Ecological requirements, distribution, and population density of the European Stonechat *Saxicola rubicola* in a high mountain area of the central Apennines, Italy

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Abstract - The European Stonechat (*Saxicola rubicola*) is generally considered a lowland breeder with exceptional occurrences in the mountainous areas of Italy and Greece. The occasional observation of a small but significant population of stonechat at 1850 m a.s.l. in the central Apennines led us to investigate the ecological requirements of the species in this high mountain area. Using the territory mapping method, we identified all breeding territories and their ecological characteristics. We found a close association between the stonechat and the prostrate shrub juniper *Juniper communis ssp. alpina* and discussed the structural similarity of this shrub with the natural heath and moorland habitat of the stonechat in Germany and Great Britain. The surprisingly high population densities found in this study compared to those of neighbouring lowland agricultural habitats suggest that heathland with prostrate shrubs is the original natural habitat of the stonechat wherever the climate permits, from sea level in northern Europe to 2000 m above sea level in Mediterranean countries. Preliminary results from a small sample area show that the mountain breeding stonechat has a long breeding season, from its arrival in early March until its departure in late October. We argue the role of the juniper heaths for shelter and food supply during and after the frequent snow showers in early spring. The association of the stonechat (and other species) with prostrate shrub lands indicates the importance of conserving this habitat in Italy, where the stonechat has recently been classified as endangered (EN) on the national red list. To this end, we recommend in-depth studies on the stonechat-prostrate shrub association in other high mountain areas in Italy and abroad, where, on the one hand, increasing industrialisation of agriculture and, on the other hand, vegetation encroachment due to abandonment of agro-pastoral activity lead to rapid habitat loss and seriously threaten the lowland populations of the stonechat.

Key words: European Stonechat, distribution, central Apennines, high mountain areas, population density, prostrate shrub heaths, *Juniper ssp.alpina,* ecological association, mountain habitat conservation.

Riassunto - Esigenze ecologiche, distribuzione e densità di popolazione del Saltimpalo europeo *Saxicola rubicola*) in un'area di alta montagna degli Appennini centrali abruzzesi.

Il Saltimpalo europeo (*Saxicola rubicola*) viene generalmente ritenuto un nidificante di pianura con presenze eccezionali nelle aree montane di Italia e Grecia. L'osservazione occasionale di una piccola ma significativa popolazione di saltimpalo a 1850 m s.l.m. nell'Appennino centrale ci ha indotto a indagare sulle esigenze ecologiche della specie in questa zona di alta montagna. Utilizzando il metodo della mappatura del territorio, abbiamo identificato tutti i territori riproduttivi e le loro caratteristiche ecologiche nell'area di studio. Abbiamo riscontrato una stretta associazione tra il saltimpalo e l'arbusto prostrato di ginepro ssp alpino e discusso la somiglianza strutturale di questo arbusto con l'habitat naturale di brughiera e lande del saltimpalo in Germania e Gran Bretagna. Le densità di popolazione sorprendentemente elevate riscontrate in questo studio rispetto a quelle dei vicini habitat agricoli di pianura suggeriscono che le brughiere ad arbusti prostrati costituiscono l'habitat naturale originario del saltimpalo, ovunque il clima lo consenta, dal livello del mare nell'Europa settentrionale fino ai 2000 m s.l.m. nei Paesi mediterranei. I risultati preliminari ottenuti in una piccola area campione dimostrano che il saltimpalo anche in alta montagna ha una lunga stagione riproduttiva, dal suo arrivo all'inizio di marzo fino alla sua partenza alla fine di ottobre. Discutiamo il ruolo delle brughiere di ginepro per il riparo e l'approvvigionamento di cibo durante e dopo i rovesci di neve, frequenti all'inizio della primavera. L'associazione del saltimpalo (e non solo) con le brughiere arbustive prostrate indica l'importanza della conservazione di questo habitat in Italia, dove il saltimpalo è stato recentemente classificato come minacciato nella lista rossa nazionale. A tal fine, si raccomandano studi approfonditi sull'associazione saltimpalo-arbusti prostrati in altre aree di alta montagna in Italia e all'estero, dove da un lato la crescente industrializzazione dell'agricoltura e dall'altro l'invasione della vegetazione dovuta all'abbandono dell'attività agropastorale portano a una rapida perdita di habitat e minacciano seriamente le popolazioni di pianura del saltimpalo.

Parole chiave: Saltimpalo, Appennino centrale, alta montagna, densità di popolazione, brughiere prostrate, ginepro *ssp. alpino*, associazione ecologica, conservazione habitat montano.

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INTRODUCTION

The Stonechat *Saxicola rubicola* is a polytypical species with a Palaearctic-Paleotropical distribution, which in Italy is more widespread up to ca. 1000 m, with scarce and localised occurrences up to 1400-1500 m and max. of 1800-1850 m in the Alps, 1900-1950 in the Abruzzo Apennines and 1920 m on Mount Etna in Sicily (Brichetti & Fracasso, 2022). Its altitudinal distribution follows a parabolic profile with high frequency values at sea level, decreasing rapidly with increasing altitude (Meschini, 2011; Hueting, 2022). This representation of detection frequency does not consider the altitudinal distribution of the Italian territory, nor the vegetation cover suitable for the species along the altitudinal gradient, nor the

survey effort employed at the different altitudes. Likewise, the ecological requirements and the environments frequented by the species during the breeding season at lower altitudes are well known and described both in Italy and abroad (Great Britain, Germany, the Netherlands) with population densities that rarely exceed 2 cp/ 10 ha. (Cramp & Simmons, 1988; Urquhart & Bowley, 2002 Brichetti & Fracasso, 2022), whilst at altitudes above 1,500 m, there is a lack of in-depth research into both the environmental requirements of the stonechat and the capacity of the mountain habitat to support the species' reproduction. Information is limited to occasional sightings during the breeding season on the Ornitho.it portal (https://www.ornitho.it), sketchy distribution and habitat data in ornithological atlases, and the abundance assessments of the MITO monitoring (Fornasari *et al*., 2010), which focus not so much on actual values but on recording changes in relative values over the long term. Given the worrying conservation status of the stonechat in Italy, classified EN (endangered) in the Italian Red List (Gustin *et al*., 2021), it is necessary to fill the knowledge gaps on the ecological preferences, distribution, abundance, and threats of the species at altitudes above 1000 m a.s.l. For this reason, when at the beginning of September 2021, we accidentally identified 3 territories of stonechat in presence of juveniles in an area of about eighteen hectares between 1650 and 1850 m a.s.l. along the south-western slopes of Mount Cefalone (AQ), we decided to study the ecological requirements of the stonechat, breeding at altitudes above 1500 m a.s.l. Its occurrence and population density in specific habitats at these elevations should provide insights into its requirements and offer valuable guidance for habitat conservation.

MATERIALS AND METHODS

Study period

During the breeding season of 2022, we carried out surveys from the beginning of June to the end of October to map all occupied territories in the study area and to confirm the three territories that prompted us to start this research, found at the beginning of September 2021. From June to the end of July, in the following breeding season of 2023, we monitored all the areas surveyed the previous year between the beginning of August and the end of October, when the birds were engaged in moulting and their consequent lower contactability made the surveys less reliable. (Haukioja, 1971; Vega Rivera *et al*., 1998). In addition, during the same period, we surveyed the few suitable areas not visited in the previous breeding season. In 2023, in a restricted sample area of 25 hectares near the Campo Felice bauxite mine, we extended the study period from March, when the first birds arrive, until the end of October, when the last birds leave the area. This allowed us to obtain clusters of data that should provide a better understanding of some aspects of the population dynamics in the sample area, like weather influence and phenology.

Study area

At first sight, the common feature of the three stonechat territories between 1650 and 1850 m a.s.l. was the presence of a dwarf shrub, *Juniper communis* ssp. alpina, with sparse perches, just above the tree line. Therefore, we selected a large study area in the central Apennines with alternating presence and absence of prostrate shrubs at altitudes between 1500 and 2100 m above sea level. The environmental screening of the breeding territories and population density in this area should reveal the ecological requirements of the stonechat, breeding in a natural, uncultivated mountain habitat. The calcareous massif of Monte Velino, whose summit reaches 2486 m a.s.l., is located in the inland sector of the central Apennines (Fig. 1B), in the province of L'Aquila, and is almost equidistant from the Tyrrhenian coast to the west and the Adriatic coast to the east. The study area, with a total area of 5,500 ha and centre coordinates 42°12'50" N - 13°25'24" E, was selected in the northern sector of the imposing chain, in the area commonly known as Montagne di Lucoli, with a vertical range between 1450 m a.s.l. at Piani di Pezza and 2174 m a.s.l. at Monte Puzzillo (Fig. 1A).

The morphology of the area is characterised by the formation of two vast intramontane basins of tectonic-carstic origin (Campo Felice and Piani di Pezza), and a wide valley of glacial origin (Valle del Puzzillo). The mountain ridges that surround and separate these geomorphological structures, are defined in a clockwise direction and starting from the north-western extremity of the area: M. Orsello (2043 m); M. Cefalone (2143 m); Serralunga (1909 m); Monte Rotondo-Colle del Nibbio-Punta dell'Azzocchio-Cimata di Pezza-Cimata del Puzzillo ridge at altitudes between 1914 and 2140 m; Vena Stellante-il Costone (2239 m); Coste del Morretano (2131 m) and, finally, the Fratta-Cornacchia-Puzzillo ridge between 1878 and 2174 m.

The mountain ridges described develop in all cardinal directions, resulting in a wide variability of slope exposures. Except for a few cases, the slopes are up to 30% steep, with some exposed and hardly accessible sections. Due to the strong permeability of the limestone substrate, the hydrography is rather poor.

The climatic analysis of the Italian territory according to the criteria of Rivas-Martinez *et al*. (2011) carried out by Pesaresi *et al*. (2014) highlights for the study area the oceanic temperate macroclimate with an upper supratemperate thermotype and an ombrotype from lower humid to upper humid according to elevation. Subsequent analyses confirm this climatic interpretation of the area (Cutini *et al*., 2021, Stanisci *et al*. 2021). The climate of the Piano di Pezza, part of the study area, was framed in the same way by Ciaschetti *et al*. (2006). It should also be emphasised that the particular position of the two basins Piani di Pezza and Campo Felice often determine the phenomenon of thermal inversion with winter temperatures dropping as much as 30 degrees below 0 in the lower layer (between 5 and 10 meters thick) of the air column. These climatic characteristics determine a number of important parameters, such as the duration and consistency of snow cover at different altitudes, and the duration, frequency, and severity of dry periods in summer. Both have a decisive impact on the vegetation microclimate.

In addition to the zonal macroclimate, exposure, relief and altitude decisively affect the microclimate and can vary considerably within a few meters (Körner, 2021).

The Serralunga, the southern slope of the Monte Rotondo-Cimata del Puzzillo chain and the Piani di Pezza, about 25% of the study area, fall within the boundaries of the Sirente-Velino Regional Natural Park.

In the altitudinal range 1500-2200 m a.s.l. of the survey area, the vegetation landscape is characterised by a few units that can be classified in the following categories summarized from vegetational studies in the region (Avena & Blasi, 1980; Blasi *et al.,* 1990; Petriccione, 1993; Stanisci, 1997; Corbetta *et al*.,1999; Pirone *et al.,* 2007; Pirone, 2016).

- Woodland community (1500-1800 m), with an area of 1250 ha (22%), including 100 ha of coniferous reforestation. The forests consist almost exclusively of Beech (*Fagus sylvatica*).
- Hygrophilous formations of shrubby willows *Salix spp* (1500-1600 m) - 2%; vertical development: 150-300 cm. These small communities have emerged in the basins of the abandoned bauxite and crushed stone quarries at Campo Felice and Piani di Pezza.
- Mountain shrubs (1500-1900 m) - 2%; vertical development: 50-200 cm. Shrubs are the least widespread vegetation element in this area. In fact, we found only one rather compact *Juniperus communis* grove extending for about fifty hectares along the southern slope of Monte Orsello between 1500-1650 m.
- Prostrate montane evergreen shrublands (1500-2100 m a.s.l.). Vertical development: between 20-50 cm. In the study area, favoured both by ecological conditions and, in some sectors, by the coppicing of the forest and the action of grazing, they represent the most widespread vegetation (1750 ha, ca. 32%). Isolated shrubby elements tower above the homogenous cover of the prostrate formations with an aerial development of between 50-150 (200) cm. These shrublands are usually present above the tree line (1700 m a.s.l.), but under certain circumstances, particular climatic conditions can create a double tree line, with the normal upper one and the other at the lower limit of the forest, where tree growth is not possible due to extremely low temperatures during periods of thermal inversion in winter. This is the case in the Campo Felice (1600 m a.s.l.) and Piani di Pezza (1500 m a.s.l.) basins and determines the double tree line ecotone with abundant juniper heath growth on both sides of the beech forest.
- Secondary grasslands (1500-1700 m) with a total area of approximately 1400 ha (25%) are mainly located in the Campo Felice and Piani di Pezza basins; vertical development: 10-50 cm.
- Primary grasslands (1700-2200 m) with an estimated area of 400 ha (7 %); vertical development: 10-30 (60) cm. The high-mountain primary grasslands that develop beyond the limits of the beech forest and prostrate shrublands are conditioned by soil characteristics, exposure and grazing, forming complex mosaics composed of a large number of associations. Over 2000 m. a.s.l., discontinuous grassland environments form in the upper plateaus. At the base of the snow beds, where there is a significant accumulation of soil, mesophile grasslands develop.
- Chasmophytic and azonal vegetation (1500-2200 m).
- Pioneer vegetation of gravel and screes, glaericola (1500-2100 m) - area of approximatelty 400 ha (7 %) with discontinuous cover; vertical development: 50-250 cm.

Study species

The stonechat is a species with marked morphological and attitudinal characteristics that are easily recognised in the open field both in flight, during trophic activities, and perched, typically on elevated elements, when scanning the territory for prey or predators. As a territorial species par excellence, it defends its territory, between 0.8 and 4 ha in area, throughout the nesting period (Urquhart & Bowley, 2002). A pair occupies well-defined spaces with rare excursions outside its breeding territory (disturbance and/or escape from predators), so sighting 'clusters' may consist of a few successive observations of the same individual to give a measure of habitat suitability.

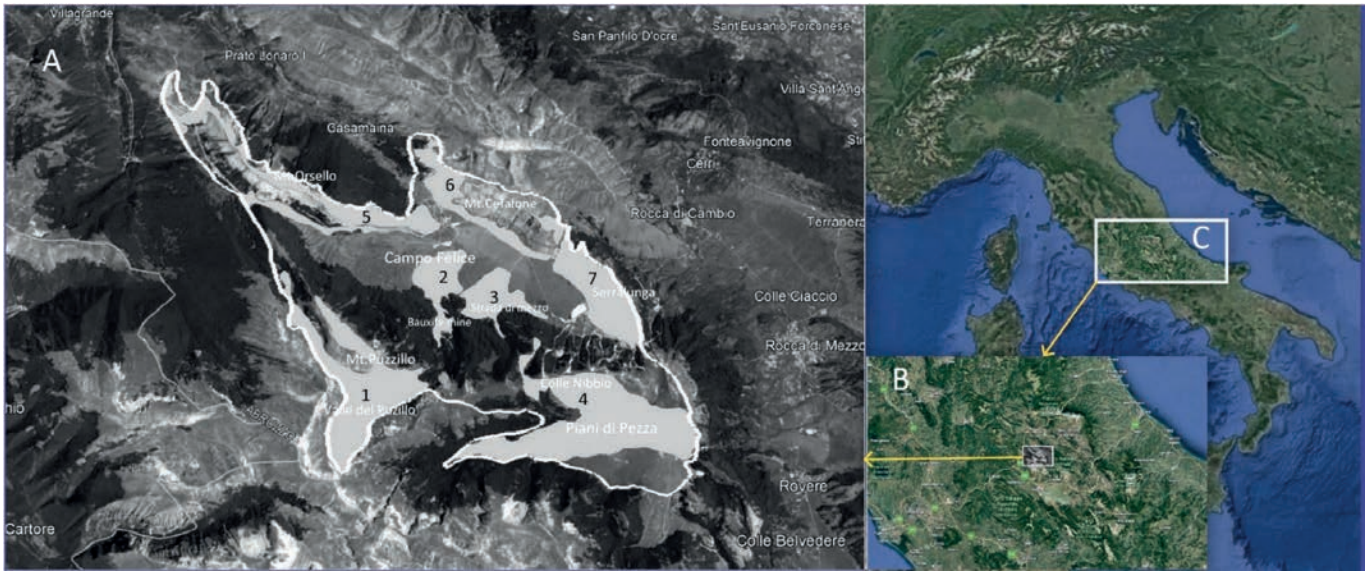

Fig. 1 – Study area (white line) with the 7 macro-areas (in grey) selected for population density estimates (A) and its position in Central Italy (B) and Italy (C). Google Earth: Landsat / Copernicus Data SIO, NOAA, U.S. Navy, NGA, GEBCO. / Area di studio (linea bianca) con le 7 macroaree (in grigio) selezionate per la stima della densità di popolazione (A) e la sua posizione in Italia centrale (B) e in Italia (C). Google Earth: Landsat / Copernicus Data SIO, NOAA, U.S. Navy, NGA, GEBCO.

Methods

For the definition of the areas to be surveyed, we applied a first 'stratification' (Gregory *et al*., 2004), excluding those areas where the presence of the species was highly unlikely, such as forests, screes, and areas inaccessible due to excessive steepness with slopes above 35 degrees. A second stratification was applied during the fieldwork, devoting less attention to areas where, according to the results obtained, the probability of observation was minimal (e.g., extensive grazed or summit grasslands without perches).

For monitoring, we used the mapping method (Bibby *et al*, 2000; Gregory *et al*., 2004). Territory mapping of a single species requires at least four visits of each territory (Gregory *et al*., 2004). The extension of the area surveyed, and the difficulty of the terrain did not allow us to repeat all the tracks four times in the same breeding season. However, the confirmation of all 40 territories along the tracks repeated at least four times in the two subsequent years (2022 and 2023) should allow for the assumption that also the position of other territories identified in just a single visit would be confirmed by four or more surveys. Furthermore, the efficiency of the surveys increases with the contactability of a species, which, in the case of the stonechat in a mountainous environment, is excellent. The vegetation does not exceed 50 cm in height and allows any movement of the birds to be recorded even with the naked eye and successive determination, when perched, with binoculars or spotting scopes, if necessary. Thus, although not sufficient to determine the exact territory extension, we believe that even a single visit to each investigated area can still allow for a reasonably accurate estimate of the distribution and population density of the stonechat on the one hand and its habitat characteristics on the other. Presumably, if ever, density values might be underestimated but not overestimated.

We selected walking routes through all accessible open areas (thus excluding those with a slope greater than 35 degrees) without discriminating a priori between suitable and unsuitable areas, except for the premise of the first stratification. Among these areas, we distinguish the six main target areas: the Monte Orsello chain, the Monte Cefalone-Passo della Brecciara chain, the Colle Nibbio- Monte Rotondo chain, Campo Felice up to the beech forest edge and bauxite mine, the Monta Fratta-Monte Puzzillo chain, including both the underlying Morretano Valley and the Puzzillo Valley and finally the Piani di Pezza. Along the tracks, we made regular stops approximately every 200 m to assess the presence of the species with acoustic and optical detection (binoculars and telescope). The distance of 200 m between successive stopping points is justified by the fact that breeding territories with a qualitatively uniform environment and a maximum area of four hectares (Urquhart & Bowley, 2002) can be considered nearly circular with a maximum radius of 110 m. Before reaching each subsequent observation point, we had a preliminary look at that point for a few minutes from a long distance with the telescope, thus avoiding any possible disturbance of both the birds and their natural on-site position later verified from a shorter distance. In this way, from posts with maximum visual aperture chosen on-site, we recorded all individuals of stonechat present within a radius of approximately 150 m and visually estimated the vegetation cover with its biological (species and ecological association) and structural (vegetation height, slope) characteristics.

In addition, we verified the simultaneous presence of two adult males in adjacent territories to avoid any bias in the allocation of territories. The average time taken for each km, equivalent to 20 ha investigated, was one hour. We introduced the exact location of all birds in their territory as geo-referenced data in the ornitho.it database. Where data cluster size permitted, we calculated the size of the territories and home ranges in two ways: i) minimum convex polygon (Hayne, 1949), which contains the topographic cluster of all sightings and defines the area where the birds spend most, if not all, of their time; ii) total suitable area investigated divided by the number of different males surveyed in that area. In the case of saturation of the surveyed area, i.e., with the maximum number of pairs that the environment can support, this area contains the breeding territory of any male and a buffer zone separating it from adjacent stonechat territories.

The investigated area corresponds to the 200 m wide strip along the walking route (100 m on both sides). We calculated this area with the aid of Google Earth Pro tools.

We estimated the land cover for each territory within a radius of 100 m around its probable centre with the division into four categories: i) bare rock and gravel outcrops; ii) prostrate shrubs (dwarf juniper, bearberry); iii) shrubs or other elements used as perches; iv) high mountain grassland (*Carex, Sesleria*).

In the present survey, we decided not to search directly for the location of nests to avoid disturbance. Nests in lowland agricultural environments, usually positioned on the ground under the herbaceous vegetation at the edge of drainage ditches or under a shrub, can be found rather easily and quickly in the temporary absence of the adults. On the contrary, searching for nests on the ground well hidden under the dense and thorny foliage of dwarf juniper would take a long time and would inevitably cause disturbance to the microhabitat surrounding the nest. Therefore, we deduced the location of the nests indirectly from behavioral indications: transport of nest material by the female, food transported to the chicks not yet fledged, the site where newly fledged chicks, unable to travel long distances, spend most of their time and position of the male on guard during incubation of the eggs by the female usually not far from the nest.

RESULTS

During the two breeding seasons (2022 and 2023), we investigated 2000 ha of the 5000 ha study area after excluding wooded areas (1250 ha), screes and rupestrian environments (375 ha), summit grasslands above 1900 m a.s.l. (375 ha) and part of the secondary grasslands of Campo Felice and Piani di Pezza (1000 ha). We found 113 breeding territories in 2022. In 2023, we found another 35 territories in areas not surveyed in the previous year and confirmed the presence in 48 of the 52 territories visited in both breeding seasons. In the two years (2022 and 2023), we carried out at least four control visits of 40 territories out of all 148. These control visits consistently confirmed each breeding site and enabled estimates of the territory area. In all territories surveyed, dwarf juniper was present alternated by grassy meadows with scattered stands of *Rhamnus alpina*

subsp. fallax, Rosa pendulina, Viburnum, Raven Pear, Sorbus chamaemespilus, and *Pinus nigra*. Stony skeleton was often present but not decisive. We found no territories in environments lacking dwarf juniper. Fig. 2 represents the percentage of the territory area occupied by prostrate Juniper for all stonechat territories surveyed in 2022.

The apparent selection preference for territories covered roughly 50% by juniper was consistent along the altitudinal gradient, as shown in Fig. 3.

Excluding elevation from 1900 m to 2000 m, where only one territory was found, the distributions in Figs. 2 and 3 suggest a preference of the stonechat for 40 to 50 % ground cover with dwarf juniper, but it also breeds with lesser or greater cover between 20 and 80 %. With an assessed average rocky skeleton cover of 7.5 %, the remaining cover with juniper-associated alpine grassland varies between 42.5 and 52.5%.

In all the territories surveyed, there were some vegetal perches at least twice as high as the dwarf shrub environment. In the undulating areas of the Piani di Pezza, Campo Felice, the bauxite mine area, and the Puzzillo Valley, also the tops of the moraine knolls were used as perches and guard posts. In extensive heaths on the slopes lacking suitable perches, we found no stonechat territories. An example of the need for perches was the presence of a single stonechat territory on the southern slope of Colle Nibbio at 1750 m a.s.l. precisely where a small depression allowed the growth of a Pinus nigra as a suitable perch (Fig. 4).

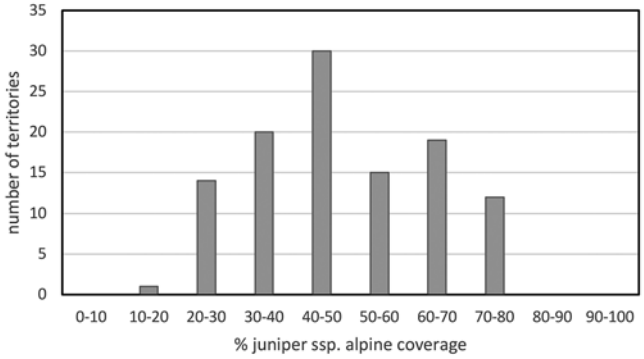

Fig. 2 – Number of territories with increasing juniper ssp. alpine coverage. / Numero di territori con copertura alpina crescente di ginepro ssp.

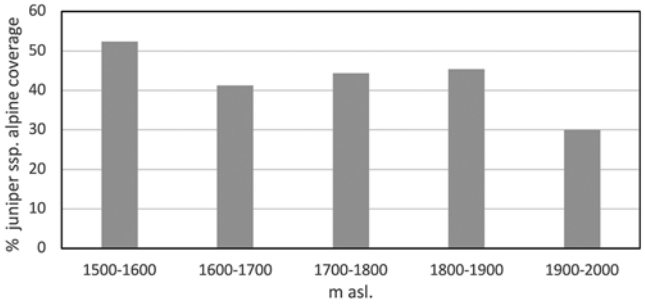

Fig. 3 – Medium juniper ssp. alpine coverage of stonechat territories over the elevational gradient. / Copertura media di ginepro ssp. alpina dei territori del saltimpalo lungo il gradiente altitudinale.

Fig. 4 – Juniper ssp. alpine shrublands on the southern slope of Colle Nibbio at 1750 m. a.s.l. without suitable perches except the one at the center where we have found the only breeding territory of the stonechat in the area (photograph by S. Hueting). / Arbusteto di ginepro ssp. alpina sul versante meridionale del Colle Nibbio a 1750 m s.l.m. senza posatoi adatti, tranne quello al centro dove abbiamo trovato l'unico territorio riproduttivo del saltimpalo nella zona (fotografia di S. Hueting).

To establish whether the necessary presence of dwarf juniper was due to its prostrate structure or to its general biological properties, we surveyed a control area of 30 ha at the base of the southwestern slope of Monte Orsello. Here, between 1350 and 1500 m above sea level, the habitat is characterised by the presence of upright common juniper with similar percentages of coverage (about 40%) to those found for prostrate juniper at higher altitudes on the same slope. The population density was found to be 0.7 pairs/10 ha, much lower than at higher altitudes (Tab. 1) where dwarf juniper was present as shown in Fig. 5.

Behavioural observations of single individuals or families of stonechats indicated the relevance of dwarf juniper for reproduction and nest site:

- the female carried nest-building material inside a dwarf juniper shrub (Fig. 6);
- recently fledged young unable to fly for long distances were always perched on juniper bushes probably very near to their nest;
- during the incubation period of the female, the male spent most of its time perched on a juniper bush;
- adults bring food entering into juniper bushes or feeding recently fledged young on juniper dwarf shrub. We saw an adult male take prey in a meadow at 1537 m a.s.l. It then flew uphill for 60 m with the prey, left it in a juniper bush at 1557 m a.s.l. and returned to capture more prey in the same meadow;
- we have never observed behaviour indicating the presence of nests outside the juniper shrub cover.

Based on the ecological preferences shown by the stonechat, we determined the areas suitable for its reproduction inside seven sectors (1 to 7 in Fig. 1) of the study area with a total investigated area of 2000 ha.

Tab. 1 shows the distribution and population density of the species in the suitable parts of the seven macro-areas, identified along the altitudinal gradient. Finally, Tab. 2 contains data on the presence of the stonechat obtained by increased survey frequency in a restricted sample area of 25 hectares near the Campo Felice bauxite mine. In Tab. 2, data of first sightings do not represent data of stonechat spring arrival in the study area. However, during the earliest visit of March 23 to the sample area, eight out of ten territories were found to be occupied, suggesting that the first stonechats arrived several days before March 23. Further investigation into the phenology of the mountain breeding stonechat population is currently ongoing (to be published in a next paper) and suggests that their spring arrival begins in the first days of March.

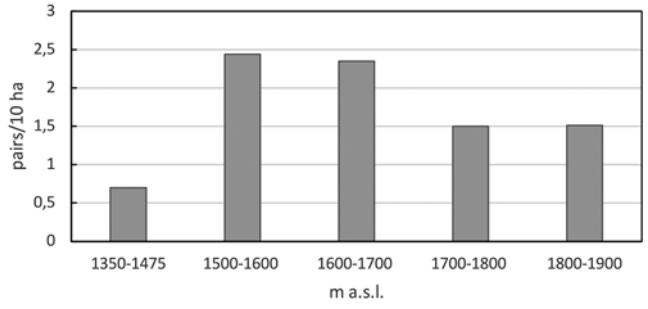

Fig. 5 – Population density over the elevation gradient in pairs/10 ha. / Densità di popolazione lungo il gradiente altimetrico in coppie/10 ha.

Tab. 1 – Distribution (T, territories) and population density (pairs/10 ha) of the stonechat in suitable habitat (SH) of seven macro areas along the altitudinal gradient. / Distribuzione (T, territori) e densità di popolazione (coppie/10 ha) del saltimpalo nell'habitat idoneo (SH) di sette macroaree lungo il gradiente altitudinale.

Macro area	Survey area, ha	1500-1600 m a.s.l.			1600-1700 m a.s.l.			1700-1800 m a.s.l.			1800-1900 m a.s.l.			All elevations		
		T	SH, ha	Pairs/ 10 ha	T	SH, ha	Pairs/ 10 ha	T	SH, ha	Pairs/ 10 ha	T	SH, ha	Pairs/ 10 ha	T	SH, ha	Pairs/ 10 ha
Puzzillo	400							4	20	2	5	43	1.16	9	63	1.43
Miniera	150				18	64	2.81 (3.2)							18	64	2.81
St.Mezza	150				2	18	1.11	1	12	0.83				3	30	1
Nibbio/Pezza	500	43	192	2.24 (3.0)	1	17	0.60	2	38	0.53				46	247	1.86
Orsello	300	2	7	2.85	13	51	2.55	4	26	1.54	1	2	5	20	86	2.33
Cefalone/Forcamiccia	250	7	20	3.50	7	26	2.69	5	20	2.5	7	34	2.06	26	100	2.58
Serralunga	250	10	35	2.85	5	20	2.50	7	37	1.89	2	20	1	24	112	2.14
Total area	2000	62	254	2.44	46	196	2.35	23	153	1.5	15	99	1.51	148	702	2.02
Population density		2.44 pairs/10 ha			2.35 pairs/10ha			1.50 pairs/10 ha			1.51 pairs/10 ha			2.11 pairs/10 ha		

Tab. 2 – Numerical breeding codes (British Trust of Ornithology), first and last sightings, total number of cluster data (N) and territory area (ha) for the years 2022 and 2023. / Codici numerici di riproduzione (British Trust of Ornithology), primo e ultimo avvistamento, numero totale di cluster (N) e area del territorio (ha) per gli anni 2022 e 2023.

	2022				2023				2022/2023
Territory	Code	First sighting	Last sighting	N data	Code	First sighting	Last sighting	N data	Territory area (ha)
1	2	16/6	21/7	2	12	23/3	29/9	8	1.00
2	3	16/6	17/10	2	14	23/3	29/9	14	1.34
3	3	16/6	25/10	4	12	23/3	29/9	17	1.76
4	3	16/6	17/10	4	3	23/3	18/10	12	1.43
5	3	21/7	25/10	2	14	23/3	18/10	14	0.86
6	3	21/7	7/10	3	12	29/3	29/9	10	1.75
7	3	21/7	7/10	2	3	23/3	29/9	12	1.63
8	3	21/7	21/7	1	12	23/3	29/9	11	0.46
9	12	21/7	21/7	1	3	23/3	29/9	12	1.00
10	12	7/10	7/10	1	12	22/4	9/8	5	0.96
Total area of all territories									12.19
Average territory area									1.22
Total sample area									25.00
Average home range									2.50

Fig. 6 – Female stonechat with nesting material on juniper ssp alpine shrub just before reaching the nest hidden inside (photograph by S. Hueting). / Femmina di saltimpalo con il materiale per il nido su un arbusto di ginepro ssp. alpina poco prima di raggiungere il nido nascosto all'interno (fotografia di S. Hueting).

DISCUSSION AND CONCLUSIONS

The European stonechat, as a lowland breeder, is a well-studied species. However, knowledge of the ecological requirements, reproduction, and population dynamics in high mountain habitats is scarce or even lacking at all. In this study, we describe for the first time some aspects of a stonechat population breeding in a high mountain area above 1500 m a.s.l. in Central Italy. In suitable habitat, strictly associated with the presence of the alpine juniper shrub (Figs. 2 and 3) the population density is surprisingly high with values rarely reported in lowland populations (Tabs. 1 and 2). These results are consistent with the MITO monitoring report of common breeding birds in Italy between 2000 and 2004 (Fornasari *et al*., 2010), where the stonechat showed a decreasing abundance with altitude but with a significant discontinuity at 1500 m where abundance increased to 10%

of the abundance at sea level. Fig. 5 of the present study shows the same discontinuity with maximum population densities between 1500 and 1700m a.s.l. Below 1500 m, vegetation encroachment, afforestation, and absence of dwarf shrubs limit abundance and population densities. Between 1500 and 1600 the abundant alpine juniper heaths in the Piani di Pezza and Campo Felice basins sustain population densities at 2.5 pairs/10 ha with maximum values of 4 pairs /10 ha (Tab. 2). Here, at 1620 m above sea level, we found ten territories in both 2022 and 2023, with an average territory area of 1.22 hectares and an average home range of 2.5 hectares, which included a buffer zone between adjacent territories. We found evidence of breeding in eight of the ten territories and two pairs, possibly breeding, in the remaining ones. At altitudes above 1650 m a.s.l., population density decreases lightly. This decrease might be due to the increasing influence of the local climatic conditions in spring when stonechats arrive and occupy their territories (Fig. 7). Above the tree line in the central Apennines, from 1700 m a.s.l. upwards, snow cover often protracts until the end of April, creating a mosaic-like pattern of snow beds and interspersed uncovered vegetation up to 1900 m a.s.l. Above this altitude, complete snow cover persists for too long and does not allow the stonechat to settle within the time required to start breeding.

Important preliminary data (Tab. 2) on the phenology of the sample population show that the stonechat is an obligatory migratory species at altitudes above 1500 m a.s.l. in the central Apennines. The reproductive season starts surprisingly early for a mountain breeding species, with the arrival of the first males well before the end of March when all territories were found occupied by at least one individual, while all other migratory breeding species associated with the dwarf juniper heath were still absent. Evidently, the stonechat, as a short-distance migrant, has the opportunity to choose the best territory, which compensates for the inconvenience of the harsh conditions of early spring. From March to the end of April, frequent snowfalls covered the area with several cm of snow (Fig. 7). Under these circumstances, the prostrate juniper offered shelter and food under its canopy, saving the birds. Fall migration starts at the end of September, with the last birds leaving the area the last week of October. It is noteworthy that the environmental conditions at the end of October in both 2022 and 2023 were excellent, with an abundant presence of prey (orthoptera) and mild temperatures. Thus, the fall migration of our study population seems to be triggered by endogenous rhythms and photoperiod, excluding altitudinal movements to lower areas forced by changes in temperature and food availability.

Our results clearly demonstrate the stonechat's ability to survive in high mountain habitats. In Central Italy above 1500 m a.s.l. its presence is strictly associated with the alpine juniper prostrate shrub (Figs. 2 and 3). We did not find any breeding evidence of the stonechat above 1500 m a.s.l. without presence of this shrub. These findings implicate that the distribution and abundance of the stonechat in high mountain areas might be proportional to the distribution of the juniper dwarf shrub. According to a report by the European Environment Agency (EEA), the main strongholds of alpine juniper are found in the Pyrenees (Spain), the Massif Central (France), the Alps, the Apennines in Italy and the high mountains of Bulgaria (https://eunis.eea.europa.eu/

Fig. 7 – Panorama of the sample area near the bauxite mine in the Campo Felice plain with territories 1, 2, 3, 5 and 9, on 28 March 2023 (photograph by S. Hueting). / Panorama dell'area campione nei pressi della miniera di bauxite nella piana di Campo Felice con i territori 1, 2, 3, 5 e 9, il 28 marzo 2023 (fotografia di S. Hueting).

habitats/8148). Unfortunately, although bird atlases and single observations confirm the presence of the stonechat in those high mountain areas, we did not find any systematic analysis of its habitat preferences and population dynamics. In Spain, the altitudinal breeding range of the stonechat is reported to be between 300 and 1300 a.s.l. (Martí & Del Moral, 2003), although exceptionally present in juniper groves at 2200 m a.s.l. in the Sierra Nevada with densities of 0.45 ind. /10 ha. (Zamora & Barea-Azcón, 2015). In France, in the Auvergne-Rhône-Alpes district, out of 150,000 observations of stonechat, only 481 were reported between 1500 and 2000 m a.s.l. (Tarier patre, l'Atlas de la faune vertébrée de la LPO Auvergne-Rhône-Alpes et ses partenaires) but in the Parc national des Ecrins, between 1977 and 2022, 13.8 % of the stonechat observations were reported above 1500 m a.s.l. (Tarier pâtre - Saxicola rubicola | Biodiv'Écrins - Parc national des Écrins (ecrins-parcnational.fr). On the Massif Central, between 1300 and 1400 m, density of 0.2 pairs/10 ha was observed (Lovaty, 2022). For the whole of France, it is considered rare or absent above 1300 m a.s.l. (Cahiers d'Habitat "Oiseaux" - MEEDDAT- MNHN). In Switzerland, it is rare above 800 m a.s.l. but with sporadic reports in 1998-2012 between 1500 and 2050 m a.s.l. (Knaus *et al*., 2018). In Bulgaria, at a latitude similar to that of the study area, it breeds between 0 and 600 m a.s.l., but with several reports in the mountains between 1500 and 2200 m a.s.l., including historical ones (1932, Vitosha; 18-23.07.1933 above the Rila Monastery at approx. 1,800 m a.s.l.) (Iankov, 2007). Finally, in Italy, the occurrence in the Alps above 1500 m a.s.l. is considered quite exceptional (Caula *et al*., 2009), but the 301 occasional sightings, not the result of targeted surveys, reported from 2010 to 2023 on the portal www.ornitho.it (operational since 2009), suggest a more consistent presence. For the whole of Italy, 749 observations above 1500 m a.s.l., mainly in the Apennines (our study area excluded), are reported. Although these data are scattered and not circumstantiated, they indicate a potential correspondence between areas of occurrence of the stonechat and the distribution of alpine juniper. Clearly, further investigation is needed to confirm the association of the stonechat and the alpine juniper heaths outside our study area.

The vegetation structure preferred by the stonechat in our study area resembles the natural lowland habitats of the stonechat in inland Great Britain (Glaves, 1998; Pearce-Higgins & Grant, 2006; Callion, 2015), the Netherlands (van Oosten, 2016) and Germany (Mildenberger, 1950; Pfeifer, 2000), characterized by heaths and moors of ericaceae (*Calluna vulgaris*), *gorse Ulex europaeus*, bracken *Pteridium* sp. and creeping willow *Salix repens*. Thus, the structure of the natural (vs agricultural) stonechat habitat, unaffected by human transformation, seems to be the same throughout its breeding range, possibly for the following reason. Like the other heaths, the dwarf juniper heath provides a microclimate beneath the canopy of the prostrate shrubs that is markedly different and less variable than that on the outside, which is of vital importance in spring when weather conditions can be extreme (Körner, 2021; Körner & Hiltbrunner, 2021). Protected from snow, wind, excessive summer heat and predators, the stonechat finds an excellent environment here for breeding, resting and shelter. Jähnig *et al*. (2018) in their study of the distribution and diversity of birds in an Alpine forest shrub ecotone confirm 'the general overall importance of shrubs can easily be understood as they provide nesting habitat for shrub-nesting species, provide shelter in harsh weather conditions and can shield birds from predators'. Moreover, the longevity and resilience of the dwarf juniper and the phytosociological association to which it belongs in the Apennines (Stanisci, 1997) guarantee a long-term stable breeding habitat for the stonechat. Indeed, 20 records of the presence of the species, collected occasionally in different areas of the study area between 2013 and 2020 (Hueting & Santucci, unpublished), all fall within territories surveyed during the study period between 2021 and 2023, and thus consistently demonstrate the stability of the breeding territories over the years.

The close association between the stonechat and dwarf juniper heathland leads to a general reflection on the ecological characteristics of the species and its present distribution in Europe. Although considered a lowland breeder, more widespread in lowland agricultural areas at altitudes of less than 600 m above sea level, it seems unlikely that the stonechat colonised these areas before pre-existing natural environments such as coastal and mountain heaths. Evolution generated the stonechat species around 2 million years ago (Wink *et al*., 2002), long before the advent of pastoralism and the invention of agriculture and the subsequent deforestation of Europe. It is possible, therefore, that its current ecological needs reflect those associated with the prehistorical open area vegetation along the coasts and above the tree line, the heaths. Even during and between the last ice ages, the distribution of the stonechat may have followed the successive contractions and expansions of dwarf juniper heaths longitudinally and altitudinally (Covas & Blondel, 1998; Michalczyk *et al.*, 2010). In traditionally managed agricultural areas, which have progressively replaced forests since 1000 A.D. (Kaplan *et al*., 2009) the species has found an additional ecological niche favourable to reproduction though allowing population densities that rarely exceed 2 pairs /10 ha (Brichetti & Fracasso, 2022). A maximum density of 1.7 pairs /10 ha (69 pairs /415 ha) was recorded in a test area in such a traditionally managed agricultural environment in central Italy at 730 m a.s.l., 40 km from the study area (Hueting, unpublished results). These values indicate that the agricultural environment, although suitable, is not able to sustain the population densities recorded in the optimal mountainous environment.

Because the stonechat in the high mountain range of the central Apennines appears to be closely associated with the presence and distribution of the dwarf juniper, its fate is therefore linked to that of this shrub, which is hardy, long-lived (Thomas *et al*., 2007; Pellizzari *et al*., 2014) and widely distributed above the tree line. In the central Apennines, its presence increased by 10% between 1954 and 2012 largely due to the abandonment of intensive mountain pastures (De Toma *et al*., 2022). Nonetheless, the authors argue a positive effect of moderate grazing on dwarf shrub encroachment, furthermore, recommended by the EEA for the conservation of the dwarf shrub habitats in high mountain areas. As long as climate change, with prolonged periods of summer drought and heat waves, does not prevent its further spread (Garcia *et al*. 1999), the stonechat will be able to maintain and perhaps increase its montane range in the central Apennines. In the European

Red List of Habitats, the Alpine and subalpine Juniper scrub is considered 'least concerned' stating that "the habitat is widely spread in the territory of the EU. In the past 50 years, an increase in area of about 10% has been observed and only 5% are slightly degraded. Though the estimated future trend indicates a relatively good prospect, we have to take some threats into consideration, like global warming, afforestation and tourism. Appropriate monitoring of this habitat type is recommended" (https://eunis.eea.europa.eu/habitats/8148). According to this recommendation, important long-term research on the role of climate change in the ecology of the mountain habitat of the central Apennines is underway (Stanisci *et al*., 2021; De Toma *et al*., 2022) although limited to its vegetation only. It seems to us opportune to include in these investigations animal species (insects, reptiles, birds and mammals) that reproduce within the high mountain ecological niches and their respective plant associations, as already suggested in 2014 in a study on changes in vegetation cover in the mountains of the central Apennines (Stanisci *et al*., 2014). Also, Chamberlain *et al*. (2012) emphasise the need for in-depth research on the dynamics of the alpine ornithic population along the altitudinal gradient as it is related to the vegetation present along the gradient (Chamberlain *et al*., 2016). In particular, the recent endangered status of the stonechat in Italy (Gustin *et al*., 2021), even though it is not considered an Alpine species, requires a greater understanding of its ecological requirements and possible threats to its high mountain habitat. Therefore, we hope for thorough and accurate censuses of other mountain populations of the stonechat in Italy, both in the Alps and the Apennines, where it has its current stronghold and possibly its original habitat.

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Data storage

All data were uploaded to the Ornitho.it database and can be obtained in an excel file upon request from the authors.

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