



# Shall we go to the mountains or to the sea for the winter holidays? Occurrence drivers and cultural relevance of the climate-vulnerable Snow Bunting *Plectrophenax nivalis* in Italy

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## ARTICLE INFO

### Keywords:

Conservation  
Nature-based recreation  
Passeriformes  
Social networks  
Species Distribution Models  
Winter

## ABSTRACT

The non-breeding distribution and ecology of many migratory songbirds are often poorly studied, but very relevant for their conservation in a changing climate. The Snow Bunting is the most northerly breeding passerine worldwide, and winters in temperate/temperate-cold areas. Characterised by specialisation for cold climate and strong migratory connectivity, it underwent a recent range contraction and is declining because of rising winter temperatures. Investigating its migration and wintering distribution and ecology is relevant to understand the possible impacts of climate change. We used citizen science records to describe and model the species distribution during migration and winter in Italy, and evaluated its cultural relevance. Snow Buntings occur in Italy in November-mid April, mostly clustered in northern and, particularly, north-eastern regions (coasts and plateaus in mountain regions); all the observations involving >12 individuals occurred at a single site in the Lessinia plateau. The elevation pattern of observations (both during winter and migration) showed a bimodal distribution (mostly at the sea level and in middle-elevation mountains, peaking around 1500 m asl). Species Distribution Models showed that the most suitable areas largely coincide with the areas from where most observations occurred, and were similar during winter and migration. Such areas are characterised by relatively cold and dry climates, and by flat or gentle sloping terrain largely occupied by open or semi-open habitats (grassland, pastures, sandy habitats). Snow Buntings had a much higher occurrence rates in social media/networks than other bunting species, indicating that nature recreationists have a particular preference for this species, which can be used as a flagship species. The species will likely suffer from ongoing climate variation, and preserving suitable open landscapes, with grassland-dominated habitats, is key to the maintenance of suitable stop-over and wintering sites. At the same time, this would also benefit many declining breeding species.

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## 1. Introduction

The non-breeding distribution and ecology of many bird species, and particularly of migratory songbirds, are often poorly studied, especially when compared to the breeding ones. Nevertheless, knowledge about the “dark side of the year” is equally valuable and important for conservation, since winter is a challenging period that can carry over through the following breeding season, affecting breeding performance, population growth (López-Calderón et al., 2017; Sutton et al., 2021) and survival (Szostek and Becker, 2015). This might be especially relevant in the cases of specialised ecological requirements, extreme site-fidelity to stop-over or wintering sites (Gherardi-Fuentes et al., 2022; Chan et al., 2023), or strong migratory connectivity (Ambrosini et al., 2019). Under a dramatically changing climate, pressures and dynamics acting on non-breeding periods and range may be key to the fate of migratory species (de Zwaan et al., 2019).

The Snow Bunting *Plectrophenax nivalis* is one of the most northerly breeding species (and the most northerly breeding passerine worldwide; Snell et al., 2018), nesting in circumpolar regions and wintering in temperate and temperate-cold areas. Contrary to many migratory species that migrate to search for better and less stochastic environments, in winter the Snow Bunting can tolerate harsher conditions than those experienced in its breeding grounds, with populations or individuals - especially the most northerly ones - wintering e.g. in continental, harsh steppe areas of Siberia (Snell et al., 2018). In the Western Palearctic, Snow Buntings largely winter in central European countries, but every winter a non-negligible number of individuals spend the cold season in more southern regions (Sighele and Janni, 2010; Ramos et al., 2014).

This species has shown a range contraction in the last few decades, e.g. in Fennoscandia (Keller et al., 2020), where also the breeding population is declining, possibly because of a reduced food availability in its wintering ground (Dierschke and Bairlein, 2002). The species is likely undergoing a decline throughout most of its range, suffering from the impacts exerted by climate change (Macdonald et al., 2012; Fossey et al., 2015; McKinnon et al., 2016; Keller et al., 2020; O'Connor et al., 2022). Moreover, strong migratory connectivity has been reported in Snow Buntings, with most individuals from certain breeding populations moving to the same non-breeding areas (Macdonald et al., 2012). Strong connectivity between breeding and non-breeding grounds can hamper the ability of a population to respond to large scale climate changes (Ambrosini et al., 2019) and to winter habitat loss (Webster and Marra, 2005).

Thus, investigating migration and wintering distribution and ecology of the species could be relevant to understand the possible impacts of climate change, which are expected to modify the winter dynamics of the species (Macdonald et al., 2016), and to contribute to its conservation. So far, processes and dynamics occurring at stop-over sites and wintering grounds have been reported to be particularly important for other migratory bunting species (Vickery et al., 2014; Kamp et al., 2015; Edenius et al., 2017; Gremion et al., 2022).

In Italy, the Snow Bunting is a rare but regular migrating and wintering species, and it is the frequent target of birdwatchers and wildlife photographers. However, its distribution and ecology during the cold season have never been investigated. With this work, by relying on citizen science records, we aim at describing its distribution during the migration and wintering periods, highlighting the main occurrence areas and investigating the potential drivers of occurrence at a large scale. Investigating the distribution and status of Snow Bunting at the southern margin of its winter distribution could help understand the potential sensitivity to, and the effects exerted by, climate change, as it has been done for the southern breeding range of the species (Hayhow et al., 2018).

In addition, climate-sensitive species may be used as flagship species to raise awareness about the consequences of climate change on biodiversity and the conservation implications. A growing body of literature is focusing on the potential relevance of online social networks for conservation science and environmental education (Roberge, 2014; Rezaei et al., 2022; Costadone and Balzan, 2023). Snow Buntings are generally appreciated by birdwatchers and nature photographers, but their potential relevance in this regard had never been investigated. By scanning social networks and comparing the relative abundance of social and media items (taking into account the number of species observations) of the species with that of other buntings, we evaluated the potential cultural relevance of wintering Snow Buntings.

## 2. Methods

### 2.1. Data collection

We used citizen science data to explore the distribution, and its relative variation, of Snow Bunting wintering in Italy or migrating through it. We relied on the most used portals of citizen science data for avian species (the platform [www.ornitho.it](http://www.ornitho.it), and the recent [ubird.ebnitalia.it](http://ubird.ebnitalia.it) database; the former had been already used as source of data for previous work on other species; Brambilla et al., 2020a, 2022). Data was made available by two NGOs (CISO and EBN, March 2023). We considered the data uploaded into the platforms between 2010 and spring 2022, and removed all duplicates (i.e., the same data contained both in CISO and EBN datasets).

We defined as wintering period the core of the cold season, between 15 December and 15 February, when migratory movements are less likely to occur, based on i) the period commonly considered as the wintering one for birds spending the winter in Italy (Brichetti and Fracasso, 2015), and ii) a visual check of occurrence patterns in our data, which revealed major stability in the wintering period. We considered all the observations outside this period (i.e., between 16 February and 14 December) as potentially involving migrant birds. Then, on the basis of the periods of observation at each site, we distinguished between sites used as i) exclusive wintering sites, ii) exclusive stop-over sites, iii) both as wintering and stop-over sites.

## 2.2. Snow Bunting occurrence and potential distribution in Italy

We performed a two-scale analysis to define the relative occurrence of the species over the country, and to define the main potential occurrence areas and the most relevant drivers of Snow Bunting occurrence. As a first step, we computed the number of observations per cell of a  $10 \times 10$  km grid to evaluate the species' occurrence rate at the national scale. Then, we assessed the elevation of each occurrence record using the 25-m resolution EU-DEM (Digital Elevation Model; v1.0; provided by the European Environment Agency and publicly available).

Secondly, we built Species Distribution Models (SDMs) separately for wintering and migration records, to evaluate the potential occurrence of suitable environments for the two different phenological phases, by working on a grid made by  $1 \text{ km} \times 1 \text{ km}$  cells covering all Italy. As potential predictors of environmental suitability for Snow Buntings, we considered different environmental variables encompassing climate, topography, and land-use/land-cover (LULC). Climatic variables, considered as mean values over each cell, were selected from bioclimatic ones known to be important for bird distribution (Thuiller et al., 2019), i.e. mean annual temperature (BIO1), annual range in temperature (BIO7), annual precipitation sum (BIO12), and precipitation seasonality (BIO15). Topographic variables were slope and solar radiation, entered as mean values over the cell, computed based on the 25-m resolution EU-DEM. Solar radiation was calculated as the average summer-spring global solar radiation, taking into account shadowing reliefs, for 21st March, 21st June and 22nd September, in GRASS GIS (Neteler et al., 2012). LULC variables were entered as percentage cover of selected CORINE land cover (European Environment Agency, 2016) categories (Table 1) over the cell (following Brambilla et al., 2022).

We considered records from the two periods (as defined above) separately, removed duplicates (i.e. records from the same  $1 \text{ km} \times 1 \text{ km}$  cell), and trained and tested models on spatially independent data. The modelling framework we adopted was the same as previous works carried out on similar spatial scales (e.g. Arnoldi et al., 2022), mainly oriented at preventing overfitting to build models that can be demonstrated to be robust and well performing also on independent data, and hence generalisable. We used fine-tuned MaxEnt models, worked out according to the procedure described in Brambilla et al., (2022), (2023) and the relative scripts (Brambilla, 2022), and evaluated them by checking diagnostic statistics over the testing datasets. The procedure we employed is based on the selection of regularization multiplier, response curves (linear and/or quadratic), variables included in the model, and number of iterations, based on the calculation of the Akaike's information criterion corrected for small sample size (Brambilla, 2022). 100,000 background points were scattered all over Italy. Occurrence data were partitioned into four spatially independent groups, using the checkerboard 2 function in ENMeval package (Muscarella et al., 2014). Models were trained on data coming from three partitions and tested on the remaining one to perform models' evaluation over independent data. In this way, it was possible to explicitly evaluate the potential risk of overfitting by comparing the Area Under the Curve (AUC) of the Receiver Operating Characteristics (ROC) over the training and testing datasets, and by evaluating the omission rate at the minimum training presence over the testing dataset. All data processing and analyses were performed in R (R Development Core Team, 2020), using the packages SDMtune (Vignali et al., 2020) and raster (Hijmans and et al., 2020).

**Table 1**

List of environmental (bioclimatic, topographical, and land-use/land-cover) variables used to model Snow Bunting distribution in Italy. All variables were elaborated in relation to the  $1 \text{ km} \times 1 \text{ km}$  grid; for each cell of the grid, we computed the average value (bioclimatic and topographical variables) or the proportional cover (land-use/land-cover; see main text). Digit acronyms refer to CORINE Land Cover category labels.

Acronym	description
BIO1	mean annual temperature
BIO7	annual range in temperature
BIO12	annual precipitation sum
BIO15	precipitation seasonality
slope	mean values over the cell
solar radiation	mean values over the cell
141	green urban areas
231	pastures
244	agro-forestry areas
311	broad-leaved forest
312	coniferous forest
313	mixed forest
321	natural grasslands
322	moors and heathland
323	sclerophyllous vegetation
324	transitional woodland-shrub
331	beaches, dunes, sands
332	bare rocks
333	sparsely vegetated areas
334	burnt areas
335	glaciers and perpetual snow

### 2.3. Evaluating Snow Bunting cultural relevance

To assess whether Snow Bunting can effectively act as a flagship species representing taxa threatened by climate change, we counted (using the search engine of each application) the number of posts on X, pictures on flickr.com and Instagram and videos on Youtube, ‘tagged’ with the Italian name of each species, and compared it with the number of ‘social records’ of the other bunting species occurring (as breeding, migratory or wintering species) in Italy (Supplementary material, Appendix 1, Table A1). For the Ortolan Bunting *Emberiza hortulana*, we combined the Italian species’ name with the genus name *Emberiza* to exclude non-relevant items generated by the social media and social network algorithms due to the different meanings associated with the Italian name. For each social media and network, we computed a relative index for each species by dividing the species’ number of posts/pictures by the highest value recorded across all the considered species for that social media or network (Barve, 2014; Edwards et al., 2021). Then, we computed an average social index (ASI) as the average value of the relative indexes for each species over the different platforms. We then estimated the relative ‘availability’ of each species by counting the overall number of records for each species uploaded in ornitho.it (since 2010; computation made on 27th December 2023, h 10:00 a.m., the same date as the search on social networks), considering only the bunting species (genera *Emberiza*, *Calcarius* and *Plectrophenax*) with at least 10 records uploaded in the ornitho.it platform (12 species with 64+ records). We hypothesised that, if there is no ‘preference’ for a given species, the number of occurrences on the social media and networks will be more or less proportional to the number of records, i.e. to the species ‘availability’; otherwise, if there is a preference toward the Snow Bunting or any other species, the number of online items will be proportionally higher for that species. We therefore used the ratio between ASI and the number of observations in ornitho.it to assess possible preferences.

## 3. Results

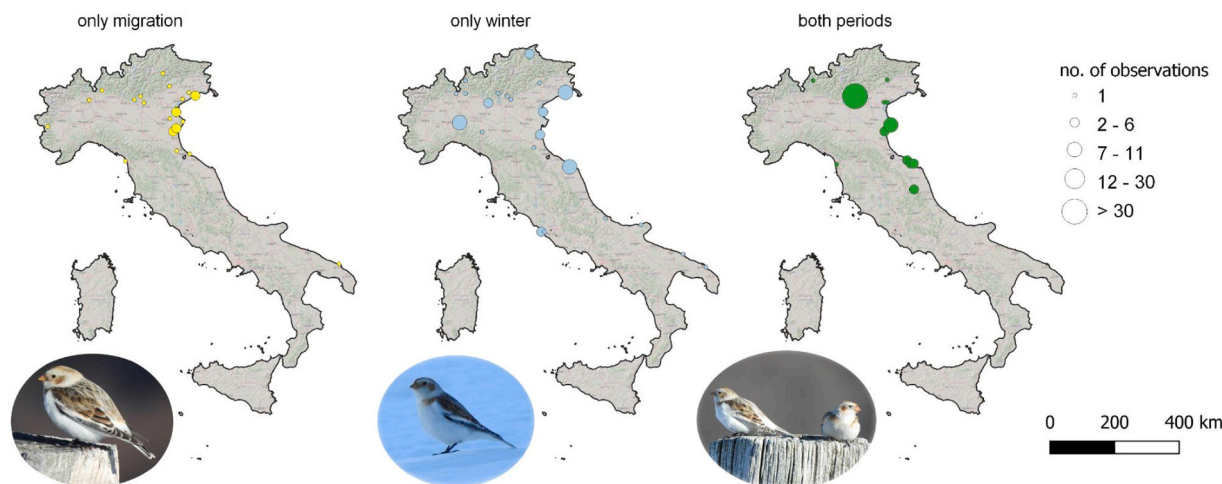
### 3.1. Snow Bunting occurrence and distribution

According to the 467 data retrieved, Snow Buntings occur in Italy between the first half of November and the first half of April. The number of individuals recorded ranged from 1 to 67, with all the observations involving more than 12 individuals (and up to 67) occurring at a single site, Bocca di Selva in the Lessinia plateau (Veneto region, province of Verona).

Snow Bunting observations were recorded in 57 10 km-cells: 23 cells hosted only observations (1–11) during the wintering period and 21 cells represented migration-only sites, featuring between one and five records, generally of a very few individuals. In 13 cells there were records (between 2 and 175) both during the wintering and the migration periods. Therefore, considering both exclusive (migration or winter) and migration+winter cells, the total number of cells hosting winter records was 36 (1–120 records) and the total number of cells with migration records was 34 (1–55 records). Removing the cell including Bocca di Selva, the maximum number of observations in the two periods were 53 and 7 for the wintering and migration period, respectively. The distribution of occurrence areas did not appear to be randomly scattered over Italy. In fact, the occurrence of bunting observations was especially clustered in northern and, particularly, north-eastern regions (Fig. 1).

The elevation pattern of Snow Bunting observations showed a bimodal distribution of the species’ records. Snow Buntings indeed occurred mostly at the sea level and in middle-elevation mountains, with a peak around 1500 m asl, and the maximum elevation reaching 1967 m (Fig. 2). 230 records were below 100 m, and 192 between 1250 and 2000 m: only less than 10% of all records fell between 100 and 1250 m asl. Such a pattern was found for all records and for wintering and migration periods separately (Fig. 2).

SDMs selected only linear features for both periods, and performed well on the training and testing datasets, showing similar



**Fig. 1.** Distribution of Snow Bunting observations in Italy during the winter and migration periods. Background is made of Open Street Map and hillshade derived from the EU-DEM (see text).

evaluation statistics over the two spatially independent data partitions and zero omissions at minimum training presence value on testing dataset (see Table 2 for models' details). SDMs showed that the most suitable areas largely coincide with the areas from where most observations occurred (compare Fig. 1 and Fig. 3).

The distribution of suitable sites was similar during winter and migration period (Fig. 3), and was affected mostly by slope, annual temperature, annual range in temperature, precipitation seasonality (all with negative effect on both periods), and by natural grassland (with positive effect on both periods). In addition, winter distribution was also affected by the cover of pastures and by sandy habitats (beaches, dunes, sands), which were the only other land-cover variables showing positive effects, and by annual precipitation (negative effect). The permutation importance of different variables is reported in Table 3, together with the variables' effect. In short, Snow Buntings during the non-breeding season in Italy seem to exploit relatively cold and dry areas, flat or gently sloping, and characterised by herbaceous vegetation and sandy soils. Such features are mostly found along northern Adriatic coasts and in some plateau areas; among the latter, Lessinia stands out as the most suitable area in northern inland Italy, whereas other suitable sites are scattered through the central Apennines.

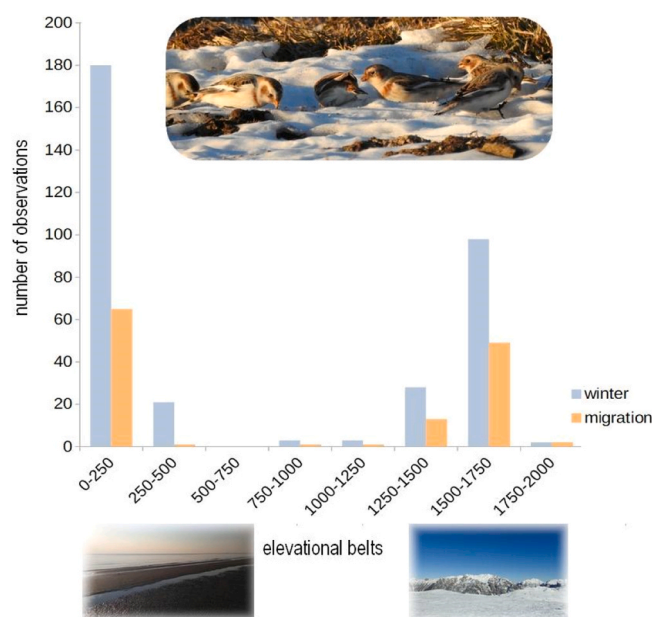
### 3.2. Snow Bunting cultural relevance

Snow Buntings was by far the species with the highest ratio between the average social index (ASI) and the number of observations in ornitho.it. The value for the species was more than double the value of all other species (Fig. 4 and Supplementary material, Appendix 1, Table A2). Such a pattern suggested an overrepresentation of Snow Buntings in the social network compared to all other bunting species occurring in Italy.

## 4. Discussion

Species with peculiar ecological requirements and high specialisation for cold climates are particularly threatened by ongoing global changes (O'Connor et al., 2022; Brambilla et al., 2022). Birds include a large number of climate-sensitive species and thus have been frequently considered as indicators in terms of ongoing and expectable impacts of modifications in climate (Freeman et al., 2018; Riddell et al., 2019; de Gabriel Hernando et al., 2021). Furthermore, they are generally perceived as charismatic, popular species (Santangeli et al., 2023), and hence can potentially help increase the awareness and sensitivity about the threats posed to wild species and the ecosystems they inhabit by climate and environmental change.

The evaluation of avian distribution and its drivers is key to understanding the potential impact of climate and environmental change (Engler et al., 2017; Norberg et al., 2019). Until now, most research efforts have focused on the breeding period (Engler et al., 2017). However, non-breeding distribution may be equally important to assess the potential implications of climate change, especially for migratory birds, which can experience multiple aspects of global change as they move, often over very large scales, from their breeding to their wintering grounds and vice versa (Stevens et al., 2023). With this study, we evaluated the distribution of an arctic species, the Snow Bunting, during the winter and migration period in Italy, at the southern margin of its wintering range. Furthermore, we demonstrated its cultural relevance linked to the high appeal that this species exerts on nature recreationists.



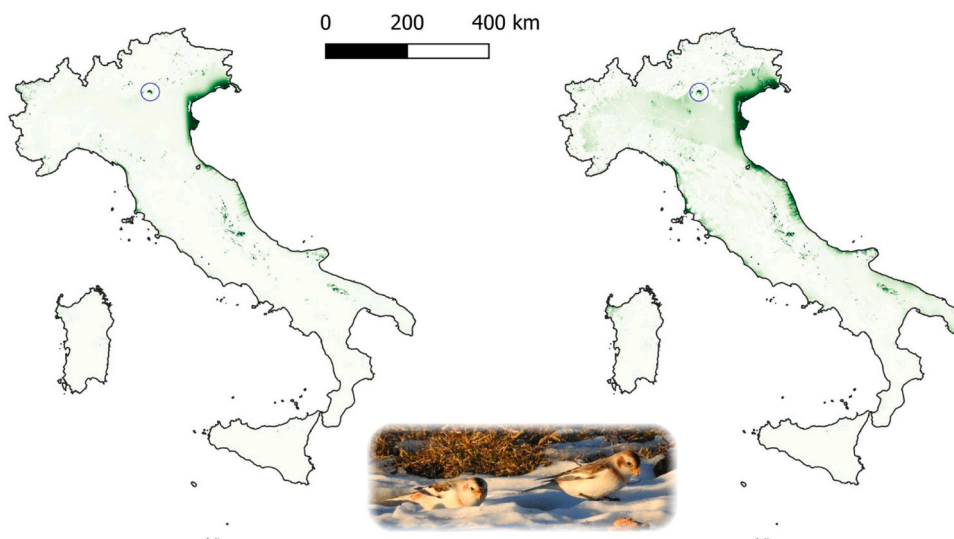
**Fig. 2.** Elevational distribution (m above sea level) of Snow Bunting observations in Italy, 2010–2022. Example photographs feature the northern Adriatic coast (left) and Lessinia plateau (right), the sites from which most of the observations came.



**Table 2**

Species Distribution Models' features and performance: sample size for training and testing datasets, Area Under the Curve of the ROC (receiver operating characteristics) plot (AUC) over the training and testing datasets, omission rate at minimum training presence (OR\_MTP) over the test dataset.

	migration	winter
N training	41	59
N testing	8	13
AUC train	0.91	0.91
AUC test	0.93	0.88
OR_MTP	0.00	0.00



**Fig. 3.** Environmental suitability (from light green/low suitability to dark green/high suitability) for Snow Bunting during the migration (left) and winter (right) periods in Italy according to the respective MaxEnt models. Blue circles indicate location of the Lessinia plateau (main occurrence site for the species in Italy; dark green patch within the circle).

#### 4.1. The cultural relevance of Snow Buntings

Snow Buntings showed the highest ratio between records on social networks and number of observations, indicating that nature recreationists (birdwatchers, nature photographers, nature lovers) have a particular preference for this compared to the other species belonging to the same avian family. Such a pattern may be linked to the aesthetic attractiveness of the species, which shows by far the highest rating compared to the other bunting species occurring in Italy, according to the results of a global evaluation of bird aesthetic attractiveness (Haukka et al., 2023). Some other peculiar traits of the species might explain such a pattern, like its marked adaptation to cold climate and arctic environments despite its considerably small body size, or its gregarious and relatively confident behaviour. The consequences of such a preference are not only evident in the ratio between occurrence and exploitation by observers and photographers, but can be perceived also in the visitation rates of key localities frequented by the species. A striking example is represented by the most important site for the species in Italy, Bocca di Selva, in the Lessinia plateau in Veneto pre-Alps. In ornitho.it (accessed 10th December 2023), at the moment of our search there were 1199 records for “winter” (21st December – 21st March) at Bocca di Selva, of which 205 referred to Snow Buntings - more than one sixth of total observations, despite 50 species had been reported there for the same period. Conversely, only 146 records were found for “summer” (21st June – 21st September) at the same site. This pattern contrasts with all other localities in the same pre-alpine area, where the number of observations is generally higher during the summer, and such a difference could be attributed to the attractiveness of the regularly occurring wintering Snow Buntings.

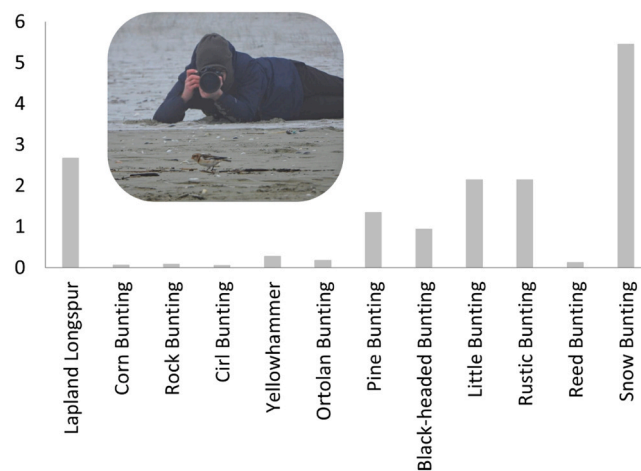
#### 4.2. Snow Bunting distribution in the non-breeding period

According to the data we retrieved, Snow Buntings occur in Italy exclusively from November to April. They do not evenly or randomly occur over different regions, but rather concentrate on northern Adriatic coasts and on plateaus (or, secondarily, valley floors) in mountain regions. More irregular sightings have been reported from the Tyrrhenian coast and a few inland sites. The distribution of observations matches well that of suitable environments, both during the migration and the wintering period. Suitable areas are characterised by relatively cold and dry climates, and by flat or gentle sloping terrain largely occupied by open or semi-open

**Table 3**

Permutation importance and the relative standard deviation (PI  $\pm$  SD) according to the tuned MaxEnt models, computed according to ten permutations, and relative linear effect.

Variable	PI $\pm$ SD	effect
<b>Migration period</b>		
slope	33.3 $\pm$ 0.02	negative
bio7	29.0 $\pm$ 0.01	negative
bio15	10.4 $\pm$ 0.01	negative
bio1	10.2 $\pm$ 0.01	negative
solar_med	9.6 $\pm$ 0.01	negative
natural grassland	7.5 $\pm$ 0.00	positive
<b>Winter period</b>		
bio7	21.5 $\pm$ 0.01	negative
slope	17.7 $\pm$ 0.02	negative
bio1	15.5 $\pm$ 0.01	negative
solar_med	10.6 $\pm$ 0.02	negative
bio15	6.6 $\pm$ 0.01	negative
sclerophyllous vegetation	6.2 $\pm$ 0.02	negative
broad-leaved forest	6.1 $\pm$ 0.01	negative
bare rocks	3.8 $\pm$ 0.01	negative
sparsely vegetated areas	3.5 $\pm$ 0.01	negative
bio12	3.0 $\pm$ 0.00	negative
transitional woodland-shrub	2.2 $\pm$ 0.01	negative
coniferous forest	1.7 $\pm$ 0.01	negative
natural grassland	0.9 $\pm$ 0.00	positive
pastures	0.3 $\pm$ 0.00	positive
mixed forest	0.3 $\pm$ 0.00	negative
beaches, dunes, sands	0.3 $\pm$ 0.00	positive



**Fig. 4.** The ratio between social items per species and availability (expressed as number of observations in ornitho.it).

habitats, such as grassland-like ones (pastures or natural grasslands) and sandy areas. Quite strikingly, most observations occurred either around the sea level (and mostly along the coast), or in mountains at middle elevation (mostly around 1500 m asl, but up to 2000 m), whereas records in between these two belts were much sparser and rarer. This peculiar pattern is related to the occurrence of suitable environments, with open landscapes with grassland and sandy habitats, mostly found along low-lying coasts and at mid elevations in mountain ranges (particularly in the Prealps and central Apennines). Indeed, grassland-like and sandy habitats were the only ones resulting in positive effect on the environmental suitability for snow buntings, whereas taller vegetation types exerted negative effects.

Based on the observed distribution and modelled environmental suitability, the occurrence of the species will likely suffer from ongoing climate variation, and in particular from temperature increase, given the linear negative effect that average temperature exerts on environmental suitability for Snow Buntings. Furthermore, in inland areas like Lessinia the occurrence of the species seems to be linked to the presence of snow on the ground, irrespective of its thickness (Sighele and Lerco, 2015). Given the forecast scenario of decreasing snow cover in the Alpine region (Matiu and Hanzer, 2022), which could be even worse in pre-alpine areas, this could further impact the habitat suitability for wintering Snow Buntings.

Such an expected negative impact mirrors the one forecast for many other cold-adapted species in central-southern Europe, either during the breeding (Brambilla et al., 2022) or non-breeding period (de Gabriel Hernando et al., 2021). Preserving suitable open

landscapes, with grassland-dominated habitats, and relatively unaltered coastal habitats along sandy seashores, is key to the maintenance of suitable stop-over and wintering sites for this climate-sensitive species. At the same time, such measures would also benefit several breeding species that are declining in the same areas because of grassland reduction or degradation, both in Alps and pre-Alps (e.g. Assandri et al., 2019; Brambilla et al., 2021; Anderle et al., 2023) and in the Apennines (e.g. Brambilla et al., 2020b), or because of alteration and heavy disturbance in low-lying coasts (e.g. Puglisi and Meschini, 2016).

### CRedit authorship contribution statement

**Mattia Brambilla:** Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Chiara Bettega:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Corrado Alessandrini:** Writing – review & editing, Validation, Supervision, Conceptualization. **Luciano Ruggieri:** Writing – review & editing, Investigation, Data curation. **Francesca Roseo:** Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data Availability

Data not already included in the paper are publicly available at the following link: [https://doi.org/10.13130/RD\\_UNIMI/DTC3BG](https://doi.org/10.13130/RD_UNIMI/DTC3BG)

### Acknowledgements

We are particularly grateful to all the observers that recorded their bunting observations in ornitho.it and ubird.ebnitalia.it, to M. Azzolini for his help and the inspiring discussions on the species, to A. Ravagnani for the picture of Snow Bunting and photographer in Fig. 4, and to two anonymous reviewers for the helpful comments on a first draft of the manuscript.

### Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gecco.2024.e02875](https://doi.org/10.1016/j.gecco.2024.e02875).

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