were not able to take flight after landing on these patches, often were visited by dotterels. These patches may offer easily accessible nutrition for the dotterel, in exchange for minimum effort, which may lead to more time spent on incubating eggs or brood care. Such use of snow patches has also been proven to increase with altitude which fits the traits of the dotterel (Antor, 1995). However, one alternative explanation could be that changes in vegetation following human induced changes are more imminent in south facing slopes, and that the dotterel therefore thrives on north facing slopes which may have a less dense vegetation cover.

Height analysis

We observed a significant upwards elevational shift in our longest period, from the year of 1970 to 2022, with an increase of 17.4 m. a.s.l. each decade. This supports our hypothesis, that climate change, and perhaps other human induced changes have caused an elevational shift in the Norwegian population of dotterel. As for the shorter period of 2008 to 2022, we did not find a significant change. Our findings are in line with earlier studies, which found a moderate elevational shift in an alpine bird species (Couet et al., 2022; Pernollet et al., 2015). Additionally, since we observed most territories to be clustered close to the mountain summits within our study sites (figure 6D), the dotterel might not have much habitat to use as a buffer if shifts in elevation continues in future years.

The mean temperature in Norway as a whole has increased with 1.1 degrees Celsius since the year 1900 (Miljødirektoratet, 2022a), as for Dovre it has increased with 0.87 degrees Celsius (Vanneste et al., 2017). Additionally, Vanneste et al. (2017) observed a change in the vegetation in the lower alpine zone in Dovre, where vascular plants such as dwarf shrubs become more prominent. This increase in the abundance of vascular plants could act as a driver for elevational shift in the dotterel since we observed zero territories below 1200 m a.s.l. where plants such as shrubs become more abundant. Vanneste et al (2017) observed that the increase in temperature momentarily declined in rapidness in recent years, and if this also affects other alpine areas in Norway, it could support that we did not observe a significant elevational shift in the period of 2008-2022, given that climate change acts as the main driver. Other possible effects of climate change in the Dovre-region, is the increased abundance of large saplings above the historical treeline (Hofgaard et al., 2009), and if the increase in temperature continues we might observe a future upward shift in the treeline. Since the treeline has so far remained stable but changes in field-layer vegetation have been observed, it might be more critical to address the changes in the field-layer within the lower alpine zone. Additionally, areas that today are at risk of being overgrown by trees is often under the elevation of 1100 m a.s.l. within our study area (NIBIO, 2023b). A general trend in Norway is that changes in land use, such as less grazing from livestock, causes these open areas to be regrown with trees (Bryn & Angeloff, 2015), and this is likely the cause within our study area as well.

To determine if climate change or local factors are the main driver for the observed elevational shift is difficult, and more data regarding the interactions between these factors are needed

(Couet et al., 2022; Ewing et al., 2020; Pepin et al., 2015; Vanneste et al., 2017). In Norway the number of grazing sheep has increased since the mid-1900s, while the number of cows has declined to some extent (Aune-Lundberg et al., 2021). Since we observed a negative relationship between the density of sheep and dotterel territories, high grazing pressure or trampling might lead to unfavourable conditions for the dotterel. Although having potential negative impacts on alpine bird species, grazing livestock as well as wild animals could play an important role in keeping these alpine ecosystems from become overgrown by vegetation. It is well known that grazing livestock mitigates the risk of grazing grounds being overgrown (Aune-Lundberg et al., 2021), but different kinds of livestock can influence the vegetation in different ways (Wehn et al., 2011). It may therefore be necessary to highlight the different traits of livestock if grazing is to be used as a mitigating effort against changes in alpine vegetation. It is however uncertain if the traditional grazing pressure in Norway is enough to stop or reverse such changes in vegetation (Wehn et al., 2011). Additionally, some of our study sites were characterized by being flat and homogenous, with a gradual increase in elevation towards the summits, which is somewhat identical to what has been described as being susceptible to climate change (Peterson, 2003). If the climate in the Dovre-region continues to increase in temperature, additional changes in the alpine-vegetation within our study sites might occur. If that is the case, use of grazing animals could play an important role as a mitigating tool against these changes.

Population trend

The population trend from 2008 until 2022 showed no significant change in our analysis. Arguably, if we had used a longer period, our results might have shown an increase in population from the years before 2008. When Saari (1995) conducted his study upon the population trends over 150 years, he found that the population had a dramatical decrease since the 1960s in Finland (Saari, 1995). This could suggest that the dotterel has in fact experienced a decrease in population, but that the population in Northern Europe in recent years has stabilized or even started to increase (BirdLife-Sverige, 2022). The population curve estimated by Lindström et al. (2019), which is based on data from Sweden, Norway, and Finland, also indicates an increase in Northern Europe since 2006, which might indicate a similar situation as Saari (1995) found. However, our results are in line with other recent findings such as what

Birdlife-Sverige (2022) and Lindström et al. (2019) found, where the population trends remain stable or even increases (BirdLife-Sverige, 2022; Lindström et al., 2019).

The stable population trend might be due to that the elevational shift has not progressed far enough, to yet have a significant negative effect on the population. When extrapolating our findings of the dotterel's height preference in Norway (figure 10) (table 4), we find that the preferred interval (80% of territories) in our study sites would be between 1392 m a.s.l. and 1627 m a.s.l. in 50 years, and 1479 m a.s.l. to 1714 m a.s.l. in 100 years. Compared with the preferred elevation interval in 2022, which was from 1305 m a.s.l. to 1540 m a.s.l., this would result in a loss of 20% of the preferred breeding habitat after 50 years, and when adding 100 years from 2022 we found a 60% reduction (table A6). It is however important to view these predictions with caution since they stretch far out from our analysis period. Additionally, it is not given that climate change will continue in the same rate as before, since it might accelerate its speed in future years. A global, periodic decrease in the warming rate might also occur, such as Vanneste et al (2017) observed in their study. However, our extrapolation might provide a picture of the potential threat the dotterel population may face in the future. If we address the mean elevation of dotterel territories in Norway as a whole, which equals 1293 m a.s.l. (figure 10) (table 4), changes in vegetation within the breeding sites might be more imminent. The response to climate change or local factors might not be unison across Norway, if the amount of available habitat within elevation-intervals differs between mountain ranges.

Regarding predation, generalist predators might inhabit higher elevation sites in alpine areas, if changes in climate and land use continue. Elevational and latitudinal shifts in the red fox has already been observed in arctic areas (Hersteinsson & MacDonald, 1992). Additionally, the intensity of nest predation has been proven to increase when infrastructure and cabins are built in alpine areas by species such as raven (Støen et al., 2010). We did not observe any signs of predation on adult individuals, chicks, or eggs during the study period, but we did observe ravens and gulls close to, or within the study sites. However, our field surveys were not specifically designed to obtain such data. The threat of an increased nest predation by generalists might not be an imminent threat within our study since we observed little infrastructure and few cabins. Additionally, the dotterel is known to show anti-predator behaviour, such as pretending to be hurt to draw predators away from broods and hiding eggshells after hatching, and such traits might help the dotterel to cope with an increased predation (Haftorn, 1971).

Other changes in land use, such as establishment of ski resorts have also been shown to affect alpine birds through changing availability of feeding grounds and density of insect prey (Rolando et al., 2006). Ski-resorts do not occur within our study sites, but in Oppdal such resorts do exist in alpine areas. However, on a national level ski-resorts may present challenges for the populations of alpine birds. In addition to ski-resorts, popular trails such as the pilgrimage trail within our study site or tourist cabins might attract generalists through litter left by hikers. However, to our knowledge this is not a current problem of importance within our study sites, since cabins and popular hiking trails often occurred at lower elevations than the dotterels preferred habitat. Additionally, if any direct disturbance from users of these trails and cabins were to affect the dotterel, this will likely be after the most critical stage of the breeding season (Haftorn, 1971). The dotterel is also known to be extremely tolerable to humans, to the level where the bird has been observed to tolerate to be picked up and held (Haftorn, 1971). This trait of not being nervous might also limit the negative impact of tourism within the breeding habitats.

Other forms of changes in land use, such as the establishment of wind-turbines might also have negative impacts on alpine birds, since collisions between birds and the turbines is a well-known phenomenon (Krijgsveld et al., 2009). A lot of the alpine areas in Norway are protected, but there have been several articles in the media regarding establishment of wind turbines in Finnmark. In Finnmark the dotterel is known to thrive in the elevation interval of 100 m a.s.l. to 300 m a.s.l. (Cramp, 1983), and if turbines and infrastructure is established in these areas, it would be preferable to assess if this comes in conflict with important breeding habitats. In addition to collisions, other possible consequences could be icing that is released from the rotor blades, which might further damage breeding habitats or kill on impact. We also observed the dotterel to move quite a lot in the early period of the field work, this migration between sites might make the dotterel more vulnerable to collisions.

Another factor is how invertebrate prey will respond to changes in climate or land use. Elevational shifts in insects is a known phenomenon and has already been observed in several species, but the individual species respond differently to climate change, and more studies are needed on the subject (McCain & Garfinkel, 2021). Since the dotterels main source of nutrition is insects and other invertebrates (Byrkjedal, 1989; Cramp, 1983), a shift in the availability of typical prey species could push the dotterel to higher elevations. Additionally, if several bird species are experiencing elevational shifts at the same time, competition for both space and prey might occur. A study has revealed that that mismatch between breeding events of arctic birds in Canada, and the prey species *Tipulidae* affected the growth rate in chicks negatively (McKinnon et al., 2012). Potential or future mismatches in *Tipulidae* or other key prey species for the dotterel, might affect the chicks within our study sites in a similar manner. Since the Dovre-region has experienced a warming during the last century (Vanneste et al., 2017), it is not unlikely that a development of mismatches between prey relations, such as what McKinnon et al. (2012) found, is already in development. Additionally, if changes in temperature or grazing pressure affects the coverage of the moss layer, which acts as a key habitat for *Tulipidae* (Smith et al., 2008), the availability of some prey species might decrease.

Changes in weather patterns might also affect the dotterel. If more precipitation occurs during the winter, which could potentially increase the duration of snow lay, the dotterel might have to postpone the egg laying, or move to less favourable habitats in lower elevations. However, if a warmer climate shortens the length of the snow lay, suitable habitats in higher elevations might be available earlier in the breeding season. However, if the breeding seasons in Norway becomes generally warmer, this warmth might shorten the time for one brood to hatch since warmer summers has proven to have this effect (Haftorn, 1971). This might enhance the populations fitness in the short term. Such changes in temperature might also change the composition of vegetation, which could affect the dotterel negatively. If a combination of these weather patterns occurs, where a thicker snow layer is rapidly melted by an earlier spring, more melting water could occur at shorter periods, and change the intensity of water flow from the snow melting. Another threat could be the increase of extreme weather such as drought or heavy rainfall in the breeding sites. Additionally, if weather patterns change along the migration route, the migration itself might become more dangerous (Buchan et al., 2019). Since Saari et al found that factors at the wintering grounds could drive population declines in the dotterel populations in Northern Europe (Saari, 1995), an increased frequency of extreme weather might also pose as a threat in wintering grounds. However, a more recent study found that changes in the wintering areas has not been the cause of population declines (Lehikoinen et al., 2014), but if extreme weather occurs more often in future years it might be necessary to conduct surveys in these areas as well.

Implications for management

Since we found evidence of an elevational shift it would be preferable to perform surveillance programs regarding population trends in alpine birds, to detect when shifts in elevation may start to cause population declines. Given that our extrapolations showed a further loss of 20% of breeding habitat over the next 50 years, it is not unlikely that population declines might appear in future years. We also urge future studies to continue the monitoring of the vegetation in the alpine zones in Norway, since the dotterel or other alpine avifauna might be vulnerable to changes in the field and shrub layer.

To avoid further elevational shifts and potential population declines, management can create strategies that keeps grazing from livestock and wild species at a level that counteracts changes in vegetation and maintains important breeding sites, and at the same time keep the negative effects of grazing to a minimum. However, our understanding of how different species of grazers affect the environment within the different elevation-intervals should be strengthened, so that this potential management tool might be optimized.

Our findings indicated that areas with intermediate bedrock richness acted as key habitats for the dotterel. A further examination to determine if this is a pattern on a national scale, could therefore be beneficial to determine which areas might be of the greatest value for the dotterel and species with overlapping habitats. Additionally, future studies should examine how human induced changes affects breeding success, when factors such as nest predation and prey availability is changed. Lastly, it might be beneficial to establish monitoring of wintering grounds and migration routes to strengthen our understanding of other potential drivers for population declines.

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Appendix

Site variables

Table A1: Data which were registered within our study sites for observations of the Eurasian Dotterel (*Charadrius morinellus*). The study sites (Location) are all within or close to the Dovre-region.

Location	Bedrock	Isolation (km)	Area (km^2)	Start	Survey time	Maximum m a.s.l.	Day	Grazing animals
Blåhøe	Rich	3.08	12.01	05:24	5.67	1620	24	Reindeer and sheep
Sletthøe	Intermediate	4.11	11.3	05:40	5.4	1555	25	Reindeer and sheep
Vålåsjåhøe	Rich	4.45	11.69	04:36	5.97	1407	26	Reindeer, sheep and muskox
Hjerkinnhøe	Rich	4.83	3.34	05:06	3.02	1298	27	Sheep
Storhøe (Dovre)	Rich	3.95	8.11	05:13	3.83	1453	29	Reindeer, sheep and cow
Avsjøhøe	Rich	2.85	13.49	06:48	4	1635	30	Reindeer, sheep and cow
Storhøe (Folldal)	Intermediate	6.04	8.1	05:23	4.28	1605	31	Reindeer and sheep
Tverrfjellet	Rich	1.62	1.49	06:19	0.92	1240	32	Reindeer, sheep and muskox
Grisungknatten	Rich	3.44	14.45	05:30	4	1449	34	Reindeer, sheep and muskox
Langhøe (Folldal)	Intermediate	2.97	8.99	05:38	4.87	1490	40	Reindeer and sheep
Pikhetta (Mehøe)	Rich	2.71	9.25	05:38	3	1510	41	Reindeer and sheep
Fallfosshøe	Intermediate	0.91	3.97	07:58	1	1343	41	Reindeer and sheep
Råtåsjåhøe	Rich	4.12	11.06	05:55	4.22	1583	42	Reindeer and sheep
Nystugguhøe	Very poor	5.4	14.33	06:00	4.83	1755	43	Reindeer, sheep and muskox
Nørdre Knutshøe	Intermediate	2.27	12.16	05:54	4.8	1684	43	Reindeer and sheep
Vesle Elgsjøtangen	Rich	4.3	8	06:15	4.18	1450	44	Reindeer and sheep
Steinhøe	Rich	1.92	14.84	05:48	5.87	1610	44	Reindeer and sheep
Fokstuguhøe - Storhøe	Intermediate	4.03	19.95	05:25	6	1716	46	Reindeer and sheep
Mesæterhøe	Intermediate	3.55	9.94	06:46	2.08	1425	47	Reindeer and sheep
Elgsjøtangen	Rich	4.3	17.74	06:00	4	1494	48	Reindeer and sheep
Sletthøa (Oppdal)	Very poor	3.45	17.04	09:25	4.33	1686	49	Reindeer and sheep
Finnshøa (Oppdal)	Intermediate	3.37	8.71	07:50	2.67	1438	51	Reindeer and sheep
Fatfjellet - Skardhøa	Intermediate	5.53	7.7	08:04	4	1501	52	Reindeer and sheep
Halvfarhøe	Intermediate	3.4	10	06:30	4.13	1687	53	Reindeer and sheep

Location	Bedrock	Isolation (km)	Area (km^2)	Start	Survey time	Maximum m a.s.l.	Day	Grazing animals
Kattuglehøe	Rich	3.22	10.46	06:18	3.03	1553	53	Reindeer and sheep
Gygerhøe	Rich	3.55	2.46	10:06	1.03	1388	53	Reindeer and sheep
Storvassberget	Very poor	2.19	2.26	06:42	1.03	1406	54	Reindeer and sheep
Hornsjøhøe	Intermediate	4.22	18.25	07:45	4.27	1565	54	Reindeer and sheep
Hornsjøkollen	Very poor	2.75	5	12:02	1.17	1355	54	Reindeer and sheep
Gravhøe	Very poor	3.3	18.17	06:42	3.75	1488	54	Reindeer and sheep
Sæterberget	Very poor	2.2	2.25	11:20	0.72	1386	54	Reindeer and sheep
Knutshøa	Intermediate	2.27	10.82	07:10	5.47	1690	55	Reindeer and sheep
Streitkampen	Rich	6.12	2.55	10:30	1.28	1214	56	Sheep
Olmflya	Rich	2.6	21.71	08:16	1.72	1252	57	Reindeer and sheep
Brunkollen	Very poor	3.23	6.55	09:00	2.62	1665	58	Reindeer, sheep and muskox
Veslhetta	Very poor	3.23	4.87	12:14	0.12	1669	58	Reindeer, sheep and muskox
Steinhøe (Einunndalen)	Intermediate	2.11	14.84	04:30	4.41	1348	55	Reindeer and sheep
Finnshøe	Intermediate	2.11	8	06:30	4.25	1523	55	Reindeer and sheep
Marsjøfjellet	Intermediate	2.91	13.13	04:35	5.92	1524	54	Reindeer and sheep
Lågegga	Intermediate	1.77	4.89	04:40	3	1410	53	Reindeer and sheep
Høgegga	Intermediate	1.77	4.06	08:00	2.33	1512	53	Reindeer and sheep
Fundberget	Intermediate	4.32	1.33	04:45	1.25	1277	52	Reindeer, sheep and cow
Digerkampen	Intermediate	2.97	7.71	06:15	3.42	1493	52	Reindeer and sheep
Setalberget	Intermediate	2.97	5.58	09:50	2	1370	52	Sheep

Alternative GLM

Table A2: An overview over the best suited top model, and alternative less-suited top models. The site variables within the models explain the number of observed territories of the Eurasian Dotterel (*Charadrius morinellus*) within or close to the Dovre-region.

Variables used	Top model	AIC
Area, Observers, Isolation, Maximum elevation, Sheep/km^2, Survey duration, Bedrock nutrition, Number of grazing species	Bedrock nutrition, Survey duration, Sheep/km^2	**124.32**
Area, Observers, Isolation, Maximum elevation, Sheep/km^2, Bedrock nutrition, Number of grazing species	Area, Bedrock nutrition, Sheep/km^2	129.53
Observers, Isolation, Maximum elevation, Sheep/km^2, Survey duration, Bedrock nutrition, Number of grazing species	Survey duration, Bedrock nutrition, Sheep/km^2	124.32
Area, isolation, bedrock nutrition, Number of grazing species	Maximum elevation, Bedrock nutrition, Sheep/km^2	141.37
Isolation, Bedrock nutrition, Number of grazing species	Isolation, Bedrock nutrition, Sheep/km^2	148.37
Survey duration, Observers, Area	Survey duration, Observers	137.43

Citizen science assessment

Elevational shift in Southern Norway

We investigated if the rate of elevational shifts differed between regions. Regions are a random factor and elevation depends on region. This is why region was used as a random factor in the main analysis (figure A1) (table A3).

Tabell A3: Elevational shifts in the southern parts of Norway, regarding territories of the Eurasian dotterel (Charadrius morinellus). The period is from 1970 – 2022.

Variable	Estimate	Std. Error	t value	p value
Intercept	**-2234.3**	**546.1**	**-4.1**	**<0.001**
Year	**1.74**	**0.27**	**6.4**	**<0.001**

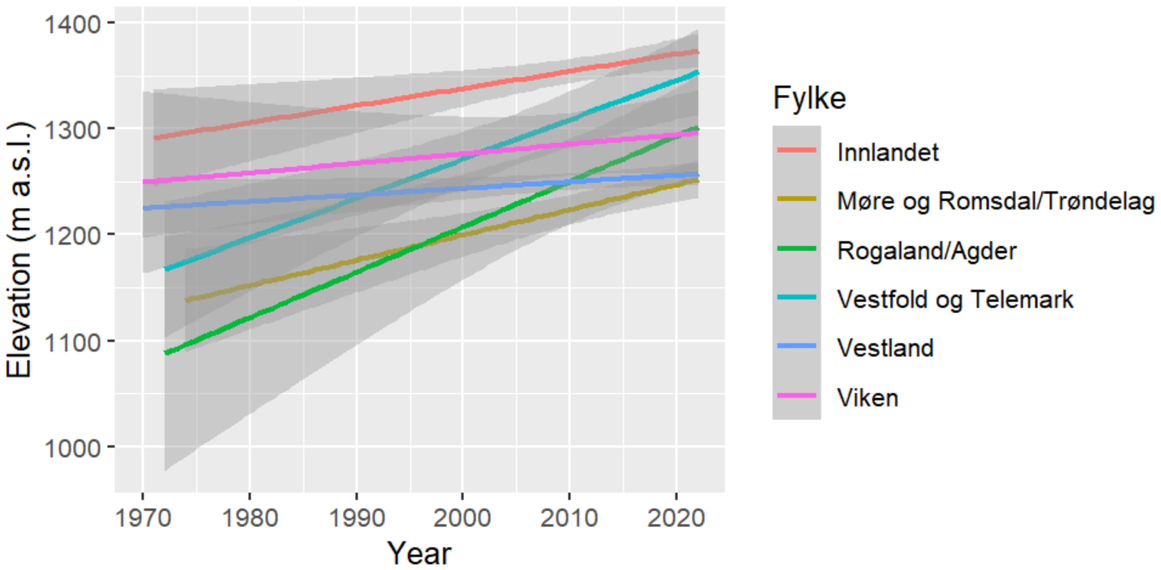

Figure A1: An overview over the elevational shifts in the southern parts of Norway, regarding territories of the Eurasian dotterel (*Charadrius morinellus*). The period is from 1970 – 2022.

Behaviour of birdwatchers

We investigated if the change in elevation in the Eurasian dotterel (*Charadrius morinellus)* was caused by birdwatcher visiting higher elevations in recent years than before. We therefore compared the dotterel with two similar species within alpine habitats. We wanted to address if users of "artsobservasjoner" have registered observations of birds even higher than the dotterel. The snow bunting (*Plectrophenax nivalis*) had observations in high elevation, which shows that birdwatchers have visited high-elevation site throughout our study period. This means that dotterel territories in high elevation could have been observed and reported during the whole period (Table A4) (Figure A2).

Table A4: Behaviour of birdwatcher for the period of 1970 – 2022 in the southern parts of Norway. The figure represents the species of Eurasian Dotterel (Charadrius morinellus), Rock Ptarmigan (Lagopus muta), and the Snow Bunting (Plectrophenax nivalis).

Variable	**Estimate**	**Std. Error**	**t value**	**p value**
Intercept	**-2754.7**	**543.1**	**-5.1**	**<0.001**
Rock ptarmigan	**-81.6**	**6.5**	**-12.6**	**<0.001**
Snow bunting	**88.4**	**7.1**	**12.5**	**<0.001**
Year	**2**	**0.3**	**7.4**	**<0.001**

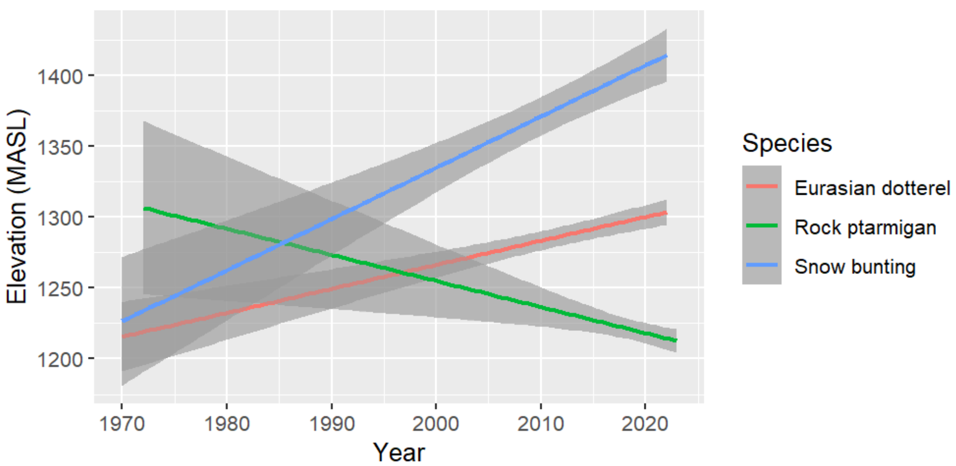

Figure A2: An overview of the elevation of observed birds in alpine areas for the period of 1970 – 2022 in the southern parts of Norway. The figure represents the species of Eurasian Dotterel (*Charadrius morinellus*), Rock Ptarmigan (*Lagopus muta*), and the Snow Bunting (*Plectrophenax nivalis*).

Effort across regions

We investigated if the effort of bird watchers differed significantly between the regions, and if the number of observations were similar across the period. The regions consist of the counties of Innladet, Vestland og Telemark, Viken, and the merged counties of Møre og Romsdal/Trøndelag and Rogaland og Agder. This was done to detect biases in our analysis regarding elevational shifts. We found that there were regional biases, which means that region is a covariate in our main analyses (table 5) (figure A3).

Table A5: Effort of birdwatchers across six different regions in Norway, regarding observations of the Eurasian Dotterel (*Charadrius morinellus)*. The period is from 1970-2022.

Variable	Estimate	Std. Error	t value	p value
Intercept	-18.2	12	-1.5	0.151
Region	**7.7**	**1.3**	**6.1**	**<0.001**

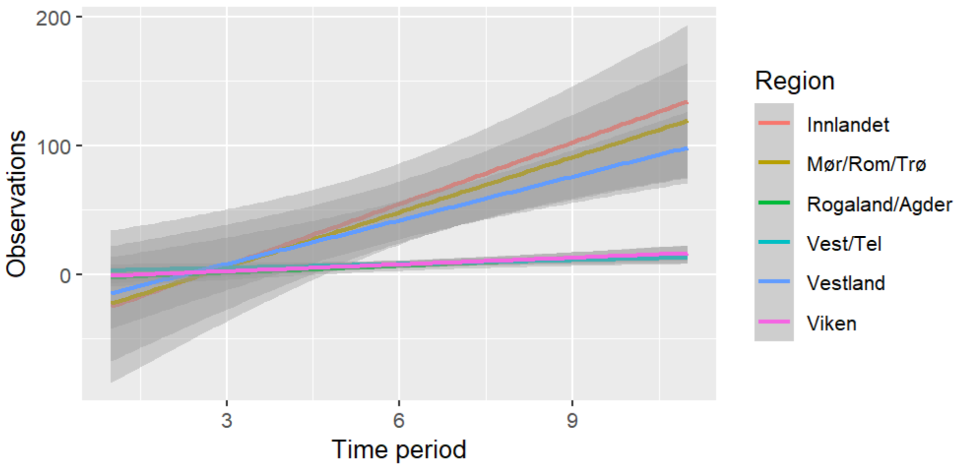

Figure A3: Effort of birdwatchers across six different regions in Norway, regarding observations of the Eurasian Dotterel (*Charadrius morinellus)*. The period is from 1970-2022 and is represented by 12 different time periods.

Distribution of observations across study sites

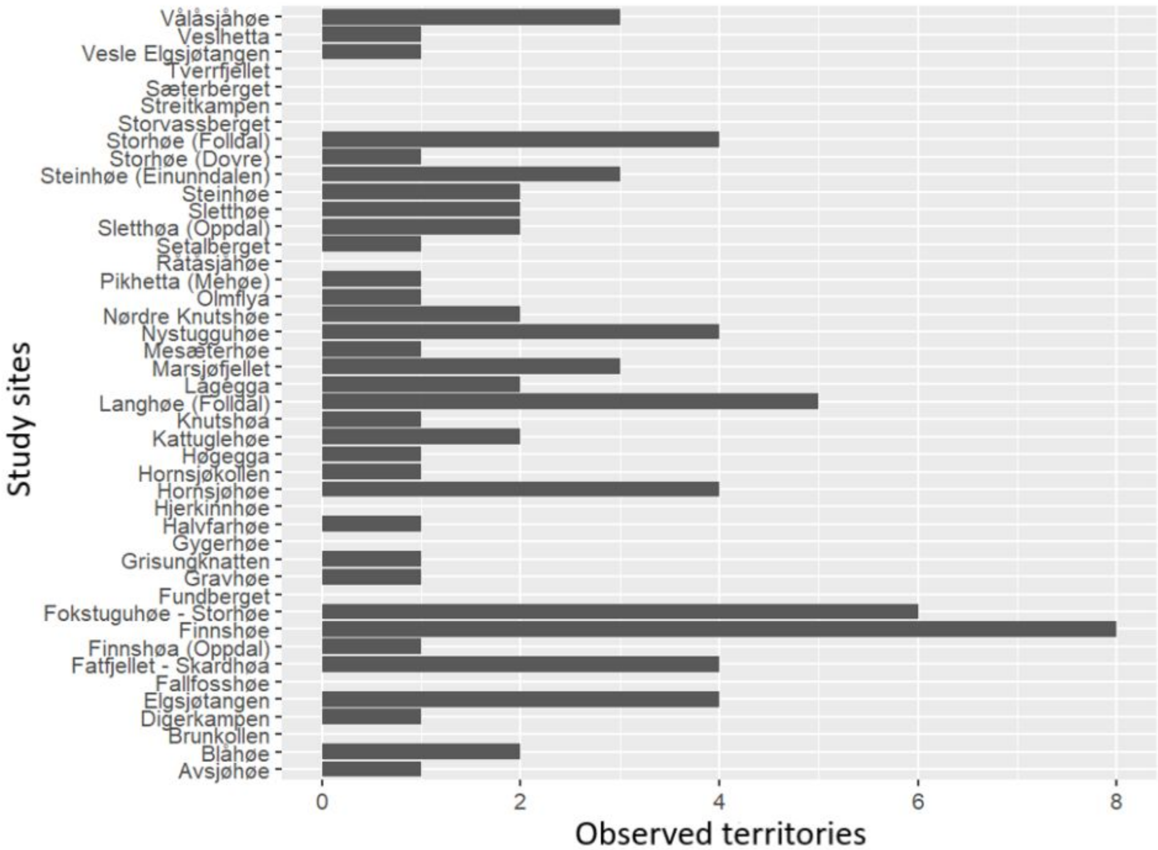

Figure A4: Distribution of territories of the Eurasian Dotterel (*Charadrius morinellus*), across our study sites in the Dovre-region.

Available area

Table A6: The distribution of available habitat (km²) within our study sites in the Dovre-region.

Height (m a.s.l.)	**Area (km²)**	**Elevation interval**	**Area (km²)**
1200	392.88	1200-1250	65.15
1250	327.73	1250-1300	74.55
1300	253.18	1300-1350	71.22
1350	181.96	1350-1400	51.49
1400	130.47	1400-1450	42.41
1450	88.06	1450-1500	31.26
1500	56.8	1500-1550	25.58
1550	31.22	1550-1600	17.98
1600	13.24	1600-1650	9.87
1650	3.37	1650-1700	3.06
1700	0.31	1700-1750	0.31

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