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Distribution and conservation status of the herpetofauna of Dugi Otok Island, Croatia

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Abstract

The first overview of the amphibians and reptiles of Dugi Otok Island, Northern Dalmatia, is presented, based on the published data and new records collected during the last twenty years. A total of 15 species are present on the island, of which only one was not recorded on our surveys. In comparison to other islands of Northern Dalmatia, Dugi Otok is the second most diverse island in terms of herpetofauna, just after Pag Island. The main threats to the amphibians and reptiles on the island are the disappearance and degradation of aquatic habitats, the abandonment and succession of traditional agricultural fields and olive groves and the increasing presence of several invasive species.

Key Words

Adriatic Islands, Amphibia, conservation, field survey, protection, Reptilia

Introduction

Amongst the numerous islands on the Croatian coast, Dugi Otok has always been interesting for its reptiles and amphibians. The herpetofaunal literature of the island includes questionable and invasive species records and has never been reviewed holistically. Our goal is to provide the first comprehensive report of the state of the island's reptiles and amphibians. Given the growing anthropogenic pressures, it is important to provide a baseline of the current knowledge for the sake of future management and conservation.

Island characteristics

Dugi Otok is an island located in the eastern part of the Adriatic Sea, in Croatia. It is located in northern Dalmatia and it belongs to the Zadar archipelago, along with Pag, Pašman, Ugljan, Vir and various other smaller islands and islets. With an area of 113.31 km^2, Dugi Otok is the seventh largest island in the Adriatic Sea (Duplančić Leder et al. 2004). It is an elongated island and has a northwest-southeast axis parallel to the Croatian coast. The island is 44.55 km long, but at most only 4.55 km wide (Magaš 1993), which explains the island's name (in Croatian "dugi" means long and "otok" means island).

Most of the islands in the Adriatic Sea, including Dugi Otok, are quite young in origin and were isolated by rising sea levels due to the melting of the polar ice caps. Dugi Otok was separated approximately 10,000 years ago from the Dalmatian mainland (Forenbaher 2002). Before then, such landbridge islands were connected to the mainland during the Wisconsin-Würm glaciation when global sea levels were approx. 135 m lower than at present (Bell and Walker 2005). The formation of ice caps in that period lowered the sea level to the point that the entire northern part of the Adriatic Sea was above sea level (Rodić 1970). Dugi Otok belongs to the mega-geomorphological region of the Dinaric mountain system and specifically to the macro-geomorphologic region of North Dalmatia. The island consists

of Cretaceous rocks, of which limestone is predominant, but dolomite is also present. The most significant terrain type is karst and the most common feature of it are karren ("grižine" in Croatian) formed by water erosion (Džaja 2017).

A significant part of the landscape on Dugi Otok Island are karst fields or "polja", flat areas traditionally used for crop cultivation or pastures. Due to their agricultural use, many of them encompass natural or artificial aquatic habitats, such as ponds or wells. On Dugi Otok Island, according to topographic maps and satellite imagery, about 50 such ponds and wells are known (Fig. 1A). Two karst fields, Velo and Malo Žmansko jezero, are periodically filled with water and are the only seasonal lakes present on the Adriatic Islands. Some of this water has been diverted to the water supply system of the southern part of the island, which has resulted in the reduction of annual flooding and a decrease in freshwater wetlands (Magaš 2019). In addition, in the southern part of the island lies Lake Mir, the region's largest aquatic habitat. The water of this Lake has even higher salinity than the neighbouring sea due to the high rates of evaporation and significant inflow of saltwater (Juračić et al. 2003; Džaja 2017).

According to the Köppen climate classification, Dugi Otok has a Mediterranean climate with hot summers (Csa) (Šegota and Filipčić 2003). With regards to the vegetation cover, Dugi Otok is located in the Eu-mediterranean vegetation zone where forests and maquis prevail (Trinajstić 2008; Pandža and Milović 2013). The middle and northern parts of the island are mostly covered with dense vegetation such as maquis, overgrown fields and olive groves (Fig. 1C). Natural vegetation cover is only absent around settlements where it was cut down and the area used for grazing or agriculture (Fig. 1B). In the southern part of the island, the vegetation is somewhat reduced, especially in karst fields where grassland prevails. In the past, fields were managed with controlled fires and used for grazing (Pevalek 1930; Pandža and Milović 2013). By changing the natural vegetation, opening quarries, building drystone walls and growing olive gardens and vineyards, humans have had a great impact on the island landscape (Džaja 2017).

Dugi Otok harbours several protected areas, the largest being Telašćica Nature Park, located in the southern part of the island. It was established in 1988 because of its rich flora and fauna, geomorphological features, important seabed communities and archaeological remains (Nature Park Telašćica 2020). Telašćica is also part of the Natura 2000 ecological network, as the entire area of the Park belongs to the Special Areas of Conservation (SAC) and Special Protection Areas (SPA) under both the Habitats Directive and the Birds Directives (Bioportal 2020).

History of herpetological exploration

The first records of amphibians and reptiles on Dugi Otok were provided by Hirtz (1930) who recorded 10 species: *Bufotes viridis* (Laurenti, 1768), *Hyla arborea* (Linnaeus, 1758), *Pseudopus apodus* (Pallas, 1775), *Hierophis gemonensis* (Laurenti, 1768), *Malpolon insignitus* (Geoffroy de St-Hilaire, 1809), *Natrix natrix* (Linnaeus, 1758), *Telescopus fallax* (Fleischmann, 1831), *Zamenis situla* (Linnaeus, 1758), *Hemidactylus turcicus* (Linnaeus, 1758) and *Podarcis melisellensis* (Braun, 1877). Four of these species were also later reported by Pavletić (1964) as present in the collection of the Museum of Natural History in Zagreb. Additionally, Škvarč (2000) reported the presence of *Podarcis siculus* (Rafinesque-Schmaltz, 1810) on the island and also several individuals of *Testudo hermanni* Gmelin, 1789. Other species such as *Caretta caretta* (Linnaeus, 1758) were later found by Kuljerić and Lukin (2002) and *Elaphe quatuorlineata* (Lacepede, 1789) by Madl (2017). One of the more interesting species records on the island was *Xerotyphlops vermicularis* (Merrem, 1820) (Grillitsch et al. 1999). However, this record is of questionable validity and the species is not considered to be part of the fauna of Croatia (Jelić et al. 2015).

The aim of this research is to review the distribution and status of the herpetofauna of Dugi Otok Island, based on published literature data and new observations. Threats to the long-term conservation of threatened species are also discussed.

Materials and methods

To obtain a more complete overview of the herpetofauna of the island, all available literature was consulted. Additionally, extensive field data about reptiles and amphibians of Dugi Otok were collected over the last 20 years by the authors. A total of 30 sites were explored, some of them only once, while the most promising were visited several times. Details about the surveyed localities are included in Suppl. material 1 and in Fig. 2. Taxonomy follows Speybroeck et al. (2020).

List of visited localities:

1. Dugi Rat, peninsula Okuklje;
2. Veli Rat, Garbice;
3. Komorine;
4. Veli Rat;
5. Polje, Vela Lopata;
6. Polje, cove Sakarun;
7. Soline;
8. Božava, Polje;
9. Božava;
10. Dragove;
11. Dragove, Polje;
12. Brbinj;
13. Brbinj, Razvršje;
14. Savar, Malo polje;
15. Kalac;
16. Luka;
17. Žman, Goričina;
18. Žman, Progon;
19. Žman, Slotino polje;
20. Velo i Malo jezero;
21. Dugo polje;
22. Stivanje polje;

Figure 1. A. A pond situated near Lojišće Bay on Dugi Otok, a typical aquatic habitat on the Adriatic Islands. (Photo by Ana Štih); **B.** Grassland habitats in the south of Dugi Otok (Photo by Ana Štih); **C.** Olive groves in the northern part of the Island, a suitable habitat for many reptile species. (Photo by Daria Kranželić).

Table 1. Distribution of amphibians and reptiles on Dugi Otok. The numbering of the localities where a species was detected in this survey follows the list given in the Methods section (see also Fig. 2).

	Systematic species list	Localities detected in this survey	Literature records	Red Book status ***	Conservation status
Amphibians					
*	*Bufo bufo* (Linnaeus, 1758)	–	Kryštufek and Kletečki 2007	LC	
1.	*Bufotes viridis* (Laurenti, 1768)	2, 8b, 9, 11, 13, 14, 20, 21, 22, 25, 26, 27, 28, 30	Hirtz 1930; Pavletić 1964; Škvarč 2000; Kobašlić 2002; Kuljerić and Lukin 2002; Planinc 2002; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010	LC	Strictly protected
2.	*Hyla arborea* (Linnaeus, 1758)	2, 6, 8b, 18, 21, 22, 25, 28, 30	Hirtz 1930; Pavletić 1964; Kobašlić 2002; Kuljerić and Lukin 2002; Planinc 2002; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010	LC	Strictly protected
*	*Pelophylax ridibundus* (Pallas, 1771)	–	Dieckmann 2006	LC	
Reptiles					
3.	*Testudo hermanni* Gmelin, 1789	9, 27	Škvarč 2000	NT	Strictly protected
4.	*Trachemys scripta* Thunberg in Schoepff, 1792 **	21, 27	Koren et al. 2018	/	
5.	*Caretta caretta* (Linnaeus, 1758)	1	Kuljerić and Lukin 2002; Planinc 2002; Lazar et al. 2004; Lončar 2005	VU	Strictly protected
6.	*Hemidactylus turcicus* (Linnaeus, 1758)	2, 11, 16, 22, 26	Hirtz 1930; Pavletić 1964; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckmann 2006; Kryštufek and Kletečki 2007; Žagar et al. 2013	LC	
7.	*Podarcis melisellensis* (Braun, 1877)	2, 3, 4, 5, 6, 7, 8a, 10, 11, 13, 14, 15, 18, 20, 22, 27, 28, 29	Hirtz 1930; Radovanović 1959a; Radovanović 1959b; Pavletić 1964; Raynor 1989; Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010; Žagar et al. 2013	LC	Strictly protected
8.	*Podarcis siculus* (Rafinesque-Schmaltz, 1810)	18, 25, 26, 27, 28	Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Podnar et al. 2005; Dieckman 2006; Žagar et al. 2013	LC	
9.	*Pseudopus apodus* (Pallas, 1775)	2, 4, 5, 6, 7, 8a, 11, 13, 14, 16, 18, 19, 20, 21, 27, 28, 29	Hirtz 1930; Škvarč 2000; Planinc 2002; Kuljerić and Lukin 2002; Lončar 2005; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010; Žagar et al. 2013	LC	Strictly protected
*	*Xerotyphlops vermicularis* (Merrem, 1820)	–	Grillitsch et al. 1999	NA	
10.	*Elaphe quatuorlineata* (Lacepede, 1789)	6, 8a, 12, 13, 14, 18, 19	Madl 2017	NT	Strictly protected
11.	*Hierophis gemonensis* (Laurenti, 1768)	2, 3, 4, 5, 6, 7, 8a, 16, 21, 27, 28	Hirtz 1930; Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010; Žagar et al. 2013	LC	Strictly protected
12.	*Malpolon insignitus* (Geoffroy de St-Hilaire, 1809)	6, 8a, 14, 16, 17, 19, 22, 23, 24, 27, 28, 29	Hirtz 1930; Kuljerić and Lukin 2002; Planinc 2002; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010; Žagar et al. 2013	LC	
13.	*Natrix natrix* (Linnaeus, 1758)	20	Hirtz 1930; Cvitanić 1959; Lončar 2005; Kuljerić and Lukin 2002; Dieckmann 2006; Kryštufek and Kletečki 2007	LC	
14.	*Telescopus fallax* (Fleischmann, 1831)	–	Hirtz 1930; Planinc 2002; Lončar 2005; Dieckmann 2006; Kryštufek and Kletečki 2007; Žagar et al. 2013	NT	Strictly protected
15.	*Zamenis situla* (Linnaeus, 1758)	3, 18, 27	Hirtz 1930; Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010; Žagar et al. 2013	NT	Strictly protected
*	*Vipera ammodytes* (Linnaeus, 1758)	–	Dieckmann 2006	LC	Strictly protected

*Doubtful records, not included in the species list; ** Invasive allochthonous species; *** Categories in the Red Book of Amphibians and Reptiles of Croatia: EN – Endangered, VU – Vulnerable, NT – Near Threatened, LC – Least Concern, DD – Data Deficient, NA – Not Assessed

23. Zaglav, M. Paterišćak;
24. Sali, cove Magrovica;
25. Sali, Dolac;
26. Sali;
27. Sali, Saljsko polje;
28. Sali, Kruševo polje;
29. Lake Mir;
30. Loišće cove.

In order to put our data into perspective, a comparison with the amphibians and reptiles of other north Dalmatian Islands was carried out (Table 2). These islands include: Prvić, Pag, Olib, Vir, Iž, Ugljan, Pašman, Kornati, Žut, Murter and Žirje. Published sources supporting these species lists are given in Table 2.

Results and discussion

According to the literature overview, 19 species, four amphibians and 15 reptiles, have been reported at one point or another for Dugi Otok Island (Table 1). During this survey, we confirmed the presence of all species, except two species of amphibians (*Pelophylax ridibundus* and

Table 2. Records (sources below) of reptiles and amphibians found on other north Dalmatian Islands. Asterisks (*) indicate questionable records not included in the official island species list.

	Dugi Otok	Kornati	Žut	Murter	Pag	Pašman	Prvić	Ugljan	Vir	Žirje	Iž	Olib
Surface area (km²):	**113**	**32**	**15**	**18**	**284**	**60**	**2.4**	**51**	**22**	**15**	**17**	**26**
Amphibians												
Bufo bufo (Linnaeus, 1758)	*											
Bufotes viridis (Laurenti, 1768)	x	x			x					x		
Hyla arborea (Linnaeus, 1758)	x				x							
Pelophylax ridibundus (Pallas, 1771)	*				x							
Reptiles												
Testudo hermanni Gmelin, 1789	x		x		x				x	x		
Emys orbicularis (Linnaeus, 1758)		x			x							
Trachemys scripta Thunberg in Schoepff, 1792	x				x							
Caretta caretta (Linnaeus, 1758)	x				x			x				
Hemidactylus turcicus (Linnaeus, 1758)	x	x	x		x		x	x		x		
Tarentola mauritanica (Linnaeus, 1758)								x				
Lacerta trilineata Bedriaga, 1886					x							
Podarcis melisellensis (Braun, 1877)	x	x	x		x	x	x	x		x	x	
Podarcis siculus (Rafinesque-Schmaltz, 1810)	x			x	x	x	x	x			x	x
Pseudopus apodus (Pallas, 1775)	x	x			x					x		
Xerotyphlops vermicularis (Merrem, 1820)	*											
Dolichopis caspius (Gmelin, 1789)												x
Elaphe quatuorlineata (Lacepede, 1789)	x		x							x		
Hierophis gemonensis (Laurenti, 1768)	x	x	x		x			x		x		
Malpolon insignitus (Geoffroy de St-Hilaire, 1809)	x	x	x		x			x		x		
Natrix natrix (Linnaeus, 1758)	x				x							
Platyceps najadum (Eichwald, 1831)					x							
Telescopus fallax (Fleischmann, 1831)	x		x		x			x		x		
Zamenis longissimus (Laurenti, 1768)								x				
Zamenis situla (Linnaeus, 1758)	x			x	x					x	x	
Vipera ammodytes (Linnaeus, 1758)	*				x				x			
Total number	**19**	**7**	**7**	**2**	**19**	**2**	**3**	**9**	**2**	**10**	**3**	**2**

Bufo bufo) and three species of reptiles (*Telescopus fallax*, *Xerotyphlops vermicularis* and *Vipera ammodytes*) (Suppl. material 1). Of these, *P. ridibundus*, *B. bufo*, *X. vermicularis* and *V. ammodytes* are considered highly doubtful species for Dugi Otok Island and, while listed in Tables 1 and 2, are not included in the official species list.

Out of all species reported for Dugi Otok, five have been assessed and are listed in the Red Book of Amphibians and Reptiles of Croatia: *C. caretta* as Vulnerable (VU) and *T. hermanii*, *E. quatorlineata*, *T. fallax* and *Z. situla* as Near Threatened (NT) (Jelić et al. 2015). A total of 11 species are also strictly protected through the Nature Protection Act (OG 80/13, 15/18, 14/19, 127/19) (Anonymous 2016) (Table 1).

Species records are based on following references: Kornat: Hirtz 1930, Koren et al. 2011; Žut: Koren et al. 2011; Murter: Lončar 2005; Pag: Kobašlić 2002, Schweiger 2004, Lončar 2005, Portada 2009, Žagar et al. 2013; Pašman: Lončar 2005; Prvić: Lončar 2005; Ugljan: Lončar 2005, Kryštufek and Kletečki 2007; Vir: Lončar 2005; Žirje: Lauš 2010; Iž: Hirtz 1930, Kletečki et al. 2009; Olib: Lončar 2005, Kletečki et al. 2009. Island surface areas based on: Duplančić Leder et al. 2004.

Amphibia

Bufo bufo (Linnaeus, 1758) – Common Toad

Only one literature record is available for *B. bufo* from Dugi Otok (Kryštufek and Kletečki 2007). The validity of this record is questionable, as it is not mentioned in any other primary publication on the herpetofauna of the island. In the present investigation, the species was not recorded anywhere on the island. With no verified observations, no deposited specimens and only a single literature record, we do not consider this species to be present on the island. *B. bufo* prefers humid habitats like ponds, marshes and forests (Speybroeck et al. 2016) and all these suitable habitats are rare on Dugi Otok. This species is generally rare on the Adriatic Islands and has so far been recorded only on a few large islands such as Cres (Tóth et al. 2006), Krk (Mršić et al. 1989), Rab and Hvar (Kobašlić 2002).

Bufotes viridis (Laurenti, 1768) – European Green Toad

The first record of *B. viridis* on Dugi Otok was given by Hirtz (1930), who found it in Sali and its surroundings. Since then, it has been commonly recorded on the island (Pavletić 1964; Škvarč 2000; Kobašlić 2002; Kuljerić and Lukin 2002; Planinc 2002; Dieckmann 2006). During the present research, we recorded the species at 14 localities (Table 1) across the whole island. In Croatia, it is widely distributed, both on the mainland and on many Adriatic Islands such as Krk, Cres (Kobašlić 2002), Rab (Karaman 1921), Pag (Vamberger 2012), Kornat (Koren et al. 2011), Brač, Hvar, Korčula, (Barun et al. 2010), Lastovo (Vervurst 2009) and Mljet (Kobašlić 2002).

Hyla arborea (Linnaeus, 1758) – European Tree Frog

The occurrence of the *H. arborea* on the island has been reported by many researchers (Hirtz 1930; Kobašlić 2002; Kuljerić and Lukin 2002; Planinc 2002). During this survey,

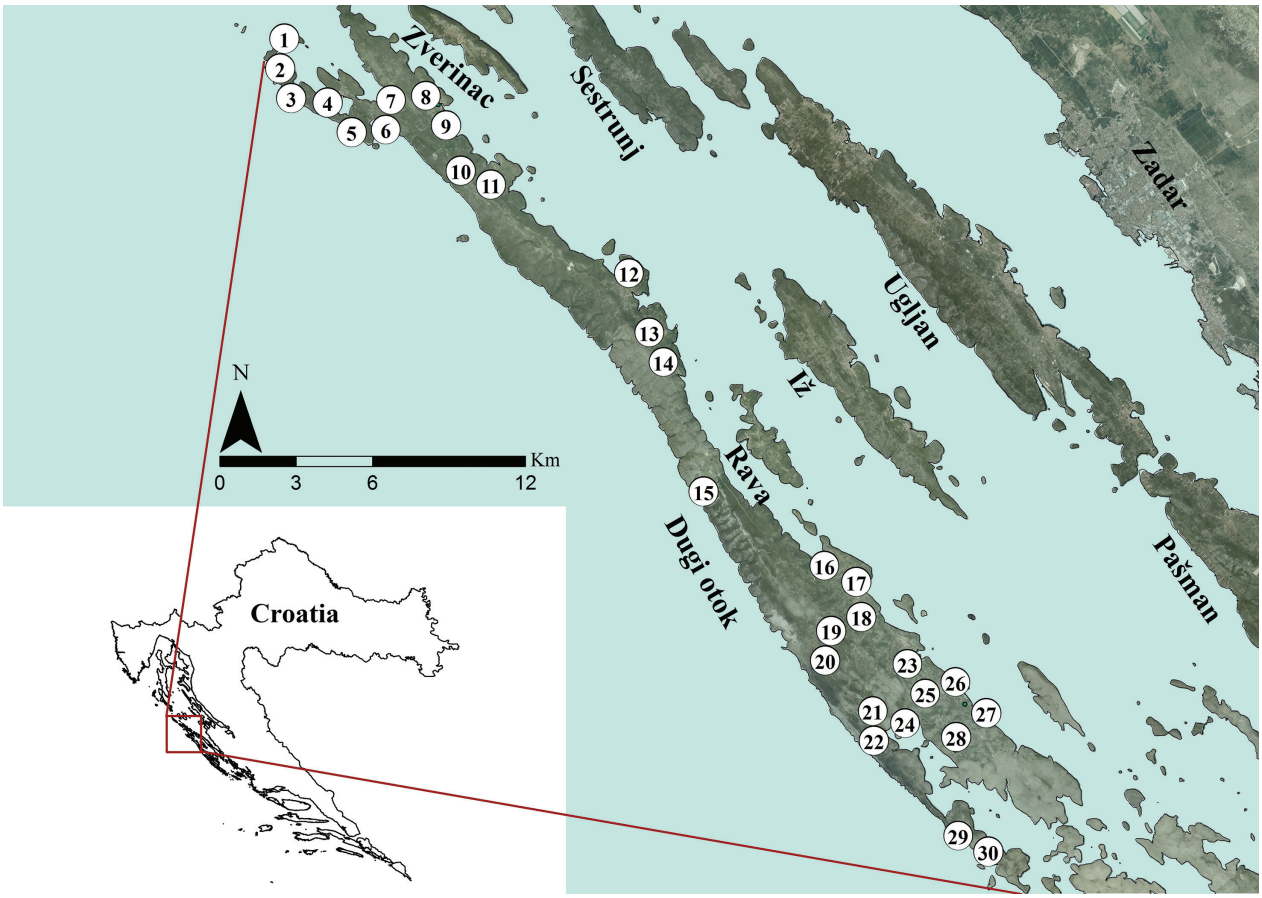

Figure 2. The map of Dugi Otok Island with surveyed localities. Numbers on the map are equal to the number of locations given in the Materials and Methods section.

we found the species at nine localities throughout the island (Table 1). It is typically present around freshwater ponds and seasonal lakes, usually on nearby trees or surrounding vegetation. Notably, one undeveloped juvenile individual was recorded in Loišće cove, in the vicinity of a brackish pond, with no freshwater bodies close by. While some frog species have been recorded to live and reproduce in saline habitats (Hopkins and Brodie 2015), including some species in the genus *Hyla*, no such records exist for *H. arborea*. Therefore, this observation is important because it suggests that the species can tolerate and may even reproduce in some brackish habits on Dugi Otok. Further surveys of ponds would be needed to verify the presence of eggs or tadpoles and provide additional evidence for reproduction. Overall, the decline of freshwater habitats on the Adriatic Islands likely represents a threat to the long-term survival of this species and should be monitored in the future. *H. arborea* is found throughout the mainland, as well as on some Adriatic Islands and has been recorded from Krk, Cres (Tóth et al. 2006), Pag (Vamberger 2012), Lošinj, Brač, Hvar (Kobašlić 2002) and Korčula (Barun et al. 2010).

***Pelophylax ridibundus* (Pallas, 1771) – Marsh Frog**

Pelophylax ridibundus was mentioned only once for Dugi Otok (as *Rana ridibunda*) by Dieckmann (2006), who recorded one specimen which had been run over by a car. During our survey, we visited during different seasons almost all water bodies on the island, but never recorded any water frogs. Due to the absence of any other records and the similarity of DOR individuals to the widespread *B. viridis*, which also inhabits the island, we consider this record to be questionable and do not consider this species to be present on the island. In Croatia, the species is widely distributed and can be found on some islands including Krk (Tóth et al. 2006), Cres, Pag, Rab, Mljet (Kobašlić 2002) and Korčula (Cafuta 2004).

Reptilia

***Testudo hermanni* Gmelin, 1789 – Hermann's Tortoise**

The only literature record of this species on Dugi Otok was given by Škvarč (2000) who recorded five tortoises in a garden in Sali and states that they were brought from Zadar. During the present survey, we recorded the species in two locations, Božava and Sali (Table 1, Fig. 3A). In both locations, they were found in gardens where they were kept as pets. Given the absence of the species from natural habitats, we do not consider this species to be native to Dugi Otok. The closest natural presence of this species is on the mainland in the vicinity of Zadar (Boris Lauš, pers. obs.). The closest natural island

Figure 3. A. Hermann's Tortoise (*Testudo hermanni* Gmelin, 1789) found on Dugi Otok in Božava. The individuals were kept as pets in a garden (Photo by: Daria Kranželić); **B.** A Four-lined snake, *Elaphe quatuorlineata* (Lacepede, 1789), found on Dugi Otok near the Sakarun cove (Photo by Toni Koren); **C.** A Leopard Snake, *Zamenis situla* (Linnaeus, 1758), found on Dugi Otok near Komorine (Photo by: Bruno Schmidt).

populations are on the islands of Pag in the north and on Brač and Hvar in the south (Jelić et al. 2015). Occasional translocated individuals have been recorded on Žut Island (Koren et al. 2011) and Sestrunj islands (Boris Lauš, pers. obs.). In Croatia, it is widely distributed along the coastline, from Istria to Konavle, including many islands, such as Krk, Cres (Toth et al. 2006), Pag (Vamberger 2012), Mljet (Grbac 2009), Brač and Hvar (Lončar 2005). In the past, the species had been popular as a pet and as such, it had been moved illegally outside its natural range (Ljubisavljević et al. 2011).

***Trachemys scripta* (Thunberg in Schoepff, 1792) – Pond Slider**

The Pond Slider is a non-native invasive species in Croatia. Koren et al. (2018) were the first to record this species on Dugi Otok. In their study, six individuals were found in a pond near Sali. During our survey, individuals were recorded in the same location and in another pond in Dugo Polje which is west of Sali (Table 1). It is also possible they have been released into other smaller ponds on the island, so this needs to be investigated during future surveys. In Croatia, the species can be found throughout a variety of mainland regions and also on some islands, such as: Krk, Pag, Vir, Šolta and Korčula (Koren et al. 2018).

This terrapin species is native to North America and is considered to be one of the 100 most invasive species in the world (Lowe et al. 2000). It is popular as a pet, but humans frequently release them into nature, which consequently causes great disruption to the local flora and fauna. The species impacts pond ecosystems by altering the stability of freshwater food webs (Ficetola et al. 2009; Lindsay et al. 2013).

***Caretta caretta* (Linnaeus, 1758) – Loggerhead Sea Turtle**

The first observation of this species was made in 1990 in the waters surrounding Dugi Otok (Lazar et al. 2004). Other researchers reported findings of a skeleton and a juvenile on the beach (Kuljerić and Lukin 2002; Planinc 2002). During the present survey, we recorded one dead specimen on the beach in the northern part of the island (Table 1). Loggerhead Sea Turtles are the most abundant sea turtles in the Mediterranean Sea (Margaritoulis et al. 2003). In the sea waters of Croatia, they only feed and overwinter, while the nesting takes place in Greece, Cyprus and Turkey (Margaritoulis et al. 2003). This marine species is threatened because of incidental bycatch mortality by the trawling fishery (Casale et al. 2004; Pulcinella et al. 2019), as well as by plastics pollution of marine ecosystems (Ostiategui et al. 2016; Arcangeli et al. 2019).

***Hemidactylus turcicus* (Linnaeus, 1758) – Turkish Gecko**

This is a common and widespread species on the island (Hirtz 1930; Pavletić 1964; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckmann 2006). During our survey, we recorded it at five locations, mostly around human settlements (Table 1). The species originates in the Middle East and is nowdays quite widespread in the Mediterranean because of accidental past anthropogenic translocation (Carranza and Arnold 2006). In Croatia, it is widely distributed in coastal areas, including many islands (Lisičić et al. 2012), such as adjacent Kornat and Žut (Koren et al. 2011), Cres (Bruno 1988), Krk, Lošinj (Tóth et al. 2006), Rab, Pag, Ugljan (Lončar 2005), Brač, Korčula (Cafuta 2004), Hvar (Vilaj 2014), Lastovo (Vervurst 2009) and Mljet (Sopotnik and Vamberger 2016).

***Podarcis melisellensis* (Braun, 1877) – Dalmatian Wall Lizard**

The species was first recorded by Hirtz (1930), who noted that the lizard was very common on the island and was mostly represented by the form *modesta*, while the normal striped form was very rare. The species has also been recorded by other researchers (Pavletić 1964; Raynor 1989; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckmann 2006; Barun et al. 2010). We also recorded this species at 18 locations (Table 1). In Croatia, it is widely distributed in areas with a Mediterranean climate from Istria in the north along the coastline to the far south, as well as on many neighbouring islands: Kornat, Žut (Koren et al. 2011), Pag (Vamberger 2012), Pašman, Prvić, Ugljan, Žirje, Iž and Olib (Lončar 2005).

***Podarcis siculus* (Rafinesque-Schmaltz, 1810) – Italian Wall Lizard**

This species was reported on Dugi Otok only recently in the southern part of the island (Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Dieckmann 2006). We recorded the species at five locations, all of them in the southern part of the island (Table 1). In general, this species is much rarer than *P. melisellensis* and most individuals were found around human settlements or in the nearby karst fields. Given the lack of other historical records and limited distribution, it is possible that this is a recently-introduced species on the island. However, determining this would require confirmation through genetic studies. Instances of human-facilitated introductions are known from several locations in the Adriatic, as well as other parts of the Mediterranean (Podnar et al. 2005). In Croatia, it is widely distributed along the coastline, from Istria to Konavle, as well as on many islands, including the neighbouring islands of Kornat (Koren 2012), Molat, Veliki Laganj (Podnar et al. 2005), Iž, Pašman and Ugljan (Lončar 2005).

***Pseudopus apodus* (Pallas, 1775) – European Glass Lizard**

Pseudopus apodus was reported early on to be common in karst fields and maquis on Dugi Otok (Hirtz 1930; Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Dieckmann

2006; Kryštufek and Kletečki 2007; Barun et al. 2010). During the present research, individuals were recorded at 17 locations (Table 1). In Croatia, the Glass Lizard is widely distributed along the coastline, from Istria to Konavle, including many islands, such as Krk, Cres (Tóth et al. 2006), Pag (Vamberger 2012), Rab, Silba, Šolta, Mljet, Vis (Lončar 2005), Brač (Barun et al. 2010), Hvar (Vilaj 2014) and Lastovo (Vervust et al. 2009).

***Xerotyphlops vermicularis* (Merrem, 1820) – European Worm Snake**

Grillitsch et al. (1999) published a record of this snake collected in 1977 near Sali by Peter Weish. The specimen was allegedly put into a glass jar with samples of earthworms. It is possible that this specimen was misplaced and that it originates from another location outside of Croatia (Jelić et al. 2015). Focused searching for this species failed to produce a positive record during the field survey (Štih et al. 2013). As stated by Jelić et al. (2015), this record is highly questionable and the occurrence of this species is very unlikely in Croatia overall. As a result, the regional threat status of the species has not been assessed. The closest natural occurrence of this species is in Montenegro (Speybroeck et al. 2016). As a result, the Worm Snake cannot be considered to be present on Dugi Otok, nor without any confirmation, in Croatia.

***Elaphe quatuorlineata* (Lacepede, 1789) – Four-Lined Snake**

The first record of the *E. quatuorlineata* on Dugi Otok was made by Madl (2017) who recorded several individuals, close to the settlements of Luka, Žman and Zaglav. During our survey, the species was recorded on seven locations throughout the island, the southernmost finding being Velo and Malo jezero (Table 1, Fig. 3B). It is probably more widespread on the island, but has not so far been recorded in the southern parts of the island, within the borders of Telašćica Nature Park. The Four-Lined Snake is widely distributed in the Mediterranean biogeographic region of Croatia, from Istria in the north along the coastline to the far south, as well as on many islands, such as Krk, Cres (Tóth et al. 2006), Lošinj, Rab, Korčula, Hvar (Lončar 2005), Žut (Koren et al. 2011), Vis (Lucić 2007) and Brač (Barun et al. 2010).

***Hierophis gemonensis* (Laurenti, 1768) – Balkan Whip Snake**

The first record of *H. gemonensis* on Dugi Otok was made by Hirtz (1930) who claimed it was not as common as other snake species on the island. More recently, this species was also recorded by other researchers (Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Lončar 2005; Dieckman 2006; Kryštufek and Kletečki 2007; Barun et al. 2010). During the present investigation, the species was recorded at 11 localities (Table 1). In Croatia, it is widely distributed along the coastline, from Istria to southern Dalmatia, including many islands, such as Krk, Cres (Tóth et al. 2006), Lošinj, Silba, Šolta, Mljet, Šipan (Lončar 2005), Rab (Pawlowski and Krämer 2009), Vis (Lucić 2007) and Hvar (Barun et al. 2010).

***Malpolon insignitus* (Geoffroy de St-Hilaire, 1809) – Eastern Montpellier Snake**

Hirtz (1930) states that *M. insignitus* is a common species on Dugi Otok. He recorded several individuals on the island itself, but also on neighbouring ones, such as Rava and Lavdara. The species has also been recorded by other researchers across the island (Kuljerić and Lukin 2002; Planinc 2002; Dieckmann 2006; Kryštufek and Kletečki 2007; Barun et al. 2010). During our survey, the species was recorded at 12 localities (Table 1). In Croatia, it is widely distributed along the coastline, from Istria to southern Dalmatia, as well as on many islands, such as Cres (Tóth et al. 2006), Pag (Vamberger 2012), Kornat, Žut (Koren et al. 2011), Mali Drvenik, Čiovo, Šolta, Šipan (Lončar 2005), Brač, Hvar, Korčula (Barun et al. 2010) and Mljet (Žagar et al. 2013).

***Natrix natrix* (Linnaeus, 1758) – Grass Snake**

Several records of this species exist for the island (Hirtz 1930; Kuljerić and Lukin 2002, Lončar 2005). During the present survey, the species was recorded only at a single locality, at Velo and Malo jezero in 2014 (Table 1). The site was visited subsequently multiple times, but with no additional sightings. This may indicate that the species has a small population and is threatened. Furthermore, no other records of the species have been found on adjacent islands. Given this scarcity, we consider this population important and conservation measures need be taken to protect it and surrounding habitats. A systematic mapping of the species occurrence in the aquatic habitats of the island would be a good starting point in order to assess its status. The species is widespread on mainland Croatia, but inhabits only some islands such as Krk (Zadravec and Lauš 2011), Cres (Tóth et al. 2006), Rab, Šolta, Korčula (Lončar 2005) and Pag (Vamberger 2012).

***Telescopus fallax* (Fleischmann, 1831) – European Cat Snake**

This is one of the rarest snake species on the island and has been mentioned only twice in literature. The first record was made by Hirtz (1930) who even then stated that the species was not common on the island. All the individuals recorded during his research were provided by locals who encountered them close to settlements, while some were preserved in bottles with spirits. Other researchers also reported one dead specimen found in a glass jar on Dugi Otok (Planinc 2002). During our survey, we could not confirm the presence of this species on the island. As the species is almost completely crepuscular or nocturnal,

species-appropriate search methodology needs to be used. This includes searching for this snake at dusk and at night in the most suitable habitats, such as stony areas, maquis, gardens, dry stone walls or close to human settlements (Speybroeck et al. 2016). The closest record of the species to Dugi Otok is on the neighbouring islands of Iž (Hirtz 1930) and Ugljan (Kryštufek and Kletečki 2007), which also have similar habitats. In the rest of Croatia, *T. fallax* is widely distributed in areas with a Mediterranean climate, ranging from Istria in the north and along the coastline to the far south, as well on many islands, such as Cres (Tóth et al. 2006), Krk, Pag (Lončar 2005), Lošinj, Rab, Silba, Korčula, Mljet, Vis (Lončar 2005), Hvar (Barun et al. 2010) and Žut (Koren et al. 2011).

***Zamenis situla* (Linnaeus, 1758) – Leopard Snake**

This is another elusive species, mostly active at sunset and sunrise (Hirtz 1930). It has been recorded on the islands several times, but cannot be regarded as common (Hirtz 1930; Škvarč 2000; Kuljerić and Lukin 2002; Planinc 2002; Kryštufek and Kletečki 2007; Barun et al. 2010). In the present survey, we recorded the species in three locations (Table 1, Fig. 3C). In Croatia, it is distributed along the coastline, from Dalmatia in the north down to the Konavle area in the south, as well as on many islands, such as Krk, Cres (Tóth et al. 2006), Pag, Lošinj, Hvar, Vis (Lončar 2005) and Korčula (Žagar et al. 2013).

***Vipera ammodytes* (Linnaeus, 1758) – Nose-Horned Viper**

The Nose-Horned Viper has been mentioned only once for Dugi Otok by Dieckmann (2006) as a personal communication from Mario Schweiger. However, given that Schweiger did not see the species himself, this record needs to be considered invalid. Underscoring the dubious nature of this record is the complete lack of snakebite fatalities on the island. It is possible that this snake was confused with another species, such as a juvenile *E. quatuorlineata* or even *Z. situla* or *T. fallax*. The species is also not present on adjacent islands (Table 2). island populations of this snake are not common and have been only reported from larger islands, such as Krk (Ursenbacher et al. 2008), Pag (Žagar et al. 2013), Korčula (Lončar 2005), Brač (Barun et al. 2010) and Hvar (Vilaj 2014).

Species distribution and conservation

The Adriatic islands, in general, do not represent optimal habitats for amphibians, due to their karstic origins and limited number of freshwater habitats. Accordingly, the low number of amphibian species on Dugi Otok is not surprising and reflects patterns that have been observed on other islands in Croatia (Kryštufek and Kletečki 2007), as well as other islands in the eastern Mediterranean (Corti et al. 1999). Only larger islands with more diverse habitats, such as Krk or Cres, have higher amphibian diversity (Tóth et al. 2006; Kryštufek and Kletečki 2007). In comparison to other north Dalmatian Islands, Dugi Otok is the second largest after Pag (Table 2). This is reflected in the fact that only these two islands harbour more than one amphibian species. Other smaller islands only have populations of *B. viridis* or are completely without amphibians (Table 2). Although more surveys would be beneficial on these smaller islands, it appears that the main reason for this paucity is that amphibians depend on aquatic habitats which are very limited on smaller islands. This dearth of surface water also means that droughts can have particularly severe effects on amphibians, often leading to disappearance of local populations (Meffe and Carroll 1997).

Compared to amphibians, reptile diversity is much greater on the Adriatic Islands, because reptiles prefer higher temperatures and are less limited to humid environments (Corti et al. 1999; Kryštufek and Kletečki 2007). Accordingly, in terms of reptile diversity, Dugi Otok is one of the richest islands in the Adriatic (Kryštufek and Kletečki 2007). Amongst the North Dalmatian Islands, it is the second richest, just after Pag. Pag is twice the size of Dugi Otok and a positive correlation between size and species number is expected on theoretical grounds (MacArthur and Wilson 1967). Given the incomplete herpetological surveys on most North Adriatic Islands, except Pag (Vamberger 2012), Kornat, Žut (Koren et al. 2011) and Žirje (Lauš 2010), it is difficult to generalise. Additional surveys of smaller islands would improve the knowledge of the herpetofaunal distribution in the region. Still, some patterns emerge even with the limited data available. Some species are widespread and present on most of the islands, such as *P. melisellensis*, *H. turcicus*, *H. gemonensis* and *M. insignitus* (Table 2). Certain species occurrences on the islands are probably not natural, but can be attributed to humans. For example, *T. hermanni*, according to current knowledge, was most probably brought to the island as a pet, though there remains also a small possibility that a natural population exists.

Threats to native species

The main threat to amphibians and reptiles in the Mediterranean area, as well as on Dugi Otok, is the loss, fragmentation and degradation of habitats as a direct or indirect result of human activities (Cuttelod et al. 2009). Probably the most endangered habitats are freshwater aquatic habitats which, nowadays, experience strong anthropogenic stressors. These habitats can disappear completely, resulting in the loss of limited breeding sites for amphibians (Jelić et al. 2015). For example, ponds may be intensively used for irrigation agriculture and the water from smaller ponds can almost be depleted during summers. On the other hand, ponds can also disappear following the abandonment of traditional agricultural practices. As tourism gains in prominence, agriculture is often neglected, resulting in unimpeded succession of habitats, as ponds are not cleared from overgrown vege-

tation anymore. Still, on the islands there are many examples where ponds continue to be maintained as part of traditional agriculture practices, such as Dugo Polje, Kruševo Polje and Žman Lakes (Fig. 1). Additionally, in some areas, ponds have a negative connotation as "mosquito breeding places" and are abandoned or even intentionally destroyed. One such example is the former pond in the northern part of the island, in Sakarun Bay, which was intentionally filled in with sand and other material to expand the beach for tourism (Fig. 1). Ponds also present a habitat for invasive species, like the mosquitofish *Gambusia holbrooki* Girard, 1859 which has been reported at Žmanska jezera (Kahriman 2019) and which can negatively influence the amphibian populations through predation on tadpoles (Vannini et al. 2018). Additionally, introduction of herpetofaunal species, while boosting local species richenss, can also sometimes have a negative effect on the native amphibian and reptile communities (Corti et al. 1999). The most obvious example is *T. scripta* which is non-native for Croatia, but has been released into the wild on Dugi Otok.

The abandonment of former agricultural fields, vineyards and olive groves represents perhaps the main threat to the reptiles on the islands, as it can result in the fragmentation of suitable habitats, through the loss of basking spots and hiding places. Therefore, agricultural abandonment can impact reptile populations by limiting the amount of habitat available for reproduction and survival (Todd et al. 2010). Other drivers of habitat fragmentation are expanding road networks and increasing vehicle traffic. Roads impact nearby habitat quality and reduce its connectivity, as animals may get killed while crossing them. As such, roads represent barriers and inhibit species movement between habitats (Colino-Rabanal and Lizana 2012). During our survey, several dozen specimens, mostly snakes, were found killed on the road. Certain studies on Mediterranean Islands (Krawczyk et al. 2019) on the impact of roads and other anthropogenic structures, also show that they influence the abundance and species richness of reptiles, with numbers and diversity declining as one approaches such structures.

As is the case with other Adriatic Islands, feral domestic cats (*Felis catus*, Linnaeus, 1758) also represent an important threat to the herpetofauna of the island. A large number of domestic cats, often abandoned, can be seen in and around settlements, roaming free. Feral and abandoned cats were already recorded on Dugi Otok in 1930, when they were most frequent in the southwest part of the island (Hirtz 1930). They were also recorded in large numbers throughout the island in the present research. Cats can negatively impact reptile populations as they use these reptiles for food (Bonnaud et al. 2011; Krawczyk et al. 2019). In a study done on two Adriatic Islands, Silba and Olib, amongst reptiles consumed by cats, *P. siculus* was the predominant species in their diet, but a few cases of snake consumption were also recorded (Lanszki et al. 2016). During our survey of Dugi Otok, a certain number of snake individuals had injuries which were consistent with this kind of cat attacks. As this is not only a problem for reptiles, but also for other vertebrate and invertebrate groups, it should be addressed in the future – laws prohibiting stray cats on the Adriatic Islands should be implemented.

The impacts of an invasive mammalian predator are best seen in the case of the Small Indian Mongoose, *Herpestes auropunctatus* (Hodgson, 1836), which is present on several Adriatic Islands, like Korčula, Hvar, Čiovo and Škarda (Barun et al. 2010), as well as the nearby mainland, but which is still absent from Dugi Otok. The mongoose was first brought to Mljet island in 1910 for the eradication of *V. ammodytes*, which was reported to occur in large numbers on the island (Mader 2010). Shortly after the introduction of mongoose, the viper was proclaimed rare on the island (Hirtz 1927) and the same is true even today (Jelić et al. 2012). A comparison of the herpetofaunal diversity on islands with, and without, the mongoose revealed the decline and even disappearance of species on islands harbouring this invasive mammal (Barun et al. 2010). A possible mongoose translocation to Dugi Otok could pose a great danger to local herpetofauna species and endanger some species which already exist only in small populations on the island. It is necessary to develop an appropriate eradication protocol that can be implemented should this mongoose appear on the island.

Conclusion

Although the amphibians and reptiles of Dugi Otok Island were first surveyed over 90 years ago, no critical review of their diversity has been completed to date. In total, 15 species are known to occur on the island. Four species, *B. bufo*, *P. ridibundus*, *X. vermicularis* and *V. ammodytes*, erroneously reported in the past, are currently considered to not be present. In comparison with other north Dalmatian Islands, Dugi Otok has a diverse herpetofauna, being second only to the twice larger Pag Island. Given the limited availability of freshwater habitats on Dugi Otok, the most threatened species are those connected to such habitats, like *H. arborea* and *B. viridis*. Reptile species can also be affected by this, for example, *N. natrix*, for which only a single recent observation exists on the island. In some parts of the island, vegetation succession constitutes a serious threat, as the number of open rocky or grassland habitats is very limited and heliothermic species like *Z. situla* or *E. quatuorlineata* are rare on the island.

Another threat to the herpetofauna of the island is the increasing presence of invasive species (e.g. domestic cats *F. catus*, Mosquito fish *G. holbrooki* and Pond Sliders *T. scripta*). In order to preserve the island's fauna, a plan to regulate the number of alien invasive species should be established and implemented. On the island, four species from Annex II of the Habitats Directive have been recorded (*Z. situla*, *C. caretta*, *T. hermanni* and *E. quatuorlineata*); for these, monitoring protocols should be devel-

oped and implemented in order to track their population trends on the island. Our survey can be used as a baseline study on the diversity and distribution of amphibians and reptiles of Dugi Otok Island and as a starting point for future ecological studies and conservation actions.

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Supplementary material 1

List of visited localities

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Data type: localities data

Explanation note: The list of sites includes the toponym, a brief description of the habitat, altitude (in m above sea level), geographic coordinates, field visit dates, and observers' initials. The localities are arranged geographically from northwest to southeast of the island.

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