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Curriculum Diversità Animale

Classe di laurea LM-6

Orthopterans distribution along an altitudinal gradient in the NW Alps: an insight on abundance and detectability

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Summary

Alpine Orthopterans

Grasshoppers and crickets consist of about 28 907 species worldwide (Cigliano et al., 2021) and 1 000 in Europe (Heller et al., 1998), hitherto. In the latter, they principally inhabit grassland (51.6%) and shrubland (47.3%), whereas species linked to wooded habitat (18.8%) usually prefer forest edges, clearings or sparse forests (Hochkirch et al., 2016). These arthropods are mainly herbivorous, thus playing an important role in the nutrient cycle (Blumer & Diemer, 1996), the food chain (Joern, 1986) and in the ecosystem functioning (Soliveres et al., 2016).

Alps are an important biodiversity hotspot hosting many endemic and threatened orthopteran species (Hochkirch et al., 2016). In the last century the alpine chain has undergone several changes and still is today: on the one hand, temperatures are increasing significantly (Beniston, 2006; Brunetti et al., 2009) driving an upward shift of plants (Lenoir et al., 2008) and animal species (Cerrato et al., 2019; Viterbi et al., 2020); on the other hand, abandonment of traditional management practices (Hinojosa et al., 2016) has favoured the advancement of successional stages and the loss of open areas (Gellrich et al., 2006) threatening many grassland species (Rocchia et al., 2018; Stefanescu et al., 2009).

Orthopterans are considered good indicators of habitat quality (Bazelet & Samways, 2011; Gerlach et al., 2013) and many studies confirm their sensitivity to changes in vegetation structure and management practices in mountain areas (e. g. Marini et al., 2009; Walcher et al., 2019). Moreover, the impact of climate change on orthopterans has been demonstrated by various authors (e. g. Löffler et al., 2019; Poniatowski et al., 2020) but we found only few researches focused on mountain areas (e.g. Fumy et al., 2020; Geppert et al., 2021).

My thesis work is divided in two main sections: in the first one I focused on the description of the orthopteran fauna in three protected areas of the NW Italian Alps and the characterization of the assemblages along elevational gradients through species richness, Shannon-Wiener index and the changes of species Indicator Value (IndVal) for altitudinal belts and habitats over three different time periods. In the second section, I investigated how climatic and environmental variables affect orthopteran species' abundance along elevation, using N-mixture models in order to account for detection probability.

Alpine Biodiversity Monitoring Project

In 2006 the Gran Paradiso National Park started an Alpine Biodiversity Monitoring Program (ABMP) with the aim of describing patterns of biodiversity along elevation and monitoring the changes over time (Viterbi et al., 2013). The project is based on a multi-taxa approach which consist of six invertebrate groups (Ground beetles, Rove beetles, Ants, Spiders, Butterflies, Grasshoppers and Crickets) and Birds. Each taxon is sampled according to a standard sampling protocol in order to obtain semi quantitative data comparable in space and time. Since 2007, two additional protected areas of the Western Italian Alps, the Orsiera-Rocciavré Natural Park and the Veglia-Devero Natural Park, have adopted the ABMP, while in 2013 the ABMP was extended to three National Parks, Val Grande National Park, Stelvio National Park and Dolomiti Bellunesi National Park, thus expanding the geographical gradient related to the Italian Alps.

For my thesis work, I considered the Grasshoppers and Crickets (Orthoptera) data collected following the ABMP protocol during the period 2006-2019 in three protected areas of the Western Italian Alps: Gran Paradiso National Park, Orsiera-Rocciavré Natural Park and Veglia-Devero Natural Park.

Study area, sampling protocol and data collection

The study area is situated in the NW Italian Alps and it is split in five sites: Gran Paradiso National Park (GPNP), Orsiera-Rocciavré Natural Park (ORNP), Orrido di Foresto Natural Reserve (FNR), Veglia-Devero Natural Park (VDNP) and Alta Valle Antrona Natural Park (AANP) (Fig.1).

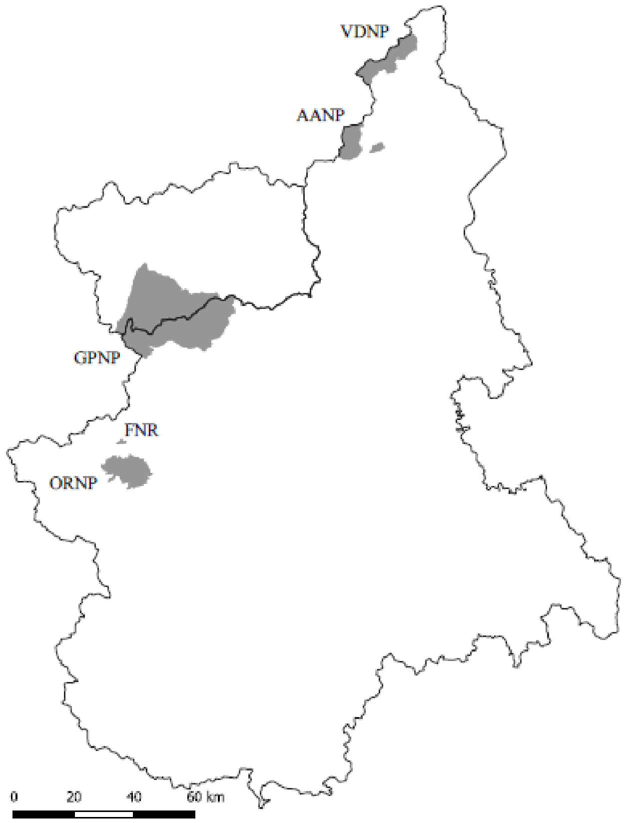


Fig. 1 Geographical framework of the study area

GPNP extends for 720 km^2 and it consists of two valleys in Piedmont and three in Aosta Valley. The dominant land cover classes are rocks and grasslands, which cover 31% and

27% of the area, respectively, followed by 24% of forests and 6% of shrubs. It was the first site starting the ABMP in 2006 with five altitudinal transects (*Gran piano – Orco valley* and *San Besso – Soana valley* in Piedmont; *Lauson – Cogne valley, Orvieille – Savarenche valley* and *Vaudalettaz – Rhêmes valley* in Aosta Valley) ranging from 1231.88 m to 2645.27 m a.s.l. Each transect is composed of five to seven sampling sites (plots).

ORNP has a surface of 110 km^2 while the FNR covers about 2 km^2. The first area is mainly characterized by grasslands (39%) and woodlands (35%), followed by rocks (18%) and shrubs (7%). The Foresto Natural Reserve is a xero-thermic area which occupy a little portion of the larger ORNP area and it is characterized by a peculiar vegetation, typical of Mediterranean climate. The sampling activities in these areas started in 2007 and they were performed along three transects in the ORNP (*Chisone, Sangone, Susa*), where the elevation goes from 1387.26 m to 2591.45 m a.s.l., and one in the FNR (*Foresto*) ranging from 630.14 m to 1287.20 m a.s.l. The number of plots varies from four to six.

VDNP has an area of 86 km^2 and the AANP extends for about 75 km^2. Considering the two protected areas together, grasslands and rocks are the predominant land cover types, showing the same percentages as in GPNP; forests cover 22% while shrubs occupy 6% of the area. Data collection started in 2007 along three transects in VDNP (*Bandiera, Devero* and *Veglia*) and an additional transect in the AANP (*Antrona*) has been investigated starting from the second biennium (2012-2013). The altitude varies from 1109.24 m to 2573.69 m a.s.l.

All protected areas, except FNR, are characterized by a continental climate showing modest differences in terms of climatic regimes (highest monthly precipitation and lowest annual mean temperature in the VDNP).

Thanks to the climatic and environmental characteristics, the study area can be considered a representative sample of the Western Italian Alps (Viterbi et al., 2013).

The ABMP consists of two years of data collection followed by four years of inactivity, therefore, to date there have been three sampling periods: 2006-2008 (2006-2007 GPNP; 2007-2008 ORNP and VDNP), 2012-2013, 2018-2019. The plots are located every 200 m in height along each of the thirteen elevational transects (Fig. 2). The plot named VEA (VDNP area) was sampled only in 2007 so we did not include it in any part of this work.

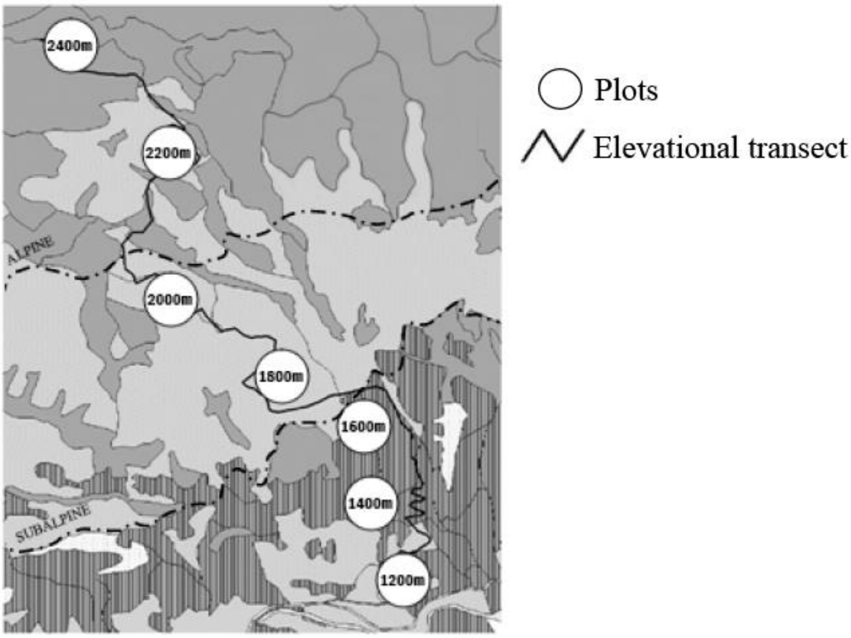


Fig. 2 Diagram showing the plots distribution along the elevational transect (Viterbi et al., 2013)

In the first time period (2006-2008) 65 plots were investigated while in the following years (2012-2013 and 2018-2019) 74 plots, overall.

We sampled orthopterans according to the *ring counts* method (Gardiner et al., 2005) along a 200 m-long linear transect. The ring is a plastic cylinder 50 cm in height, with a 150 cm diameter (about 0.18 m^2). Walking along the transect, we placed the cylinder on the ground 30 times, alternating random and opportunistic attempts (Fig. 3). We collected and counted all the trapped orthopterans occurring in the cylinder. Each individual was identified at species level in the field, however for uncertain specimens further investigations were performed in laboratory. The surveys were carried out monthly between mid-July and the end of September for a total of three replicate per year. In addition to faunistic data, for each sampling site we collected microclimatic data recording the hourly air temperature with data-loggers (Thermochron iButton, DS1922L, Maxim, Sunnyvale, CA, U.S.) throughout the sampling season.

Moreover, we defined the main habitat cover type of each plot using land cover data derived from aerial photos and validated in the field (Agroselviter, 2009; Meloni et al., 2009).

Figure 3 Ring counts.

Chapter 1-The Orthopteran fauna of three protected areas in the NW Italian Alps

Data analyses

Orthopteran fauna description

Orthopteran data collected during the first two sampling periods of the monitoring program were published for ORNP, FNR (Giuliano et al., 2017), VDNP and AANP (Battisti et al., 2016). Whereas data from the GPNP have not been published yet. The first part of the thesis focused on the updated checklists for Grasshoppers and Crickets found in the three protected areas.

Firstly, we cleaned the database deleting all the observations that could not be determined at species level; then we compiled the checklists based on data from both the ABMP and the available literature for the study areas. We verified data from the bibliographical resources checking if the locations reported fell within the protected areas. When the location was not explicit the data was not included. Individuals attributable to the genus *Anonconotus* or to *Chorthippus (Glyptobothrus) biguttulus* group were identified as species complex due to identification difficulty (Massa et al., 2012). Species nomenclature follows the one adopted in the Fauna d'Italia (Massa et al., 2012) whereas we set the species chorology according to Stoch & Vigna Taglianti (2005) and the IUCN classification as in the European Red List (Hochkirch et al., 2016).

Temporal changes of orthopteran distribution along elevation

In subsequent analysis, we decided to exclude data relating to *Foresto* transect because it is characterised by a different elevational gradient (low montane belt; 630.14 – 1287.20 m a.s.l.) and habitats (xerothermic area with dry prairies and rock outcrops) making this transect not comparable with the others. Data from the highest three plots of *Bandiera* transect (VDNP) were also excluded since no orthopteran individuals were ever sampled there. First, we classified each plot by elevational belt (montane 1200-1800 m a.s.l.; subalpine 1800-2200 m a.s.l.; and alpine above 2200 m a.s.l.) and by dominant habitat type (woodland, ecotone and grassland). Afterwards, we calculated the total number of species sampled (Species richness, S) and the Shannon-Wiener Index (H') per plot in each time window. We used the function *diversity* from the package "*vegan"* (version 2.5-7) to calculate the latter (Oksanen et al., 2020).

Next, we applied a non-parametric regression method (*loess*) to the two above mentioned variables obtaining a graphic representation of how species richness and diversity changed in the three areas along elevation over time.

Then, to test the association between orthopteran species, elevational belts and habitats we calculated the IndVal (Indicator Value) index (Dufrêne & Legendre, 1997). This method integrates the "specificity" of a species (the exclusivity for a precise group of sites) and its "fidelity" (the frequency within the same group). IndVal can vary from 0 (no indication) to 1 (maximum indication) for each species. The statistical significance is calculated through a Monte Carlo test, based on 999 permutations and performed using the function *multipatt* of the "*indicspecies*" package (version 1.7.9) (De Cáceres & Legendre, 2009). We decided to remove from this analysis three plots (*OB*, *VB* and *VA*, from GPNP) since during the whole period (2006-2019) of the project less than 30 individuals were collected in these plots, for a total of 4 species for each plot. Finally, we calculated the IndVal values by time windows in order to point out changes among elevational belts and habitats over time in the three parks. We considered the species that showed IndVal values higher or equal to 0.75 as indicator of a given habitat type or elevational belt. When the species occur in each group, the *p value* cannot be calculated (De Cáceres, 2020). In this case (*p value* = NAs), we accounted for the species with IndVal higher or equal to 0.75 anyway. All the above-mentioned analyses were performed using the software R (version 4.1.0) (RCore Team, 2021).

Results

Orthopteran fauna description

During the ABMP, 48 orthopteran species were sampled in the ORNP and FNR (Table 1), 38 in the GPNP (Table 2), 22 in the VDNP and AANP (Table 3). However, we found presence data for additional species in literature and faunistic database. Therefore, overall, 53 species were reported for ORNP and FNR, 42 for GPNP and 23 for VDNP and AANP. ORNP and FNR host the highest number of endemic species (7), followed by GPNP (3). In GPNP, *Gran piano* host the highest species richness in all three periods; in ORNP and FNR, *Foresto* is the richest transect in the third period while *Susa* is the poorest in all time windows. The highest number of species in the VDNP was found along the *Antrona* transect, followed by *Veglia*.

Table 1. Checklist of the Orthoptera in the Orsiera-Rocciavrè Natural Park and Foresto Natural Reserve. The nomenclature follows Massa et al. (2012). Species in bold are only found in Foresto, highlighted species are endemic. F=Foresto, CH=Chisone, SA=Sangone, SU=Susa. Data derived from bibliography:[1]La Greca, 1985; [2] Coll. Fontana, 1996, CkMap; [3]Griffini, 1897; [4]Mancini&Bonicelli, 2002, Piemonte Region Faunistic Database; [5]Nadig, 1987; [6]Savoldelli P., unpublished data; [7]Coll. Fontana, 1972, CkMap; [8]Coll. Museum of Verona, 1919, CkMap; [9]Coll. Goidanich, CkMap; [10]Galvagni, 2005; [11]Giuliano D., unpublished data; [12]Sindaco, 2005, Piemonte Region Faunistic Database; [13]Sindaco, 2002, Piemonte Region Faunistic Database.

	Species	IUCN	CHO	2007-2008				2012-2013				2018-2019				Bibliography
				F	CH	SA	SU	F	CH	SA	SU	F	CH	SA	SU	
CAELIFERA	*Aeropus sibiricus* (Linnaeus, 1767)	LC	SIE		x	x	x		x	x	x		x	x	x	1, 2
	***Aiolopus strepens* (Latreille, 1804)**	**LC**	**EUM**									**x**				**3, 4**
	Arcyptera fusca (Pallas, 1773)	LC	SIE		x		x		x	x	x		x	x	x	1, 2
	Calliptamus italicus (Linnaeus, 1758)	LC	ASE	x	x			x		x		x				
	***Calliptamus siciliae* Ramme, 1927**	**LC**	**MED**	**x**				**x**				**x**				
	Chorthippus (Chorthippus) dorsatus (Zetterstedt, 1821)	LC	SIE					x	x		x		x			
	Chorthippus (Chorthippus) parallelus (Zetterstedt, 1821)	LC	SIE	x	x	x		x	x	x	x		x	x	x	
	Chorthippus (Glyptoborthrus) gr. biguttulus	LC	EUR	x	x	x		x	x	x	x	x	x	x	x	
	Chorthippus (Glyptobothrus) apricarius (Linnaeus, 1758)	LC	ASE		x	x			x	x	x	x	x	x	x	1, 5
	Chorthippus (Glyptobothrus) cialancensis Nadig, 1986	LC	ALSW													6
	Chorthippus (Glyptobothrus) vagans (Eversmann, 1848)	LC	TUE	x	x			x	x	x		x	x			
	Epipodisma pedemontana (Brunner von Wattenwyl, 1882)	LC	ALPW		x	x	x		x	x	x		x	x	x	1,7
	Euchorthippus declivus (Brisout, 1848)	LC	SEU	x				x				x	x			
	Euthystira brachyptera Ocskay, 1826	LC	ASE	x	x			x	x	x		x	x		x	1,2
	Gomphocerippus rufus (Linnaeus, 1758)	LC	SIE			x				x				x		

	***Mecostethus parapleurus* (Hagenbach, 1822)**	**LC**	**SIE**									**x**				[3]
	Myrmeleotettix maculatus (Thunberg, 1815)	LC	SIE			x							x	x		[5]
	***Oedaleus decorus* (Germar, 1826)**	**LC**	**CAM**	**x**				**x**				**x**				
	Oedipoda caerulescens (Linnaeus, 1758)	LC	CEM	x		x		x	x	x		x	x			[8]
	Oedipoda germanica (Latreille, 1804)	LC	TUE	x		x		x	x			x				
	Omocestus (Dirshius) haemorrhoidalis (Charpentier, 1825)	LC	ASE	x	x	x		x	x	x		x	x	x		
	***Omocestus (Omocestus) rufipes* (Zetterstedt, 1821)**	**LC**	**CEM**					**x**				**x**				
	Omocestus (Omocestus) viridulus (Linnaeus, 1758)	LC	ASE		x	x	x		x	x	x		x	x	x	[1]
	Pararcyptera alzonai Capra, 1938	EN	ALPW													[2]
	***Pezotettix giornae* (Rossi, 1794)**	**LC**	**EUM**	**x**				**x**				**x**				
	Podisma pedestris (Linnaeus, 1758)	LC	ASE													[3]
	Psophus stridulus (Linnaeus, 1758)	LC	PAL			x			x	x			x	x		
	Stauroderus scalaris (Fischer de Waldheim, 1846)	LC	ASE	x	x	x	x	x	x	x	x	x	x	x	x	[1, 2]
	***Stenobothrus fischeri* (Eversmann, 1848)**	**LC**	**CAM**					**x**				**x**				
	Stenobothrus lineatus (Panzer, 1796)	LC	SIE	x	x	x		x	x	x		x	x	x		
	Stenobothrus nigromaculatus (Herrich-Schaeffer, 1840)	LC	SIE		x	x	x	x	x	x	x		x	x	x	[1]
	Tetrix bipunctata (Linnaeus, 1758)	LC	SIE					x								
	Tetrix tenuicornis (Sahlberg, 1893)	LC	TUE						x							
ENSIFERA	*Anonconotus gr.*	LC	ALP		x	x	x		x	x	x		x	x	x	[9], *A. occidentalis*[10], *A. ghilianii*[5,1]
	Barbitistes alpinus Fruhstorfer, 1920	LC	AWNA			x					x		x	x		
	Bicolorana bicolor (Philippi, 1830)	LC	SIE		x				x							
	Chopardius pedestris (Fabricius, 1787)	LC	CEU	x		x				x		x				
	Decticus verrucivorus (Linnaeus, 1758)	LC	ASE						x							[1]
	Dolichopoda azami Sauley, 1893	LC	ALPW													[11]

	Ephippiger terrestris (Yersin, 1854)	LC	ALSW						x							
	Leptophyes boscii Fieber, 1853	LC	SEU													[12]
	***Leptophyes laticauda* (Frivaldsky, 1867)**	**LC**	**CEU**	**x**								**x**				
	Metrioptera saussuriana (Frey-Gessner, 1872)	LC	CEU		x	x				x				x		
	Nemobius sylvestris (Bosc, 1792)	LC	CEU	x		x		x		x		x		x		
	***Oecanthus pellucens* (Scopoli, 1763)**	**LC**	**CAM**	**x**								**x**				
	Phaneroptera nana Fieber, 1853	LC	WPA													[13]
	Pholidoptera aptera (Fabricius, 1793)	LC	CEU				x			x	x					
	Pholidoptera griseoaptera (De Geer, 1773)	LC	EUR					x		x	x	x		x	x	
	Platycleis albopunctata grisea (Fabricius, 1781)	LC	CAE	x	x			x				x	x			
	Polysarcus denticauda (Charpentier, 1825)	LC	SEU			x			x	x				x		[5, 2]
	***Saga pedo* (Pallas, 1771)**	**LC**	**SIE**					**x**				**x**				
	Tettigonia cantans (Fuessly, 1775)	LC	ASE			x			x		x	x			x	[1]
	***Tettigonia viridissima* Linnaeus, 1758**	**LC**	**PAL**					**x**				**x**				
			TOT	19	18	22	8	24	24	24	15	27	21	20	13	
				F	CH	SA	SU	F	CH	SA	SU	F	CH	SA	SU	

*Table 2. Checklist of Orthoptera in the Gran Paradiso National Park, endemic species are highlighted. GP=Gran piano, S=Soana, V=Vaudalettaz, L=Lauson, O=Orvieille. The nomenclature follows Massa et al. (2012). Data derived from bibliography: [1]Baroni, 2015; [2]Salfi, 1932; [3]La Greca, 1985; [4]Kindler et al., 2012; [5]Massa, 2010; [6]Galvagni, 2005. *Anonconotus pusillus is classified as Near Threatened and Anonconotus ghilianii as Least Concern*

	Species	IUCN	CHO	2006-2007					2012-2013					2018-2019					Bibliography
				GP	S	V	L	O	GP	S	V	L	O	GP	S	V	L	O	
CAELIFERA	*Aeropedellus variegatus* (Fischer de Waldheim, 1846)	EN	CAE																1
	Aeropus sibiricus (Linnaeus, 1767)	LC	SIE	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1
	Arcyptera fusca (Pallas, 1773)	LC	SIE				x	x				x	x			x	x	x	1
	Bohemanella frigida (Boheman, 1846)	LC	SIE			x					x					x			1
	Calliptamus italicus (Linnaeus, 1758)	LC	ASE	x					x										
	Chorthippus (Chorthippus) dorsatus (Zetterstedt, 1821)	LC	SIE	x	x			x	x	x				x	x				
	Chorthippus (Chorthippus) parallelus (Zetterstedt, 1821)	LC	SIE	x	x		x	x	x	x		x	x	x	x		x	x	
	Chorthippus (Glyptobothrus) apricarius (Linnaeus, 1758)	LC	ASE		x			x		x					x				
	Chorthippus (Glyptobothrus) gr. biguttulus	LC	EUR	x			x	x	x	x	x	x	x	x	x	x	x	x	*C. brunneus*[1], *C. eisentrauti*[1]
	Chorthippus (Glyptobothrus) vagans (Eversmann, 1848)	LC	TUE						x					x					
	Depressotetrix depressa (Brisout de Barneville, 1848)	LC	MED				x			x					x		x		
	Epipodisma pedemontana (Brunner von Wattenwyl, 1882)	LC	ALPW	x		x		x	x	x	x	x	x	x	x	x	x	x	1, 2, 3
	Euthystira brachyptera Ocskay, 1826	LC	ASE	x					x	x			x	x			x	x	1
	Gomphocerippus rufus (Linnaeus, 1758)	LC	SIE		x	x		x		x	x	x	x		x	x	x	x	1
	Mecostethus parapleurus (Hagenbach, 1822)	LC	SIE						x					x	x				
	Myrmeleotettix maculatus (Thunberg, 1815)	LC	SIE			x					x					x			1, 3
	Oedaleus decorus (Germar, 1826)	LC	CAM																4

	Oedipoda caerulescens (Linnaeus, 1758)	LC	CEM	x					x			x		x			x	x	[1]
	Oedipoda germanica (Latreille, 1804)	LC	TUE						x			x	x	x		x	x	x	[1]
	Omocestus (Dishius) haemorrhoidalis (Charpentier, 1825)	LC	ASE				x	x	x	x		x	x	x			x	x	[1]
	Omocestus (Omocestus) rufipes (Zetterstedt, 1821)	LC	CEM	x				x	x	x			x	x	x		x		
	Omocestus (Omocestus) viridulus (Linnaeus, 1758)	LC	ASE	x	x		x	x	x	x	x	x	x	x	x	x	x	x	[1]
	Podisma pedestris (Linnaeus, 1758)	LC	ASE																[1]
	Stauroderus scalaris (Fischer de Waldheim, 1846)	LC	ASE	x	x		x	x	x	x	x	x	x	x	x	x	x	x	[1]
	Stenobothrus lineatus (Panzer, 1796)	LC	SIE	x	x		x		x	x		x		x	x		x	x	[1]
	Stenobothrus nigromaculatus (Herrich-Schaeffer, 1840)	LC	SIE						x			x							[1]
	Stenobothrus ursulae Nadig, 1986	VU	ALPW							x					x				[1, 5]
	Tetrix bipunctata (Linnaeus, 1758)	LC	SIE												x				
	Tetrix subulata (Linnaeus, 1758)	LC	OLA							x					x		x		
ENSIFERA	*Anonconotus gr.*	*	ALP		x					x					x				[6], *A. pusillus*[1], *A. ghilianii*[6]
	Barbitistes fischerii (Yersin, 1854)	LC	WEU																[2]
	Barbitistes serricauda (Fabricius, 1794)	LC	CEU											x					
	Chopardius pedestris (Fabricius, 1787)	LC	CEU						x			x	x	x	x			x	
	Decticus verrucivorus (Linnaeus, 1758)	LC	ASE	x	x			x	x	x		x	x	x	x		x	x	[1]
	Leptophyes laticauda (Frivaldsky, 1867)	LC	CEU											x					
	Metrioptera saussuriana (Frey-Gessner, 1872)	LC	CEU	x	x				x	x				x	x				
	Nemobius sylvestris (Bosc, 1792)	LC	CEU	x					x	x				x					
	Pholidoptera aptera (Fabricius, 1793)	LC	CEU						x				x	x			x		
	Pholidoptera griseoaptera (De Geer, 1773)	LC	EUR						x	x				x	x				
	Platycleis albopunctata grisea (Fabricius, 1781)	LC	CAE	x					x			x		x			x		
	Tettigonia cantans (Fuessly, 1775)	LC	ASE	x	x				x	x				x	x				

	Tettigonia viridissima Linnaeus, 1758	LC	PAL											x					
			TOT	17	12	5	9	13	25	22	8	16	15	26	22	10	19	15	
				GP	S	V	L	O	GP	S	V	L	O	GP	S	V	L	O	

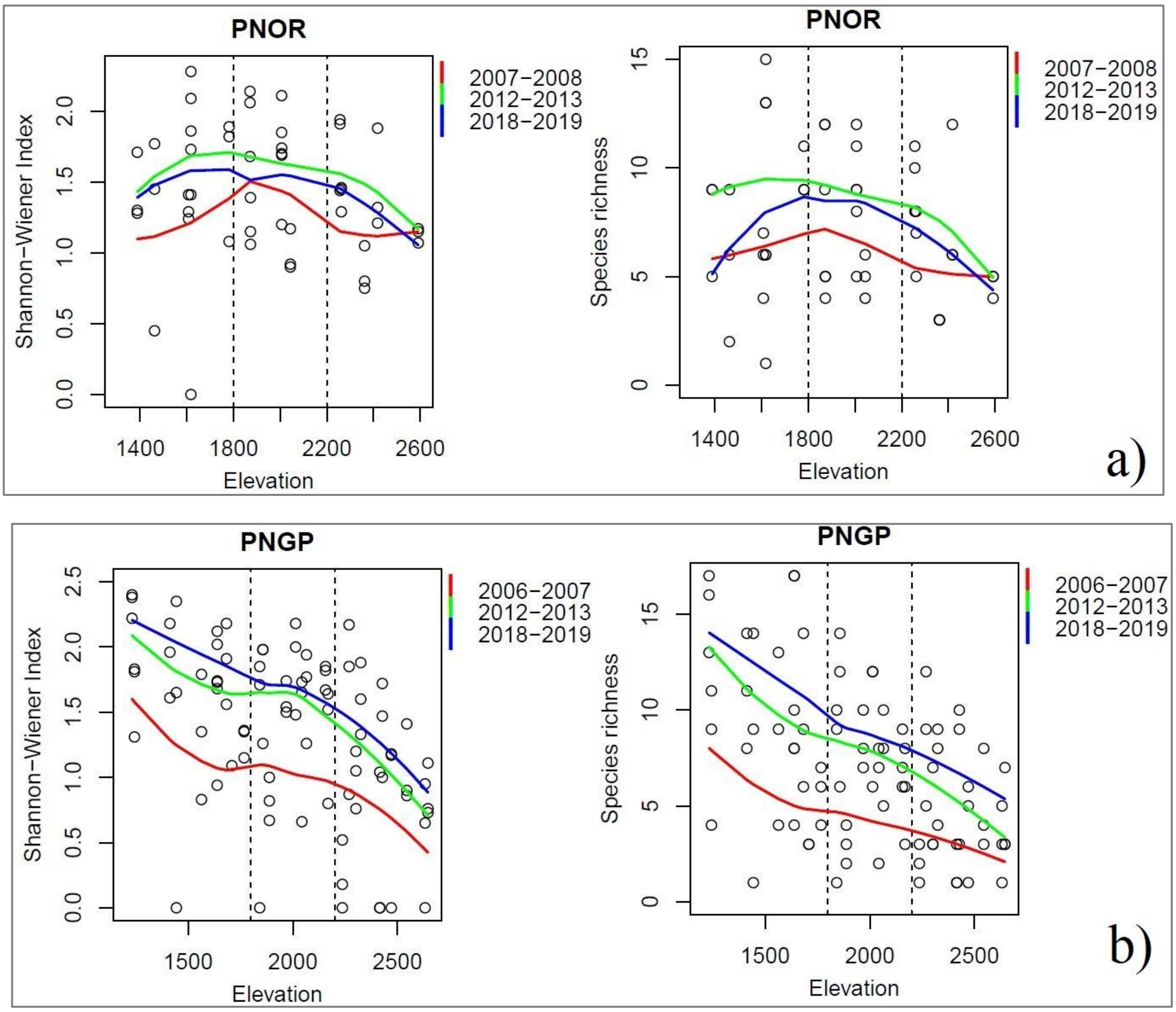
Table 3. Checklist for the Alpe Veglia and Alpe Devero Natural Park and Alta Valle Antrona Natural Park. The nomenclature follows Massa et al. (2012). A=Antrona, BA=Bandiera, VE=Veglia, DE=Devero. Data derived from bibliography: [1]Battisti et al., 2016.

	Species	IUCN	CHO	2007-2008				2012-2013				2018-2019				Bibliography
				A	BA	VE	DE	A	BA	VE	DE	A	BA	VE	DE	
CAELIFERA	*Aeropus sibiricus* (Linnaeus, 1767)	LC	SIE		x	x	x		x	x	x	x	x	x	x	
	Bohemanella frigida (Boheman, 1846)	LC	SIE				x				x				x	
	Chorthippus (Chorthippus) dorsatus (Zetterstedt, 1821)	LC	SIE					x				x				
	Chorthippus (Chorthippus) parallelus (Zetterstedt, 1821)	LC	SIE			x		x				x				
	Chorthippus (Glyptobothrus) apricarius (Linnaeus, 1758)	LC	ASE			x				x				x		
	Chorthippus (Glyptobothrus) gr. biguttulus	LC	EUR		x	x	x	x	x	x	x	x	x	x	x	
	Chorthippus (Glyptobothrus) vagans (Eversmann, 1848)	LC	TUE										x			
	Depressotetrix depressa (Brisout de Barneville, 1848)	LC	MED													1
	Euthystira brachyptera Ocskay, 1826	LC	ASE			x		x		x		x		x		
	Oedipoda germanica (Latreille, 1804)	LC	TUE					x		x		x		x		
	Omocestus (Omocestus) rufipes (Zetterstedt, 1821)	LC	CEM					x				x				
	Omocestus (Omocestus) viridulus (Linnaeus, 1758)	LC	ASE		x		x	x	x	x	x	x	x	x	x	
	Psophus stridulus (Linnaeus, 1758)	LC	PAL					x				x				
	Stauroderus scalaris (Fischer de Waldheim, 1846)	LC	ASE			x	x	x		x		x		x	x	
ENSIFERA	*Antaxius difformis* (Brunner von Wattenwyl, 1861)	LC	ALP					x				x				
	Barbitistes alpinus Fruhstorfer, 1920	LC	AWNA									x				
	Chopardius pedestris (Fabricius, 1787)	LC	CEU							x		x		x		

	Decticus verrucivorus (Linnaeus, 1758)	LC	ASE			x			x	x		x	x	x	x	
	Meconema thalassinum (De Geer, 1773)	LC	EUR					x								
	Phaneroptera nana Fieber, 1853	LC	WPA									x				
	Pholidoptera aptera (Fabricius, 1793)	LC	CEU		x		x		x	x		x	x			
	Pholidoptera griseoaptera (De Geer, 1773)	LC	EUR					x				x				
	Platycleis albopunctata grisea (Fabricius, 1781)	LC	CAE					x		x		x		x		
			TOT	/	4	7	6	13	5	11	4	18	6	10	6	
				A	BA	VE	DE	A	BA	VE	DE	A	BA	VE	DE	

Temporal changes of Orthoptera distribution along elevation

In GPNP (Fig. 4b) and in VDNP (Fig. 4c) S and H’ decrease as the altitude increases, whereas in the ORNP both variables seem to follow a hump-shaped distribution with their optimum close to the edge between the montane and the subalpine belts (Fig. 4a). Observing more carefully Fig. 4a, in the second time period (2012-2013) S shows higher values in the montane belt. In this way the hump-shaped curve is less evident than in 2018-2019, nearly assuming a declining shape as elevation increases. The S and H’ values are highest in the third time period (2018-2019) for GPNP and VDNP, while in ORNP the second sampling period (2012-2013) shows the highest values. In general, the curves relating to the first time period (2006-2008) are anomalous with respect to the subsequent periods. Actually, in 2006-2008 the values for the two variables and the general shape of the curves were affected by the fact that fewer plots were sampled during the first years of monitoring activities in VDNP (2007-2008) and GPNP (2006) because of logistical constraints.



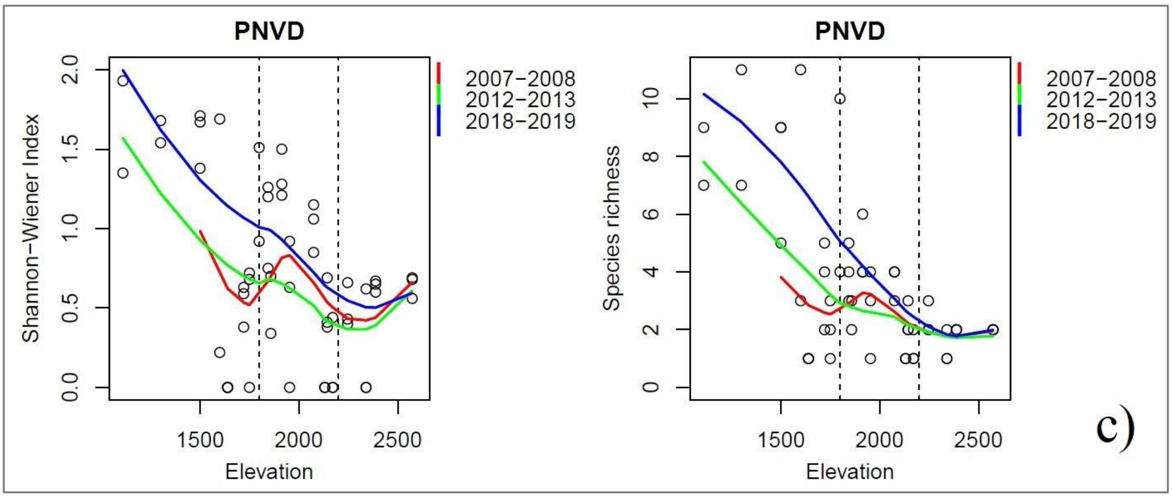


Fig. 4 Shannon-Wiener Index (left) and Species richness (right) for the three areas: ORNP (a), GPNP (b), VDNP(c). Dashed lines identify the limits between the elevational belts (1800 and 2200 m a. s.l).

The results of the IndVal for the elevational belts are reported in Table 4 while in Table 5 the results for the main habitat types. For all time periods and areas, *Aeropus sibiricus* showed high values for the subalpine and alpine belts. Regarding the habitat groups, in GPNP it was an indicator species for all habitats in the first period (2006-2007) while in the last biennium (2018-2019) only for grassland. Moreover, *Stauroderus scalaris* was an indicator species for all elevational belts and habitats during the last two time windows (2012-2013, 2018-2019) in ORNP, whereas in GPNP this species became additionally associated to grassland in 2012-2013 and to the alpine belt in the last period (2018-2019). We noticed *Epipodisma pedemontana* as an indicator species for the alpine belt in both GPNP and ORNP but in the latter it resulted highly associated also to the subalpine belt in the last two periods (2012-2013, 2018-2019). Furthermore, this species showed high IndVal values for ecotone and grassland in all time windows in ORNP. In 2012-2013 and 2018-2019, *Chorthippus gr. biguttulus* had high values for all elevational belts and habitats in GPNP, whereas it resulted as indicator for the montane and subalpine belts in VDNP. We noticed *Omocestus viridulus* as an indicator species for all altitudinal belts in 2007-2008 in ORNP and in the last two periods in the GPNP (2012-2013, 2018-2019). In VDNP this species showed high values in 2018-2019 for the montane and subalpine belts, in the same area it was an indicator for woodland and ecotone for the whole sampling period.

Table 4. IndVal results for altitudinal belt divided by park and time period. 1= the species is IndVal species in the group, 0= the species is not IndVal species in that group.

GPNP						
Species	*Montane*	*Subalpine*	*Alpine*	*IndVal*	*p value*	
Aeropus sibiricus	0	1	1	0.870	0.002	2006-2007
Stauroderus scalaris	1	1	0	0.826	0.004	
Stauroderus scalaris	1	1	0	0.863	0.013	2012-2013
Aeropus sibiricus	0	1	1	0.858	0.001	
Chorthippus gr. biguttulus	1	1	1	0.788	NA	
Epipodisma pedemontana	0	0	1	0.786	0.003	
Chorthippus parallelus	1	0	0	0.779	0.003	
Omocestus viridulus	1	1	1	0.766	NA	
Aeropus sibiricus	0	1	1	0.918	0.001	2018-2019
Stauroderus scalaris	1	1	1	0.910	NA	
Stenobothrus lineatus	1	1	0	0.821	0.004	
Chorthippus parallelus	1	0	0	0.803	0.004	
Epipodisma pedemontana	0	0	1	0.796	0.002	
Omocestus viridulus	1	1	1	0.788	NA	
Chorthippus gr. biguttulus	1	1	1	0.788	NA	
Tettigonia cantans	1	0	0	0.752	0.001	
ORNP						
Species	*Montane*	*Subalpine*	*Alpine*	*IndVal*	*p value*	
Anonconotus gr.	0	1	1	0.984	0.002	2007-2008
Epipodisma pedemontana	0	0	1	0.895	0.003	
Aeropus sibiricus	0	1	1	0.882	0.011	
Omocestus viridulus	1	1	1	0.750	NA	
Epipodisma pedemontana	0	1	1	0.949	0.004	2012-2013
Aeropus sibiricus	0	1	1	0.931	0.006	
Anonconotus gr.	0	1	1	0.915	0.008	
Stauroderus scalaris	1	1	1	0.829	NA	
Aeropus sibiricus	0	1	1	0.921	0.008	2018-2019
Epipodisma pedemontana	0	1	1	0.894	0.007	
Anonconotus gr.	0	1	1	0.886	0.037	
Stauroderus scalaris	1	1	1	0.791	NA	
VDNP						
Species	*Montane*	*Subalpine*	*Alpine*	*IndVal*	*p value*	
Aeropus sibiricus	0	1	1	0.922	0.017	2007-2008
Aeropus sibiricus	0	1	1	0.881	0.004	2012-2013
Chorthippus gr. biguttulus	1	1	0	0.829	0.028	
Bohemanella frigida	0	0	1	0.794	0.016	
Omocestus viridulus	1	1	0	0.866	0.047	2018-2019
Aeropus sibiricus	0	1	1	0.864	0.018	
Bohemanella frigida	0	0	1	0.797	0.013	
Chopardius pedestris	1	0	0	0.791	0.012	
Chorthippus gr. biguttulus	1	1	0	0.829	0.036	

Table 5. IndVal results for habitat divided by park and time period. 1= the species is IndVal species in the group, 0= the species is not IndVal species in that group.

GPNP						
Species	*Woodland*	*Ecotone*	*Grassland*	*IndVal*	*p value*	
Stauroderus scalaris	1	1	0	0.822	0.010	2006-2007
Aeropus sibiricus	1	1	1	0.756	NA	
Stauroderus scalaris	1	1	1	0.851	NA	2012-2013
Chorthippus gr. biguttulus	1	1	1	0.788	NA	
Stauroderus scalaris	1	1	1	0.910	NA	2018-2019
Chorthippus gr. biguttulus	1	1	1	0.788	NA	
Aeropus sibiricus	0	0	1	0.785	0.031	
Chorthippus parallelus	1	1	0	0.784	0.005	
ORNP						
Species	*Woodland*	*Ecotone*	*Grassland*	*IndVal*	*p value*	
Anonconotus gr.	0	1	1	0.979	0.002	2007-2008
Epipodisma pedemontana	0	1	1	0.894	0.005	
Aeropus sibiricus	0	1	1	0.881	0.010	
Anonconotus gr.	0	1	1	1.000	0.001	2012-2013
Epipodisma pedemontana	0	1	1	0.949	0.003	
Aeropus sibiricus	0	1	1	0.929	0.002	
Stauroderus scalaris	1	1	1	0.829	NA	
Polysarcus denticauda	0	0	1	0.756	0.027	
Anonconotus gr.	0	1	1	0.985	0.001	2018-2019
Aeropus sibiricus	0	1	1	0.918	0.004	
Epipodisma pedemontana	0	1	1	0.894	0.008	
Stauroderus scalaris	1	1	1	0.791	NA	
Chorthippus apricarius	1	1	1	0.750	NA	
VDNP						
Species	*Woodland*	*Ecotone*	*Grassland*	*IndVal*	*p value*	
Aeropus sibiricus	1	1	1	0.886	NA	2007-2008
Omocestus viridulus	1	1	0	0.856	0.038	
Omocestus viridulus	1	1	0	0.859	0.015	2012-2013
Omocestus viridulus	1	1	0	0.911	0.013	2018-2019
Aeropus sibiricus	1	1	1	0.806	NA	

Discussion

Orthopteran fauna description

The ABMP main goal is describing the faunal communities of different taxa along elevation and identifying trends over time. The checklists are a collateral result, in fact the *ring counts* method is not exhaustive for the characterization of the orthopteran fauna of the study area. However, these data represent a first step to increase knowledge of orthopteran assemblages in different alpine contexts.

ORNP is the richest area (53 species, 48 in the ABMP and 5 in literature), hosting 36% of the Orthoptera described in NW Italy (Sindaco et al., 2012), whereas VDNP is the poorest (23 species, 22 in ABMP and 1 in literature). Because of its warmer climate *Foresto* transect plays an important role in the higher number of species found in ORNP. Indeed, 10 species were exclusively detected in this area. As supported by literature, many orthopteran species are favored by high ambient temperatures (Willott et al., 1998) and increasing temperature affects positively species richness in Orthopteran communities (Fumy et al., 2020). We could likely assert, conversely, that cooler areas host less Grasshoppers species as confirmed by VDNP.

Data derived from the last biennium (2018-2019) of ABMP allow to update the checklists previously drawn up by Giuliano et al. (2017) and Battisti et al. (2016), for ORNP and VDNP respectively. During the last time window, in the context of ABMP, *Aiolopus strepens* and *Mecostethus parapleurus* were collected for the first time in *Foresto* transect (FNR), confirming previous observations reported on Ckmap and the Piemonte Region Faunistic Database (Giuliano et al., 2017). In the same time span, for the first time we found *Chorthippus (Glyptobothrus) vagans* in *Bandiera* transect (VDNP), *Barbitistes alpinus* and *Phaneroptera nana* in *Antrona (AANP)*.

The checklist for GPNP is the first attempt to describe the orthopteran fauna of this area: we sampled 38 species along the ABMP altitudinal transects and found 4 additional species recorded in bibliographical resources. Overall, 42 species occur within the Gran Paradiso National Park boundaries.

In this study we considered *Anonconotus* sp. and *Chorthippus* gr. *biguttulus* as species complex due to identification complexity (Massa et al., 2012) but Baroni (2015) confirmed that *Anonconotus pusillus*, *Chorthippus eisentrauti* and *Chorthippus brunneus* are present in the GPNP, specifically in Cogne Valley. Besides these insights, we found in GPNP additional interesting species at conservation level. We found *Myrmeleotettix maculatus,* a quite common species in western Alps but with a rather fragmented distribution along the Italian peninsula (Massa et al., 2012), in Rhêmes valley, in one plot only (VE, *Vaudalettaz*) and limited to a small area. This species inhabits well exposed grasslands and it is negatively affected by shrub and tree encroachment (Schuch et al., 2011). Therefore, it could be important to investigate more carefully this species' ecology and population trends in response to abandonment in order to detect any decline, especially in the Alps.

Epipodisma pedemontana is the only representative of the European endemic genus *Epipodisma* and we detected it in all five transects of GPNP (*Gran piano –Orco valley*, *San Besso – Soana valley*, *Lauson – Cogne valley*, *Orvieille – Savarenche valley* and *Vaudalettaz – Rhêmes valley*). It is listed as Near Threatened (Hochkirch et al., 2016) with a declining population trend even though this last information is mainly based on the subspecies *Epipodisma pedemontana waltheri* (Voisin, 2003), located in France, while the Italian subpopulation status is still unknown (Zuna-Kratky et al. 2016).

Stenobothrus ursulae is a steno-endemic species of the Italian Graian Alps and it is listed as Vulnerable D2 in the European Red List (Hochkirch et al., 2016). We found this species exclusively in the highest two plots of *Soana valley*, in line with its known distribution (Baroni & Masoero, 2018; Massa et al., 2012).

Aeropedellus variegatus is listed as Endangered B2 ab (III, IV, V) at European level (Hochkirch et al., 2016) and it was detected in Cogne Valley (Baroni, 2015; La Greca, 1985).

Massa et al. (2012) reported the presence of *Barbitistes fischeri* on the basis of an observation by Salfi (1932) in Orco Valley (GPNP), however its accuracy has been questioned because this species has never been observed since (Nadig, 1987). *B. fischeri* is well distributed in France, up to the Maritime Alps, thus further and more accurate investigations are desirable.

In general, GPNP hosts several interesting species but it would be interesting to investigate further the orthopteran fauna using other sampling techniques. For example, the use of acoustic devices such as AudioMoth could be a complementary and useful tool to detect some cryptic species (e. g. *Chorthippus* gr. *biguttulus*) and to record arboreal species in wooded areas.

Temporal changes of Orthoptera distribution along elevation

The general descending values of S and H' along elevation are consistent with other results available in literature for orthopterans (Sindaco et al., 2012; Wachter et al., 1998). We noticed a difference between S curve shapes of 2012-2013 and 2018-2019 in the montane belt (1200-1800 m a.s.l.) for ORNP area. Orthoptera are negatively affected by the interruption of management practices (Marini et al., 2009) because open habitats, the most inhabited by this taxon (Hochkirch et al., 2016), often evolve to more mature vegetational stages when abandoned. Therefore, the lower species richness in the last time window could be a consequence of shrubs and trees encroachment at lower altitudes (Rocchia et al., 2018).

Moreover, ORNP is the only area where the last time window (2018-2019) shows lower values than 2012-2013, we think there might be some local dynamics that need further investigations.

Aeropus sibiricus can be found in all elevational belts investigated but it is more abundant above the timberline because it prefers warm and dry grasslands (Massa et al., 2012). Hence the indicator values for the subalpine and alpine belts are consistent with its ecology. However, in GPNP, the IndVal values for the habitat could suggest a potential evolution in the vegetational structure of the plots classified as woodland and ecotone: in 2006-2007, this species was associated with all habitat types whereas in 2018-2019 it showed high values for grassland only. This change was already recorded in 2012-2013 but the *p value* was slightly not significant (0.051), so we did not report this result in Table 5. Hence, the clearings where *Aeropus sibiricus* was initially found likely underwent tree and shrub encroachment due to the abandonment of management practices, resulting in less abundant populations in woodland and ecotone.

Stauroderus scalaris is a generalist species (Massa et al., 2012) and our results for ORNP are consistent with it. Furthermore, we recorded an altitudinal expansion in 2018-2019 in GPNP. Values from the previous time window (2012-2013) already suggested an increase in the abundance of this species in grassland, the most widespread habitat at highest elevation. Moreover, we observed *Epipodisma pedemontana* as an indicator species also for the subalpine belt since 2012-2013 in ORNP probably because this species abundance increased in the above-mentioned elevational range. Its presence at lower altitudes was already recorded by high IndVal values for the ecotone in the whole sampling period (2007-2019).

We considered *Chorthippus* gr. *biguttulus* as a complex, so our suggestions are approximations based on the ecology of the species potentially present in the study areas (*Chorthippus biguttulus*, *Chorthippus brunneus*, *Chorthippus eisentrauti*). They occupy almost every elevation belt, they are mesophilic or thermophilic and prefer dry grasslands but some species are also found in forest clearings (Massa et al., 2012): contextually, this group was associated to all habitats and elevation belts in GPNP, whereas in VDNP it showed high values only for the montane and subalpine belts probably due to the cooler temperatures compared to the other protected areas.

Our results for *Omocestus viridulus* in the VDNP are consistent with the species ecology because it is eurytherm, mostly found at 1500-2000 m a.s.l., and it is mesohygrophilous or hygrophilous (Massa et al., 2012). In GPNP, in the first time window (2006-2007), this species was not an indicator for any elevational belt while from 2012-2013 it showed high

values for all of them potentially because of unknown local dynamics on which it is difficult to speculate with the data currently available. Lastly, in ORNP, we noticed *Omocestus viridulus* as an indicator species for the elevational belts only in 2007-2008. A viable explanation could be the increasing temperature recorded for the three protected areas (Cerrato et al. 2019) which could have led to increased dryness. However, more local and detailed data are needed to demonstrate this potential relationship.
Beside this changes in time, we identified *Aeropus sibiricus*, *Epipodisma pedemontana* (GPNP, ORNP), *Anonconotus* sp. (ORNP) and *Bohemanella frigida* (VDNP) as species indicator for the alpine belt in line with Sindaco et al. (2012).

Chapter 2- Orthopterans abundance estimates accounting for detectability

In this chapter we focused on orthopteran counts carried out in the GPNP during 2019 because the data were recorded keeping track of which species and how many individuals were found in each ring count (sampling attempt). This data collection approach allowed us to test and perform N-mixture model procedure.

Data analysis

Species selection

We decided to investigate which habitat, meteorological and climatic variables influenced the detectability and the abundance of three target species, *Stauroderus scalaris*, *Omocestus viridulus* and *Aeropus sibiricus*, because they showed temporal changes of IndVal values throughout the ABMP time periods as reported in the first chapter. Moreover, we decided to include *Chorthippus* gr. *biguttulus* in our analysis because this species complex is well distributed along the elevational gradient. Even though *Chorthippus* gr. *biguttulus* group consist of different species identities, we considered it for the analysis because the ecology of the species belonging to the complex is quite consistent (see chapter 1 for details, Massa et al., 2012) and we therefore assume a uniform ecological response.

Explanatory variables

Using QGIS version 3.16 (QGIS Development Team, 2021), we calculated the mean annual solar radiation (KWh, rad) and the percentages of habitat cover for each plot, considering it as a circular surface of 100 m radius centred on the central pitfall trap of the five used for the collection of surface-active arthropods contextually to the ABMP (Viterbi et al., 2013). We obtained land cover percentages from a land cover map developed by GPNP botanical service through aerial photos analysis and on field validation. We considered the habitat types attributable to wetlands (wetland_veg), woodlands (wood), shrublands (shrub), grasslands (grassland), screes (screes) and cliffs (cliff_veg). The last two categories include habitats that host peculiar vegetational communities growing in fissures and on superficial soils of rock surfaces.

Besides, for each plot, we used the hourly air temperature recorded by iButtons, to calculate the mean temperature of the sampling season (from 02/07/2019 to 30/09/2019) (t_seas) and the mean daily temperature of sampling session (t_day). Temperature data series was first checked for the presence of outliers. We considered as outliers those observations that lie outside 1.5 * *IQR*, where IQR, the 'Inter Quartile Range' is the difference between 75th and 25th percentiles.

Moreover, in order to define the structural diversity at the microhabitat level of each plot, we used data derived from detailed vegetation samplings where each plot was subdivided in five quadrants (25 m^2) placed around the pitfall traps. For each subarea, the cover percentages were estimated for rocks and gravel, soil, litter, moss layer, herbaceous layer, short shrubs, high shrubs and woods. Then, micro habitat heterogeneity (H_micro) was calculated for each plot as the mean value of the Shannon-Wiener index of each quadrant.
Subsequently, the vascular plant species present in each quadrant were listed, quantified and associated to their Landolt indices (Landolt et al., 2010). At last, we associated a value of moisture to each plot using the average of Landolt index for humidity (hum) of all the plant species present in the plot weighted for the mean cover values of each species.
We also included the sky cover conditions (sunny, partly cloudy, cloudy and changeable) (sky) in our analysis.
Before the analysis, we tested the correlation for all the continuous variables using the *cor* function with *spearman* method and set 0.70 as a threshold (Dormann et al., 2013).

N-mixture models

N-mixture models assume closed population among sampling occasions (Royle & Dorazio, 2006), but nymphs' development occurs throughout our sampling season so that an immature individual caught in the first sampling period (July) could be sampled as an adult in the second one (August). To overcome this issue, we analysed separately the three sampling periods (July, August, September) and divided the thirty attempts planned by the sampling protocol in three subsets of ten each in order to obtain three full observations (secondary periods) per plot per sampling period (primary periods). The subsets can be considered as actual different sampling replicates therefore respecting the closure population assumption and assuming constant species availability among sampling occasions (Kéry & Royle, 2015).
We excluded GPD, VA and VB from the analysis because for GPD temperature data were not available since the data-logger got lost, while in the other two plots we collected less than ten individuals in total throughout the sampling period and we considered them unsuitable for orthopterans a priori.
Prior to analysis, all explanatory variables were centered and scaled to make them comparable and to facilitate the model fitting (Becker et al., 1988). Then, for each species and for each sampling period, we tested models based on biological hypotheses adding covariates to the constant model ρ. λ. using the *unmarked* package (Fiske & Chandler, 2011) in the statistical environment R 4.1.0 (RCore Team, 2021).
We applied a two-step modelling procedure by which covariates for detection (ρ) were added

first while keeping abundance (λ) constant at null. We then considered the highest-ranked model for detection in all subsequent models for abundance (Kroll et al., 2010). In particular, we tested as important variables for orthopteran detectability (observation process), sky cover (sky) and mean day temperature during sampling activity (t_day), while for abundance (state process) we used all the remaining habitat and climatic variables.

We modelled abundance according to the Poisson distribution (P) for *Stauroderus scalaris*, *Omocestus viridulus* and *Chorthippus* gr. *biguttulus* whereas we selected the Zero-Inflated Poisson (ZIP) for *Aeropus sibiricus* because of the many zero counts due to its narrow altitudinal distribution. To select the best models, we used the Akaike's Information Criterion corrected for small sample sizes (AICc; Hurvich & Tsai, 1989) with the *aictab* function from *AICcmodavg* package. We then tested the goodness of fit (Gof) of the selected models running 1000 replicates with the function *parboot*, considering as a good fitting model the one showing p>0.05 (Kéry & Royle, 2015).

Results

We successfully modelled the first period (July) for *Aeropus sibiricus, Stauroderus scalaris* and *Omocestus viridulus*, the second one (August) for *Chorthippus* gr. *biguttulus*. None of the third sampling period (September) had enough data to make models converge.

Based on mean estimates, *Aeropus sibiricus* resulted the most abundant species in July (10.84 ± 4.20), followed by *Stauroderus scalaris* (5.65 ± 1.90) and *Omocestus viridulus* (2.54 ± 0.80). The mean abundance for *Chorthippus* gr. *biguttulus* was estimated to be 3.04 ± 0.78.

The results of the model selection are reported in the Supplementary materials and so are the outputs of the Gof tests.

Three species out of four (*Omocestus viridulus*, *Chorthippus* gr. *biguttulus* and *Stauroderus scalaris*) showed a quadratic relationship between the detectability and the mean daily temperature, the detectability showed the optimum in a range of temperature between about 12°C and 16°C (Fig. 5). Conversely, the detectability of *Aeropus sibiricus* appeared slightly affected by the weather conditions: the probability of detection was higher with sunny weather and decreased as the sky covered (Fig. 6).

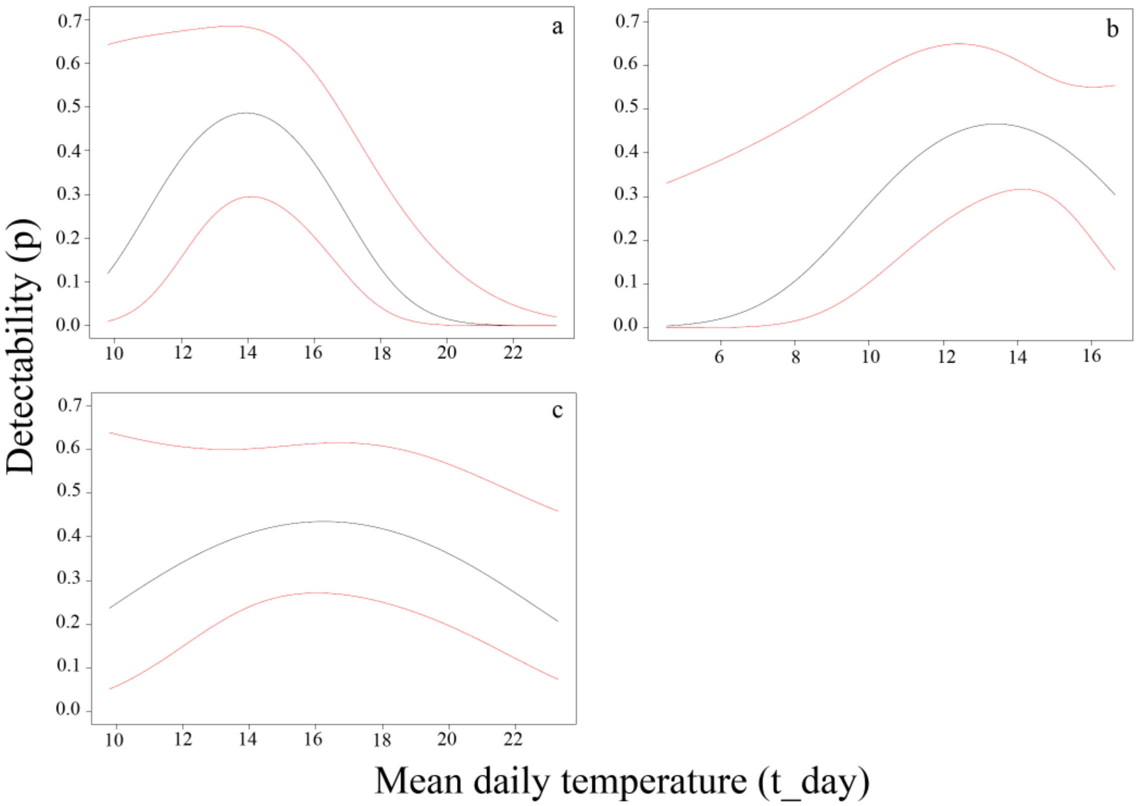


Fig. 5 Detection probability of Omocestus viridulus (a), Chorthippus gr. biguttulus (b) and Stauroderus scalaris (c) in relation to daily mean temperature (C°). The red lines represent the 95% CI.

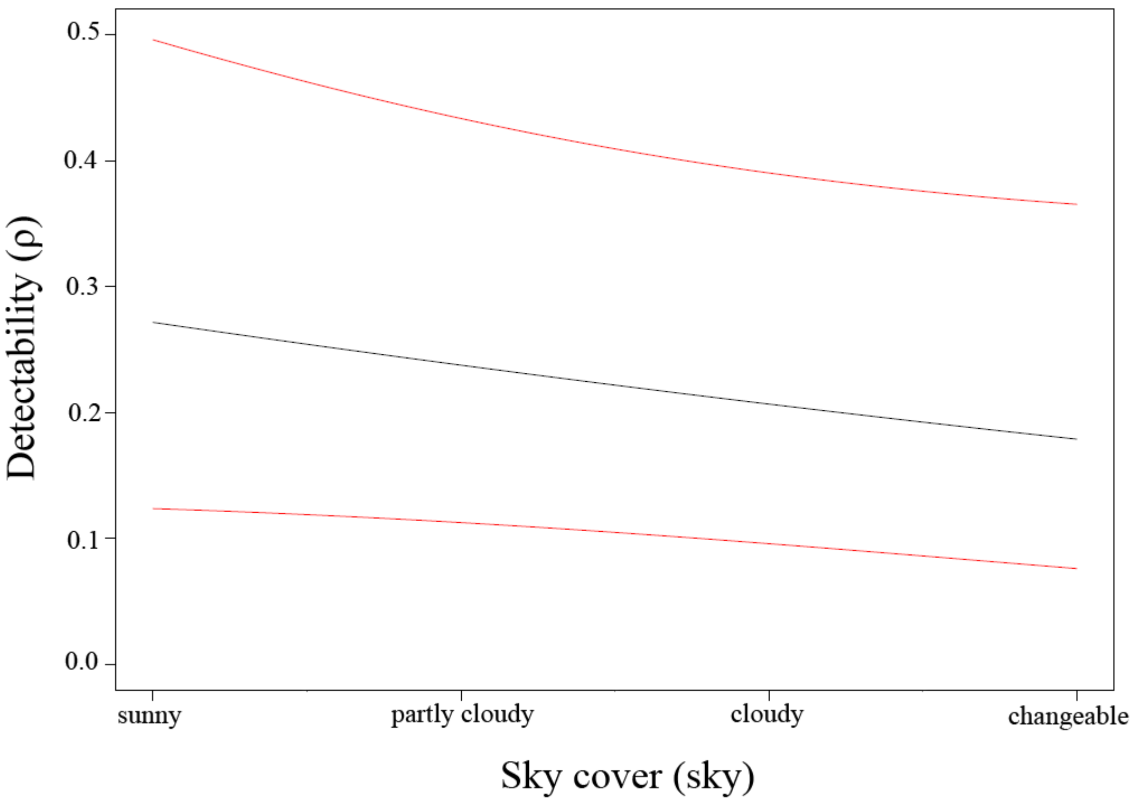


Fig. 6 Detection probability of Aeropus sibiricus in relation to the sky cover. The red lines represent the 95% CI.

The selected model for *Stauroderus scalaris* (AICc = 299.34, S1) included additive linear effects of the mean seasonal temperature, the percentage of grassland and a quadratic effect of humidity on abundance (Table 6). The abundance of this species is positively related to the seasonal temperature and the percentage of grassland whereas it decreases as the humidity increases (Fig. 7).

Table 6 Details of estimates for Stauroderus scalaris

	Covariate	*Estimate*	*SE*	*z*	*P-value*
Detectability	(Intercept)	-0.2622	0.369	-0.7098	0.4779
	t_day^2	-0.2117	0.119	-17.764	0.0757
	t_day	0.0214	0.275	0.0778	0.9380
Abundance	(Intercept)	17.996	0.234	7.695	1.42e-14
	t_seas	0.7744	0.174	4.461	8.18e-06
	grassland	0.4331	0.139	3.124	1.78e-03
	hum	-0.0876	0.141	-0.621	5.35e-01
	hum^2	-0.3393	0.131	-2.583	9.80e-03

We selected the second best performing model for *Chorthippus* gr. *biguttulus* (AICc = 262.91, S2) following the principle of parsimony (Anderson & Burnham, 2004) and because it had a better fit (p-value = 0.801) than the first one (p-value = 0.056) (See supplementary materials, Goodness of fit). Therefore, the abundance of this species appears to be higher as the solar radiation increases (Table 7, Fig. 8a). On the contrary, the abundance of *Omocestus viridulus* is best described by a negative relation with the same covariate (AICc = 170.98, S3, Table 8) (Fig. 8b).

Table 7 Details of estimates for Chorthippus gr. biguttulus

	Covariate	*Estimate*	*SE*	*z*	*P-value*
Detectability	(Intercept)	-0.1394	0.333	-0.418	0.676
	t_day^2	-0.5167	0.260	-1.986	0.047
	t_day	-0.0839	0.395	-0.212	0.832
Abundance	(Intercept)	1.03	0.198	5.21	1.93e-07
	rad	0.67	0.170	3.93	8.33e-05

Table 8 Details of estimates for Omocestus viridulus

	Covariate	*Estimate*	*SE*	*z*	*P-value*
Detectability	(Intercept)	-0.565	0.433	-1.31	0.19174
	t_day^2	-1.089	0.414	-2.63	0.00859
	t_day	-1.491	0.512	-2.91	0.00359
Abundance	(Intercept)	0.718	0.286	2.51	1.20e-02
	rad	-0.640	0.154	-4.16	3.22e-05

According to the selected model for *Aeropus sibiricus* (AICc = 266.47, S4), the abundance of this species drops dramatically as the percentage of woodland increases and is slightly affected negatively by the degree of humidity (Fig. 9). Moreover, according to the ZIPparameter (Table 9), we noticed that 11% of all plots are not suitable for *Aeropus sibiricus* in principle.

Table 9 Details of estimates for Aeropus sibiricus

	Covariate	*Estimate*	*SE*	*z*	*P-value*
Detectability	(Intercept)	-0.808	0.562	-1.44	0.150
	sky	-0.179	0.133	-1.35	0.179
Abundance	(Intercept)	-0.107	0.843	-0.127	8.99e-01
	wood	-3.906	0.947	-4.125	3.70e-05
	hum	-0.411	0.104	-3.972	7.13e-05
Zero-inflation		-2.04	1.01	-2.03	0.0428

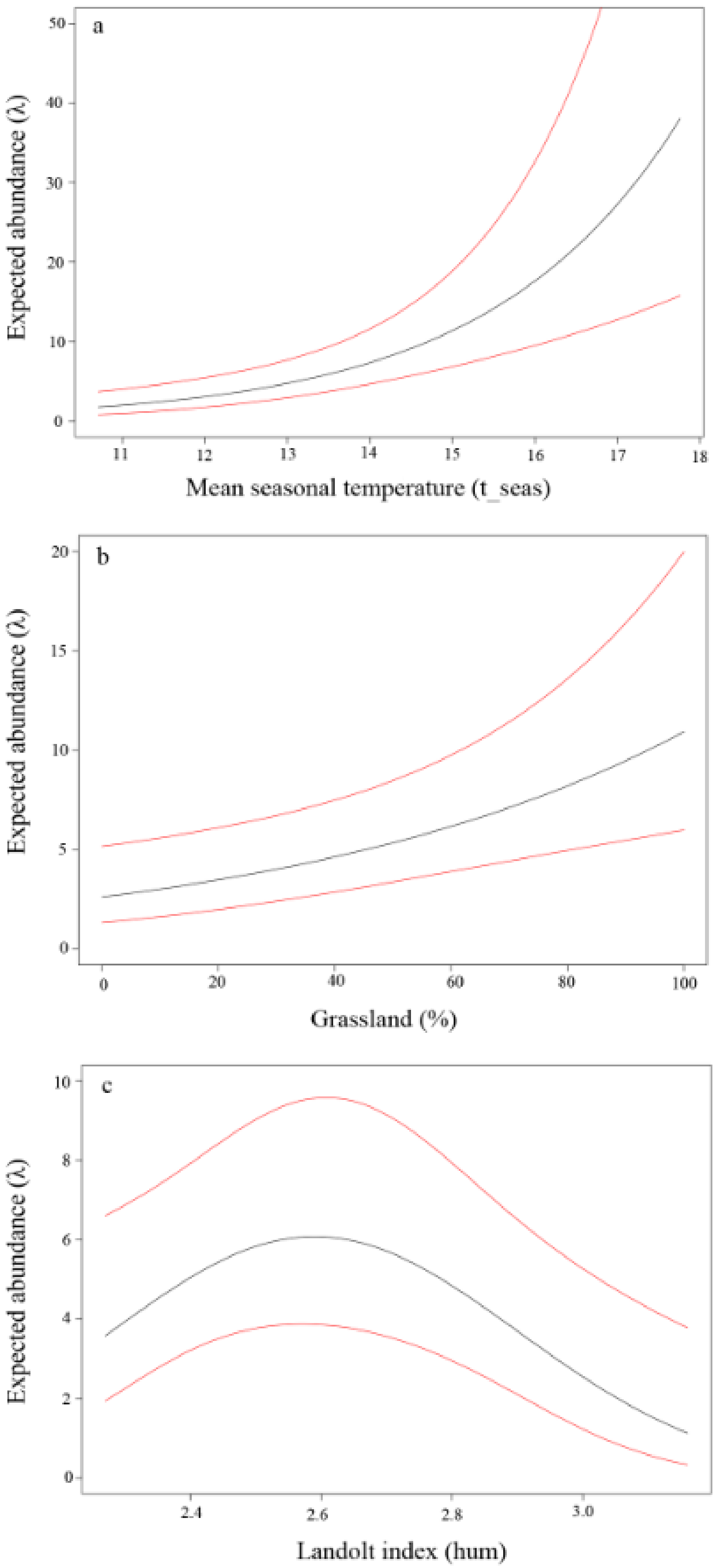


Fig. 7 Estimated abundance in relation to the mean seasonal temperature (a), the percentage of grassland (b) and the humidity (c) for Stauroderus scalaris. The red lines represent the 95% CI.

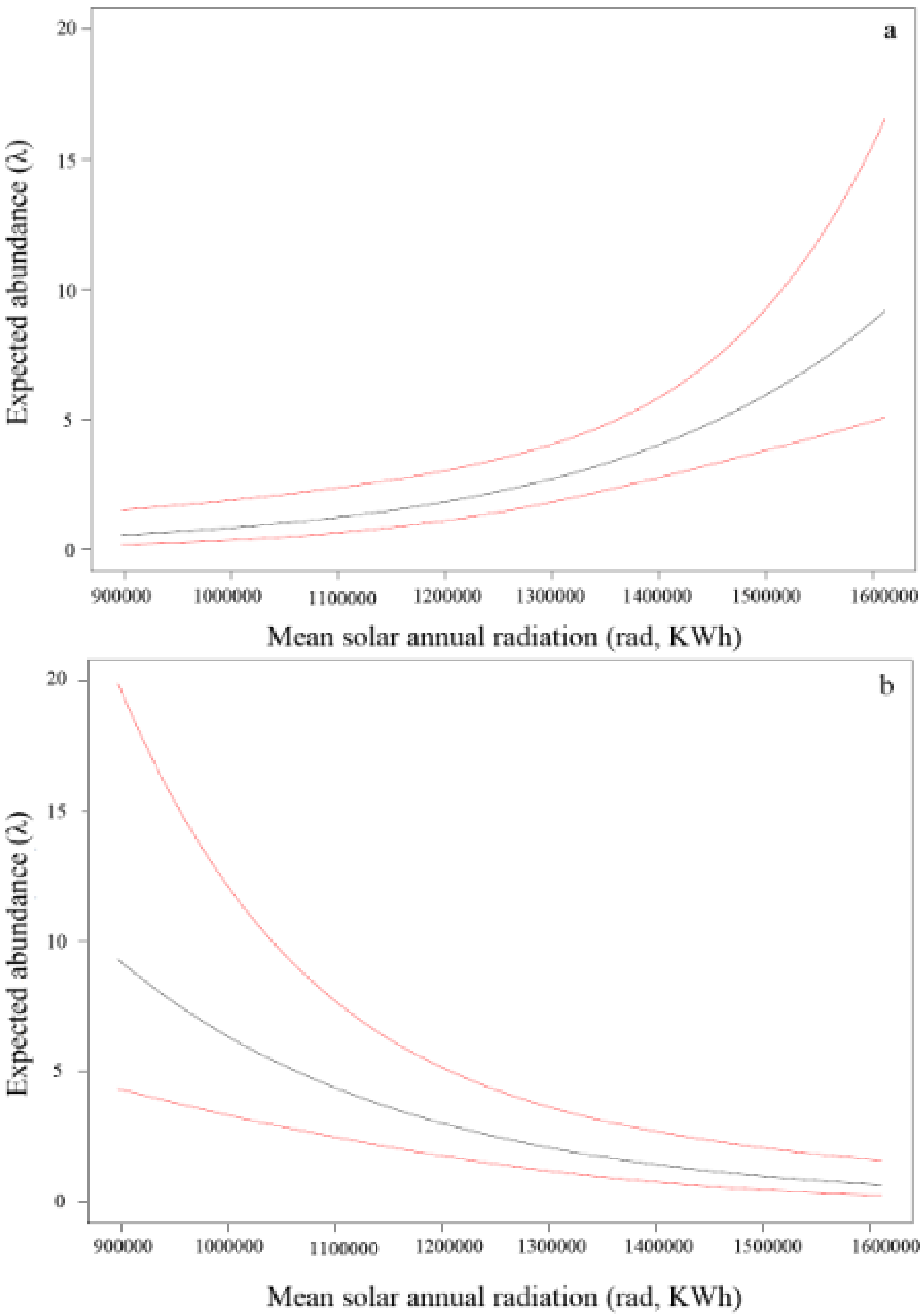


Fig. 8 Estimated abundance in relation to solar radiation for Chorthippus gr. biguttulus (a) and Omocestus viridulus (b). The red lines represent the 95% CI.

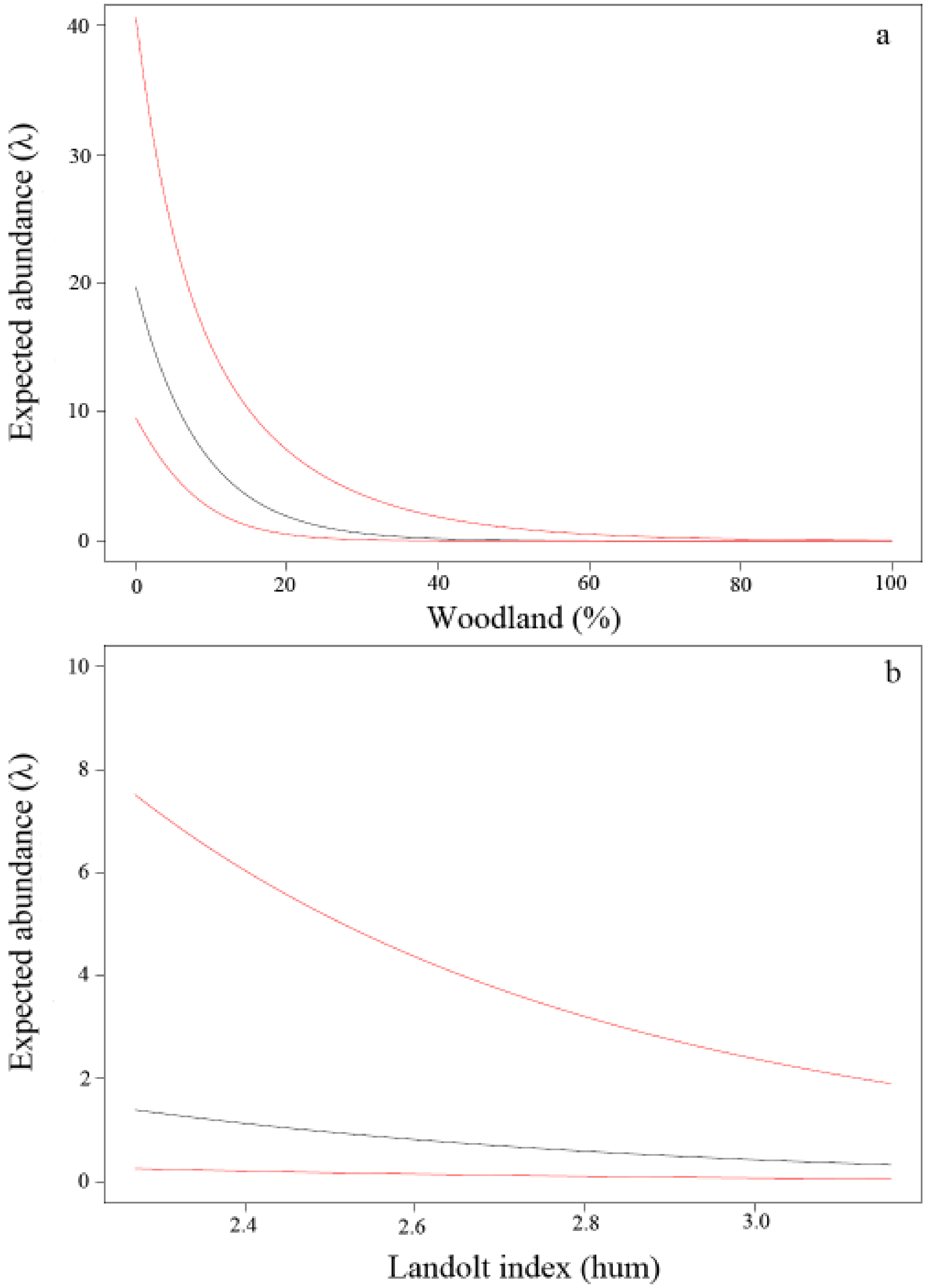


Fig. 9 Expected abundance of Aeropus sibiricus in relation to the percentage of woodland (a) and the degree of humidity derived from the Landolt index (b)

Discussion

In line with our mean estimates of abundance, Battisti et al. (2016) reported that *Aeropus sibiricus* was the most abundant species in VDNP considering together all the elevational belts while in ORNP this species was the most abundant in the alpine belt (Giuliano et al., 2017). Conversely, *Omocestus viridulus* was the second most abundant in VDNP (Battisti et al., 2016) while we found it was *Stauroderus scalaris*.

Being ectotherms, Orthopterans rely on external heat to reach the body temperature needed for their daily activities (Chappel & Whitman, 1990). In line with this, the selected models for *Stauroderus scalaris*, *Omocestus viridulus* and *Chorthippus* gr. *biguttulus* highlighted that these species are harder to detect at low mean temperatures probably because they are less active. On the contrary, the decrease of the detection probability at higher temperature could reflect a critical aspect of the sampling method used: in warmer days Orthopterans are more active so, during the ring counts, where the operator walks along the transect and lay the plastic cylinder on the ground, the individuals might be more reactive to movements and could move away faster. In this context, the use of the N-mixture models allows to keep in consideration this methodological limitation adjusting the abundance estimates based on the detectability of the species.

On the other hand, *Aeropus sibiricus* seems not to be affected by the daily temperature probably because this species inhabits a narrow elevational range compared to the other species so this parameter varies less markedly. Yet, the sky cover was selected as the most relevant variable on detectability. The type of clouds and their coverage degree can limit the quantity of solar radiation at ground level (Martínez-Chico et al., 2011) so the weather conditions may influence the time span in which orthopterans reach the ideal body temperature.

It is interesting to notice that the temperature was relevant for the detectability of species with macropterous males and females. *Stauroderus scalaris*, *Omocestus viridulus* and *Chorthippus* gr. *biguttulus* are good flyers and, therefore, as the temperature rises, they are more mobile and have greater escape abilities. Conversely, *Aeropus sibiricus* shows a sexual dimorphism with macropterous males and usually short-winged females (brachypterous). This morphological characteristic likely supports the lack of influence of temperature on the detectability of this species, in fact *Aeropus sibiricus* has reduced mobility regardless the temperature.

However, it would be interesting to test if the detectability varies with sex for orthopterans in general and which covariates influence it for apterous species such as *Epipodisma pedemontana*.

An increasing trend for temperature was reported locally in the past (Cerrato et al., 2019) and it is likely that this is still the case today, meanwhile Rocchia et al. (2018) observed an expansion of woodlands at lower altitudes over a period of twelve years in the same area. In this context, the positive influence of the seasonal temperature and the percentage of grassland on the abundance of *Stauroderus scalaris* could have an important role on the future dynamics of the orthopteran communities. Contextually, in the first chapter we already noticed an altitudinal expansion for this species (Chapter 1, Table 4). Therefore, it would seem likely to hypothesize that the loss of open areas at low and middle altitudes together with milder temperatures and the presence of suitable habitats at high altitudes could favor an additional upward expansion of this species over time.

The positive and the negative relationship between the abundance and the solar radiation for *Chorthippus* gr. *biguttulus* and *Omocestus viridulus* respectively, are in line with their ecology (Massa et al., 2012). In fact, the species of the *Chorthippus biguttulus* complex are mostly thermophilic whereas *Omocestus viridulus* is more hygrophilous. These relations could help understand more about our findings in the first chapter (Table 4). In VDNP, *Chorthippus* gr. *biguttulus* was an indicator species of the montane and subalpine belts whereas it was ubiquitous in GPNP. We hypothesized that the cooler climate at high altitudes of VDNP could represent an altitudinal limitation for this species complex. Since the solar radiation is positively related with temperature (Shen & Wang, 2011), our finding about the positive relationship between the abundance of *Chorthippus* gr. *biguttulus* and the solar radiation is an additional evidence in favor of its thermophilic preferences and as a consequence to a negative suitability to cold climates.

Indeed, we argue to be cautious to generalize the results we obtained for GPNP to other areas because the species might respond differently to the same variables in different geographical contexts. However, these hypotheses could be a starting point for further analysis in which we could include data from the other areas investigated in the first chapter.

In the first chapter, we noticed that *Aeropus sibiricus* was no longer an IndVal species for woodland in 2018-2019 (Chapter 1, Table 5) and we hypothesized that it could have been a sign of the encroachment of the vegetational succession at lower elevations. The results from the negative relation between its estimated abundance and the percentage of woodland seem to support this hypothesis as this species is expected to disappear where the wood cover is more than 40%.

Conclusions

The results of my work seem to suggest changes over time within orthopteran communities along an altitudinal gradient, probably as a response to the increasing temperature and to the evolution of the vegetational structure at lower altitudes due to the abandonment of traditional management practices. This pattern is not an exception but rather an additional contribution to the knowledge about the modifications occurring on different taxa assemblages in the last decades in an alpine context as reported for example for butterflies (Cerrato et al., 2019), dung beetles (Tocco & Villet, 2016) and birds (Rocchia et al., 2018).
In this changing context, it is very important to recognize population trends and the driving forces behind them to adopt adaptive management strategies.
We are aware of the limits of the sampling method used for Orthopterans in the ABMP but we demonstrated that it could be easily improved keeping track of the outcome of each sampling attempt and using the N-mixture models to perform the analysis. In fact, with this simple data collection correction, we were able to obtain reliable estimates of abundance based on detectability.
In the future, we hope to extend these analysis to the other protected areas involved in the project in order to verify if the species respond differently in different geographic areas and to implement the estimates of species detectability calculated in the present thesis in models based on the long term Orthopteran data collected in ABMP to obtain reliable trends of abundance over time.

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Supplementary material

Model selection

S1 Model selection for Stauroderus scalaris, in bold the selected one

N-mixture models	*K*	*AICc*	*ΔAICc*	*Wi*	*Acc. Wi*
$\rho_{t\_day+t\_day^2}$ $\lambda_{t\_seas+grassland+hum+hum^2}$	**8**	**299.34**	**0.00**	**0.65**	**0.65**
$\rho_{t\_day+t\_day^2}$ $\lambda_{t\_seas+grassland}$	6	301.43	2.09	0.23	0.89
$\rho_{t\_day+t\_day^2}$ λ_{t_seas}	5	305.17	5.83	0.04	0.92
$\rho_{t\_day+t\_day^2}$ $\lambda_{t\_seas+hum+hum^2}$	7	305.26	5.91	0.03	0.95
$\rho_{t\_day+t\_day^2}$ $\lambda_{t\_seas+H\_micro}$	6	306.04	6.70	0.02	0.98
$\rho_{t\_day+t\_day^2}$ $\lambda_{t\_seas+hum}$	6	306.24	6.90	0.02	1.00
$\rho_{t\_day+t\_day^2}$ λ_{H_micro}	5	312.23	12.88	0.00	1.00
$\rho_{t\_day+t\_day^2}$ $\lambda.$	4	316.04	16.70	0.00	1.00
$\rho_{t\_day+t\_day^2}$ $\lambda_{grassland}$	5	318.10	18.76	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{shrub}	5	318.62	19.28	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{hum}	5	318.71	19.37	0.00	1.00
ρ_{t_day} $\lambda.$	3	318.81	19.47	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{rad}	5	319.03	19.68	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{wood}	5	319.08	19.73	0.00	1.00
$\rho.$ $\lambda.$	2	322.20	22.86	0.00	1.00
ρ_{sky+t_day} $\lambda.$	6	326.57	27.22	0.00	1.00
ρ_{sky} $\lambda.$	5	330.54	31.20	0.00	1.00

S2 Model selection for Chorthippus gr.biguttulus, in bold the selected one

N-mixture models	*K*	*AICc*	*ΔAICc*	*Wi*	*Acc. Wi*
$\rho_{t\_day+t\_day^2}$ $\lambda_{\%soil+rad}$	6	258.04	0.00	0.89	0.89
$\rho_{t\_day+t\_day^2}$ λ_{rad}	**5**	**262.91**	**4.88**	**0.08**	**0.96**
$\rho_{t\_day+t\_day^2}$ $\lambda_{\%soil}$	5	264.50	6.47	0.03	1.00
$\rho_{t\_day+t\_day^2}$ λ_{hum}	5	271.30	13.26	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{shrub}	5	271.98	13.94	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{cliff_veg}	5	274.48	16.44	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{H_micro}	5	275.48	17.44	0.00	1.00
$\rho_{t\_day+t\_day^2}$ $\lambda_{grassland}$	5	276.57	18.54	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{wood}	5	276.76	18.72	0.00	1.00
$\rho_{t\_day+t\_day^2}$ $\lambda.$	4	279.12	21.08	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{screes}	5	280.23	22.19	0.00	1.00
$\rho_{t\_day+t\_day^2}$ λ_{t_seas}	5	280.32	22.28	0.00	1.00
ρ_{sky} $\lambda.$	5	287.22	29.19	0.00	1.00
$\rho.$ $\lambda.$	2	287.77	29.73	0.00	1.00
ρ_{t_day} $\lambda.$	3	289.86	31.82	0.00	1.00
$\rho_{t\_day+sky}$ $\lambda.$	6	290.54	32.51	0.00	1.00

S3 Model selection for Omocestus viridulus, in bold the selected one

N-mixture models	*K*	*AICc*	*ΔAICc*	*Wi*	*Acc. Wi*
$\rho_{t\_day+t\_day^2}$ λ_{rad}	**5**	**170,98**	**0**	**0,99**	**0,99**
$\rho_{t\_day+t\_day^2}$ λ_{screes}	5	181,3	10,32	0,01	0,99
$\rho_{t\_day+t\_day^2}$ λ_{hum}	5	183,25	12,27	0	0,99
$\rho_{t\_day+t\_day^2}$ λ_{H_micro}	5	183,88	12,9	0	1
$\rho_{t\_day+t\_day^2}$ $\lambda_{\%soil}$	5	184,01	13,03	0	1
$\rho_{t\_day+t\_day^2}$ λ_{t_seas}	5	184,62	13,64	0	1
$\rho_{t\_day+t\_day^2}$ $\lambda.$	4	184,78	13,8	0	1
$\rho_{t\_day+t\_day^2}$ λ_{wood}	5	187,26	16,28	0	1
$\rho_{t\_day+t\_day^2}$ $\lambda_{wetland\_veg}$	5	187,32	16,34	0	1
$\rho_{t\_day+t\_day^2}$ λ_{shrub}	5	187,59	16,61	0	1
$\rho_{t\_day+t\_day^2}$ $\lambda_{grassland}$	5	187,75	16,77	0	1
$\rho_{t\_day+t\_day^2}$ λ_{cliff_veg}	5	187,82	16,84	0	1
ρ_{t_day} $\lambda.$	3	196,46	25,48	0	1
$\rho.$ $\lambda.$	2	196,76	25,78	0	1
ρ_{sky} $\lambda.$	5	199,14	28,15	0	1
ρ_{sky+t_day} $\lambda.$	6	199,98	29	0	1

S4 Model selection for Aeropus sibiricus, in bold the selected one

N- mixture models	*K*	*AICc*	*ΔAICc*	*Wi*	*Acc. Wi*
p_{sky} $\lambda_{wood+hum}$	**6**	**266.47**	**0**	**0.51**	**0.51**
p_{sky} $\lambda_{wood+rad+hum}$	7	266.91	0.44	0.41	0.92
p_{sky} $\lambda_{wood+rad}$	6	270.24	3.77	0.08	1
p_{sky} λ_{wood}	5	280.04	13.58	0	1
p_{sky} $\lambda_{wood+shrub}$	6	282.84	16.37	0	1
p_{sky} λ_{rad}	5	305.6	39.14	0	1
p_{sky} $\lambda_{grassland}$	5	309.82	43.36	0	1
p_{sky} $\lambda_{\%soil}$	5	325.19	58.72	0	1
p_{sky} λ_{t_seas}	5	325.89	59.42	0	1
p_{sky} $\lambda.$	4	329.92	63.46	0	1
p_{sky} λ_{shrub}	5	330.41	63.94	0	1
p_{sky} λ_{cliff_veg}	5	330.67	64.2	0	1
p_{sky} λ_{H_micro}	5	331.98	65.51	0	1
$p.$ $\lambda.$	3	337.83	71.37	0	1
p_{t_day} $\lambda.$	4	340.54	74.08	0	1

Goodness of fit (Gof)

S5 Outputs of the Gof. In bold the model for Chorthippus gr. Biguttulus which we rejected due to the principle of parsimony

Species	*N-mixture model*	*mean*	*Standard deviation*	*p-value*
Stauroderus scalaris	$\rho_{t\_day+t\_day^2}\ \lambda_{t\_seas+grassland+hum+hum^2}$	56.9	513	0.968
Chorthippus* gr.*biguttulus	$\boldsymbol{\rho_{t\_day+t\_day^2}\ \lambda_{\%soil+rad}}$	**596**	**1329**	**0.0559**
Chorthippus gr.*biguttulus*	$\rho_{t\_day+t\_day^2}\ \lambda_{rad}$	27	928	0.801
Omocestus viridulus	$\rho_{t\_day+t\_day^2}\ \lambda_{rad}$	64.3	1344	0.424
Aeropus sibiricus	$p_{sky}\ \lambda_{wood+hum}$	25.2	191	0.759