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The Balearic herpetofauna: a species update and a review on the evidence

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Abstract. Here, we update the current list of amphibian and reptile fauna present in the Balearic Islands, probably the most outstanding case in the Mediterranean and of the most in the world where massive species introduction is in conflict with the survivorship of highly restricted endemic taxa. Resulting of a long term evolution in insularity, endemic herpetofauna was already decimated during the Pleistocene but, after the human colonisation of the archipelago, the introduction of alien species, passive or deliberate, has been provoking new extinctions and range retractions in the native herpetofauna. Such process is not interrupted but has even intensified during the last years. The current species list is composed by five amphibians (one native) and 21 reptiles (2 native). A critical review of the evidence on extinctions and introductions is provided together with the conservation implications. Compared to the last review (Mayol, 1985) six new reptile species are now naturalised or are in process of naturalization, colubrid snakes constituting the most conflicting element due to their predator role.

Keywords. Balearic Islands, amphibians, reptiles, alien species, conservation.

INTRODUCTION

In a globalised world, the introduction of species out of their original ranges is becoming one of the most serious threats to biodiversity (IUCN, 2000; Nentwig, 2007). Amphibians and reptiles are among the groups which are most widely introduced and simultaneously most threatened by introductions, the recent large monographs on this topic (Lever, 2003; Kraus, 2009) reflecting the acuteness of the problem. Distinctions are to be made between alien (those transported and released outside their native ranges by human activities, intentionally or not), naturalised (those aliens maintaining reproductive populations) and invasive (those, aliens or not, that menace biodiversity) species (IUCN,

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2000; Kraus, 2009). Not all introduced species become naturalised although many do, and not all are invasive but some can be (Kraus, 2009).

Of all the habitats and regions undergoing species introductions, islands are the most exposed since many alien species become invasive being harmful for local biota. Native species evolving in insular conditions often loose ability for competing, eluding predators and facing disease, becoming vulnerable to alien competitors, predators or parasites (Whittaker and Fernández-Palacios, 2007). As a result, many insular faunas deviate from equilibrium theory on the basis of geographical features (MacArthur and Wilson, 1967; Whittaker and Fernández-Palacios, 2007) because of the repeated species invasions and substantial loss or decrease in their native species (IUCN, 2000). Amphibian and reptiles are not an exception to this rule and the cases of *Boiga irregularis* in Guam (Savidge, 1987; Engbring and Fritts, 1988), *Anolis carolinensis* in Bonin Islands (Japan) (Hasegawa et al., 1988) and *Anolis sagrei* in Cayman Islands (Losos et al., 1993) are especially paradigmatic.

Being one of the world biodiversity hotspots (Myers et al., 2000), the Mediterranean Basin is unique in having so ancient interactions between biota and human activities (Blondel and Aronson, 1999). Because of this, distinguishing autochthonous from allochthonous species and natural from modified habitats, may be difficult and often speculative. In fact, some authors have arbitrarily proposed Neolithic for distinguishing between native and alien species within a region (Manchester and Bullock, 2000), although Pre-Neolitic interactions are also feasible. Molecular tools and paleontological record are available for assessing both extinctions and introductions but these evidences are not free of uncertainty. Actually, key remains may be lacking from fossil record and the best molecular calibrations do not unambiguously distinguish human introductions from recent natural colonisations.

Here, we update the current list of amphibian and reptile fauna present in the Balearic Islands, probably the most outstanding case in the Mediterranean and of the most in the world where massive species introduction is in conflict with the survivorship of highly restricted endemic taxa. A critical review of the evidence on extinctions and introductions is provided together with the conservation implications.

THE (PALEO)GEOGRAPHICAL FRAMEWORK AND THE HUMAN ARRIVAL

The Balearic Islands are located in the Western Mediterranean, occupying an area of 4800 km^2 (Llorenç et al, 2007) which harbours a huge number of endemic species of fauna (Pons and Palmer, 1996) and flora (Alomar et al., 1997). This high level of endemicity can be associated to the ancient isolation of the archipelago, which has not been connected to mainland since the end of the Messinian, about 5.33 my BP (Cavazza and Wezel, 2003). The abrupt refilling of the Mediterranean after this period (García-Castellanos et al., 2009) was responsible for not only the definitive separation from the continent but also for the fragmentation between the Pityusic (Ibiza, Formentera) and the Gimnesic (Mallorca, Menorca) subarchipelagos. Because both are separated by deep sea channels, they were never reconnected during the subsequent sea level fluctuations during the Plio-Pleistocene. In contrast, shallow channels within subarchipelagos allowed repeated connections, especially during the Glaciations (Emig and Geistdoerfer, 2004).

The first human settlements date from the third millennium BCE (Bover et al., 2008). Paleontological mammal studies suggest coincidence with the disappearing of autochthonous species (*Myotragus balearicus* Bate 1909, *Hypnomys morpheus* Bate 1919, *Hypnomys mahonensis* Bate, 1919) and the first appearing of new species (*Atelerix algirus* Lereboullet, 1842, *Mustela nivalis* Linnaeus, 1766) in the fossil record (Alcover, 1979a; Bover et al., 2008). Such coincidence of human arrival with extinctions, range retractions and introductions applies to herpetofauna and is common to other Mediterranean islands (Corti et al., 1999). Nevertheless, human activities have intensified during the last century, completely modifying the appearance of the islands, particularly Mallorca, the most damaged by the tourism industry. Currently, pet keeping is also becoming extended, and fauna recovery centres are receiving a large list of different alien species. Most of them have not succeeded in the naturalisation process, but those achieving it constituted an additional factor threatening native species.

A recent analysis based on regression models establishes a link between anthropogenic factors and present-day extinctions and colonisations, at least for reptiles (Ficetola and Padoa-Schioppa, 2009). However, some amphibian and reptile extinctions clearly predate the arrival of humans to the archipelago (Bover et al., 2008). For Menorca, Plio-Pleistocene reconnection to Mallorca has been invoked as causative factor but reasons for the Late Pleistocene extinctions (i.e., in Ibiza) remain unclear (Bover et al., 2008), although they may be linked to temperature fluctuations.

AN UPDATED SPECIES LIST

The current list of amphibians and reptiles in the Balearic Islands is constituted by five amphibians (Table 1) and 21 reptiles (Table 2), including those reported here for the first time. Mallorca is the island that harbours the highest species richness (22). The status of each species is briefly commented below.

AMPHIBIANS

Pelophylax perezi (Seoane, 1885)

The Iberian Water Frog is considered introduced in unknown date probably for insect control. It is present in all the main islands but Menorca (Pleguezuelos, 2004; Pérez-Mellado, 2005) and it does not appear in the fossil record. However, water frogs are morphologically conservative and phylogenetic support for its allocthonous status and putative origin is still lacking (Sumida et al., 2000; Plötner and Ohst, 2001). Competitive interaction with the native *Alytes muletensis* have been suggested (Román, 2004) and predation on this species has been demonstrated (Alcover et al., 1984).

Bufo balearicus Boettger, 1880

Among the green toads (*Bufo viridis* complex), those inhabiting Southern Italy, Corsica, Sardinia and the Balearics are now considered a distinct species (Stöck et al., 2006). The presence of the species in the Balearics is considered the result of an ancient, human-

Table 1. List of amphibians of the Balearic Islands (Ar: Alien species without evidence of recent reproduction; Na: Naturalized Alien species; Nv: Native species; -: absent).

	Mallorca	Menorca	Ibiza	Formentera	Cabrera
ANURA					
Pelophylax perezi	Na	Ar	Na	Na	-
Bufo balearicus	Na	Na	Na	-	-
Alytes muletensis	Nv	Ex	-	-	-
Alytes obstetricans	-	Ar	-	-	-
Hyla meridionalis	-	Na	-	-	-

Table 2. List of terrestrial reptiles of the Balearic Islands (Aa: Acclimatised Alien species without evidence of reproduction; Ex: Extinct; Na: Naturalised Alien species; Nr: Native species without evidence of recent reproduction; Nv: Native species; -: absent).

	Mallorca	Menorca	Ibiza	Formentera	Cabrera
CHELONIA					
Testudo hermanni	Na	Na	-	-	-
Testudo graeca	Na	-	Ex	Na	-
Emys orbicularis	Na	Na	-	-	-
Trachemys scripta	Na	Aa	Aa	-	-
Chrysemys picta	Na	-	-	-	-
Mauremys leprosa	Na	Aa	-	-	-
Chelydra serpentina	Aa	-	-	-	-
SQUAMATA					
Chamaeleo chamaeleon	Aa	-	-	-	-
Tarentola mauritanica	Na	Na	Na	Na	Na
Hemidactylus turcicus	Na	Na	Na	Na	Na
Podarcis lilfordi	Nv	Nv	-	-	Nv
Podarcis pytiusensis	Na	-	Nv	Nv	-
Podarcis sicula	-	Na	-	Na	Na?
Psammodromus algirus	Na	-	-	-	-
Scelarcis perspicillata	-	Na	-	-	-
Timon lepidus	Aa	-	-	-	-
Macroprotodon mauritanicus	Na	Na	-	-	-
Natrix maura	Na	Na	-	-	-
Malpolon monspessulanus	Aa	-	Na	Aa	-
Hemorrhois hippocrepis	Na	-	Na	-	-
Rhinechis scalaris	Aa	Na	Na	Aa	-

mediated introduction (Mayol, 1985). Lack of old fossils in the Balearics and subfossils associated to Neolithic settlements in the Balearics, together with the similarities in mating calls and plasma proteins point to a Tyrrhenian origin (Hemmer et al., 1981). Never-

theless, because transmarine colonisations have been demonstrated for this group (Stöck et al., 2006) and the few samples analysed (Stöck et al., 2006), more work is still needed to provide complete support for the polarity of the colonisation. The species is widespread in the Gymnesics but populations in Ibiza are decreasing (Palerm, 1997). No interactions with local herpetofauna have been described (Pleguezuelos, 2004).

Alytes muletensis (Sanchiz and Adrover, 1977)

The autochthonous status of the Balearic midwife toad is well supported by molecular, (Fromhage et al., 2004, Martínez-Solano et al., 2004), morphological (Martínez-Solano et al., 2004) and paleontological evidence (Alcover and Mayol, 1981; Bover et al., 2008). Results from phylogenetic studies reasonably fit with a scenario of Messinian vicariance with the Betic-Rifean *Alytes* species (Fromhage et al., 2004; Martínez-Solano et al., 2004). Early Pleistocene to Holocene fossils (Bover et al., 2008) suggest a widespread distribution in Mallorca, the species being currently restricted to the Serra de Tramuntana mountain chain (Román, 2004) where it was rediscovered alive only 30 years ago (Mayol et al., 1981; Mayol and Alcover, 1981). Holocene fossils from Menorca, currently ascribed to *A. muletensis* (Bover et al., 2008), also indicate recent extinction in this island. Catastrophic predation by the viperine snake, *Natrix maura* and, eventually competition with the *Pelophylax perezi*, are considered responsible for this range retraction/extinction and continue menacing the surviving populations (Román, 2004). Experimental work, nevertheless, indicates that tadpoles may have developed anti-predatory response after the introduction of *N. maura* (Griffiths et al., 1998). The accidental spread of the fungus *Batrachochytrium dendrobatidis*, causative agent of the chytridiomycosis, to wild populations from captive breeding within a reintroduction program, constituted another serious threat for this species (Walker et al., 2008).

Alytes obstetricans (Laurenti, 1768)

The Common Midwife Toad is found in Western Europe, including Great Britain where it has been introduced (Beebee and Griffiths, 2000). The species was first reported for the Balearics in 2007 in two localities of Maó (Menorca), where several individuals were observed, some of them males carrying egg masses (Carrera and Pons, 2010). Its presence has been considered a consequence of trade of exotic live plants for ornamental purposes (Carrera and Pons, 2010) but phylogenetic studies are necessary to determine its origin considering the complexity of this group (Martínez-Solano et al., 2004). Menorca is, then, the first island where its introduction has been documented (Kraus, 2009). No interactions with native herpetofauna have been observed.

Hyla meridionalis (Boettger, 1874)

The Stripeless Tree Fog is found in Menorca where is considered introduced (Esteban et al., 1994). No fossils exist but no Menorcan specimens have been incorporated in the recent phylogenetic studies on this group (Recuero et al., 2007; Stöck et al., 2008). Nevertheless, such studies coincide in indicating that even the Iberian populations are introduced from North Africa. Further molecular studies should determine the origin of the Menorcan populations. No inference with the extant native species is indicated (Pleguezuelos, 2004).

Extinct amphibians

Painted Frogs, *Discoglossus* sp., have been described for the Pleistocene of Mallorca and Plio-Pleistocene of Menorca (Bover et al., 2008). The ancient origin of this genus (Fromhage et al., 2004) suggests at least a Messinian colonisation of the archipelago. The possible extinction of such forms during the Middle Pleistocene predates the arrival of humans and could be related to glaciations. *Latonia* sp. (Discoglossidae) is also known from the Early Pliocene of Menorca but disappeared during the faunal turnover of the late Pliocene, probably due to the contact with the Mallorcan fauna (Bover et al., 2008).

REPTILES

Testudo hermanni Gmelin, 1789

The Hermann's Tortoise ranges throughout the northern Mediterranean Basin and is found in many islands including Mallorca and Menorca, where is widespread. Balearic subfossil remains from archaeological sites indicate ancient introduction (3000 year BP) probably as food source (Mayol, 1985). Molecular results corroborate the non-native status of this species in the Balearics and a Western Mediterranean origin (Fritz et al., 2006). No interactions with other herpetological species have been described but its role regarding herbivory and seed dispersal has not been investigated in the archipelago.

Testudo graeca Linnaeus, 1758

The Spur-thighed Tortoise is native to North Africa and the Middle East. In the Balearics it is restricted to W Mallorca (Calvià, E Andratx and S Puigpunyent) and a possibly extinct population in Formentera. No fossil or subfossil remains are available, which advocates for a recent introduction, dated from 19th century (Pleguezuelos, 2004). Phylogenetic analysis support this hypothesis since no mtDNA variation is found between Mallorca and NW African coast (Fritz et al., 2009). Even if the species is not native to the Balearics and other Mediterranean inlands, these often healthy populations may be of conservation value eventually serving as back-ups if mainland populations were declining as considered by some authors (Vamberger et al., 2011). Similarly to the previous species, no information on interactions is available either with herpetofauna or with native flora.

Extinct terrestrial chelonians

Native land tortoises different from *Testudo* are well represented in the post-Messinian fossil record from the archipelago (Bover et al., 2008). *Cheirogaster gimnesica* (Bate, 1914) is known from the Pliocene of Menorca and *Cheirogaster* sp. from the Plio-Pleistocene of Ibiza. Both had disappeared during the climatic fluctuations in the Middle Pleistocene before the arrival of humans (Bover et al., 2008).

Emys orbicularis (Linnaeus, 1758)

Widespread in the Western Palaearctic, the European Pond Terrapin is widespread through the lagoons and the ponds of Menorca and much localised in NE Mallorca (Albufera de Alcudia). According to Mayol (1985), the species would have been introduced as pet during the Roman times or even earlier. This is supported by the lack of fossils (Bover et al., 2008) and historical records (Mayol, 1985). Phylogenetic analysis (Velo-

Antón et al., 2008) ascribes the Menorcan specimens to the Italian lineage, also reaching NE Iberia, Corsica and Sardinia. No present interference with native species is detected and it is even menaced by the desiccation of wetlands (Pleguezuelos, 2004). Nevertheless, it has been hypothesised that may have contributed to the decline of *Alytes muletensis* in both islands (Pleguezuelos, 2004) at lowlands.

Trachemys scripta Schoepff 1792

Having its original range in the Mississippi Basin, the Red-eared Terrapin has now successfully established abundant breeding populations in Central, South America, Africa, Asia and Europe (Lever, 2003). The arrival and breeding of this species to islands has also been confirmed (i.e., British Virgin Islands, Owen et al., 2005; Canary Islands, Rodríguez-Luengo, 2001; Cayman Islands, Lever, 2003). The occurrence of this species in the Balearics has previously been reported for Mallorca (Rivera and Arrivas, 1993; Avellà, 1998; Pleguezuelos, 2004; Pinya et al., 2007) and Menorca (Rivera and Arrivas, 1993; Avellà, 1998; Filella, 1999; Pleguezuelos, 2004; Pérez-Mellado, 2005), and its reproduction in Mallorca (Mas and Perelló, 2001; Pérez-Mellado, 2005; Pinya et al., 2007). Now, its presence is extended to Ibiza and Formentera where its reproduction is still not confirmed. The origin in all cases is pet trade. In the Natural Park of s'Albufera de Mallorca, several dozens of animals are captured with funnel traps every year. Recent studies in SE France indicate that *T. scripta* excludes *Emys orbicularis* from basking sites (Crucitti et al., 1990; Cadi and Joly, 2003) decreasing its body condition and its increasing mortality (Cadi and Joly, 2004). Potential effects for native herpetofauna as amphibian predator and pathogen transmitter have been suggested (Martínez-Silvestre et al., 2011).

Chrysemys picta (Schneider, 1783)

The Painted Turtle is native to United States and southern Canada and has been imported as a pet to Florida, Philippine Islands (Uetz et al., 2010) and Malta (Despott, 1913). Its presence has been reported for the s'Albufera de Mallorca Natural Park but its reproduction is still not confirmed (Pinya et al., 2007). No interactions with native herpetofauna are known.

Mauremys leprosa (Schweiger, 1812)

The Spanish Terrapin has previously been reported for Menorca (Lortet, 1887; Alcover, 1979b; Alcover and Mayol, 1981; Rivera and Arrivas, 1993), its arrival being related to pet trade (Kraus, 2009). In Mallorca, it is now successfully breeding in an abandoned lignite mine in the centre of the island (Pinya et al., 2007). Moreover, several males and females of adult sizes have recently been collected in the s'Albufera de Mallorca Natural Park (Pinya et al., 2008). The same potential threatens mentioned for other terrapins apply to this species.

Chelydra serpentina (Linnaeus, 1758)

The Common Snapping Turtle is native from North, Central and Northern South America. Its introduction due to pet trade has been reported in other islands like the Canary Islands (Pleguezuelos, 2004) or Guam (Leberer, 2003). The species was first reported for the Balearics in 2004, when an almost 15 kg female was captured in the

s'Albufera de Mallorca Natural Park (Pinya et al., 2007). Since then, two more adults have been captured when crossing roads. It is suspected that a small population may occur in this humid area but breeding is still not confirmed. In a second locality near Palma de Mallorca city, it has also been observed (Pinya et al., 2007) without any evidence of reproduction. No interactions with the native or introduced herpetofauna have been observed although it exists a potential threaten to local aquatic fauna as birds, amphibians and reptiles, like *E. orbicularis* or *P. perezi*.

Chamaeleo chamaeleon (Linnaeus, 1758)

The Common Chameleon is a Southern Mediterranean species. It is widely distributed in most of the countries of North Africa, Middle Orient, Arabic Peninsula, Turkey, Iberian Peninsula, Apulia (Italy) and several islands from the Aegean Sea and Malta (Klaver, 1981, Razzetti and Sindaco, 2006). This range is at least partially resulting of introductions, and in some areas where the species was reported (i.e., Sicily, Crete) there is no evidence of naturalised populations. Populations in Southern Iberia derive from two independent colonisations from Morocco (Paulo et al., 2002) whereas another species, *Chamaeleo africanus* Laurenti, 1768 was introduced from the Nile Delta, Egypt to the Peloponnese (Dimaki et al., 2008). The Common Chameleon was never reported before for the Balearic Islands (Mayol, 1985, Bover et al., 2008). Since 2004 some isolated individuals have been collected by fauna recovery centres across Mallorca, but especially close to the most populated villages and cities. Its presence appears to result from isolated individuals, as a consequence of pet trade. Phylogenetic analysis of such specimens may reveal their putative relationships with the conspecific populations already analysed around the Mediterranean Basin (Dimaki et al., 2008) although disentangle Iberian from North-western African origin may be difficult. It is also noticed that transmarine colonisations have been demonstrated for other chameleon species (Raxworthy et al., 2002). Although some pregnant females have been collected in the wild, currently, the naturalization of the species in Mallorca cannot be assumed.

Tarentola mauritanica (Linnaeus, 1758)

The Moorish Gecko ranges the Iberian Peninsula, NW Africa and many other continental and insular areas throughout the Mediterranean Basin. Phylogenetic evidence (Harris et al., 2004a, 2004b; Perera and Harris, 2008; Rato et al., 2010) suggests that the species has recently colonised the Italian Peninsula, the Balkans and many Mediterranean islands, probably by passive transport. Selective forces have, however, been identified by comparing mtDNA and nDNA profiles (Rato et al., 2010). Samples from Menorca, included in such studies, belong to the most widespread lineage found across the Mediterranean clearly support its alien status, but the origin of the colonisation remains uncertain. On the other hand, unidentified gecko remains are also known from the Pliocene of Menorca (Bover et al., 2008) which may suggest successive gecko colonisations and extinctions. Although predation on lacertid juveniles has been reported, it shares habitat with *Podarcis lilfordi* and *P. pityusensis* in many islets without any obvious negative effects on them (Pleguezuelos, 2004).

Hemidactylus turcicus (Linnaeus, 1758)

The Mediterranean Gecko ranges the Middle East, the Mediterranean Basin and also multiple sites around the Gulf of Mexico. Analysis of mtDNA (Carranza and Arnold,

2006) indicates a recent westwards expansion human-mediated from the Middle East across the whole Mediterranean region and then across the Atlantic Ocean. This includes the populations found in the Balearic Islands, the ascription of the Menorcan Pliocene gecko fossils to this species being unlikely. However, more recent analysis on nDNA also suggests that selection may be an important force shaping the genetic diversity of this species (Rato et al., 2011). No negative impact on native herpetofauna has been described (Pleguezuelos, 2004).

Podarcis lilfordi (Günther, 1874)

The Lilford's Wall Lizard is endemic to the small islets around Mallorca, Menorca and Cabrera. Pliocenic Menorcan fossils of small lacertids were identified as *Podarcis* sp. whereas the abundant remain in both main islands from the Early Pleistocene to the Holocene are ascribed to *P. lilfordi* (Bover et al., 2008). Molecular studies (Brown et al., 2008; Terrassa et al., 2009) are compatible with the paleogeological scenario, including the Messinian colonisation, the vicariance between Menorca and Mallorca at the end of the Pliocene and the Pleistocenic separation of Cabrera. In all cases, genetic distances between islets belonging to the same area are minute. Interestingly, a population has survived in a tiny island inside a Menorcan lagoon (Triay, 2000). All this evidence, hence, corroborates both native status of current islet populations and its recent extinction in the main islands. Such extinction is attributed to the introduction of alien predators, especially mammals and snakes (Mayol, 1985), although the Pliocenic ancestors of this species were in contact with snakes at least in Menorca (Bover et al., 2008). Nevertheless, experimental studies have demonstrated relaxed mechanisms of tail autotomy in this species when compared to continental ones (Pérez-Mellado et al., 1997), which even decrease when rats are absent from the islets (Pafilis et al., 2008). Moreover, competitive exclusion by *P. sicula* has already taken place at least in one Menorcan islet (Pérez-Mellado, 2002b).

Podarcis pityusensis (Boscá, 1883)

The Ibiza Wall Lizard is endemic to Ibiza, Formentera and nearby islands. In contrast to *P. lilfordi*, it is present and abundant in the main islands and introduced populations are known for Mallorca and the Iberian Peninsula (Carretero et al., 1991; García-Porta et al., 2001; Pérez-Mellado, 2002a). Fossils attributed to *Podarcis* sp. and to *P. pityusensis* are known for the Pliocene and Late Pleistocene of Ibiza, respectively. In the same way, phylogenetic studies (Brown et al., 2008) support a Messinian origin and the autochthonous status in the Pityusic islands. The absence of *Macroprotodon mauritanicus* from this subarchipelago is commonly invoked to explain the survival of the species in the main islands but experiments have also demonstrated that tail autotomy is easier in this species than in *P. lilfordi* (Pérez-Mellado et al., 1997). The single stable populations introduced in Mallorca is urban and do not contact with *P. lilfordi*, which is restricted to the islets.

Podarcis sicula (Rafinesque, 1810)

The Italian Wall Lizard mainly ranges the Italian Peninsula, Corsica, Sardinia and Sicily, but some populations are also found in Turkey, Cyprus, Israel, Tunisia, France, Iberian Peninsula and United States. It is widespread in Menorca where does not overlap with *P. lilfordi* and lacks fossil record. More recently, a colony has been in Sant Jordi, Ses Salines

(Mallorca). Its phylogenetic affinities are with Sicilian populations rather than with Corsican or Sardinian ones which suggest long distance introduction (Podnar et al., 2005). Together with this colonising capacity, this species is able either to displace native *Podarcis* (Nevo et al., 1972; Downes and Bauwens, 2002) or to hybridise with them (Capula, 1993, 2002; Capula et al., 2002). Thus, it constitutes a serious threat for the Balearic species, especially for *P. lilfordi* whose small and fragmented range makes it extremely vulnerable (Pérez-Mellado et al., 2008). In fact, if the information of an introduction from the Mallorcan colony to Cabrera would be confirmed, the important populations of native *P. lilfordi* will risk extinction.

Psammodromus algirus (Linnaeus, 1758)

Widely distributed across SE France, Iberian Peninsula and NW Africa, the Large Psammodromus has recently been reported for several localities from SE Mallorca (Masius, 1999; Vicens, 2005). Current observations in other parts of the island suggest that it is starting to spread out to S Mallorca (Llucmajor). Further analysis of genetic markers will determine whether the source population is located in Iberia or in North Africa (Carranza et al., 2006, Carretero et al., 2009). It must be remarked that the high reproductive output (Carretero and Llorente, 1997), the favourable habitat (Carretero et al., 2002) and the lack of other lacertid species in non urban areas of Mallorca, may favour a rapid progression of the species in the island with unknown consequences. It is, for instance, expectable that if abundant it could serve as prey and keeping high numbers of predators as *Macroprotodon mauritanicus*, or the newly introduced colubrids (see below), then preventing any eventual reintroduction of native lizards.

Scelarcis perspicillata (Duméril and Bribon, 1839)

The Moroccan Rock Lizard ranges the Atlas and other mountain massifs of Morocco, NW Algeria as well as Menorca where it has an irregular distribution associated bare rocks, walls and cliffs. It was considered introduced based on the disjoint distribution with the African main range, the association of some populations with human buildings and the lack of fossils (Perera, 2002). However, the Menorcan populations are, in fact, morphologically and genetically distinct from the Moroccan populations studied to date (Harris et al., 2003; Perera et al., 2007). Only a comparative study in the whole species range, including Algerian populations, will allow demonstrating its alien status in Menorca. The species does not contact with the native *P. lilfordi* and displays habitat segregation with the introduced *P. sicula*.

Timon lepidus (Daudin, 1820)

The Ocellated Lizard is a typical reptile from the western European regions under Mediterranean climate (Mateo, 2002) including NW Italy, SW France and most of the Iberian Peninsula (Mateo and Cheylan, 1997). In the last decade some individuals have been observed in the SE of Palma de Mallorca city (Mallorca), in an old sandstone quarry. There is no evidence of reproduction in this site since neither juveniles nor egg were found. Although overseas dispersal has been postulated for the genus (Paulo et al., 2008), a single introduction of isolated individuals is more likely. In nature, the species predates upon small lacertids (Castilla et al., 1991) but no native species are present in the Mallorca main island.

Macroprotodon mauritanicus Guichenot, 1850

After the recent taxonomic revision (Wade, 2001; Carranza et al., 2004) the False Smooth Snakes, *Macroprotodon* sp., have been split into several taxa. One of them, *M. mauritanicus*, occupies N Tunisia, NW Algeria, Mallorca and Menorca. On the basis of the separate range, almost null genetic variation between Mallorca and Africa (Carranza et al., 2004) and lack of fossil record (Bover et al., 2008), the species is considered introduced in the Balearics, probably from Roman times (Pleguezuelos, 2004). It has been considered responsible for the extinction of *P. lilfordi* in Mallorca and Menorca, due to its saurophagous diet and the temporal coincidence between its arrival to the Balearics and the extinction of this species in the main islands (Mayol, 1985).

Natrix maura (Linnaeus, 1758)

The Viperine Snake is distributed on both continental sides of Western Mediterranean, being considered introduced in Sardinia, Mallorca and Menorca. In the Gymnesics, where no fossils are available, the species would have been imported from ancient times (Alcover and Mayol, 1981). Molecular studies corroborate its alien status in Mallorca and point to a European origin (Guicking et al., 2006). In Serra de Tramuntana (Mallorca), the presence of this species is negatively correlated with tadpole density of *A. muletensis* (Pleguezuelos, 2004) which suggests that its predation pressure constitute an important threat for the species (Román, 2004). The species have been supposed to be responsible for the extinction of *A. muletensis* and *Discoglossus* sp. in Menorca (Pleguezuelos, 2004). The first seems realistic while the second is unlikely since the painted frogs had disappeared earlier in the fossil record (Bover et al., 2008).

Malpolon monspessulanus (Hermann, 1804)

The Montpellier Snake occupies a Circum-Mediterranean range although the western and eastern populations are strongly separated in the phylogeny and may represent different species (Carranza et al., 2006). It has recently been reported for the Balearics. Namely, its arrival is associated with the trade of old olive trees used for ornamentation which snakes were found hidden inside the roots (Oliver and Álvarez, 2010; Álvarez et al., 2010), the same way of *P. sicula* in Hyères island, France (Bruekers, 2003) and in Rioja, Iberian Peninsula (Valdeón et al., 2010). Currently, there are several observations and captures of adult individuals of both sexes in Mallorca, Ibiza and Formentera (Álvarez et al., 2010), suggesting that breeding may be a matter of time. Ensuring the origin of the introductions may be difficult if the samples carry the most widespread haplotypes that are found both in Iberia and North Africa (Carranza et al., 2006). Currently, the species had been considered introduced only in Lampedusa, between Sicily and Tunisia (Corti and Lo Cascio, 2002). In the future, this euryphagous snake may represent a serious threat for native lacertid species, especially in Ibiza, and, if reached, in the small islets, which is likely considering its swimming abilities.

Hemorrhois hippocrepis (Linnaeus, 1758)

The Horseshoe Snake is found in the Iberian Peninsula and NW Africa, as well as in some Mediterranean islands (Zembra, Pantelleria, Sardinia) were is said to be introduced (Bruno and Hotz, 1976; Pleguezuelos and Feriche, 2004). Original observations indicate

that this species arrived by the same way and almost at the same time than *M. monspessulanus*. Its reproduction is confirmed by the observation of juveniles and pregnant females in Capdepera, NW Mallorca, although recently several individuals have been observed in the rest of the island. Currently, there is a dense population in Mallorca and it also has arrived to Ibiza where it started to reproduce (Oliver and Álvarez, 2010; Álvarez et al., 2010). Uncertainty about the origin would also affect this species when molecular markers could be analysed due to the same reason than in the previous species (Carranza et al., 2006). Threatens for native herpetofauna could also be similar.

Rhinechis scalaris (Schinz, 1822)

The Ladder Snake is endemic to Iberian Peninsula and adjacent SE France. It was previously reported as a member of the Balearic herpetofauna (Alcover and Mayol, 1981; Kotsakis, 1981; Mayol, 1985) although its presence was restricted to Menorca (Esteban et al., 1994), where no fossils are known. The preliminary phylogeographic analysis of this species (Nulchis et al., 2008), not including Menorcan samples, found no variation in the mtDNA. No new haplotypes are, hence, expected for Menorca but if they would appear would pose doubts on its introduced status. Recent observations, however, indicate its presence also in Mallorca, Ibiza and Formentera, where it has arrived by the same way as *M. monspessulanus* and *H. hippocrepis* (Oliver and Álvarez, 2010¸ Álvarez et al., 2010). Nevertheless, its biological impact on herpetofauna is expected to be less serious in comparison to those species because it almost exclusively consumes birds and mammals (Pleguezuelos et al., 2007).

Extinct snakes and amphisbaenians

As previously commented, fossil snakes, namely, viperids (*Vipera natiensis* Bailon, Garcia-Porta and Quintana-Cardona, 2002 and *Vipera* sp.) and colubrids (*Coluber* sp.) are know for the Early and Middle Pliocene of Menorca (Bailon et al., 2002; Bover et al., 2008). An amphisbaenian (*Blanus* sp.) is also found in the same assemblages (Bover et al., 2008) in agreement other Plio-Pleistocenic remains from Sardinia, Sicily and the Italian Peninsula (Delfino, 2003). Both snakes and worm lizards disappeared from the Balearic fossil record in the Pleistocene (Bover et al., 2008).

To summarise, prior to the humans arrival, the Balearic herpetofauna was the result of a long term evolution in insularity producing Pliocenic amphibian and reptile lineages endemic to the three main island groups (Figure 1). Such endemic taxa were decimated during the Pleistocene sea level and climate fluctuations. After the human colonisation of the archipelago, the introduction of alien species, passive or deliberate, caused new extinctions and range retractions in the native herpetofauna. Such process is not interrupted but has even intensified during the last years (Fig. 1).

Of the current herpetofauna of the Balearic Islands, just one amphibian (*A. muletensis*), and two reptiles (*P. lilfordi* and *P. pityusensis*) are considered native. Thus, since humans arrived it has become an increasing of amphibian richness of five times and about 10.5 times in case of reptiles (Fig. 2), being the Squamata the order which included a highest number of new species. The last updated checklist of amphibians and reptiles (Mayol, 1985) considered a total of four amphibians and 15 reptiles with a percentage of introduced

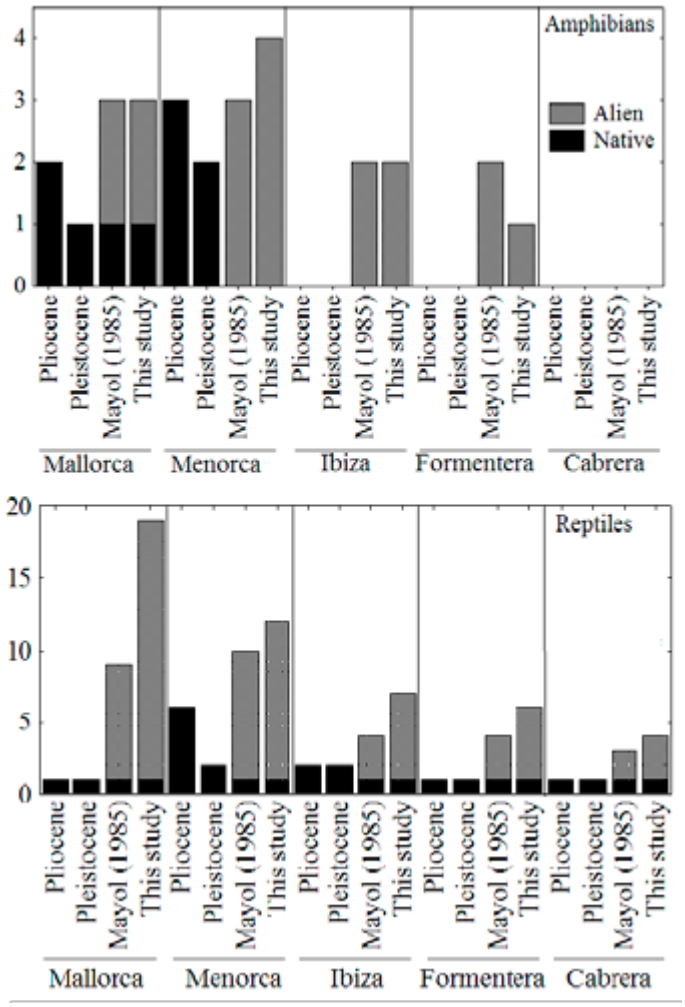

Fig. 1. Ancient and recent changes in the Balearic terrestrial herpetofauna.

species in amphibians of 75% and of 60% in reptiles. Since then a total of six new species of reptiles have been naturalised or are in process of naturalization in the Balearic Islands.

The considerable biogeographic differences between the alien species are to be taken into account. Some of them come, in fact, from historical introductions which may suppose either that they are now integrated in the Balearic ecosystems or that their removal would be even more traumatic. This may apply to the geckos, the European Pond Terrapin and the land tortoises. Beyond their origin, their conservation actions require cautiousness, particularly when they are endangered in their original ranges (for a discussion on this topic, see Böhme, 2002). In such cases (i.e., *Emys orbicularis*) preventing the impact from new aliens as in the case of would be advisable. On the other hand, evidence is still insufficient

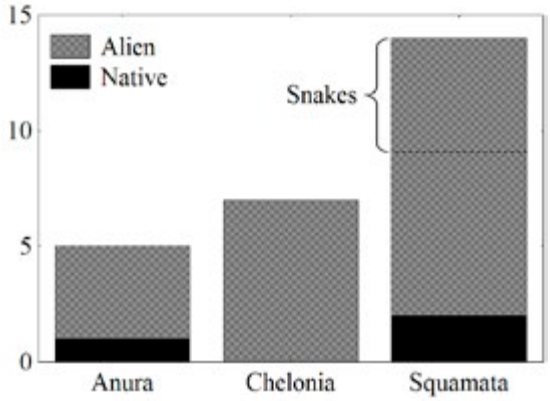

Fig. 2. Global balance of the current taxa of the introduced (black) and native (white) amphibian and reptiles of the Balearic Islands.

to determine the status of some species and a principle of caution suggest further research before taking management decisions (i.e., *B. balearicus*, *H. meridionalis*, *S. perspicillata*).

On the other hand, colubrid snakes constitute the most conflicting aliens due to its predator role. In Mallorca, they are expected to predate upon the geckos and the recently introduced *Psammodromus algirus*, as well as local mammals and birds. However, in Ibiza and Formentera, the occurrence of snakes in the wild was never documented before. Impact on *P. pityusensis* could be similar to the case of *P. lilfordi* after the introduction of *M. mauritanicus* and other vertebrates some centuries ago to Mallorca and Menorca which caused the extinction of its populations in the main islands. Effects could be even more acute since the new alien snakes have a higher predator potential than the African False Smooth Snake. In consequence, it can be considered that the threat to the endemic herpetofauna in the Balearic Archipelago is increasing. Although time passes, the list of amphibians and reptiles continues growing as it is showed since the eighties (Mayol, 1985) and probably will not stop if legal effective measures are not taken seriously to control the entrance of alien species to these islands.

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