

Ecological Monographs

APPENDIX S1

Traditionally managed landscapes do not prevent amphibian decline and the extinction of paedomorphosis

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TABLE S1. Location and abiotic aquatic habitat features of the populations of paedomorphic alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro.

#	Locality	Municipality	Coordinates	Elevation	Species	habitat	Area	Depth
1	Trnovačko jezero	Plužine	18.72 E 43.25 N	1,521 m	<i>alpestris</i>	lake	196,400 m ²	9.2 m
2	Vražje jezero	Žabljak	19.14 E 43.08 N	1,415 m	<i>alpestris</i>	lake	89,000 m ²	10.6 m
3	Zminičko jezero	Žabljak	19.24 E 43.10 N	1,291 m	<i>alpestris</i>	lake	80,100 m ²	3.8 m
4	Ridsko jezero	Plav	20.03 E 42.57 N	1,971 m	<i>alpestris</i>	lake	26,400 m ²	5.1 m
5	Kapetanovo jezero	Nikšić - Kolašin	19.23 E 42.81 N	1,687 m	<i>alpestris</i>	lake	115,500 m ²	37 m
6	Manito jezero	Kolašin	19.24 E 42.80 N	1,781 m	<i>alpestris</i>	lake	18,400 m ²	13.5 m
7	Bukumirsko jezero	Podgorica	19.55 E 42.60 N	1,449 m	<i>alpestris</i>	lake	26,850 m ²	18.8 m
8	Crni Kuk: Smrdelj	Nikšić	18.5 E 42.8 N	1,050 m	<i>alpestris</i>	pond	108 m ²	4 m
9	Kopilje: Katranara	Podgorica	19.2 E 42.5 N	878 m	<i>alpestris</i>	well	9,6 m ²	1.5 m
10	Brotnjik	Podgorica	19.3 E 42.5 N	1,099 m	<i>alpestris</i>	well	20 m ²	4.5 m
11	Seoca: Ubli na Krnjski Do ¹	Podgorica	19.2 E 42.5 N	945 m	<i>alpestris</i>	well	22 m ²	3.2 m
12	Vilusi: Cerova lokva	Nikšić	18.5 E 42.7 N	954 m	<i>graecus</i>	pond	53 m ²	2.5 m
13	Vilusi: Kovačevića lokva	Nikšić	18.6 E 42.7 N	926 m	<i>graecus</i>	pond	640 m ²	2.2 m
14	Vilusi: Rutešića voda	Nikšić	18.6 E 42.7 N	840 m	<i>graecus</i>	well	21 m ²	1 m
15	Osječenica: Velika Osječenica	Nikšić	18.6 E 42.6 N	1,010 m	<i>graecus</i>	pond	886 m ²	1 m
16	Gornja Spila: Voluje oko	Nikšić	18.6 E 42.7 N	920 m	<i>graecus</i>	pond	840 m ²	2 m
17	Jabuka: Kamenica	Nikšić	18.7 E 42.6 N	1,066 m	<i>graecus</i>	pond	96 m ²	2 m
18	Rokoče: Meka Lokva	Cetinje	18.7 E 42.6 N	1,015 m	<i>graecus</i>	pond	166 m ²	>3 m
19	Bjeloši: Lašor	Cetinje	18.9 E 42.3 N	830 m	<i>graecus</i>	pond	111 m ²	>3 m
20	Ceklin: Pijavica	Cetinje	18.9 E 42.3 N	279 m	<i>graecus</i>	pond	1,488 m ²	1.5 m
21	Progonovići: Razvađa	Cetinje	19.0 E 42.4 N	381 m	<i>graecus</i>	pond	117 m ²	3.5 m
22	Brežine: Donji Lokanj	Podgorica	19.1 E 42.3 N	212 m	<i>graecus</i>	pond	306 m ²	1.2 m
23	Donji Štoj: Bregvija	Ulcinj	19.3 E 41.8 N	2 m	<i>graecus</i>	pond	370 m ²	0.7 m

Jezero means Lake; Coordinates are less accurate for ponds for conservation purposes; ¹This locality has 4 wells, a few meters apart; Depth: Maximum water depth.

TABLE S2. Historical and recent occurrence of paedomorphosis in the alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro.

#	Locality	Species	First occurrence	Last occurrence
1	Trnovačko jezero	<i>alpestris</i>	1959: Radovanović, 1961	1979: IBISS
2	Vražje jezero	<i>alpestris</i>	1965: Pocrnjic, & Kosovic, 1966	1979: IBISS
3	Zminičko jezero	<i>alpestris</i>	1959: Radovanović, 1961	1980: Breuil, 1985
4	Ridsko jezero	<i>alpestris</i>	1954: Collection IBISS	1954: IBISS
5	Kapetanovo jezero	<i>alpestris</i>	1959: Radovanović, 1961	1959: Radovanović, 1961
6	Manito jezero	<i>alpestris</i>	1959: Radovanović, 1961	1985: Popadić, 1985
7	Bukumirsko jezero	<i>alpestris</i>	1948: Radovanović, 1951	1991: IBISS; pers. obs.
8	Crni Kuk: Smrdelj	<i>alpestris</i>	2002: IBISS; pers. obs.	2005: IBISS; pers. obs.
9	Kopilje: Katranara	<i>alpestris</i>	1997: IBISS; pers. obs.	2005: pers. obs.
10	Brotnjik	<i>alpestris</i>	2004: IBISS; pers. obs.	2016: pers. obs.
11	Seoca: Ubli na Krnjski Do ¹	<i>alpestris</i>	2004: IBISS; pers. obs.	2016: pers. obs.
12	Vilusi: Cerova lokva	<i>graecus</i>	2004: pers. obs.	2004: pers. obs.
13	Vilusi: Kovačevića lokva	<i>graecus</i>	1983: Džukić, & Kalezić, 1985	1984: Džukić & Kalezić, 1985
14	Vilusi: Rutešića voda	<i>graecus</i>	1983: Džukić, & Kalezić, 1985	2016: pers. obs.
15	Osječenica: Velika Osječenica	<i>graecus</i>	1970: Džukić, 1981	1990: IBISS
16	Gornja Spila: Voluje oko	<i>graecus</i>	1984: Džukić, & Kalezić, 1985	2004: pers. obs.
17	Jabuka: Kamenica	<i>graecus</i>	2004: IBISS	2004: IBISS
18	Rokoče: Meka Lokva	<i>graecus</i>	2004: IBISS	2004: IBISS
19	Bjeloši: Lašor	<i>graecus</i>	1992: IBISS	2004: pers. obs.
20	Ceklin: Pijavica	<i>graecus</i>	1992: IBISS	2002: pers. obs.
21	Progonovići: Razvađa	<i>graecus</i>	2002: pers. obs.	2002: pers. obs.
22	Brežine: Donji Lokanj	<i>graecus</i>	1990: IBISS	1990: IBISS
23	Donji Štoj: Bregvija	<i>graecus</i>	1989: IBISS; pers. obs.	2004: pers. obs.

IBISS: Institut za Biološka Istraživanja 'Siniša Stanković' (Belgrade, Serbia); pers. obs.: Mathieu Denoël, Georg Džukić, Miloš L. Kalezić; Breuil, M. (1985). Etude des mesures possibles pour assurer la protection des biotopes de Tritons alpestres *Triturus alpestris* du Parc National des Ecrins: Rapport du Marché d'étude 69/84, Parc National des Ecrins ; Džukić, G. (1981). Prvi nalaz neotenicne populacije malog mrmoljka *Triturus vulgaris* (Linnaeus), 1758 in Yugoslavia. Glasnik Republički Zavod za Zdravstvenu Zastitu Prirode - Prirodnjackog Muzeja Titograd, 14, 71-77 ; Kalezić, M. L., & Džukić, G. (1985). Ecological aspects of the smooth newt (*Triturus vulgaris*) paedomorphosis from Montenegro. Arhiv Bioloskih Nauka, 37, 43-50; Pocrnjic, Z., & Kosoric, D. (1966). New finding-sites of neotenic alpine tritons (*Triturus alpestris* F.). Bulletin Scientifique, Beograd, A, 11, 251; Popadić, A. (1987). Planininski mrmoljak, *Triturus alpestris* (Urodela, Amphibia) u Manitom jezeru (Crna Gora). M.Sc.Thesis, Univerzitet u Beogradu, Belgrade, Serbia ; Radovanović, M. (1951). A new race of the Alpine newt from Yugoslavia. British Journal of Herpetology, 1, 93-97; Radovanović, M. (1961). Neue Fundorte neotenischer Bergmolche in Jugoslawien. Zoologischer Anzeiger, 166, 206-218.

TABLE S3. Examined specimens of alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in the collection of the IBISS Museum (Institut za Biološka Istraživanja ‘Siniša Stanković’, Belgrade).

#	Locality	Species	Paedomorphs	Museum references
1	Trnovačko jezero	<i>alpestris</i>	yes	1477-2208
2	Vražje jezero	<i>alpestris</i>	yes	352-2642
3	Zminičko jezero	<i>alpestris</i>	yes	1034-309-1477-1479-2485-2653-2760
4	Ridsko jezero	<i>alpestris</i>	yes	1477
5	Kapetanovo jezero	<i>alpestris</i>	yes	1477-1502
6	Manito jezero	<i>alpestris</i>	yes	1471-2419
7	Bukumirsko jezero	<i>alpestris</i>	yes	1477-1279-1629-1848-1990-2238-2422-2632-2682
8	Crni Kuk: Smrdelj	<i>alpestris</i>	yes	2334
9	Kopilje: Katranara	<i>alpestris</i>	yes	1810
10	Brotnjik	<i>alpestris</i>	yes	2227
11	Seoca: Ubli na Krnjski Do	<i>alpestris</i>	yes	2478
12	Vilusi: Cerova lokva	<i>graecus</i>	yes	2515-2619
13	Vilusi: Kovačevića lokva	<i>graecus</i>	-	-
14	Vilusi: Rutešića voda	<i>graecus</i>	-	-
15	Osječenica: Velika Osječenica	<i>graecus</i>	yes	1851-2210-2215-2216-2594
16	Gornja Spila: Voluje oko	<i>graecus</i>	yes	2603
17	Jabuka: Kamenica	<i>graecus</i>	yes	1293
18	Rokoče: Meka Lokva	<i>graecus</i>	yes	2291
19	Bjeloši: Lašor	<i>graecus</i>	-	-
20	Ceklin: Pijavica	<i>graecus</i>	yes	2260
21	Progonovići: Razvađa	<i>graecus</i>	-	-
22	Brežine: Donji Lokanj	<i>graecus</i>	yes	2629
23	Donji Štoj: Bregvija	<i>graecus</i>	yes	2630-2684

Jezero means lake; Paedomorphic state (i.e. maturity of gilled specimens) on each population validated by M. Denoël in April 2017. Maturity of specimens from localities 13, 14, 19 and 21 were validated during fieldwork by G. Džukić & M. Kalezić. Information on IBISS collections can be found in Džukić, G., Cvijanović, M., Urošević, A. et al. (2015). The batrachological collections of the Institute for Biological Research "Siniša Stanković". Bulletin of the Natural History Museum, 8, 118-167.

TABLE S4. Corine Land Cover surrounding ponds and lakes with records of pedomorphosis in alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro.

#	Locality	Species	agriculture		100m buffer natural		mosaics		agriculture		1000m buffer natural		mosaics	
			1990	2012	1990	2012	1990	2012	1990	2012	1990	2012	1990	2012
1	Trnovačko jezero	<i>alpestris</i>	0	0	40.84	40.84	0	0	0	0	83.14	83.17	0	0
2	Vražje jezero	<i>alpestris</i>	0	100	100	0	0	0	0.04	97.79	34.70	2.21	11.65	
3	Zminičko jezero	<i>alpestris</i>	0	0	46.19	45.31	53.81	54.69	0	0	84.91	84.92	15.09	18.59
4	Ridsko jezero	<i>alpestris</i>	0	0	100	100	0	0	0	0	100	92.47	0	24.17
5	Kapetanovo jezero	<i>alpestris</i>	0	0	100	100	0	0	0	0	93.68	100	0	37.49
6	Manito jezero	<i>alpestris</i>	0	0	100	100	0	0	0	0	99.82	100	0	37.41
7	Bukumirsko jezero	<i>alpestris</i>	0	0	100	100	0	0	0	0	98.37	98.38	1.63	42.36
8	Crni Kuk: Smrdelj	<i>alpestris</i>	0	0	93.14	93.22	6.86	6.78	0	0	70.29	70.42	29.71	29.58
9	Kopilje: Katranara	<i>alpestris</i>	0	0	0	0	100	100	0	0	61.99	62.06	38.01	44.58
10	Brotnjik	<i>alpestris</i>	0	0	100	100	0	0	0	0	91.37	94.19	0	0
11	Seoca: Ubli na Krnjski Do	<i>alpestris</i>	0	0	100	73.23	0	0	0	0	83.44	36.51	8.45	9.16
12	Vilusi: Cerova lokva	<i>graecus</i>	0	0	99.38	100	0.62	0	0	0	66.83	100	33.17	0
13	Vilusi: Kovačevića lokva	<i>graecus</i>	0	0	0	100	100	0	0	0	20.02	100	79.98	0
14	Vilusi: Rutešića voda	<i>graecus</i>	0	0	100	100	0	0	0	0	78.68	100	21.32	27.34
15	Osječenica: Velika Osječenica	<i>graecus</i>	0	0	0	100	100	0	2.93	2.82	16.73	90.32	73.42	0
16	Gornja Spila: Voluje oko	<i>graecus</i>	0	0	31.50	100	68.50	0	0	0	41.74	100	58.26	0
17	Jabuka: Kamenica	<i>graecus</i>	0	0	18.61	100	81.39	0	0	0	24.99	100	75.01	0
18	Rokoče: Meka-Lokva	<i>graecus</i>	0	0	0	100	100	0	0	0	58.86	100	41.14	0
19	Bjeloši: Lašor	<i>graecus</i>	93.22	0	6.77	100	0	0	26.04	19.23	73.96	91.59	0	0
20	Ceklin: Pijavica	<i>graecus</i>	0	0	55.32	57.11	44.68	42.89	0	0	57.65	59.31	40.63	40.48
21	Progonovići: Razvađa	<i>graecus</i>	0	0	100	94.23	0	5.77	0	0	99.41	85.89	0.59	14.11
22	Brežine: Donji Lokanj	<i>graecus</i>	0	0	100	100	0	0	0	0	99.11	99.05	0.89	0.95
23	Donji Štoj: Bregvija	<i>graecus</i>	93.12	98.36	6.87	0	29.81	9.55	36.95	42.41	62.10	18.28	0	29.48

Jezero means Lake; Data show the main land-use categories according to Corine Land Cover (percentages). Mosaics are mixtures of agriculture and natural landscapes.

TABLE S5. Alteration of the aquatic habitat in the populations of paedomorphic alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro: occurrence of introductions of fish and crayfish, and habitat destruction.

#	Locality	Species	Fish ²	Crayfish ²	Destruction ³	Cyprinidae	Salmonidae	Ictaluridae
1	Trnovačko jezero	<i>alpestris</i>	1	0	0	1	1	0
2	Vražje jezero	<i>alpestris</i>	1	1	0	1	1	0
3	Zminičko jezero	<i>alpestris</i>	1	1	0	1	1	0
4	Ridsko jezero	<i>alpestris</i>	1*	0	0	0	1	0
5	Kapetanovo jezero	<i>alpestris</i>	1	1	0	1	1	0
6	Manito jezero	<i>alpestris</i>	1	0	0	0	1	0
7	Bukumirsko jezero	<i>alpestris</i>	1	0	0	1	1	0
8	Crni Kuk: Smrdelj	<i>alpestris</i>	0	0	0	0	0	0
9	Kopilje: Katranara	<i>alpestris</i>	0	0	1	0	0	0
10	Brotnjik	<i>alpestris</i>	0	0	0	0	0	0
11	Seoca: Ubli na Krnjski Do	<i>alpestris</i>	0	0	0	0	0	0
12	Vilusi: Cerova lokva	<i>graecus</i>	0	0	0	0	0	0
13	Vilusi: Kovačevića lokva	<i>graecus</i>	1	0	0	1	0	0
14	Vilusi: Rutešića voda	<i>graecus</i>	0	0	0	0	0	0
15	Osječnica: Velika Osječnica	<i>graecus</i>	1	1	0	1	0	0
16	Gornja Spila: Voluje oko	<i>graecus</i>	1	0	0	0	0	1
17	Jabuka: Kamenica	<i>graecus</i>	0	0	0	0	0	0
18	Rokoče: Meka Lokva	<i>graecus</i>	0	0	0	0	0	0
19	Bjeloši: Lašor	<i>graecus</i>	0	0	0	0	0	0
20	Ceklin: Pijavica	<i>graecus</i>	1	0	0	1	0	0
21	Progonovići: Razvađa	<i>graecus</i>	0	0	0	0	0	0
22	Brežine: Donji Lokanj	<i>graecus</i>	1	0	0	1	0	0
23	Donji Štoj: Bregvija	<i>graecus</i>	0	0	0	0	0	0

Jezero means Lake; ² Alien species recorded since the discovery of paedomorphic newts (* no fish seen in 2016); for crayfish: Astacidae; ³ in locality 9, the well was covered by a concrete plate.

TABLE S6. Occurrence (proportion of occupied sites) of paedomorphs and metamorphs across time in the studied localities: data categorized by decades for the populations of alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro.

Species	Morph	Period	n	Occurrence	SE
<i>alpestris</i>	Paedomorphs	<1980	21	1	0
<i>alpestris</i>	Paedomorphs	1980's	10	0.7	0.15
<i>alpestris</i>	Paedomorphs	1990's	5	1	0
<i>alpestris</i>	Paedomorphs	2000's	17	0.41	0.12
<i>alpestris</i>	Paedomorphs	2010's	10	0.2	0.13
<i>alpestris</i>	Metamorphs	<1980	1	1	0
<i>alpestris</i>	Metamorphs	1980's	8	1	0
<i>alpestris</i>	Metamorphs	1990's	3	1	0
<i>alpestris</i>	Metamorphs	2000's	17	0.94	0.06
<i>alpestris</i>	Metamorphs	2010's	12	0.42	0.15
<i>alpestris</i>	Metamorphs	<1980	21	1	0
<i>graecus</i>	Metamorphs	1980's	10	1	0
<i>graecus</i>	Metamorphs	1990's	5	1	0
<i>graecus</i>	Metamorphs	2000's	17	1	0
<i>graecus</i>	Metamorphs	2010's	10	0.6	0.16
<i>graecus</i>	Paedomorphs	<1980	1	1	0
<i>graecus</i>	Paedomorphs	1980's	8	1	0
<i>graecus</i>	Paedomorphs	1990's	3	1	0
<i>graecus</i>	Paedomorphs	2000's	17	0.53	0.13
<i>graecus</i>	Paedomorphs	2010's	12	0.17	0.11

TABLE S7. Results of generalized mixed models on the occurrence through time of pedomorphic and metamorphic alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro. Models include species identity as an additional fixed factor. CI: Credible Intervals.

Factors	Paedomorphs			Metamorphs		
	Effect	95% CIs		Effect	95% CIs	
Fish presence	-1.90	-2.84	-1.13	-1.97	-3.23	-0.98
Precipitation	0.05	-0.91	1.02	0.61	-0.62	1.95
Temperature	0.28	-0.49	1.09	-0.42	-1.59	0.66
Crayfish presence	-1.46	-27.67	13.29	-0.54	-1.16	-0.01
Natural vegetation cover	-0.52	-1.65	0.40	-0.33	-1.56	0.82
Agricultural cover	-0.41	-1.44	0.60	-0.53	-1.67	0.49
Species (<i>L. graecus</i>)	-1.48	-3.23	0.10	-2.54	-4.86	-0.51
Interactions added to the model:						
Species X fish	1.10	-0.44	2.67	1.03	-7.59	15.35
Species X precipitation	-1.20	-3.02	0.50	-2.06	-4.89	0.60
Species X temperature	-0.86	-2.48	0.69	-2.38	-6.13	0.53
Species X crayfish	-15.96	-73.20	21.90	108.30	95.28	130.60
Species X natural vegetation	-0.59	-2.42	1.35	-3.25	-6.67	-0.54
Species X agricultural cover	13.77	-15.18	59.65	1.68	-10.51	22.93

FIG. S1. Extinct pedomorphs, historically described as endemic subspecies of alpine newts of Montenegro. (a) *Ichthyosaura alpestris montenegrina* from Bukumirsko Lake, (b) *I. a. piperiana* from Kapetanovo Lake and (c) *I. a. serdara* from Zminičko Lake. Specimens examined in the museum collection of the Institut za Biološka Istraživanja ‘Siniša Stanković’, Belgrade, Serbia (reference 2422, 1502: holotype, 1479: holotype, respectively). All pictured specimens are females showing developed gills and mature cloaca. Photos: Mathieu Denoël.



FIG. S2. Large variety of freshwater lentic habitats of Montenegro in which alien species (specifically fish) were introduced and in which the large populations of paedomorphic newts fully vanished, whereas metamorphs either declined or got extirpated: (a) Bukumirsko, (b) Zminičko, (c) Kapetanovo (in the background) and Manito Lakes, respectively, the type localities of the alpine newt *Ichthyosaura alpestris montenegrina*, *I. a. serdara* and *I. a. piperiana*, and (d) Velika Osjecenica pond, historically used by the Greek smooth newt *Lissotriton graecus*. Photos: Mathieu Denoël (2016).



FIG. S3. Maps of Montenegro with Corine Land Cover across time. (a) 1990, (b) 2000, (c) 2006 and (d) 2012. Dark green: natural vegetation, light green: mosaics between natural and agricultural vegetation, yellow: agriculture, red: urbanisation and blue: water; black dots: studied populations (historical presence of paedomorphosis in newts).

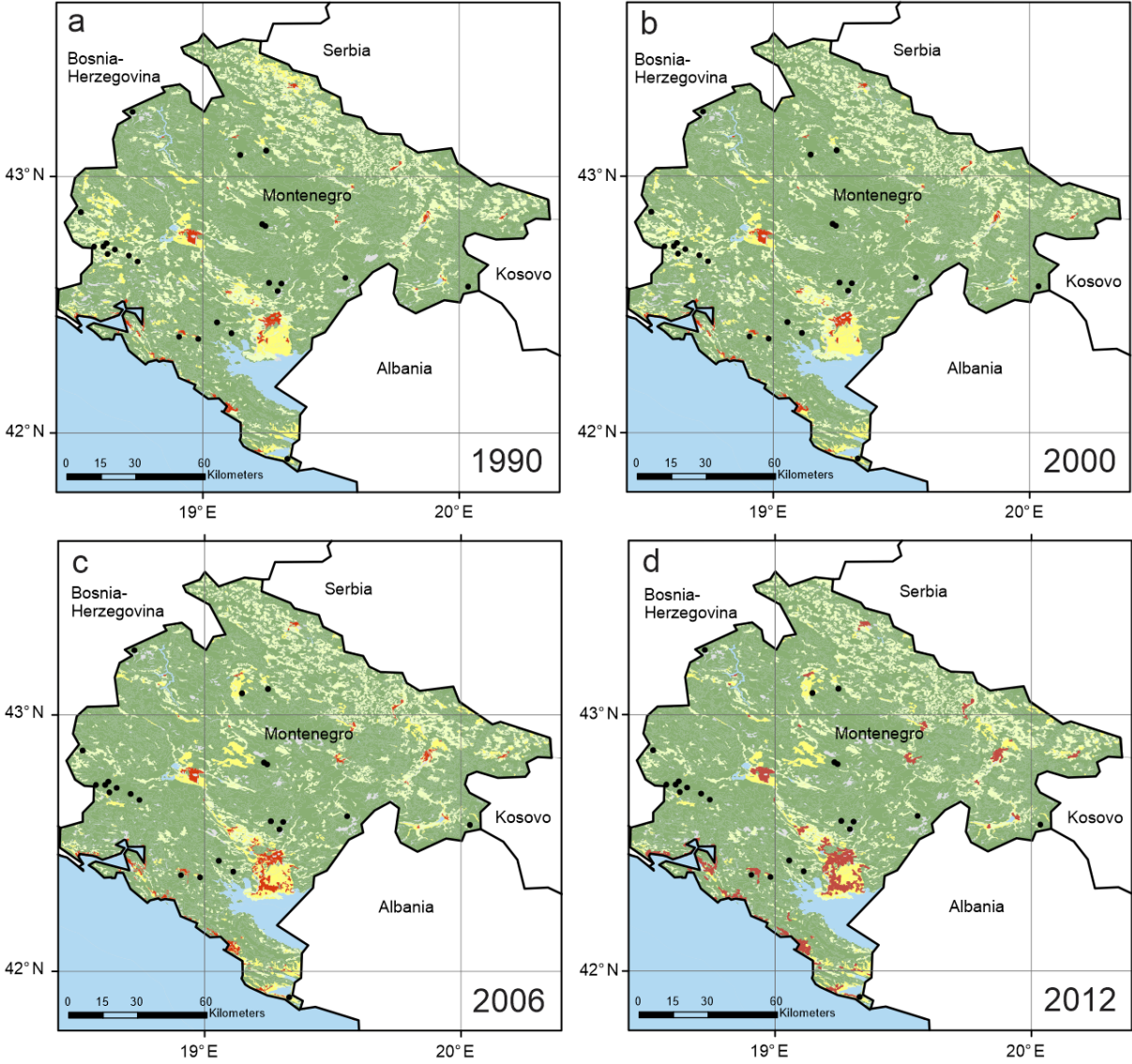
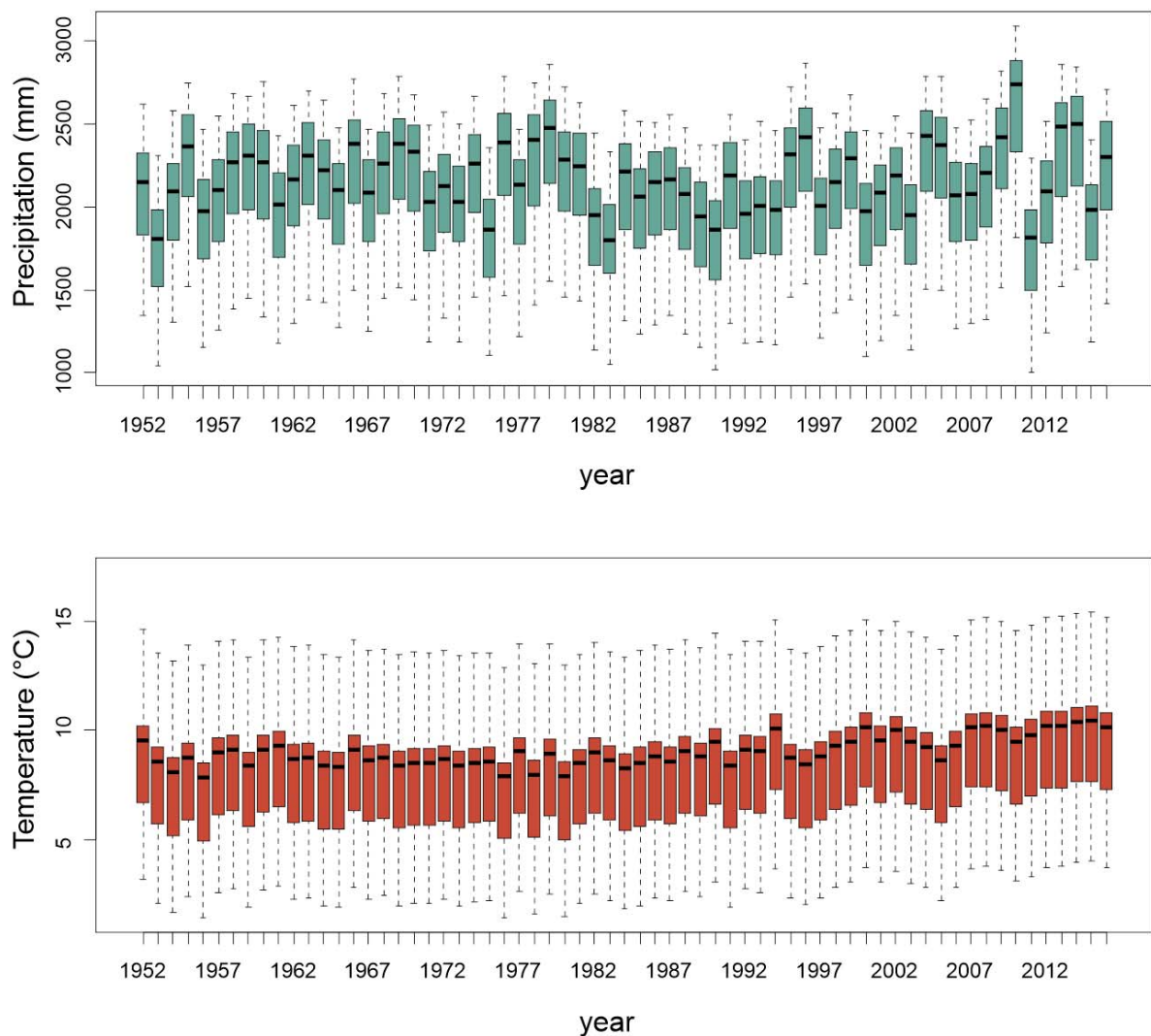


FIG. S4. Climatic variations (precipitations and temperature) in the studied localities of paedomorphosis in the alpine newts (*Ichthyosaura alpestris*) and Greek smooth newts (*Lissotriton graecus*) in Montenegro. Climatic data were extracted from the CRU 4.01 climate grids (Harris, Jones, Osborn, & Lister, 2014). Box plots show the median (dark midline), percentiles 25–75 and minimum-maximum value not higher than 1.5 IQR.



Reference:

Harris, I., Jones, P., Osborn, T., & Lister, D. (2014). Updated high-resolution grids of monthly climatic observations—the CRU TS3. 10 Dataset. *International Journal of Climatology*, 34, 623-642.