Alien herpetofauna pathways, invasions, current management practices and control method ethics: A review of some significant problems in the USA

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ABSTRACT - Regardless of nomenclature, non-indigenous, exotic, alien herpetofauna can cause dramatic changes in the ecosystems in to which they are introduced. Through human globalisation, species easily cross international boundaries (via the pet trade, hidden in cargo and as biological pest control) and make their home in new regions and waterways. Exotic amphibians and reptiles are no exception and have been introduced into the United States. Some have become invasive species, which have had a substantial negative impact on the regions economy, their new environment and resident species. Currently, the main management tools used for handling invasive herpetofauna issues in the U.S. have been prevention, education, control and eradication measures. However, there seems to be gaps in the literature regarding the use of ethics in the control and eradication methods with regard to invasive reptiles and amphibians, which should be given consideration in future management efforts. This review is not comprehensive, but rather a brief summary of the most widely recognised U.S. alien amphibian and reptile pathways into the U.S., the transition of alien herpetofauna to invasive species, current invasive management efforts, a discussion of the ethics of invasive species management and how best to move forward with research and conservation efforts. This review focuses on the U.S. states of Florida and Hawaii, and the U.S. territories of Guam and Puerto Rico, which is mainly due to much of the available research focusing on these regions due to the high instance of invasive herpetofauna. However, California, Georgia, Louisiana, New York, Ohio and Texas are also mentioned. The alien species most commonly referenced in this review are the brown tree snake (*Boiga irregularis*), bullfrog (*Lithobates catesbeianus*), Burmese python (*Python bivitattus*), Cuban brown anole (*Anolis sagrei*), Cuban treefrog (*Osteopilus septentrionalis*), European wall lizard (*Podarcis muralis*), green iguana (*Iguana iguana*), Italian wall lizard (*Podarcis sicula campestris*), Mediterranean house gecko (*Hemidactylus turcicus*), Nile monitor (*Varanus niloticus*), northern curlytail lizard (*Leiocephalus carinatus armouri*) and red-eared slider (*Trachemys scripta elegans*).

INTRODUCTION

Of the more than 500,000 estimated alien species that have been introduced into new ecosystems worldwide, there are more than 50,000 introduced species in the United States (Pimentel, 2005). Alien species provide an estimated value of US $800 billion per year and also can cause US $120 billion in damages and control measures, not to mention the ecological costs, on which are hard to put a price (Pimentel, 2005). Through various channels, alien amphibians and reptiles make their way into the United States. Some of those that enter the U.S. establish themselves in the native ecosystems and some of those that are established become invasive species. There are 56 non-native species of amphibians and reptiles known to occur in Florida and 33 non-native species of amphibians and reptiles known to occur in Hawaii - the two states most affected by invasive herpetofauna species (Krysko, 2011; Pitt, 2005; and Engemen, 2011). However, it is important to note that exotic reptiles and amphibians can be found in numerous other states and have established populations in some of those states.

Although the number of introduced species of herpetofauna is relatively low when compared with the overall number of introduced species, their impacts on their new ecosystems and economic costs on the states left with managing them are substantial. Only human-caused habitat destruction is more harmful than introduced species in respect to negative effects on native species and ecosystems (Enge et al., 2004).

This review does not cover every species of exotic amphibian and reptile in the U.S., but highlights several widely recognised species, their introduction pathways into the U.S., the means through which some have become invasive, current management practices and a discussion on the ecological ethics of managing invasives and the best way to move forward with regard to future management. It should be noted in this review that "alien species," "exotic species", "non-native species" and "non-indigenous species" are all synonyms and interchangeable.

Alien Herpetofauna Pathways into the U.S.

Human movements around the globe have easily allowed for the transfer of reptiles and amphibians from their native locales to new lands, farther and faster than ever before.

Figure 1. The brown tree snake (*B. irregularis*) is native to Australia, Indonesia and Papua New Guinea and regarded as one of the world's most destructive invasive species. It easily escaped notice in the commercial and military cargo, moving to and from the U.S. territory of Guam shortly after World War II. *B. irregularis* subsequently decimated 18 of Guam's native species, including birds, bats and lizards (Pimentel et al., 1999; Lowe, et al., 2000; Pitt, 2005; Rodda & Savidge, 2007). Photo Credit: Tom Charlton.

Figure 2. The American bullfrog *(L. catesbeianus*) has a natural range over a vast portion of eastern North America, from the Mississippi River and Great Lakes all the way east to the Atlantic Ocean, but is still considered alien and often invasive when present in non-native American habitat (Adams & Pearl, 2007). The IUCN lists the American bullfrog on its list of "100 of the World's Worst Invasive Alien Species" (Lowe, et al., 2000). Photo Credit: Michael Gadomski.

Global transportation networks have grown and thus goods and people are finding their way to even the most remote terrestrial and marine locations, therefore increasing homogeneity of species around the world and reducing biodiversity (Pitt, 2005). Exotic amphibians and reptiles are no exception and have been introduced into the United States both accidentally and intentionally.

Accidental and intentional introductions

Non-indigenous reptiles and amphibians have entered the United States accidentally as "contaminants" of trade via airports, seaports, roads, railways, canals, and even pipelines (Hulme, 2009). Invasive brown tree snakes (*Boiga irregularis*, Fig. 1), coquí frogs, geckos, and blind snakes travel around the globe as stowaways in air and sea cargo before finding their new home in the States (Pitt, 2005). While *B. irregularis* hide in the cargo of ships, coquí frogs, geckos, and blind snakes (*Ramphotyphlops braminus*) hide amongst agricultural produce (Pitt, 2005). Native to Australia, Indonesia and Papua New Guinea, the shy and nocturnal *B. irregularis*, known as one of the world's most destructive invasive species, easily escaped notice in the commercial and military cargo, which was coming to and from the U.S. territory of Guam shortly after World War II (Pimentel et al., 1999; Lowe, et al., 2000; Pitt, 2005; Rodda and Savidge, 2007).

Guam may have one of the world's most invasive reptiles, but Florida has the largest number of established non-native amphibian and reptile species in the United States (Enge et al., 2004). The United States accounts for more than 80% of the world's total trade in reptiles, many of which enter through Florida (Simmons and Burridge, 2002). Florida is especially susceptible to the establishment of alien herpetofauna and has more exotic reptiles and amphibians species than any other state, due to its major ports, US $300 million captive wildlife industry, subtropical climate, reduced native species, habitat destruction and hurricanes - the latter facilitate the release of captive animals (Enge et al., 2004; Pitt, 2005; Hardin, 2007; Engeman et al., 2011; Krysko, 2011). The main port of entry for exotic herpetofauna entering the U.S., either accidentally or intentionally, is Miami, Florida (Hardin, 2007; Pitt, 2005). In 2005 and 2006, 3,982 Florida captive wildlife facilities were permitted to have non-native species (Hardin, 2007). During the years 1989 through 2000, U.S. Fish and Wildlife Service Law Enforcement Management Information System (LEMIS) records indicate that approximately 6,067 shipments containing live nonerycine boas, pythons and relatives entered the United States, representing 404,177 individuals, 17 genera, and 40 species (Reed, 2005).

With so many exotic species entering the U.S. it is not surprising that some find their way into the wild. Due to this, along with other influencing factors, pythons and chameleons, have been introduced both accidentally and intentionally into Florida (Hardin, 2007; Pitt, 2005). They have been imported for the pet trade and either escaped or were released by owners who no longer wanted them (Pitt, 2005). Intentional releases are also responsible for introducing alien species including bullfrogs, *Lithobates catesbeianus* (= *Rana catesbeiana*, Fig. 2), and various species of turtle released as a food source, cane toads (*Rhinella* (= *Bufo*) *marina*) and poison dart frogs (*Phillobates* sp.) for biological control to combat pest species and veiled chameleons (*Chamaeleo calyptratus*) for aesthetic reasons (Pitt, 2005; Hulme, 2009).

Native introductions

Unlike the other species discussed in this review, the red-eared slider turtle (*Trachemys scripta elegans*) and the bullfrog (*L. catesbeianus*) although native to the U.S., are considered invasive in non-native parts of their range.

Figure 3. Burmese pythons (*P. bivittatus*) are usually difficult to locate, because of their camouflage and the marshy, difficult-to-navigate habitat of the Everglades where they have become established (Engeman et al., 2011). Photo Credit: Susan Jewell, U.S. Fish & Wildlife Service/Wikimedia Commons.

Figure 4. European wall lizard (*P. muralis*), a native to southern and central Europe and northwestern Asia Minor, has established a population of several thousand in urban areas within Cincinnati, Ohio. The population stems from just two introduced lizards from Italy in 1951 and its dispersal has since followed the railroad tracks (Hedeen & Hedeen, 1999). Photo Credit: Lucarelli/Wikimedia Commons.

T. scripta elegans, indigenous to the U.S. is the most widely invasive reptile species in the world due to introductions from the pet trade and food markets (Thomson et al., 2010). The native range of *L. catesbeianus* covers a vast portion of eastern North America, from the Mississippi River and Great Lakes east to the Atlantic Ocean, but is still considered alien and often invasive when present in non-native American habitat (Adams & Pearl, 2007).

Pet trade introductions

Unintended alien species introductions from other countries due to the pet trade include the Burmese python (*Python bivittatus*, formerly *Python molurus bivittatus*; Fig. 3), Nile monitor (*Varanus niloticus*) and green iguana (*Iguana iguana*). Since the 1970s, escaped and released pet *P. bivittatus* have been present in southern Florida and subsequently making their way into newspaper headlines (Engeman et al., 2011). Additionally, such natural and destructive events as Hurricane Andrew may have unintentionally released more individuals into the wild (Engeman et al., 2011).

Although, not an ideal pet, given its large size and its skittish disposition the monitor lizard *V. niloticus* is the second-most commonly sold African monitor species in the U.S. and can retail for as little as US $10 (Enge et al., 2004). Due to escapes, intentional release by owners who find them to be too much to handle or illegal release by reptile dealers trying to establish a local breeding population from which they plan to capture and sell them, *V. niloticus* has established populations in Florida (Enge et al., 2004).

Native to Central and South America and the Caribbean, *I. iguana* is also a popular pet of reptile enthusiasts. When owners are no longer interested in keeping them, they are released into the wild and, like many invasive species, populations have grown rapidly in the U.S. (Falcón et al., 2013). Although it is legal to own *I. iguana* in Florida and Puerto Rico (but illegal to import them into Puerto Rico), it is illegal to release them into the wild (Falcón et al., 2013). Hawaii, where *I. iguana* have also become established and pose a risk to endangered hibiscus and Kokia, is a different story and possessing *I. iguana* can cost up to US $200,000 in fines and 30 years in prison (Falcón et al., 2013).

Another well-documented pet trade introduction is the European wall lizard (*Podarcis muralis*, Fig. 4), a native to southern and central Europe and northwestern Asia Minor. Unlike the previously mentioned species, this species does not require a tropical habitat to thrive and has established a population of several thousand in urban areas within Cincinnati, Ohio (Hedeen and Hedeen, 1999). The population apparently stems from just two introduced lizards from Italy in 1951(Hedeen and Hedeen, 1999). The lizard's population dispersal followed the railroad tracks, due to its preference for splintered wooden ties in railroads in the human-modified habitats of its native range (Hedeen and Hedeen, 1999).

The Italian wall lizard (*Podarcis sicula campestris*, Fig. 5) was accidentally introduced to Long Island, New York due to a car accident around 1967, which released several individuals intended for a pet store (Mendyk, 2007). The city's municipal yard with its paved areas was perfect habitat for *P. s. campestris* to colonize and since then, the species has dispersed and established several populations (Mendyk, 2007). Long Island's railroads, power-lines and drainage ditches provide connected, unobstructed prime habitat for the lizards to disperse freely, including into New York City (Mendyk, 2007). Without any native lizards present in the area, *P. s. campestris* does not face direct competition for food or habitat and will likely continue to spread throughout Long Island and New York City (Mendyk, 2007). Currently, there is no evidence implicating *P. s. campestris* with environmental damage,

Figure 5. Italian wall lizard (*P. sicula*) was accidentally introduced to Long Island, New York due to a car accident around 1967, which released several individuals intended for a pet store. Long Island's railroads, power-lines and drainage ditches provide connected, unobstructed prime habitat for the lizards enabling colonization into other areas, including into New York City (Mendyk, 2007). Photo Credit: Richard Bartz/Wikimedia Commons.

Figure 6. Northern curly-tail lizard (*L. carinatus armouri*) in Morikami Gardens, Delray Beach, Florida, USA. An endemic to the islands of Little Bahama Bank, the current established population stemmed from just 20 released pairs on Palm Beach in the 1940s (Meshaka et al., 2005). Photo Credit: Ianaré Sévi/ Wikimedia Commons.

but much remains to be learned about their ecology in the U.S. (Mendyk, 2007).

Regardless of where alien herpetofauna end up in the U.S., the invasion pathways have opened up previously unavailable corridors through which thousands of alien reptilian and amphibian species enter the U.S. daily. In addition to exotic herpetofauna, the channels allow introduction of parasites and pathogens that may accompany exotic herpetofauna. It is important to understand the access points and pathways available to non-indigenous herpetofauna, since some have been known to become invasive through predation, competition and disease. Once the pathways by which alien herpetofauna enter the U.S. are fully understood, the better equipped U.S. wildlife managers and conservationists will be to prevent future introductions.

When Alien Herpetofauna Become Invasive

There is a fine line between being an introduced alien species and an invasive species. Just by being present in an ecosystem, alien species naturally will have some sort of effect on native species, whether it is beneficial or harmful, predatory or competitive, but not all will become invasive and most have negligible environmental impacts (Hardin, 2007). The non-indigenous species whose presence is truly damaging to the ecosystem's function, native inhabitants or economy will receive the designation of 'invasive species.' Although Florida and Hawaii have the greatest numbers of invasive herpetofauna in the U.S. with 30 species found in Florida and 12 found in Hawaii, there are at least 53 invasive species of reptiles and amphibians in total in the U.S. (Pimentel et al., 1999; Bergman et al., 2000). During the fiscal years 1990 to 1997, assistance was requested to alleviate damage caused by various exotic reptiles in Arizona, Guam, Louisiana, Maryland, Maine, Minnesota, Missouri, Oklahoma, Puerto Rico, Texas, Utah, and Wisconsin. This included, for example, the mangrove monitor (*Varanus indicus*) in Guam and *B. irregularis* in Hawaii and Guam (Bergman et al., 2000). The International Union for the Conservation of Nature (IUCN) lists *B. irregularis*, *L. catesbeianus*, *O. septentrionalis* and *T. scripta elegans*, which are all invasive in the U.S., on its list of "100 of the World's Worst Invasive Alien Species" (Lowe et al., 2000). Additionally about 42% of the species on the Threatened or Endangered species lists are at risk primarily because of non-indigenous species, which demonstrates the negative implications of invasive species (Pimentel et al., 1999).

Snakes

Invasive species, the same as any species, have specific ecological requirements for survival and propagation. However, successful invasive species tend to be generalists, which can reproduce effectively and abundantly, mature quickly, eat almost anything, tolerate a variety of habitats, be transported easily (either intentionally for the pet or wildlife trade or accidentally as elusive and unseen cargo), and enter a climatically similar ecosystem, which has low species diversity and is stressed by human or natural disturbance (Pitt, 2005; Salinas, 2006). The successful invasion of Guam by *B. irregularis* is due to the fact that it meets most of these criteria and does not have any natural predators on the island (Lowe, et al., 2000). Given the small size and neutral colour of *B. irregularis* and an ability to remain concealed in cargo, boats and aircraft, it poses a threat of invasion to other islands, if serious management efforts are unable to contain it (Lowe, et al., 2000). The areas most at risk are tropical hubs for traffic and trade (Lowe, et al., 2000). In areas where *B. irregularis* has proliferated, it has eliminated all breeding populations of seabirds, 10 of 13 native bird species, 6 of 12 native lizard species, and 2 of 3 bat species (Pimentel et al., 1999;

Figure 7. Brown Anole (*A. sagrei*) a native of Cuba and the Bahamas, is now found in Florida, Georgia, Texas and Hawaii. *A. sagrei* may be responsible for the displacement of native green anoles (*A. carolinensis*) (Gerber, 1991; Echternacht, 1999; Campbell, 2000). Photo Credit: Alberta P./Wikimedia Commons.

Figure 8. Mediterranean house gecko (*H. turcicus*) also found in western India, Somalia, Canary Islands and now throughout the southeastern United States. However, *H. turcicus* is being replaced by introduced competitively superior geckoes - the tropical house gecko (*H. mabouia*) and Indo-Pacific gecko (*H. garnotii*) - in Texas and Florida (Meshaka et al., 2006). Photo Credit: ZooFari/Wikimedia Commons.

Bergman et al, 2000; Lowe, et al., 2000; Wiles et al., 2003; Reed, 2005; Rodda and Savidge, 2007).

Additionally, *B. irregularis* has been responsible for power outages, livestock losses and hospitalized people with its bite (Bergmann et al., 2000). In 1987, a single snake-related power outage cost the power company more than $250,000 and according to a 1996 estimate, snake-related power outages is conservatively $1 million per year (Pimentel et al., 1999). *B. irregularis* accounts for US $12 million in damages and control costs annually (Pimentel, 2005). For all its currently documented negative effects, *B. irregularis* harmful presence may be even greater (Wiles et al., 2003). For example, seed dispersal and pollination carried out by the former residents are now severely reduced (Wiles et al., 2003). It is difficult to know with any certainty what the future holds for these plant species, which can take years to potentially go extinct, but preventing further damage through successful control of *B. irregularis* and protecting native species remain crucial (Wiles et al., 2003; Richardson and Ricciardi, 2013).

There are 315 vouchered records (verified with specimens or photographs) of Burmese pythons (*P. bivittatus*) in Florida, which are native to southern China, Vietnam, Cambodia, Thailand, Laos, Myanmar, Bangladesh, and eastern India (Krysko et al., 2011). *P. bivittatus* have increased dramatically since 2000 and have spread throughout much of southern Florida, including all of Everglades National Park (Krysko et al., 2011; Dorcas, et al., 2012). This large snake consumes mammals and birds, including endangered species, and recent research indicates that severe declines in mammal populations coincide with the expansion of *P. bivittatus* in the Everglades (Dorcas, et al., 2012). Nocturnal road surveys of mammals before 2000 displayed a 99.3% decrease in the frequency of raccoon observations and decreases of 98.9% and 87.5% for opossum and bobcat observations, respectively with no rabbits detected from 2003 to 2011 (Dorcas, et al., 2012). Given that raccoons and bobcats are considered commonly occurring mammals in the National Park, the results do not bode well for species of conservation concern (Dorcas, et al., 2012). However, according to K.G. Smith, there is "presently no evidence for an overall homogenizing effect of non-indigenous amphibians and reptiles in Florida," but this "should not be confused with an absence of the effects of non-indigenous species in Florida" and the chance for future changes (Smith, 2006).

Lizards

Of the established alien reptiles found in Florida, most are lizards (31 species, mostly iguanids and geckos). This compares to a single chelonian, the red-eared slider (*T. scripta elegans*), one crocodilian, the spectacled caiman (*Caiman crocodilus*), and three snakes (Hardin, 2007). Although *I. iguana* is well established and considered a problem species, there is no evidence indicating they are responsible for severe ecological damage and hence are only of minor concern (Hardin, 2007). On the other hand, the Nile monitor (*Varanus niloticus*), Africa's largest lizard and a voracious predator, is cause for great concern (Hardin, 2007).

The presence of *V. niloticus* in southwest Florida potentially threatens a species of special concern, the burrowing owl (*Athene cunicularia*) (Hardin, 2007) and expansion further south could potentially threaten nest sites of already vulnerable species such as the Brown Pelican (*Pelecanus occidentalis*), sea turtles, diamondback terrapins (*Malaclemys terrapin*), and the endangered American crocodile (*Crocodylus acutus*), since it is well known to feed on crocodile eggs in Africa (Enge et al., 2004; Hardin, 2007). However, other species, for example, alligators, may be less impacted, because of their

stable and large populations (Enge et al., 2004). A prolific and generalist predator, *V. niloticus* preys on arthropods, crabs, crayfishes, mussels, gastropods, fishes, anurans, lizards, turtles, snakes, young crocodiles, eggs, birds, small mammals, carrion, and even human food scraps, and hence has the potential to drastically and negatively affect local wildlife through competition for resources (food and habitat) and through increased predation pressures on native species (Enge et al., 2004).

In contrast to the assessment of Hardin (2007), Falcón et al 2013 have indicated that *I. iguana* are invasive in Florida and are considered a nuisance, considering their appetite for garden plants of the native and non-native variety (Falcón et al., 2013). *I. iguana* is present in Hawaii and other Pacific islands and will likely continue to spread, if effective control methods are not implemented (Falcón et al., 2013). They are feeding generalists and capable of severely reducing native plant populations and facilitate seed dispersal of invasive plants (Falcón et al., 2013). Although pet *I. iguana* may carry Salmonella, wild invasive individuals are unlikely to harm humans, but the same cannot be said for the local reptiles, which may contract diseases and parasites (Falcón et al., 2013). In terms of economic costs, other than consuming commercially important plants, *I. iguana* burrows create erosion damage to roads in both Florida and Puerto Rico with estimated repairs costing US $2,480/ha (Falcón et al., 2013).

The curlytail lizard (*Leiocephalus carinatus armouri*, Fig. 6), an endemic to the islands of Little Bahama Bank, has been established in Florida's southeastern coast since the 1940s, when 20 pairs were released on Palm Beach (Meshaka et al., 2005). It is now also established on sites in Florida's southwestern coast (Meshaka et al., 2005). *L. c. armouri* prefers sunny, rocky conditions that are abundant in developed areas along Florida's coastline (Meshaka et al., 2005). Where *L. c. armouri* populations are close to those of brown anoles (*Anolis sagrei*, Fig. 7), the latter have declined (Meshaka et al., 2005). Since *Anolis sagrei* is also non-native in the U.S., predation by *L. c. armouri* has acted as an unintended biological control. However, native lizards are also at risk of displacement where *L. c. armouri* is established. Those at risk include the green anole (*A. carolinensis*), six-lined racerunner (*Cnemidophorus sexlineat sexlineatus*), southeastern five-lined skink (*Eumeces inexpectatus*) and the Florida scrub lizard (*Sceloporus woodi*) (Meshaka et al., 2005).

The introduced brown anole (*A. sagrei*), a native of Cuba and the Bahamas, also may be responsible for the displacement of native green anoles (*A. carolinensis*) (Gerber, 1991; Echternacht, 1999; Campbell, 2000). The species was first observed in the Florida Keys in 1887, but did not arrive in mainland Florida until the 1940s (Garman, 1887; Oliver, 1950; Bell 1953). *A. sagrei* are now established and expanding in Florida, preferring urbanised areas, including along highways, campgrounds and hotels (Campbell 1996). The populations have spread via cars and potted plants to Georgia, Louisiana and Texas (Campbell 1996). Adult *A. sagrei* prey on smaller *A. carolinensis*, as well as displacing them from their native habitat (Gerber, 1991; Echternacht, 1999; Campbell, 2000). *A. sagrei* was first noticed in urban areas in Hawaii in the 1980's (Goldberg et al., 2002). Given the successful invasion of the southeastern U.S., it is possible that *A. sagrei* may negatively impact Hawaii's native, low-elevation insect fauna (Goldberg et al., 2002).

Figure 9. The Cuban treefrog (*O. septentrionalis*) was introduced into Florida in 1951 and has since been introduced to Hawaii, Georgia and Puerto Rico (Salinas, 2006; Glorioso et al., 2012). In Florida, *O. septentrionalis* preys on invertebrates (beetles, spiders, orthopterans, ants, roaches, and caterpillars), small vertebrates and less often, native frogs (Glorioso et al., 2012). Photo Credit: Thomas Brown/Wikimedia Commons.

Unlike *A. sagrei*, where populations are on the rise, the invasive Mediterranean house gecko, *Hemidactylus turcicus* (Fig. 8) populations are apparently declining in Florida. Native to the Mediterranean area and the Canary Islands, *H. turcicus* has, until recently, enjoyed colonization success in Florida, Louisiana and elsewhere in the southeastern United States (Conant and Collins, 1991; Meshaka et al., 2006). *H. turcicus* prefers urban areas, which can potentially be predator-free (Meshaka et al., 2006). However, recently, *H. turcicus* has been replaced by introduced competitively superior geckoes - the tropical house gecko (*H. mabouia*) and Indo-Pacific gecko (*H. garnotii*) - in Texas and Florida (Meshaka et al., 2006; Non-natives - Mediterranean Gecko, n.d.). The newly established geckos have the advantage of continuous reproduction against the more limiting seasonal reproductive cycle of *H. turcicus* (Non-natives - Mediterranean Gecko, n.d.).

Frogs

The Cuban treefrog, *Osteopilus septentrionalis* (Fig. 9), is a native of Cuba, the Bahamas and the Cayman Islands and since 1951 has been an established invasive species in Florida (Glorioso et al., 2012). In Florida, *O. septentrionalis* preys on invertebrates (beetles, spiders, orthopterans, ants, roaches, and caterpillars), small vertebrates and less often, native frogs (Glorioso et al., 2012). Yet, where *O. septentrionalis* is present, native

treefrog populations have been reduced. This is likely due to competition for food and potential *O. septentrionalis* predation on native treefrogs during different stages of the lifecycle rather than predation on adults (Glorioso et al., 2012). Female *O. septentrionalis* are not highly selective with their mates and are able to reproduce rapidly and spread easily as an invasive (Salinas, 2006). Because of this and other factors, *O. septentrionalis* has successfully invaded Hawaii, Georgia and Puerto Rico (Salinas, 2006).

In a very different region of the United States, a similar threat to native northern leopard frogs, *Lithobates pipiens,* is transpiring. The once widespread *L. pipiens* (formerly *Rana pipiens*) has declined significantly in the U.S. due to habitat destruction, climatic changes, chytrid fungus, and invasive species, for instance *L. catesbeianus* (Johnson et al., 2011). Although *L. catesbeianus* are not solely responsible for the reduction of *L. pipiens* - both species co-exist in the native northeastern U.S. range of *L. catesbeianus*, competition with and predation on *L. pipiens* occurs in the western U.S. (Johnson et al., 2011). *L. catesbeianus* requires wetlands for successful reproduction and thus *L. pipiens* fare better where wetlands are not a permanent ecological fixture (Johnson et al., 2011). Where *L. catesbeianus* are rare or absent, such as in the wetlands in northwestern Colorado, *L. pipiens* are believed to be present (Johnson et al., 2011).

Research has indicated that native red-legged frogs (*Rana aurora*), when placed in clumped-resource ponds with *L. catesbeianus* were smaller, took longer to reach metamorphosis, had lower tadpole survivorship, and lower numbers of adult frogs than those who were not placed with *L. catesbeianus* (Kiesecker et al., 2001). However, *R. aurora* that were in scattered-resource ponds with *L. catesbeianus* were less impacted by their presence (Kiesecker et al., 2001). Knowing that *R. aurora* could survive alongside *L. catesbeianus* in the latter conditions will help wildlife managers better focus their management efforts on those areas where co-habitation is not possible.

Red-eared slider turtle

The red-eared slider (*T. s. elegans*), a popular pet species, which is native to the Mississippi River drainages, and has been introduced to many parts of the U.S. and through competition threatens several native turtle species (Thomson et al., 2010; Krysko et al., 2011). One of the locations where red-eared sliders are present is the Sacramento River, the largest river drainage in California, which also supports significant populations of the native western pond turtle (*Emys marmorata*), a species of special concern in California (Thomson et al., 2010). The western pond turtle has declined significantly in many parts of its range, mainly due to habitat loss, but its population remains stable in the Sacramento River, which is why it is so important to conserve these strongholds (Thomson et al., 2010). Although *T. s. elegans* may be able to spread throughout the Sacramento River, its current concentration is near urban areas and is rare near large populations of *E. marmorata* (Thomson et al., 2010). Currently, *T. s. elegans* does not compete with *E. marmorata* for food, but that is not to say that they will not in the future (Thomson et al., 2010). The bigger concern is the potential for *T. s. elegans* to transfer disease, which could spread throughout the Sacramento drainage and render *E. marmorata* and other species at risk (Thomson et al., 2010).

Herpetofauna parasites

In addition to potentially carrying pathogens that spread disease, the exotic pet trade has opened channels for transfer of parasites, including ticks, hemogregarines and ascarid nematodes, to native U.S. reptiles (Reed, 2005). In Florida, exotic ticks, which were transported on imported tortoises, snakes, and monitor lizards, have been identified at 29 of 32 reptile premises in 18 counties (Burridge et al., 2000). Of the 4 Amblyomma tick species identified, *A. marmoreum* and *A. sparsum* are vectors of heartwater, a lethal disease of domestic and wild ruminants such as cattle, sheep, goats, and deer (Burridge et al., 2000). Once exotic ticks are introduced, research suggests that they can easily spread around Florida, with *A. marmoreum* feeding on a host reptile for up to 111 days (Burridge et al., 2000). In that time, ticks are unknowingly transferred between importers, breeders, wildlife parks and zoos, pet stores, private owners and perhaps the wild (Burridge et al., 2000). Yet, it is not clear if they are spreading to native species (Burridge et al., 2000). The pet trade may also be responsible for facilitating the spread of the deadly chytrid fungi beyond borders and accelerating the decline of amphibians globally (Reed, 2005).

Current Management Practices of Invasive Herpetofauna

Prevention through education and prohibition

It may be self evident, but prevention is the best control tool for managing invasive herpetofauna (Davis, 2012). In order to prevent future introductions of invasive species, money is best spent on educating the public and cargo inspectors (Pimentel et al., 2005). The Florida Fish and Wildlife Conservation Commission's, similar to other states in the U.S., operates a policy of education of pet owners and prevention of releases rather than prohibition, which would impact the pet industry (Hardin, 2007). Of course, prevention does not resolve the issue of already established populations of invasive species, which is why a combined effort is necessary for realistic and successful eradication or, at least, control of invasive reptiles and amphibians.

In the 1970s, regulations for captive and non-native wildlife were established in U.S., which included "risk-based bio-security for problematic species" and "prohibition of a limited number of species that posed unacceptable risks to the ecosystem, economy, or human health and safety" (Hardin, 2007). Of course, economic

interests are always at play with regard to government regulations and hence, species that clearly pose risks, are still allowed to be imported. That being said, more recent measures have been enacted to help mitigate problems associated with imported reptiles. In 2008, owners of certain large reptile species were required to implant passive integrated transponders to identify individual animals, should they escape and a "pet surrender network" is currently being developed (Hardin, 2007).

Baiting, trapping and shooting

Once established, control efforts for locating and eradicating alien herpetofauna are much more complex and expensive than prevention measures. The Burmese python is a prime example. Surprisingly, given their size, *P. bivittatus* are hard to locate, due to effective camouflage and the marshy, difficult-to-navigate habitat of the Everglades where they are found (Engeman et al., 2011). One solution is bait placement laced with Acetaminophen, the main ingredient in Tylenol® a toxin to *P. bivittatus* (Engeman et al., 2011). This method is used in Guam to control *B. irregularis* (Engeman et al., 2011). Additionally, researchers are testing the effectiveness and potential use of trap-drift fence and multi-capture traps (Engeman et al., 2011). In 2013, a public "Burmese Python Challenge" took place in Florida. "Nearly 1,600 people from 38 states - most of them inexperienced hunters" and not particularly well-trained in identifying Burmese pythons from native snakes, were set loose into the wilds of the Everglades (Dell'Amore and Andries, 2013). Scientists claimed the hunt was a success, resulting in the killing of 68 pythons, but there is concern about whether using the public in this way, especially employing inexperienced hunters, is the wisest or most humane course of action for python eradication (Dell'Amore and Andries, 2013). Due to the "sociological impact," there are now greater restrictions on possessing this and other large reptile species (Hardin, 2007). Ecologists are attempting to understand the impacts of *P. bivittatus* and it is currently unclear how far-reaching their presence will be on native species. For example, an isolated population of Boa constrictor, confined to a "habitat island" in Miami has existed since the 1970s with no expansion or other impacts (Hardin, 2007).

Florida also uses trapping and shooting of *I. iguana* for controlling the spread of this well-established species including allowing members of the public to humanely kill *I. iguana* (Falcón et al., 2013). Similar to other invasive species, complete eradication is unlikely, if even possible, which is why prevention of new releases is crucial (Engeman et al., 2011). However, intense control methods should be attempted in localized contexts such as on islands, where the effects of invasive species can be far more detrimental (Engeman et al., 2011). Eradication strategies for *I. iguana* could involve locating males during the mating season, luring nesting females with artificial nests, destroying nests and eggs, educating pet owners about negative effects of release, and granting amnesty for turning *I. iguana* in where they are illegal to keep (Falcón et al., 2013). Additionally, using dogs to find nests may prove useful, since there has been some success with this method in locating both *B. irregularis* and *I. iguana* in their native range (Falcón et al., 2013).

When it comes to management practices not all species are treated with such urgency as *P. bivittatus* or *I. iguana* in terms of public concern or finances assigned for their control. Although bullfrogs (*L. catesbeianus*) are listed by the IUCN to be among the 100 worst invaders in the world, which accounts for their negative impact on the conservation of native species, bullfrogs do not receive the attention and resources necessary for proper control methods (Lowe et al., 2000; Adams & Pearl, 2007). This is most likely due to their lack of economic impact and the difficulty faced by management agencies in controlling them (Adams & Pearl, 2007). The abundance of *L. catesbeianus* is positively related to winter and summer precipitation and wetland habitat, which is required for breeding (Ficetola et al., 2007). Therefore, preventative control methods should focus on high-risk areas with the most suitable habitat in terms of precipitation and permanent wetlands (Ficetola et al., 2007). Although *L. catesbeianus* can coexist with native amphibians, albeit with minor negative effects, it still may be advisable to eradicate *L. catesbeianus* when present in isolated ponds that are home to endangered indigenous species in order to prevent further stress on an already vulnerable population (Adams & Pearl, 2007).

Combined prevention and elimination efforts with habitat restoration

Unlike *L. catesbeianus* control of the elusive and highly invasive *B. irregularis* is a high priority for wildlife managers. If a *B. irregularis* can fit its head through a hole in a cargo ship leaving Guam, it puts any Pacific island port that Guam trades with at risk (Rodda and Savidge, 2007). Those islands whose species have not co-evolved with snakes, will be even more at risk of negative impacts from introduction of *B. irregularis* (Rodda and Savidge, 2007). In order to prevent their spread to other islands, including Hawaii, wildlife managers have had success with control measures, such as visual searches, dog searches, and snake traps in Guam airports and seaports (Rodda and Savidge, 2007). Although complete eradication has not been possible on the island, acetaminophen, a toxin to *B. irregularis,* can be used in aerial broadcast and bait stations, along with snake traps and snake barriers, to control the population (Rodda and Savidge, 2007). In terms of protecting native wildlife, fortunately, Cocos Island, 25 small islets, buoys, and rocks off Guam provide areas that are free of *B. irregularis* and hence of *B. irregularis* predation (Wiles et al., 2003). Continued planting of important roosting and nesting trees and shrubs and continuing nest box programs will not eradicate the snake problem, but will at least help local birds continue to reproduce (Wiles et al., 2003).

Biological Control

Since many invasive species, for instance *B. irregularis,* are present in new ecosystems without natural enemies - predators, parasites, pathogens and competitors - they are often able to reproduce and spread more easily in these new environments (Messing and Wright, 2006). Biological control, the introduction of an invasive species' natural enemy into their new range, has been used to try to control pest invasives, but sometimes with severely negative effects, such as introducing more invasive species (Messing and Wright, 2006). Although this is a management tool for controlling current invasives, given the history and high risks associated with biological control methods, this should be viewed as a last resort.

Risk maps

Risk-averse management tools include risk maps, which can assist conservationists in locating potential invasive species hotspots and hopefully aid in prevention of potentially negative exotic species establishment (Hulme, 2009). Risk maps should account for climatic and habitat suitability, entry points, expansion limitations, and ability to reproduce in the new ecosystem (Hulme, 2009). Once exotic species managers know where to look for future or current populations, they are then able to incorporate inspection and prevention measures such as fumigation of commodities, exclusion zones and dispersal barriers (Hulme, 2009). According to Rodda et al., *Python molurusa*, a similar species to Burmese pythons, may be able to expand their population into southern and southwestern states, considering their native range extends into similar temperate climate zones (Rodda et al., 2009). However, they go on to say, that since their limiting ecological factor has not been identified in their native distribution, "it is not yet possible to determine the equivalent North American boundaries" (Rodda et al., 2009). Although *P. bivittatus* have been reported in several locations in the U.S., the only known breeding populations are in Everglades National Park and Big Cypress National Preserve (Pyron et al., 2008). According to ecological niche models, the Everglades National Park is primary habitat, given its similarity to native ecosystem of *P. bivittatus* (Pyron et al., 2008). Since the tropical marshland is limited to southern Florida, *P. bivittatus* is unlikely to leave, even if climatically, other regions in the U.S. are suitable (Pyron et al., 2008). Models based on climate change actually show a reduction both in available suitable habitat for *P. bivittatus* in the U.S. and natural range (Pyron et al., 2008). Although *P. bivittatus* can survive in cooler climates than found in southern Florida, research shows that individuals from the established Florida population had thermoregulatory issues and were incapable of surviving winters in temperate states such as South Carolina (Dorcas et al., 2011). It is important to note that individuals of *P. bivittatus* originating from more temperate areas may be better suited to withstanding winters in areas such as South Carolina, unlike those from tropical origins (Dorcas et al., 2011). If possible, genetic variation and species' origins should be taken into consideration for management and prevention of Burmese python potential expansion in the U.S.

Importance of successful management

Successful management of invasive species is critical in safeguarding ecosystems, their native species and local economies. According to Richardson and Ricciardi's paper, decades of research implicate invasive species as contributing to native species extinctions and local ecosystem disruptions (Richardson and Ricciardi, 2013). However, it is important not to generalize, since while some invasive species have been directly linked to extinctions, such as the effects of *B. irregularis* on endemic species extinctions in Guam, not all invasive species are linked to extinction events (Gurevitch and Padilla, 2004). However, when extinctions do occur, they may not show the full story of an ecosystem's ability to function, which is why it is important for conservationists to assess the effects of invasive species on indigenous species populations to better manage the issues (Richardson and Ricciardi, 2013).

It is also important to note the distinction between invasive predatory species vs. invasive competitor species, since predators often have a greater negative effect than a competitor (Gurevitch and Padilla, 2004). Additionally, although alien species may alter their new ecosystem, it may be more important to try to incorporate them into management plans, rather than waste resources trying to eradicate them, which is often a futile task (Davis, 2011). The function of a species within a community, whether it is beneficial or harmful, should be the focus of conservationists and land managers, not whether they are native or alien (Davis, 2011). However, it is important to remember the "evolutionary context in species interactions," thus, "the more 'alien' …the greater the likelihood it will be ecologically disruptive" (Richardson and Ricciardi, 2013).

Control Method Ethics

Alien reptiles and amphibians have been entering the U.S. over the past century at unprecedented rates and their import, whether intentional or not, is very unlikely to cease in the foreseeable future. Although the majority of exotic herpetofauna entering the States do not escape or establish wild populations, some of those that have, have had serious negative impacts on native species, meriting further research and substantial funding for their management. Although prevention is the most ideal and cost-effective strategy for dealing with invasive herpetofauna, eradication or strict control over current established populations is vital. In addition to finding, testing and utilizing viable management methods, consideration must also be given to the ethics of these methods- especially eradication. Not only are some of the invasive reptiles and amphibians found here in the States vulnerable in their native ranges and merit conservation consideration, but they are also

sentient beings that should be treated humanely with regard to termination control methods.

It is also important to ask, "Are invasive species the drivers or passengers of change in degraded ecosystems?" the question A.S. MacDougall and R. Turkington asked in their 2005 paper. Most ecosystems; in which invasive species thrive; are degraded in some way, which may indicate that invasive species are not leading the negative changes, but contributing to or taking advantage of an already anthropogenically created negative situation (MacDougall and Turkington, 2005). Understanding this can help wildlife managers make better decisions with regard to control and ecosystem restoration.

Conservationists, wildlife managers and the public also should remember that exotic species are neither good nor bad in their own right, and defining them as such can be misleading (Slobodkin, 2001; Davis, 2012). A pristine, stable and diverse ecosystem and its native inhabitants are often considered "good" while a degraded and diversity-poor ecosystem is viewed as "bad" (Slobodkin, 2001). Invasive species often fall into the "bad" category, even though, and ironically so, they are often more successful at surviving than "good" species (Slobodkin, 2001). Despite their often harmful effects, invasive herpetofauna deserve humane treatment with regard to their management. Thus, it is important to identify species that are harmful, since once harm is claimed, society expects that harm to be mitigated or expelled (Davis, 2012). Additionally, species diversity is intrinsically valuable and should be preserved, but to do so, should not require demonizing other species. Doing so may lead to inhumane management and mismanagement of invasives.

Today, the European wall lizard may number in the hundreds of thousands in Ohio, but according to W. Gibbons' paper, the non-native lizards "are beloved creatures" (Gibbons, 2014). Large reptiles such as *P. bivittatus* do not have such a loving following amongst the public, which is likely why the "Burmese Python Challenge" hunt in 2013 had such a strong public turnout. Public attitudes clearly may play a role in management of invasive species. However, wildlife managers should be careful not to focus only on sensational species or public nuisance species, which can potentially lead to ignoring more ecologically damaging invasives.

Further research is required to explore all possibilities of management methods, which allow invasive species to coexist with native species. These practices may focus more on promoting the constancy of native species rather than fighting against invasive species, which may be implausible to eradicate completely, given resources available and the extent of their range. Additionally, research, combined with ethics must inform action in order to successfully and humanely manage the exotic reptiles and amphibians in the U.S. Although managing alien species is complicated by each individual species ecological adaptations, hopefully, understanding the pathways and successful and ethical management of one species can lead to more successful prevention and management of other similar alien species.

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