Chapter 5
Herpetological History of the Balearic Islands: When Aliens Conquered These Islands and What to Do Next

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Abstract Balearic herpetofauna represents a paradigmatic case of multiple biological invasions within the Mediterranean Basin, with a much higher number of alien amphibians (i.e. frogs and toads) and reptiles (i.e. lizards, snakes and turtles/tortoises) than native. The paleogeography of the Balearic Islands, located on Western Mediterranean between Spain and Sardinia, is complex, comprehending an ancient split from the continent during the late Miocene and Pleistocene climatic fluctuations connecting and disconnecting islands from one another (but not them to

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the continent) that eventually re-shaped the archipelago's biota. The archipelago has been also influenced by humans since the Neolithic, being a cross-road for alien biota between North Africa and Southern Europe, which caused range regressions and extinctions in the native herpetofauna, nowadays restricted to one amphibian and two reptiles. During the last century, tourism development, the pet trade, and cargo transport of ornamental plants have produced a new wave of biological invasions. Recently introduced snakes are of particular concern, since the effect of predation may seriously threaten the remaining native reptiles in the main islands and endemic subspecies in surrounding islets. Balearic people have a negative social perception of such snakes, mainly due to the lack of familiarity with snakes among islanders but also to the herpetophobic attitude of many Mediterranean cultures. Here we review the herpetological invasions in the Balearic Archipelago and their impacts. We further discuss the on-going management actions on alien reptiles in this archipelago, namely the control of invasive snakes in Ibiza involving monitoring, trapping, environmental education and promotion of social participation.

Keywords Alien reptiles · Balearic Archipelago · Cabrera · Formentera Humans · Ibiza · Invasive species · Islands · Gimnesic Islands Lizards · Mallorca · Menorca · Snakes · Nursery trade · Pityusic Islands Tourism

5.1 The "Deep History" of the Balearics

The Mediterranean Basin is one of the richest and most complex regions on Earth on several facets, namely geological, biological and cultural. Nowadays, it is considered one of the global biodiversity hotspots (Myers et al. 2000). The region is the result of a complex history encompassing profound geological processes such as tectonic dynamics, climatic shifts, and biogeographical interchanges (Blondel et al. 2010). All these processes have contributed to the development of a particularly rich biota. The most influential geologic events were: (1) the Messinian Salinity Crisis (from 5.9 to 5.3 Myr ago) during which the Mediterranean Sea went into a nearly complete desiccation, which allowed substantial faunal interchanges between land masses; and (2) the Pleistocene climatic oscillations between glacial and interglacial episodes (especially in the last Myr), which played a key role in molding and shaping present-day biota, including species range shifts and extinctions (Blondel et al. 2010).

The Balearic Archipelago represents an ancient and isolated system within the Mediterranean. The last separation of this archipelago from the mainland dates back to the end of Messinian salinity crisis, about 5.3 Myr ago. At that time, two sub-archipelagos arose and never contacted each other again: the western group or Pityusic Islands comprising Ibiza, Formentera and nearly 60 smaller surrounding islets; and the eastern group or Gymnesic Islands comprising Mallorca, Menorca and about 30 medium and smaller surrounding islets.

The Messinian represented the last massive terrestrial exchange of fauna between Europe and Africa and among the Balearic Islands as a whole. Since then, faunal interchanges have only taken place within each sub-archipelago islands and islets. Thus, terrestrial species evolved there in isolation during the Pliocene under mild subtropical conditions (Bover et al. 2008). Subsequent climatic changes occurred in the Late Pliocene with a shift towards a Mediterranean climate regime characterized by long summer drought (Jiménez-Moreno et al. 2010), followed by substantial oscillations in temperature and humidity during the last 2.5 million years due to glaciations (Bover et al. 2008).

Pleistocene glaciations not only brought about radical changes in climate compared to the Pliocene, but also promoted temporary connections among islands within the same sub-archipelago. A number of vertebrate groups became extinct in that period (e.g. vipers; Bailon et al. 2010). The surviving fauna underwent separate evolutionary and ecological pathways to those of their continental relatives. In particular, there was a shift from a primarily insectivorous lizard fauna to a lizard fauna with a mainly plant-based diet (Pérez-Mellado and Corti 1993), while small species shifted to gigantism (Novosolov et al. 2013), namely many populations of *Podarcis lilfordi* present in small islets (Brown and Perez-Mellado 1994).

During glaciations, the Pityusic Islands (nowadays separated by a narrow and shallow channel) were connected, therefore sharing their fauna. In the Gimnesic Islands Mallorca and Menorca, a deeper sea channel prevented their connection during the Tertiary, but not during the Pleistocene glacial phase, when they were connected several times allowing interchanges of some faunal elements. Thus, current Mallorcan and Menorcan faunas are a mixture of shared and unique elements. Last but not least, the small islets that were connected to the main islands until the end of the glaciations became isolated due to the post-glacial marine transgression.

Nowadays, the Balearic Islands have a total area of 5040 km^2 and 1428 km of coastline, lying from 80 to 300 km east of the Iberian mainland (Fig. 5.1). Mallorca is the largest island, with very diverse ecosystems and landscapes, which can be divided into three distinct districts: the Serra Tramuntana, an elevated mountain range that shapes the northern coast of the island, with the highest peak at 1445 m; the Serres de Llevant, comprising small rounded hills that mark the landscape of white-sand coves and green pine forest; and a flatland area located between the two mountain ranges and characterized by rural landscapes.

Menorca Island is predominantly flat with subtle rolling hills, and is sheltered by a small mountain range along the northern coast (347 m above sea level). Therefore, in the north, the island is more rugged, with a jagged coastline, while the south is flatter with cliffs, water-carved gullies and white-sand coves nestled amid pine trees.

Cabrera is located south of Mallorca and it was officially declared a Marine and Land National Park in 1991. It is an area with a great wealth of biodiversity, featuring a multitude of endemic invertebrates, and 150 migratory bird species stop over on the island during both their spring and autumn migrations.

Ibiza has a uniform landscape and moderate relief, the highest point being Sa Talaiassa (486 m). Habitats include marshes, dunes, saltflats (*salines*), cliffs and

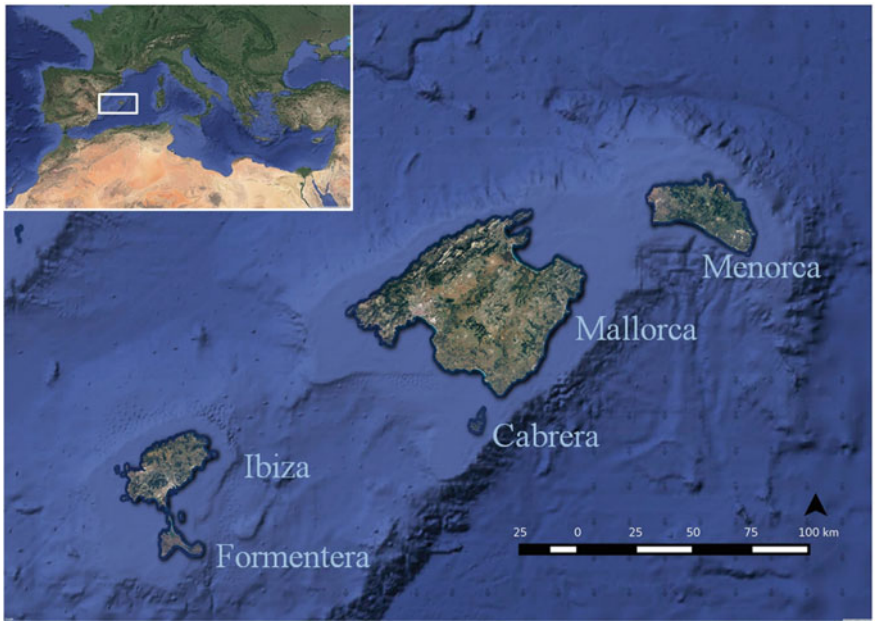

Fig. 5.1 The Balearic Archipelago and its geographical position in the Mediterranean Basin

beaches. The flat alluvial plain is formed by Quaternary calcareous deposits and two enclosing wooded hill ranges. This island is part of a Special Protection Area for Birds and The European Economic Community's Natura 2000 Network, and it is listed on the Ramsar List of Wetlands of International Importance.

Formentera is 19 km long and located 6 km south of Ibiza. It has a narrow shape that gives it a long stretch of coast (82 km) in proportion to its surface area (83 km^2). The landscape is composed of Mediterranean shrubs in dune areas as well as pine and savin (juniper) forests.

The general climate on the Balearic Islands is Mediterranean, with a hot and dry summer, mild winter and the scarce rains concentrated in autumn. During the winter the minimum temperature is 10 °C and in July temperatures can reach 35 °C (30-years standard meteorological averages; AEMET and IM 2011).

5.2 The Balearics and the Bioinvasions

5.2.1 Invasions on Islands

Islands harbour peculiar ecosystems, due to their isolation from the continents. The number and organismal taxa that can naturally reach and colonize island ecosystems is limited, the number of populations is fewer, and the total population size is

smaller than in continents. Island communities are, therefore, impoverished and unbalanced in comparison with continental ones. They experience less biotic interactions and opportunities to evolve independently and differently compared to their mainland relatives, as a result of having less competitors, predators and parasites (Whittaker and Fernández-Palacios 2007). These factors create a higher sensitivity to disturbances and vulnerability to biodiversity extinction, compared to continental ecosystems (Vitousek et al. 1996; Reaser et al. 2007; Ficetola and Padoa-Schioppa 2009).

The theory of island biogeography states that species richness on islands results from the equilibrium between colonization (as a function of distance to continent or to other islands), speciation (as a function of time) and extinction (as a function of island size and habitat heterogeneity) (MacArthur and Wilson 1967). However, humans have shifted this balance on some insular ecosystems by increasing colonisation rates by alien (introduced) species; hence islands where human impact is very high may end up with more alien species.

Biological invasions on islands are even more dangerous when the presence of native predators is low, competitors are absent, and the native species are vulnerable to the aliens or to its parasites (Whittaker and Fernández-Palacios 2007; Álvarez et al. 2010). In addition to that, islands normally have a more benign environment (i.e. more stable abiotic conditions, such as milder temperatures) and lower habitat diversity, which facilitate the establishment of invasive species (Gimeno et al. 2006).

5.2.2 *A Long History of Successive Herpetoinvasions*

The Balearic Archipelago is one of the most isolated in the Mediterranean (i.e. farther from mainland) and because of that, its exploration and discovery by humans took place later than in other archipelagos. The first records of humans on the Balearics date from the last third of the third millennium BCE (Alcover et al. 2001; Ramis et al. 2001; Bover et al. 2008). The first settlers were hunters and farmers, also herding goats, cattle, sheep and pigs, brought from the mainland (Ayuso 2001).

A long history of migratory waves followed this period, as in other parts of the western Mediterranean with high demographic growth, the discovery of new uninhabited regions and the development of maritime contacts setting the Balearic Islands in the route of several civilizations (Iberians, Nuragics (from Sardinia), Phoenicians, Greeks, Carthaginians, Romans, Byzantines, Arabs and Berbers). All these civilizations introduced alien species passively (with cargo) or voluntarily (as food source or for religious purposes). The Romans may have introduced snakes to frighten their enemies, and—associated to Aesculapius cult—to give them good luck; tortoises were introduced by several civilizations (i.e. Phoenicians, Greeks and Arabs) to serve as food and pets. The Nuragics are thought to have introduced the Balearic green toad *Bufotes balearicus* for religious purposes (Lewthwaite 1985; Chapman 1990).

During the twentieth century, an intensification of human activity occurred in the Balearic Islands, especially on Mallorca, due to massive tourism development and to the pet trade and the nursery trade (trade of live plants for ornamental purposes). These activities have resulted in range retractions in the native herpetofauna, which is nowadays composed of only one toad, the Mallorcan midwife toad (*Alytes muletensis*) and two lizards, the Lilford's wall lizard and the Ibiza wall lizard (*P. lilfordi* and *P. pityusensis,* respectively) (Pinya and Carretero 2011).

The number of species introduced to the main islands increased strikingly, with Mallorca having the highest number of assumed aliens, with 21 species, followed by Menorca with 15, both Formentera and Ibiza with eight species, and Cabrera with two introduced species. The number of observations per year has been increasing for all the alien species in the Balearic Islands, suggesting they are expanding both in terms of range and population size.

5.2.2.1 Herpetofauna Before Invasions

On Mallorca, fossils dating from the Pliocene Epoch include a giant lacertid lizard (*Maioricalacerta refelensis*), a skink (*Chalcides* sp.), and a glass lizard (*Dopasia* sp.) (Bailon et al. 2014; Bover et al. 2014). In Menorca, two post-Messinian faunas occurred: one during the Early and Middle Pliocene (Quintana 1998; Alcover et al. 1999) and the other during the Late Pliocene or Early Pleistocene (Bover et al. 2008). The first one was composed of a giant tortoise (Bate 1914), a lizard (*Podarcis* sp., likely an ancestor of Lilfordi's wall lizard, Bailón 2004), geckos (Gekkota undetermined), an amphisbaenian (Blanidae, Garcia-Porta et al. 2002; Bailon et al. 2005), and three snakes including a colubrid and two viperids (*Vipera natientis* and *Vipera* sp., Bailon et al. 2005). The Late Pliocene/Early Pleistocene records report a lizard (*Podarcis* sp.) and two amphibians (Mallorca midwife toad *A. muletensis*, Barbadillo 1987, and *Discoglossus* sp., Alcover et al. 1981; Quintana 1998).

Regarding the Pityusic Islands, three different fossil assemblages have been recorded in three different periods: during the Late Miocene/Early Pliocene, a lizard and a tortoise (Moya-Solà et al. 1984, 1999), during the Late Pliocene, a middle sized tortoise (*Cheirogaster* sp., Bour 1985) and a lizard (*Podarcis* sp, Kotsakis 1981); and in the deposits of the Late Pleistocene, a lizard species (*P. pityusensis*, Boscá 1883).

5.2.2.2 Prehistoric and Ancient Introductions (Older Than 5th Century)

The lack of older fossils in the palaeontological record on the Balearic Islands suggests ancient introductions of one toad (Balearic green toad), two turtles (Hermann's tortoise, *Testudo hermanni*; and the European pond turtle, *Emys orbicularis*), two geckos (Mediterranean house gecko, *Hemidactylus turcicus*; and the Moorish gecko, *Tarentola mauritanica*) and one snake (Ladder snake, *Rhinechis*

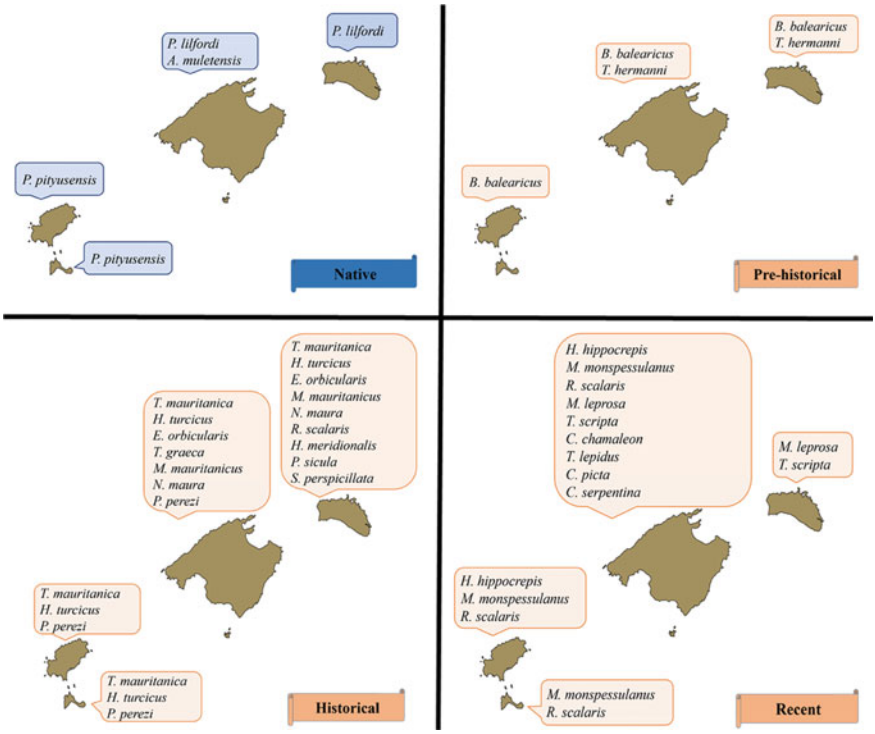

Fig. 5.2 Herpetoinvasions in the Balearic Archipelago, through time, by island

scalaris) (Fig. 5.2). The exact timing and the arrival pathway of the Balearic green toad is unknown. Both the Hermann's tortoise and the European pond turtle were introduced as a food source from the Western Mediterranean region (Fritz et al. 2006). Both gecko species were presumably introduced by passive transportation, with apparently no impact on native communities. No negative impacts on native species or ecosystems are known for these species, with the exception of the snake, which as a predator has a high risk of impact (see below).

5.2.2.3 Historical Introductions (5th Century–18th Century)

The lack of fossils combined with the low genetic differentiation observed, suggests the introduction of two frogs and nine reptiles (i.e. lizards, snakes and turtles) during historical times (Fig. 5.2): the Mediterranean tree frog *Hyla meridionalis* and Perez' frog *Pelophylax perezi*; two turtles, the European pond turtle *Emys orbicularis* and the spur-thighed tortoise *Testudo graeca*; two lizards, the Moroccan rock lizard *Scelarcis perspicillata* and the Italian wall lizard *Podarcis sicula*; and two snakes, the false smooth snake *Macroprotodon mauritanicus* and the viperine snake *Natrix maura*.

The Mediterranean tree frog could have been introduced from the south-western region of the Iberian Peninsula (Silva-Rocha 2012), either voluntarily or accidentally. It is suggested that this frog may have been unwittingly transported to the Canary Islands by the first settlers in cargos such as cattle and seeds (Recuero et al. 2007); this could also be the case in the Balearics. On the other hand, Perez's frog is suspected to have been introduced to control insects (Pinya and Carretero 2011). The latter could have had competitive interaction with the native Mallorcan midwife toad (Román 2004) and predated on this same species (Alcover et al. 1984).

Regarding the chelonians (turtles and tortoises), the pathway of introduction both for the spur-thighed tortoise and the European pond turtle is considered, similarly to pre-historical introductions, as a food resource (Velo-Antón et al. 2011; Cau et al. 2016). These two species have likely no impacts on native species, though the European pond turtle could have contributed to the decrease of Mallorcan midwife toad populations (Pleguezuelos 2004).

The Italian wall lizard arrived in Mallorca and Menorca from Sicily-Sardinia (Greca and Sacchi 1957; Silva-Rocha et al. 2012), probably involuntarily, as this species is known to live close to human populations, which increases the chances of it being introduced by passive transport. From our experience in other Mediterranean islands, this is an aggressive lizard, able to compete with native species (Silva-Rocha et al. 2012 and references within).

As to the two snakes introduced, their arrival pathways are not clear. A passive transportation could have happened in ships due to the maritime trade established between the Balearic Islands and the mainland, as may have occurred with European pond turtle in Corsica and Sardinia (Pedall et al. 2011). On the other hand, they could have been introduced for religious purposes, as referred to above. The origin of the Balearic populations of the false smooth snake is likely Tunisia, while the viperine snake populations originated from Europe, either from the Iberian Peninsula or France (Pleguezuelos 2004; Guicking et al. 2008; Silva-Rocha et al. 2015). The impacts of the false smooth snake extends beyond the native herpetofauna (i.e. Lilford's wall lizard), as they are also able to predate birds and mammals, which can cause a substantial disturbance in these insular ecological communities.

5.2.2.4 Recent Introductions (19th Century to Nowadays)

Over the past two centuries, a total of ten species were introduced in the Balearic Islands, as a consequence of increasing tourism and trade in this region (Fig. 5.2): one toad (the common midwife toad, *Alytes obstetricans*); three chelonians (the painted turtle *Chrysemys picta*, the Mediterranean turtle *Mauremys leprosa* and the pond slider *Trachemys scripta*); four lizards (the common chameleon *Chamaleo chameleon*, the occelated lizard *Timon lepidus*, the Ibiza wall lizard *Podarcis pityusensis* and the Algerian Psammodromus *Psammodromus algirus*); and three snakes (the horseshoe whip snake *Hemorrhois hippocrepis*, the Montpellier snake *Malpolon monspessulanus* and the ladder snake, the latter on islands other than Menorca where it had already been introduced).

The common midwife toad was found in Menorca in 2007, and its introduction is associated with the trade in exotic live plants for ornamental purposes (Carrera and Pons 2010); however, it has not been confirmed later than 2007. The geographical origin is unknown.

The chelonians have been introduced mostly due to the pet trade. It is important to notice that the pond slider is an invasive turtle species native to the eastern USA and adjacent areas of Mexico and introduced worldwide, which can impact on native ecosystems by predation and pathogen transmission. The common snapping turtle can also impact on local aquatic fauna, such as birds and amphibians. For the rest of the chelonians, the impacts are not known.

As to the lizards, an introduction due to the pet trade is assumed for the common chameleon, whereas for the ocellated lizard either pet trade or passive introductions through olive trees (Rivera et al. 2011) are equally possible. The origin of the former is not known, while the latter is suggested to come from southeastern Spain, based on genetic and phenotypic data (Mateo et al. 2011; Silva-Rocha 2012).

Three large snake species were introduced during the last decade: the horseshoe whip snake and the Montpellier snake during 2003 in Ibiza (the last not seen since 2010) and Mallorca; the ladder snake during 2003 in Ibiza, 2004 in Mallorca, and 2006 in Formentera (Álvarez et al. 2010; Mateo et al. 2011). In all cases, the introduction pathway is attributed to the nursery trade, through live plants for ornamental purposes (Kraus 2009; Álvarez et al. 2010).

Individuals from all the three species were found primarily in trunks of olive trees in the nursery centres of Capdepera (Mallorca) and Sant Llorenç de Balàfia (Ibiza). The origin of the first two species is thought to be the southern Iberian Peninsula. The origin of the ladder snakes is uncertain but its alien status in the Balearics is beyond doubt (Carretero and Silva-Rocha 2015). Similarly to the horseshoe whip snake and the Montpellier snake, it can be found near olive trees translocated by the importation industry (Álvarez et al. 2010). As reported by the same authors, at least one company from Spain is involved in the olive trees trade, while no importations from France and Portugal (countries where the species also ranges) are known.

The olive trade business has increased through the years in the Balearic Islands, as a consequence of a trend in garden decorations. Reptiles use the olives as a refuge and there is evidence of several species living together in old trees (Rivera et al. 2011; Graziani et al. 2006; pers. obs. of the authors), which increases the probability of introductions of multiple species in many sites. Thus, the olive trade represents an important pathway for the introduction of reptiles throughout this region, and therefore must be considered when devising prevention and conservation measures.

5.2.2.5 The Future

Ecological niche models calculated with scenarios of climate change (i.e. extreme temperature/humidity and moderate temperature/humidity), forecast an increased

suitability in most of the island territory for the alien snakes (with the exception of the false smooth snake) (Silva-Rocha et al. 2015). Indeed, recent studies suggested that climate change is already increasing the activity period and benefiting the survival and reproduction of Montpellier snake and horseshoe whip snake in the Iberian Peninsula (Moreno-Rueda and Pleguezuelos 2009; Zamora-Camacho et al. 2010). Therefore, the population size and spread of some of these Mediterranean snake species is expected to increase, with an associated increase of their impact on native biota.

Unfortunately, a projection in the future was not performed for other introduced species due to lack of records. Nevertheless, in those species coming from warm regions with heterogeneous habitats, it may be expected they will also benefit from climate change.

5.3 Italian Wall Lizard: 'Let It Be' Does not Work

The Italian wall lizard *P. sicula* represents a case where nothing was done to prevent the expansion of an introduced species (Silva-Rocha et al. 2014), which leads to its wide dispersion across islands. Analysing what was (not) done with this species in other areas, allows us to forecast the trends of this introduced species in the Balearics. In addition, the analysis of what occurs on the Balearics allows us to check those trends and to understand them in an island environment.

The species is native to the Italian Peninsula and Sicily and has been introduced in several places, including islands and coastal areas of the Eastern Adriatic, Iberian Peninsula, Turkey, North Africa and the United States. This species often inhabits human modified areas and uses ornamental plants as refuges, being very prone to accidental transportation by man. This is likely the main pathway for its expansion.

Several ecological and behaviour characteristics make the Italian wall lizard a concerning invader, able to adapt easily to a new environment and to displace native lizard species. Behavioural interference was reported with native lizards such as the Dalmatian wall lizard *Podarcis melisellensis* which has gone extinct in some small islets of the Adriatic Sea after the introduction of the Italian wall lizard by competitive exclusion, namely of basking sites (Nevo et al. 1972). Hybridization between the Italian wall lizard and other *Podarcis* species has been also reported (the Tyrrhenian wall lizard *P. tiliguerta*, the Aeollian wall lizard *P. raffonei* and the Sicilian wall lizard *P. wagleriana*; (Capula 1993, 2002; Capula et al. 2002) and may be particularly harmful for native *Podarcis* populations in small islands. In California, the Italian wall lizard *Italian wall lizard* shows a diet which overlaps with native lizards (the Western fence lizard *Sceloporus occidentalis* and Southern alligator lizard *Elgaria miulticarinata*). It may also have an impact on native lizards due to predation (Kirschbaum and Pauly 2016) and competition (e.g. in Kansas with the great plains skink *Eumeces obsoletus*, Oliverio et al. 2001). Impacts on the invertebrate community are unknown, but likely.

In Menorca, the Italian wall lizard has been present at least since the Middle Ages (Alcover et al. 1981), and nowadays is all over the island. This case exemplifies the kind of population dynamics of this species following its introduction in absence of measures to prevent its spread. A species with rapid adaptation/acclimation, like the Italian wall lizards, can easily expand all over an island. The same probably happened earlier in Sardinia, where the species is now only absent at the highest altitudes.

The extinction of Lilford's wall lizard in Menorca was probably not due to this species but to the earlier introduction of alien predators (Mayol 1985; Pérez-Mellado 1998). However, a possible arrival of the Italian wall lizard to the islets surrounding the main islands represents a high risk to the survival of microinsular populations of Lilfordi's wall lizard, as the replacement of native populations following the arrival of the Italian wall lizard have already been documented in the case of the Dalmatian wall lizard in Adriatic islets (Nevo et al. 1972). The Italian Wall lizard has already reached Ses Mones, one islet off-Menorca where Lilfordi's wall lizard is still present (Speybroeck et al. 2010; van den Berg and Zawadzki 2010).

Thus, preventive measures are a priority over other actions to avoid translocations of the Italian wall lizard from Menorca to surrounding islets, where endemic Lilfordi's wall lizard is present. This could be implemented by inspections of cargo and boats, and a campaign of public awareness for both islanders and tourists.

5.4 Ibiza and Formentera: When Social Perception Helps Conservation

The Pityusic islands, Ibiza and Formentera, remained less affected by introductions until the beginning of the twenty-first century. Because of this, the recent invasion process still can be seen in progress. Therefore, these two islands offer the opportunity to study the first stages of the invasion process as well as the effectiveness of conservation measures adopted in an appropriate time frame, i.e. soon after the introduction, with the involvement of local people.

At some point in the Pleistocene, the fauna of the Pityusic Islands was affected by a crucial and determining circumstance within the Balearic Archipelago: a massive extinction happened (Bailon et al. 2010), with no correspondence on the rest of the Mediterranean Islands (Alcover and McMinn 1993). There is only evidence of two terrestrial survivors, lizards and snails, which used to live in rock fissures. This big extinction might have been caused by a catastrophic event, such as a volcanic process—for instance, the Columbretes Archipelago, 100 km to the northwest of Ibiza had volcanic activity until 300,000 years ago. Later, during Pleistocene glaciations, as a consequence of sea level regression Ibiza and Formentera formed a single large island of more than 700 km^2, the biggest island in the Mediterranean without terrestrial mammals. During that period, paleontological records show that

the number of bird species inhabiting these two islands was rather high, since they are capable of overseas colonization and they had little competition for resources (i.e. food) and supposedly little predation pressure. Additionally, fossil raptor pellets show a large number of lizards, as well as fish (Alcover and McMinn 1993).

5.4.1 Human and Reptile Invasions

When humans arrived for the first time in the Pityusic Islands, around the end of the third millennium BCE, their dietary options would have been similar to those first human settlers found in the Polynesian islands; essentially terrestrial and sea birds, fishes, and sea mollusks. Lizards and terrestrial snails were likely too small to constitute a food resource. Hence, the existing fauna provided poor resources for sustaining a human population (Alcover and McMinn 1993).

Initially, humans brought only the Moorish Gecko (Rato et al. 2010; Pinya and Carretero 2011), the Mediterranean house gecko (Rato et al. 2010; Pinya and Carretero 2011) and the spur-thighed tortoise (Mateo et al. 2011) to the Pityusic islands. Remarkably no other reptiles, particularly no snakes, were introduced in the islands in that period (Pinya and Carretero 2011; Mateo 2015). The Phoenician newcomers ruled the entire island, placing it under the protection of the Canaanite god Bes (Mateo and Ayllón 2012). He was represented with a snake on one hand and a knife on the other, since he protected the family and the home from any evil, especially venomous snakes (Guirand 1960; Fig. 5.3). Consequently, Ibiza became the Bes' Island, its name probably coming from there (Ebusus; Mateo 2015). Almost all the coins minted in Ibiza during this Punic period showed the image of the snake-killer god (Fernández 1975; Fig. 5.3). There is a similar case: according to the tradition of the 4th century (CE), the absence of snakes in Ireland—an animal associated to the devil by Christianity—is attributed to the protection of Saint Patrick.

This aversion towards snakes and their absence on the island was adopted as an identity symbol by the Ibizan inhabitants. In contrast, on those Mediterranean locations where snakes were common and therefore considered as beneficial or neutral, their peoples worshiped gods related to snakes (e.g. Aesculapius, Astarté, Isis, Mitra; Fernández 1975; Velázquez Brieva 2007). Transport of snakes among those places was something usual and a high number of acclimatization and some naturalizations (i.e. species were able to reproduce) took place, some of them lasting until our days in most of the large and medium sized Mediterranean islands (Mateo et al. 2011).

In the 2nd century BCE, when Carthage was defeated, the Ibizan population surrendered to the Romans. They were able to keep the Canaanite dialect Punic, and the worship of the god Bes. Later, in the first century CE, when Phoenicians and Romans still coexisted unmixed in Ibiza, two Latin authors wrote about the island and the mysterious lack of snakes. The geographer Pomponius Mela, in his work *De Chorographia* (Mela, around 43 D.A.), stated:

Fig. 5.3 Coins and Bas-relief with god Bes holding the snake and the knife. Clapboard from the Ptolemaic necropolis of Saqqara (3rd century BCE). *Source* Allard Pierson Museum, Amsterdam

> (…) (Ebusus) lacks harmful or wild animals, to the point that it does not breed them nor tolerate those brought there. In front of it there is the Colubraria, that comes to my mind because, being very abundant in many malefic genus of snakes, it is completely uninhabitable; however, if someone enters a place previously surrounded by Ebusitan soil, it becomes a pleasant place without danger, because those same snakes that otherwise attack all they find so often, they flee away frightened by the appearance of the dust.

Thirty years later, Pliny the Elder, naturalist and historian, probably copying the previous author, included a similar reference in his work *Naturalis Historia* (Plinius the Elder, 77):

The soil of Ebusus banishes snakes, that from Colubraria begets them and it is very harmful for everyone, unless one brings with himself Ebusitan soil; ...

Both Latin authors assigned a magical character to the unusual absence of ophidians, as the Pityusic Islands were the largest Mediterranean Islands without snakes. By saying this, they were indirectly suggesting the existence of Ibizan soil trade to the city of Rome, as an element with occulted properties (Salazar de Mendonza 1770).

If we compare the number of acclimated species in Ibiza and Formentera before 1975 with other Mediterranean Islands, such as Mallorca or Menorca (Mateo et al.

2011), the Pityusic Islands have suffered much less historical introductions than the rest. It was only at the beginning of the 21st century that three snake species were introduced in Ibiza and Formentera. The change in agricultural practices occurred during this period may have indirectly prepared the ground for such introductions. After Spain became a member of the European Union, in 1986, the more competitive market forced Spanish farmers to transform their traditional agriculture into a mechanized one. Hence, between 1996 and 2005, more than 900,000 olive trees were ripped out ending up as firewood or used for gardening (Fortuny Santos 2002) in order to gain more agricultural fields. The massive trade of these olive trees between the south of the Iberian Peninsula and the Pityusic Islands provoked the first introduction of snakes in these islands.

The Montpellier snake was introduced to Ibiza, but it has not been sighted since 2010, and we therefore presume it did not establish and disappeared from the island.

The Ladder snake has a low capture rate in Ibiza, but is the most abundant snake in Formentera, having invaded around 350 ha of the island by 2016 (4.2% of the territory; *unpub*. data of the Balearic Government).

The Horseshoe whip snake was introduced to Ibiza and to Formentera, but seems to have disappeared from the latter, given that not a single specimen was captured during 2016. It is the most widespread in Ibiza, increasing the occupancy area quickly −148 km^2 occupied by the species by 2015 (27% of the island area).

Even though not all the traits of the natural history of the last two introduced snakes have been studied, preliminary analysis and observations indicate that both have successfully naturalized.

5.4.2 Impacts of Snake Introductions on Biodiversity

Snakes are efficient predators, and commonly absent or poorly represented in island native fauna. Therefore, their introduction on islands often dramatically impacts on the native fauna (Rodda et al. 1996). The only terrestrial vertebrate endemic to the Pityusic Islands is seriously endangered by these alien snakes.

Information on prey type and size consumed by alien predators is a key to our understanding of the success of invasive species (Herrel et al. 2008), and helps in evaluating the threat to the native organisms (Salo et al. 2007). The source populations of both the horseshoe whip snake and the ladder snake are well studied, and we compared body size, diet and reproduction between source and invasive populations.

The horseshoe whip snake in Ibiza has shifted its diet towards lizards, with the native Ibiza wall lizard, representing 55.4% of the observed prey (Hinckley et al. 2017), whilst in the diet of horseshoe whip snake in the south of the Iberian Peninsula (the source area of introduced populations) lizards represent only 24.2% of prey items (Pleguezuelos and Moreno 1990). Moreover, the high body condition (mass related to length) and the larger body size of individuals found in Ibiza offers compelling proof of the good ecological conditions experienced by the horseshoe

whip snake on this island. Remarkably, the record for the maximum body length and weight for the species in the Iberian-Balearic region (1830 mm and 1440 g) was found in Ibiza, surpassing those previously described by 105% and 213%, respectively (Hinckley et al. 2017). This evidence suggests that this species grows longer and more robust in Ibiza than in its continental range (see Table 1 in Gil and Pleguezuelos 2001). This shows a rapid functional response (likely phenotypic plasticity) of this snake's size and shape to the new biotic and abiotic situation on the island.

A similar dietary shift to the one observed in the horseshoe whip snake in Ibiza is probably occurring with the ladder snake in Formentera. Continental populations of this latter species show an endotherm-based diet (i.e. small mammals and birds) with a negligible percentage of reptiles (Pleguezuelos et al. 2007). In contrast, the preliminary study of the diet in Formentera specimens shows that more than half of their prey is constituted by the endemic Ibiza wall lizard (Samuel Pinya, pers. com.).

The secondary prey type of these ladder snakes in frequency, and primary in biomass, are micromammals, which are aliens in Ibiza, abundant, and of no conservation concern. However, these alien prey of early arrival to the island provide food resources for later aliens like the horseshoe whip snake, in a process of invasional meltdown (Simberloff and Von Holle 1999). This situation will probably have negative repercussions on the Ibiza wall lizard by a hyperpredation process (Bull and Courchamp 2009; Hinckley et al. 2017).

Snakes may also be influencing the diet of other insular, native predators, with shared prey, such as the Barn owl (*Tyto alba*). Reproduction may be changing also to be more frequent (Shine 2003), with larger clutch size (Seigel and Ford 1987), larger hatchlings (Shine 1981) or earlier maturing individuals (Parker and Plummer 1987).

Populations of Ibiza wall lizard from islets surrounding Ibiza and Formentera are also potentially menaced by the arrival of snakes. A total of 39 islets hold 23 endemic subspecies (Salvador 2015; but see Rodríguez et al. 2013). Regardless their taxonomic status, most of these microinsular populations represent unique adaptations resulting from local ecological conditions and isolation, with very small sizes and undergoing strong demographic fluctuations. The arrival of snakes in these islets may produce a catastrophic and irrecoverable event for lizard populations as they would be the only available prey. On the other hand, the probability of such arrivals are not so unlikely as these islets are very close to the main islands' coast (1.17 km on average); six snakes have been observed swimming in the sea, and a snake skin was already found in one islet (unpub. data of the authors).

Besides Ibiza wall lizard, which is listed as Near Threatened (NT) (IUCN categories and criteria applied to regional scale of the Balearic Islands; Viada et al. 2006), there are 57 native birds that nest on the Pityusic islands whose adults or pulls are within the prey size range of these snakes. Among them, there are five species listed as Vulnerable (the common quail *Coturnix coturnix*, the little ringed plover *Charadrius dubius*, the Kentish plover *C. alexandrinus*, the European turtle dove *Streptopelia turtur* and the Woodchat shrike *Lanius senator*), two as

Endangered (the Cory's shearwater *Calonectris diomedea* and the barn owl *Tyto alba*), one as Critically Endangered (the Balearic shearwater *Puffinus mauritanicus*), and six as Near Threatened. Two breeding birds are Balearic endemics: the Balearic Shearwater, that nests in surrounding islets of Ibiza and in the main island of Formentera, and the Balearic Warbler (*Sylvia balearica*), occurring in both islands.

5.4.3 Impacts of Snake Invasions on Humans

Native species of Ibiza have a great significance not only from a biological point of view, but also for the inhabitants of this island. The endemic Ibiza Wall Lizard is considered a symbol of the Pityusic Islands (Dappen et al. 2013). Ibizan and Formenteran people are proud of their lizards and their images are present everywhere: on clothes, jewelry, lizard-shaped stickers on the cars, in decorative elements such as lamps, wall figures, mirrors, etc. Magazines and pamphlets frequently exhibit the lizard, and several companies use it in their logos. It is used as a tourist attraction too, and any tourist information about the island will have the symbol on it (Fig. 5.4a and b).

What does this symbol mean? Why is it so easy to relate Ibiza and Formentera with it, instead of any other animal or plant? To answer these questions, we have to remember that the first humans that arrived to the Pityusic Islands found only lizards within the community of ground dwelling vertebrates of these islands (Bover et al. 2008). The sole terrestrial vertebrate on such area was this attractive and harmless reptile. It is the only vertebrate exclusive to Ibiza and Formentera. Different civilizations introduced other vertebrates like genets (*Genetta genetta*)

Fig. 5.4 Different examples of the presence of Ibiza wall lizard, *Podarcis pityusensis,* in the everyday cultural life of Ibiza and Formentera. Photos by E. Montes

or hedgehogs (*Erinaceus europaeus*). In a way, the lizard symbolizes the naiveté and the purity of the original Ibiza and Formentera, as well as the harmless and innocuous fauna to humans that every visitor would find there. It is the best advertising anyone can make for an idyllic place like the Pityusic Islands. As a consequence, the invasive snakes are destroying the safety sense that secularly characterized Ibiza and Formentera, islands with no dangerous species until now. In fact, rural hotels are concerned and claim that the snakes are jeopardizing their business, as they have clients that come to Ibiza precisely because no dangerous animals can be found there.

Pityusic society is also having a very strong response to the presence of snakes. They are not used to snakes so their observation causes strong social alarm. Every spring and autumn, with the increasing activity of snakes, the island government receives hundreds of calls from frightened people that have seen a snake in their properties or just want to warn the authorities and give information, eager to collaborate in solving the problem. Rural inhabitants from the high-density snake zones tell us that they do not see lizards anymore, with a mix of sadness and anger. And maybe that is the main reason why they are so eager to help; the majority of these neighbors volunteer to take care of snake-traps (see below) in order to help control the invasion. The embrace of the endemic lizards as a symbol by the locals may be the key to its conservation, and the control of snakes (Bowen-Jones and Entwistle 2002).

5.4.4 Science and Management: An Inevitable Cross-Road

Eleven years after the first report of snake introduction, during 2014 and 2015, the Ibiza Island Council (island government) carried out a pilot project to control snake populations under the scientific advice and participation of the Spanish Herpetological Society (AHE). This first approach gave useful information about distribution, density, and the methods that best worked to eradicate the snakes. The main goals of this project consisted of promoting public awareness (Boudjelas 2009) and testing methods to capture snakes. Pamphlets in three different languages were distributed among the community; informative meetings were held for neighbors, as well as formative sessions for authority agents who had to deal with emergency calls related to snakes. A unified protocol was agreed between all the authority agents.

Among the capture methods tested in 2014 (plywood cover boards, PVC double funnel traps, and box-traps—baited and unbaited), lab mice baited box-traps gave the best results. Therefore, in the second year of the project, the Ibiza Island Council arranged the manufacturing of wooden box-traps, according to their guidance, with the Arts School (Secondary Level) of Ibiza. A total of 121 snakes were captured in 2015 by 200 box traps (Table 5.1, Fig. 5.5). Trained dogs were also used and proved quite effective in detecting snakes, but not very practical in the study area,

Fig. 5.5 Wooden box trap for capturing snakes on Ibiza Island. Note the access hatch on the top, a funnel in the lateral, and the small cage for restraining the lab mouse within the snake trap. Photo by E. Ayllón

Table 5.1 Individuals of the Horseshoe Whip Snake, *Hemorrhois hippocrepis*, and the Ladder Snake, *Rhinechis scalaris*, captured in Ibiza Island during the period 2011–2016, and invaded area by the Horseshoe whip snake according to years (Minimum Convex Polygon method, from the data in Fig. 5.6)

Year	Individuals		Area (km^2)
	Horseshoe whip snake	Ladder snake	Horseshoe whip snake
2011	12	7	63.2
2012	15	5	63.7
2013	38	10	109.4
2014	95	8	96.4
2015	302	10	149.3
2016	317	38	142.8
Total	779	78	

which is covered by hundreds of kilometers of stone fences where the snakes were difficult to catch (Table 5.1).

With the information gathered from the different trapping methods, we mapped the area covered by snakes each year, to evaluate the progression of the invasion.

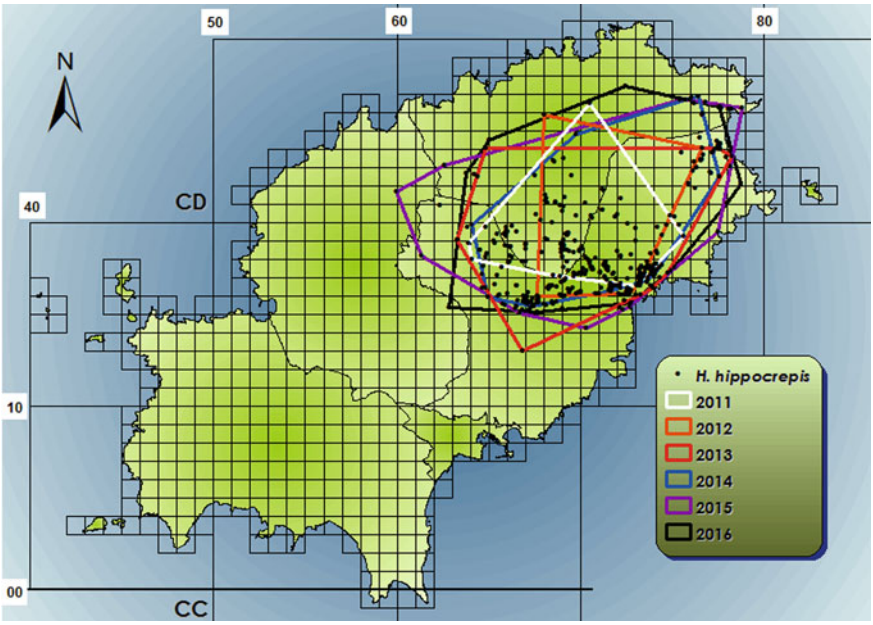

Fig. 5.6 Range of the invasive Horseshoe Whip Snake, *Hemorrhois hippocrepis*, in Ibiza Island in the period 2011–2016 (Minimum Convex Polygon method). Yearly sample size and area in Table 5.1. Figure prepared by Pedro Luis Hernandez -Sastre

As observed (Table 5.1, Fig. 5.6), the invasive population covers the northeastern sector of the island of Ibiza and the area increased in 2015, but stabilized after the intense trapping campaign of 2015–2016. These results have to be taken with caution, given that records increased inter-annually not only with the growth of the snake population within the island, but with the awareness of people and the stronger and more effective efforts to capture them (Table 5.1).

Fortunately, it seems the invasive snakes still show a contagious distribution pattern nearby the nurseries that acted as the introduction way, which is typical of the first stage of biological invasions (Williamson 1996). The apparent fast expansion observed is expected if we take into account that two of the main abiotic factors explaining the range of the reptiles, the mean annual temperature and average yearly rainfall of Ibiza, perfectly fit within the range of mean annual temperature and rainfall in their source range (Feriche 2015; Silva-Rocha et al. 2015). It is evident that the island is ideal for the spatial and demographic expansion of the species, and climate conditions will become even more favorable if predictions for climate change in this century are confirmed.

During 2015 we frequently observed scales and feces in empty traps, meaning that some snakes were able to escape. In 2016, when the Balearic Government took the control of the project, the traps were upgraded eliminating the funnels and installing just a hole of approximately 3 cm with a tilting door, only opening

towards the inside of the box. This resulted in a very high increased rate of captures (2.2 captures/day/100 traps in 2015 vs. 10.5 captures/day/100 traps in 2016). The maximum result found elsewhere in trapping invasive snakes is 2.13 (Rodda et al. 1999).

Regarding the collaboration with the local community, which has given the most important contribution to the total snake captures, 400 new traps were made in 2016 by the Ibiza Island Council and two town councils (Santa Eulària des Riu, and Sant Joan de Labritja) and were sold for a subsidized price to any citizen who was willing to take care of them, after filling out and signing a commitment. This measure comes from the people themselves, since there have been repeated requests by the community for this type of action. It has been extended and more traps are being ordered, given that the demand is not falling.

These actions were not free of conflict, though: due to the lack of staff, collaborators have to sacrifice the snakes without professional guidance. This situation leads to two complex matters; animal cruelty and government responsibility regarding eradication of invasive species. Moreover, following the current procedure, researchers do not have the control on the distribution and sampling effort of traps. Common people do not know the techniques to manipulate snakes nor the regulation about what they can do or what they are not allowed to do with them. Putting such a responsibility on people's hands is risky, as they can spread the snakes by accident. Notwithstanding these potential problems, we encourage involving citizenship in invasive animal eradication programs (Boudjelas 2009; Gallo and Waitt 2011). Public participation in invasive alien species management is important, from ethical, legal, and practical standpoints (Boudjelas 2009).

From now on, the project should grow not only in staff but also in trap numbers and spread, as the priority should be avoiding the expansion of the snakes throughout the territory of the Pityusic islands. That can be done by placing traps along the edge of the currently invaded zone, before the snakes can invade further and affect populations of the endemic Ibiza Wall Lizard in snake-free zones (Grice 2009; Melero et al. 2010). The current ground perimeter of the invaded area is approximately 36 km (Fig. 5.6). Estimating one trap every 25–30 m (Rodda et al. 1999), we will require around 1400 traps to be placed around the perimeter of the invaded area just to control the expansion, plus 200–400 more to capture and reduce the population in the high-density zone of the core areas (close to the olive tree nurseries). The effectiveness of traps increases in combination with drift fences that intercept and guide snakes towards the traps (Fitzgerald 2012). However, that procedure represents a time and economic expense even greater than the cost of the traps; that is why the abundant rock walls on the island are being used as drift fences.

The study of the natural history of invasive snakes ought to be included in the project, since it may help in understanding the biological processes that make them successful and, therefore, in fighting them more accurately (Sakai et al. 2001; Stohlgren and Jarnevich 2009). This is a typical case of island invasion: a snake-free island, poorly populated in non-flying vertebrate fauna, where invasive snakes thrive. Numerous animals have been already studied after their inclusion as vouchers in scientific collections (Hinckley et al. 2017).

5.5 Conclusion

The Balearic Islands represent another striking example of the negative effect of human-mediated species introductions on native biota as well as on local people. Here, we presented two case studies which reflect two different attitudes regarding biological invasions. First, the case of the Italian wall lizard which represents the outcomes of a negligent attitude and taught us that if we ignore the problem, it will not solve itself but will simply get worse. In this particular case, a potentially invasive species was not ever considered to be dangerous in the Balearics. As a result, it spread throughout the islands where it was introduced, threatening the native biota, namely the endemic lizards which local people care about. The second case study reflects an active attitude which resulted in a strong involvement and a close collaboration with governments and general public to face the spread of invasive species, especially of introduced snakes. A project was created to understand how the invasion is progressing and how to deal with it.

Preliminary results on snakes' density control are encouraging, indicating the effectiveness of this collaboration, but we are only at the beginning of a long-term action which also includes preventing new introductions and monitoring the status of native species populations.

While capture campaigns may allow controlling the population size and spread of introduced snakes, a major priority for the conservation of native biota is to prevent new species from arriving on the island (Wittenberg and Cock 2001). The importation of big and old trees with cozy holes which can serve as shelters for alien species need to be limited, at least during critical periods (hibernation and egg-laying period, Shine et al. 1997). That limitation would leave a safe frame of two and a half months during spring time (April–June). Moreover, it is recommended that trees entering the Pityusic Islands within those periods are kept in quarantine at the entry point (any of the two Ibiza harbors); there are some who claim to have seen a snake falling from a moving trailer full of olive trees in spring. One-month quarantine in a walled enclosure (a minimum of 1.5 m height) with a half a dozen baited box-traps, should be enough to draw every hidden species in the cargo. The benefits from selling big olive trees are so high that the economic repercussions of such measures would be easily supported by the sellers, if a regulation obliged them (McNeely 2001).

Social collaboration, turning an eradication program into a publicly accepted project, has been shown to be vital for the project. It is strongly recommended to keep that work-line involving the public through a studied strategy that allows, on one hand, that Ibizan people feel they are working for their own island and symbol, contributing with their participation to achieve the maximum number of captures throughout the island. On the other hand, means the collaborators become a useful tool to technically improve the project, facilitating the collection of data in a programmed and organized way.

After all, the main concern of this invasion is, without any doubt, the same for everybody: the serious threat to the endemic fauna. Therefore, monitoring endemic

populations is also crucial to determine whether and to what extent snake predation on lizards results on demographic impacts on lizard populations.

In conclusion, Balearic Islands exemplify an archipelago where aliens conquered the main islands and that has implications not only for biodiversity but also for the communities present. The future will determine if alien species will continue to conquer, or if the joint effort of science, policy and social participation will mitigate this invasion.

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