

1 **SUPPLEMENTARY INFORMATION**

2 **Consistent population declines but idiosyncratic range shifts in Alpine orchids under global change**

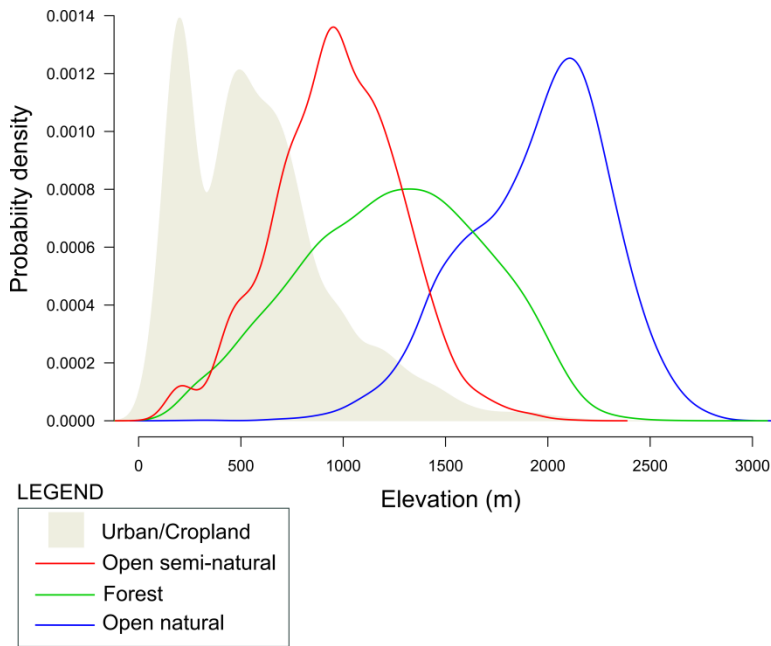
3 Costanza Geppert, Giorgio Perazza, Robert J. Wilson, Alessio Bertolli, Filippo Prosser, Giuseppe Melchiori,

4 Lorenzo Marini

5

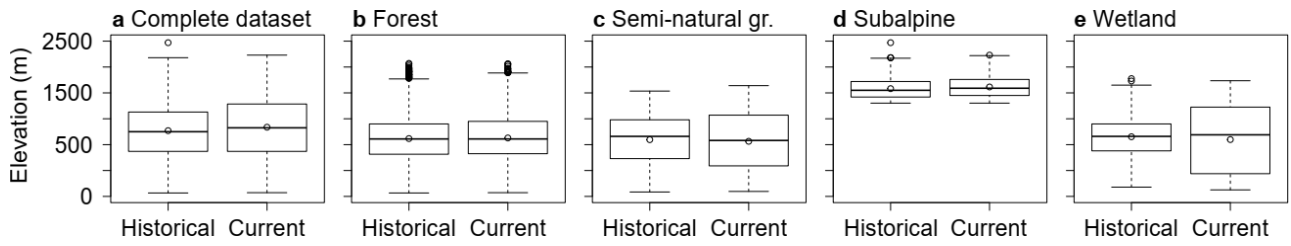
6 Supplementary Figs. S1–2 and Supplementary Tables S1–4.

7 **SUPPLEMENTARY FIGURES**



8

9 **Supplementary Figure 1** Density function of habitat availability at the regional scale over the elevational  
10 gradient. Data come from regional land-use maps. Wetlands did not present a clear elevational pattern, i.e.  
11 areas were more or less equally distributed across different elevations.



12

13 **Supplementary Figure 2** Sampling effort over the elevational gradient in both the historical (1990-2003)  
 14 and current (2004-2017) periods for the complete dataset and for each habitat type. Complete dataset: n =  
 15 10,293 historical sites, n = 11,308 current sites. Boxplots display minimum, maximum, median, first quartile,  
 16 and third quartile and were drawn using the default settings in the boxplot() function in R.

17 **SUPPLEMENTARY TABLES**

18 **Supplementary Table 1** List of the orchid species with the number of records in the historical (1990-2003)  
 19 and current (2004-2017) time periods, habitat preferences, min and max elevation reported in the dataset, and  
 20 threat category as indicated in the Italian Red List of Threatened Species\*. Red List categories as follows, in  
 21 increasing level of threat: NE – Not Evaluated; LC – Least Concern; NT – Near Threatened; VU –  
 22 Vulnerable; EN – Endangered. We followed Perazza & Lorenz (2013)<sup>34</sup> for the nomenclature of the species.  
 23 In the last column, we indicated if the species was included in the population dynamics and range shift  
 24 analyses (Hist) and/or resurvey analysis (Res).

Species	Count historical	Count current	Habitat preference	Elevation (m)		Red list	Analysis
				Min	Max		
<i>Anacamptis pyramidalis</i>	285	282	Semi-natural	85	1620	NT	Hist, Res
<i>Cephalanthera damasonium</i>	556	547	Forest	140	1650	NE	Hist, Res
<i>Cephalanthera longifolia</i>	1215	1100	Generalist	95	2040	NE	Hist, Res
<i>Cephalanthera rubra</i>	428	228	Forest	125	1700	NE	Hist, Res
<i>Chamorchis alpina</i>	224	163	Subalpine	1580	2660	NE	Hist
<i>Coeloglossum viride</i>	1285	1257	Grassland	570	2970	NE	Hist, Res
<i>Corallorhiza trifida</i>	468	187	Forest	615	2150	NE	Hist, Res
<i>Cypripedium calceolus</i>	556	259	Generalist	380	2295	LC	Hist, Res
<i>Dactylorhiza fuchsii</i>	2840	3759	Generalist	230	2450	NE	Hist, Res
<i>Dactylorhiza incarnata</i>	141	51	Wetland	179	1820	VU	Hist, Res
<i>Dactylorhiza lapponica</i>	94	35	Wetland	400	2145	VU	Hist, Res
<i>Dactylorhiza majalis</i>	66	73	Wetland	1156	2276	NT	Hist, Res
<i>Dactylorhiza sambucina</i>	521	310	Grassland	250	2220	NE	Hist
<i>Epipactis atrorubens</i>	1580	1389	Forest	160	2400	NE	Hist, Res
<i>Epipactis bugacensis</i>	0	82	Wetland	126	212	NE	Res
<i>Epipactis helleborine</i>	1020	1083	Forest	140	1890	NE	Hist, Res
<i>Epipactis muelleri</i>	158	138	Forest	184	1490	NE	Hist, Res
<i>Epipactis palustris</i>	132	48	Wetland	194	1610	NT	Hist, Res
<i>Epipogium aphyllum</i>	120	78	Forest	695	1850	VU	Hist
<i>Goodyera repens</i>	848	359	Forest	250	1960	NE	Hist, Res
<i>Gymnadenia conopsea</i>	2286	1747	Grassland	165	2620	NE	Hist, Res
<i>Gymnadenia odoratissima</i>	827	622	Grassland	100	2500	NE	Hist, Res
<i>Himantoglossum adriaticum</i>	44	203	Semi-natural	270	1030	VU	Hist, Res
<i>Limodorum abortivum</i>	338	267	Forest	66	1180	NE	Hist, Res
<i>Liparis loeselii</i>	16	13	Wetland	437	1018	EN	Res
<i>Listera cordata</i>	383	252	Forest	900	2130	NE	Hist, Res
<i>Listera ovata</i>	1472	950	Generalist	100	2235	NE	Hist, Res
<i>Neottia nidus avis</i>	1392	1440	Forest	140	1820	NE	Hist, Res
<i>Nigritella buschmanniae</i>	51	93	Subalpine	1880	2545	NE	Hist
<i>Nigritella miniata</i>	195	284	Subalpine	1280	2690	NT	Hist
<i>Nigritella rhellicani</i>	1179	1301	Subalpine	1155	2720	NE	Hist, Res
<i>Ophrys apifera</i>	22	70	Semi-natural	98	890	NT	Res
<i>Ophrys bertolonii</i>	70	55	Semi-natural	100	820	EN	Hist, Res
<i>Ophrys holosericea</i>	57	106	Semi-natural	145	1020	VU	Hist, Res
<i>Ophrys insectifera</i>	280	173	Generalist	200	2100	NE	Hist, Res
<i>Ophrys sphegodes</i>	175	134	Semi-natural	85	950	NT	Hist, Res

<i>Orchis coriophora</i>	29	6	Semi-natural	540	1330	NE	Res
<i>Orchis mascula</i>	408	223	Generalist	240	2570	NE	Hist, Res
<i>Orchis militaris</i>	389	174	Semi-natural	100	2140	NT	Hist, Res
<i>Orchis morio</i>	276	188	Semi-natural	90	1470	NT	Hist, Res
<i>Orchis purpurea</i>	121	196	Generalist	140	1500	NT	Hist, Res
<i>Orchis simia</i>	76	63	Semi-natural	90	1040	NT	Hist, Res
<i>Orchis tridentata</i>	429	224	Semi-natural	98	1540	NE	Hist, Res
<i>Orchis ustulata</i>	328	115	Grassland	215	2050	NE	Hist, Res
<i>Platanthera bifolia</i>	1313	1048	Generalist	180	2480	NE	Hist, Res
<i>Platanthera chlorantha</i>	200	67	Generalist	250	1700	NE	Hist, Res
<i>Pseudorchis albida</i>	977	1210	Subalpine	900	2705	NE	Hist, Res
<i>Spiranthes spiralis</i>	14	32	Semi-natural	90	790	NE	Res
<i>Traunsteinera globosa</i>	578	441	Grassland	375	2560	NE	Hist

25 \*IUCN & Società Botanica Italiana. Lista rossa della flora Italiana. 58 (2013).

26 **Supplementary Table 2** Effect of time (difference in years between the two surveys), historical population  
 27 size, habitat preference, elevation, and habitat alteration (yes and no) on the probability that the orchid  
 28 population survived until the resurvey. We fitted generalized linear mixed models assuming a binomial  
 29 distribution with species as random factor (see Methods). Elevation was standardized to mean 0 and SD 1 to  
 30 make elevational ranges comparable among species.

	<b>Estimate</b>	<b>SE</b>	<b>t</b>	<b>p</b>
Time	-0.094	0.086	-1.104	0.269
log (Size)	0.521	0.088	5.932	<0.001
Generalist	0.140	0.254	0.551	0.582
Grassland	-0.758	0.386	-1.962	0.050
Semi-natural grassland	-0.413	0.258	-1.602	0.109
Subalpine	-0.386	0.496	-0.778	0.437
Wetland	-0.148	0.388	-0.380	0.704
Elevation	0.274	0.092	2.984	0.003
Habitat alteration	-0.539	0.174	-3.098	0.002

31

32 **Supplementary Table 3** Effect of time (year 1990-2017), elevation and their interaction on population size  
 33 within each habitat preference category. Elevation was standardized to mean 0 and SD 1 to make elevational  
 34 ranges comparable among species. We fitted generalized linear mixed models assuming a Poisson  
 35 distribution with species and OLRE as random effects (see Methods). All variables were scaled.

	<b>Fixed factor</b>	<b>Estimate</b>	<b>SE</b>	<b>t</b>	<b>p</b>
Forest	Elevation <sup>2</sup>	-0.123	0.012	-10.546	<0.001
	Elevation	0.028	0.012	2.418	0.016
	Time	-0.163	0.012	-14.074	<0.001
	Elevation x Time	0.036	0.012	3.098	0.002
Generalist	Elevation <sup>2</sup>	-0.212	0.013	-16.879	<0.001
	Elevation	-0.093	0.012	-7.479	<0.001
	Time	-0.222	0.013	-17.610	<0.001
	Elevation x Time	0.023	0.013	1.841	0.066
Grassland	Elevation <sup>2</sup>	-0.236	0.020	-11.890	<0.001
	Elevation	0.123	0.019	6.403	<0.001
	Time	-0.140	0.019	-7.515	<0.001
	Elevation x Time	0.048	0.019	2.532	0.011
Semi-natural grassland	Elevation <sup>2</sup>	-0.095	0.030	-3.129	0.002
	Elevation	-0.172	0.030	-5.763	<0.001
	Time	0.023	0.030	0.749	0.454
	Elevation x Time	0.016	0.031	0.511	0.609
Subalpine	Elevation <sup>2</sup>	-0.175	0.026	-6.807	<0.001
	Elevation	0.066	0.025	2.690	0.007
	Time	-0.253	0.025	-10.266	<0.001
	Elevation x Time	0.049	0.024	2.022	0.043
Wetland	Elevation <sup>2</sup>	-0.136	0.074	-1.836	0.066
	Elevation	0.106	0.073	1.451	0.147
	Time	0.015	0.074	0.204	0.839
	Elevation x Time	0.086	0.075	1.153	0.249

36

37 **Supplementary Table 4** Range shifts (m year<sup>-1</sup>) calculated on resurveyed species with at least 10 records per  
 38 survey.

<b>Species</b>	<b>Rear edge</b>	<b>Optimum</b>	<b>Leading edge</b>	<b>Count Initial survey</b>	<b>Count Second survey</b>
<i>Anacamptis pyramidalis</i>	2.307	3.402	-4.566	52	38
<i>Cephalanthera damasonium</i>	1.19	1.826	-4.583	28	30
<i>Cephalanthera longifolia</i>	-0.758	10.343	-9.273	74	46
<i>Cephalanthera rubra</i>	8.284	6.285	2.334	24	18
<i>Coeloglossum viride</i>	25.528	29.605	4.376	27	12
<i>Dactylorhiza fuchsii</i>	2.958	-1.234	-3.614	96	76
<i>Dactylorhiza incarnata</i>	2.915	2.334	8.177	40	19
<i>Epipactis atrorubens</i>	3.403	3.666	6.354	56	36
<i>Epipactis helleborine</i>	-0.597	26.613	-4.22	56	45
<i>Gymnadenia conopsea</i>	15.101	42.903	-2.055	80	45
<i>Himantoglossum adriaticum</i>	-7.841	-4.428	1.398	26	13
<i>Limodorum abortivum</i>	1.093	0.201	-13.158	37	26
<i>Listera ovata</i>	-1.932	0.529	8.231	50	43
<i>Neottia nidus avis</i>	6.049	23.805	0.643	60	38
<i>Nigritella rhellicani</i>	2.878	2.748	7.459	25	16
<i>Orchis morio</i>	-2.582	-3.048	-7.309	54	22
<i>Orchis purpurea</i>	9.324	7.405	-8.974	14	10
<i>Orchis tridentata</i>	-2.068	12.285	-1.235	47	25
<i>Platanthera bifolia</i>	5.761	1.688	-8.362	64	24
<i>Pseudorchis albida</i>	14.562	-1.699	2.381	29	14

39

40