A Species Bioprofile for the Asian Water Monitor (*Varanus salvator*)

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Abstract - *Varanus salvator* (Asian Water Monitor) is the second largest species of lizard in the world and is a member of the Varanidae Family. This highly aquatic species can also be found in arboreal environments and is an active predator and scavenger. Originating from southeastern Asia, including parts of India, this species is common in the international pet trade. Its popularity in the pet trade has led to multiple introductions outside of their native range, making this a species of concern as potentially invasive to the southeastern US with ready access to the Caribbean and Latin America. As a generalist species that has already been identified in Florida, there is a high likelihood for establishment as an invasive species. In cases such as these, implementing early detection and rapid response for successful management of invasive species is critical. Here, we provide a comprehensive summary of natural history findings on the Asian Water Monitor, including management methods and potential ecological impacts as an invasive species.

Introduction

Varanus salvator (Laurenti) (Asian Water Monitor) is the second largest lizard species (Cota et al. 2009). Several regional subspecies that are ecologically similar exist across the subcontinent of India, Sri Lanka, and the tropical range of southeastern Asia (Welton et al. 2014a); they differ mostly in morphology and habitat selection (Koch et al. 2007, Pough et al. 2004). The Asian Water Monitor is diurnal and as its name suggests, is the most aquatic of the monitors (Pianka et al. 2004) lending to easy dispersal via waterways and adaptability for aquatic habitats in Florida. The species is listed as "least concern" on the IUCN Red List and is popular within the exotic pet trade (Quah et al. 2021). This popularity has made the Asian Water Monitor a potential invasive species in several regions and is of particular concern in Florida given its benign climate and similarity in habitat to the species' native ranges (Bennett et al. 2010, Ferriter et al. 2008, Quah et al. 2021).

Presently data show reports of introductions of Asian Water Monitors within the state, and other monitor species that have established populations in the state include *V. niloticus* (L.) (Nile Monitor), *V. ornatus* (Daudin) (Ornate Monitor), and *V. salvadorii* (Peters and Doria) (Crocodile Monitor) (EDDMapS 2021, Mazzotti et al. 2020). Herein we discuss the Asian Water Monitor, which, particularly because of its large size and adaptability, has the possibility of posing the greatest threat to Florida ecologically of any monitor lizard. Modern methodology is in place for

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eradication plans, but the lack of public awareness may lead to establishment of the species prior to proper management enforcements (Campbell 2005, Smith 2004).

This species bioprofile is organized to be a comprehensive tool for understanding Asian Water Monitors as a potentially invasive species. We summarize the natural history findings, scientific research, and current species management plans to inform conservation and wildlife managers, particularly in the southeastern region of the United States, about the potential harm of these non-native reptiles. Our goal continues to be improving educational awareness, identifying potential ecological impacts, and increasing attention toward improved management of the Asian Water Monitor.

Classification

Taxonomy

The Varanidae family is comprised of nearly 80 species of monitor lizards. Within the genus *Varanus,* the *V. salvator* complex consists of 12 taxa (7 species and 5 subspecies; Welton et al. 2014a). Many of these named taxa have only recently been described or elevated to their current taxonomic position (Koch and Bohme 2010, Koch et al. 2010b). Presently, there are 5 recognized subspecies of the *V. salvator* complex (Welton et al. 2014b): *V. s. bivittatus* (Kuhl), *V. s. andamanensis* Deraniyagala, *V. s. macromaculatus* Deraniyagala, *V. s. ziegleri* Koch & Bohme (Ziegler's Water Monitor), and *V. cumingi samarensis* Koch, Gaulke & Böhme (Sumar Water Monitor, a subspecies of *V. Cumingi* Martin [Yellow-headed Water Monitor], which up until 2007 was itself considered a subspecies of *V. salvator*). The diversity of the species complex is still likely underestimated, and further studies (including gene-sequencing work) will help alleviate taxonomic uncertainty (Quah et al. 2021) and ultimately lead to necessary changes in the conservation assessment and management of the species group. In the meantime, the multitude of subspecies and taxonomic uncertainty could lead to numerous misidentifications of monitor species and be a hindrance toward invasive species reporting.

Physical description

The Asian Water Monitor is one of the most widely distributed monitor species (Cota et al. 2009). Although there are currently 5 recognized subspecies of *V. salvator,* the subspecies within the complex share numerous physical characteristics, allowing for the distinction between other species within the genus (Table 1). The Asian Water Monitor possesses a large size; a long, flattened body; a long tail and neck; and an extremely long, bifurcated tongue (Fig. 1; Koch et al. 2007, Pough et al. 2004). Asian Water Monitors have well-developed eyelids, and most members of the species have recurved teeth. Its head is covered with small scales, its body is covered with small round or oval scales, and ventral scales are arranged in regular rows (Pough et al. 2004). It has light-colored pineal organs located dorsally on the head (Koch et al. 2007). This monitor has well-developed limbs, and its digits are armed with strong claws (Fig. 1). Identifying characteristics include distinctive transverse black or dark bands or rows of spots or ocelli dorsally located on individuals, small nuchal scales with light dots on the neck, and a dark brown to black head (Table 1; Koch et al. 2007). Juveniles have spots across their bodies and light under-bellies (Fig. 2; Karunarathna et al. 2008b). The Asian Water Monitor reaches massive sizes, with only a single extant species, *V. komodoensis* Ouwens (Komodo Monitor), reaching larger sizes (Fu et al. 2011, Shine et al. 1996). Previous studies have recorded individuals of the *V. salvator* subspecies complex reaching total lengths (TL) of anywhere between 0.5 m (m) to over 2 m and near 3 m (Conrad et al. 2012; Karunarathna et al. 2008 a, b; Koch et al. 2007; Lim 1958).

Although members of the subspecies complex share identifying characteristics, regional variation between subspecies exists in certain traits, including body size, morphology, and coloration (Koch et al. 2007, Shine et al. 1996). A comprehensive study on the morphology and systematics of the *V. salvator* subspecies complex was conducted by Koch et al. (2007) in compiling and comparing these

Table 1. Dorsal coloration observed in the subspecies of the *Varanus salvator* complex (adapted from Koch et al. 2007).

Taxon (native range)	Head	Neck	Back	Tail
V. s. salvator (Sri Lanka, probably northern India)	Brown to black, with 2–3 light crossbands on snout	Black, in juveniles with irregular small light dots	Black, 5–6 transverse rows of ocelli, with thin lines of light dots in between	Black, with thin and broad light crossbands, more distinctive in juveniles
V. s. macromaculatus (SE Asia, Suimatra, Borneo)	Dark, with 1–3 light crossbands on snout	Brown, with or without indistinctive light dots	Dark, with 4–7 ± distinctive transverse rows of spots or ocelli, mostly light dots or marbling in between	Dark, proximad with transverse rows of light spots or ocelli, distad fused to ± distinctive light crossbands
V. s. andamanensis (Andaman Island)	Dark, juveniles with 2 light crossbands on snout	Dark, probably with single light scales or light bordered scales	Dark, with small dots, in juveniles sometimes forming up to 6 transverse rows	Dark, with small dots or scales arranged irregularly or in crossbands
V. s. bivittatus (Java, Lesser Sundra Islands)	Dark, juveniles with 2 light crossbands on snout	Brown, mostly with lighter markings, laterally longitudinal dark stripes or spots	Dark, with 4–6 transverse rows of light spots or ocelli, spots of first rows sometimes fuse to crossbands	Dark proximad with transverse rows of light spots or ocelli, distad fused to ± distinctive light crossbands
V. salvator ssp. (Sulawesi, Moluccas)	Dark, with 2–3 light crossbands on snout	Dark, with many single light scales or dots	Dark, with light dots, or 2–5 transverse rows of light spots or ocelli	Dark, proximad light mottled, distad with ± distinctive light crossbands

traits. The study identified physical characteristics (including coloration, scale arrangement, size, and number) used to distinguish subspecies within *V. salvator*, and Table 1 outlines a few of these characteristics (for further identification between subspecies of *V. salvator,* refer to Koch et al. 2007). An understinding

Figure 1. *Varanus salvator*. Salang Village, Tioman Island, Malaysia. 2007. Photograph © Holland Rusley. From Biawak (2008.)

Figure 2. Juvenile *Varanus salvator* (Asian Water Monitor) in a tree hollow in the National Zoological Gardens. From Karunarathna et al. (2008b).

of these physiological differences in subspecies is essential for proper reporting, especially in Florida where numerous color morphs complicate identifying other invasive species (Green et al. 2020).

Genetics

In recent years, there has been an increased effort directed toward varanid genetic research. However, the lack of understanding of the genetics in the genus is apparent with the amount of taxonomic uncertainty surrounding Varanoidae. The *V. salvator* group was originally located at the basal position of the karyotypic phylogeny of varanid lizards based on morphology (King and King 1975), but this has since changed with molecular phylogeny (Ast 2001) and still warrants further investigation (Srikulnath et al. 2013). Within the *V. salvator* subspecies complex, the taxonomic level of many of the taxa are in flux (Koch et al. 2007; Welton et al. 2014a, b). The implementation of multi-locii genetic networks is one of the more recent techniques being used to address taxonomic uncertainty and alleviate the confusion surrounding the genus (Welton et al. 2013b, 2014a, 2014b).

Distribution

Habitat

The Asian Water Monitor is perhaps the most widespread of all varanids and is found in Sri Lanka, northern India, Bangladesh, Burma, Vietnam, Hainan (China), and through Malaysia east to the Indonesian islands of Sulawesi and Wetar (Cota et al. 2009, De Lisle 1996). Its ability to colonize the remote islands of Malaysia and Indonesia might be due to its adaptability to both freshwater and saltwater (Træholt 1995a) and its large size, which likely enhances its ability to withstand a lengthy sea voyage and survive landfall. The backwash from tsunamis may also play a role in dispersing water monitors (De Lisle 2007). *Varanus salvator* inhabits a wide variety of habitats across its range, from highlands (1100 m elevation) in south Sumatra to coral islands with little aquatic habitat (Pulau Tulai; Træholt 1995a) to mangrove swamps (De Lisle 2007).

The *V. salvator* species complex occurs from sea level to an altitude of 1800 m, though water monitors are typically located in the lowlands, most commonly below 600 m (Bennett et al. 2010, Gaulke 1991). The species group is closely associated with wetlands (e.g., mangrove swamps, rivers) and is often found thriving near human-modified areas/settlements, as human presence does not seem to deter these monitors (Amarasinghe et al. 2009, Gaulke 1991). Asian Water Monitors frequent locations nearby the coast, such as primary and secondary forests, agricultural (rice and palm oil) areas, and towns/villages (often those with canal systems); however, the preferred and most important habitats are those in direct vicinity of watercourses (especially in mountainous areas), such as riparian locations, mangrove vegetation/swamps and wetlands (Bennett et al. 2010, Gaulke and Horn 2004, Pianka et al. 2004). Asian Water Monitors inhabit fresh and brackish waters, tidal mudflats, and dikes (Rashid 2004), as well as deltaic swamps, evergreen rain forests, littoral forests, dried flat wetlands, clearings, and even savanna-like locations near forest edges, and can cross vast seawater distances between island locations (De Lisle 2007, Erdelen 1991, Pianka et al. 2004).

The adaptability to a variety of habitats in their native range is comparable to their spread in Florida, where they have been found in over 8 counties with diverse habitat types (Fig. 3). The species complex is found in warm tropical climates (activity temperatures recorded on Sri Lanka varied between 29.9 °C and 30.4 ± 2.1° C), often preferring thermally stable habitats to help maintain relatively constant body temperatures (*V. salvator* has a body temperature of 36–38 °C, slightly lower than terrestrial varanids) (Wickramanayake and Dryden 1993). This span of temperatures is well within the average found throughout the year in Florida, indicating only an uncharacteristic cold snap would slow their success there.

Currently, it is difficult to determine the extent of the natural expansion of monitor species throughout their native ranges; however, recent expansions include the recognition of the easternmost border of the *V. salvator* complex (central Indonesian population) as Obi Island, Maluku Province (Koch and Bohme 2010). This affinity for expansion is what makes the species a prime candidate fo spread in Florida as there are very few habitat barriers halting expansion throughout the state and potentially into parts of the Caribbean and Central America via travel over land or across water.

Members of the *V. salvator* species complex are believed to be abundant throughout their natural range, including in a variety of habitats, though little

Figure 3. *Varanus salvator* found in Broward County, FL, and held in an enclosure. From EDDMapS (2019): Eric Suarez, Florida Fish and Wildlife Conservation Commission, Bugwood.org.

population data exist (Bennett et al. 2010). In Singapore, on an 87-ha wetland reserve, a mark–recapture study of 181 water monitors had a density estimated at 3.9 ± 0.25 monitors per hectare (Rashid 2004). Based on export information from locations such as the Indo-Australian Archipelago, with no reports of concomitant population decline, relative abundance of monitors is expected to be high (Koch et al. 2013). In the Philippines, residents reported a decline in numbers likely associated with heavy hunting pressure (Koch et al. 2013), leaving hope that eradication of specimens is possible if invasion were to occur outside of its native range.

The *V. salvator* complex is considered semi-aquatic to aquatic (Gaulke and Horn 2004, Mertens 1942, Wickramanayake and Dryden 1993). Water monitors are excellent swimmers/divers, and aquatic habits provide individuals with an extra means of safety (Pianka et al. 2004). Water monitors are capable of submersion in salt water for vast distances (Rawlinson et al. 1990). In additon, they spend a fair amount of time on land and are also excellent climbers, with juveniles being more arboreal than mature adults (Pianka et al. 2004).

Introduced range

Due to habitat conversion in their native range, water monitors have been found in urban ecosystems where they had previously been absent (Kulabtong and Mahaprom 2014). There are lack of data regarding the introduction of water monitors into non-native locations; however, the first record of an Asian Water Monitor observed in the state of Florida dates back to July 1978 in Alachua County. Since then, a total of 58 individuals have been sighted in the state and include St John's, Pinellas, Broward, Palm Beach, Miami-Dade, Monroe, Hillsborough, DeSoto, Marion, Charlotte, and Lee counties ((Fig. 4; EDDMapS 2021), suggesting that

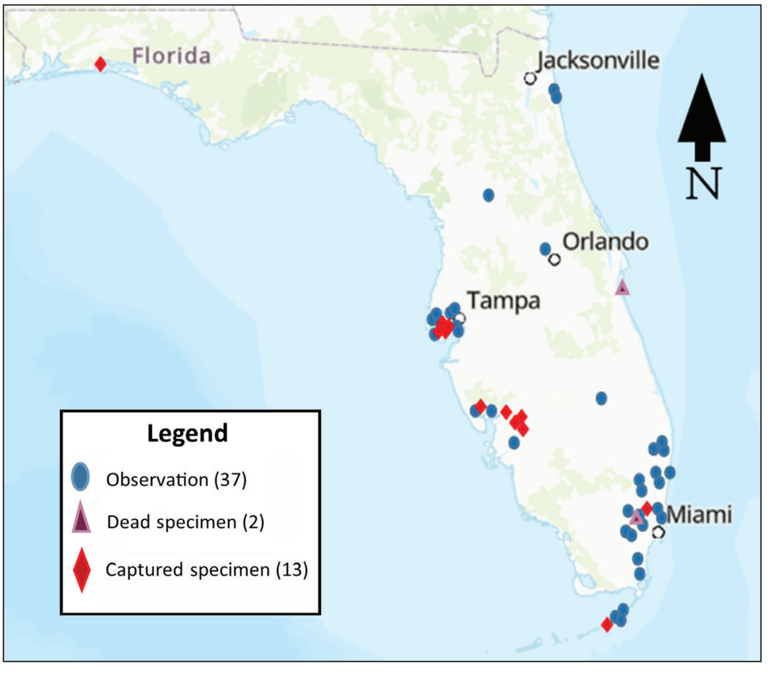

Figure 4. Map of reported sightings and/or trappings of *Varanus salvator* in Florida as of February 2022. Map made in ArcGIS using data from EDDMapS (2021).

immediate action is needed to curtail the spread of this species. Other species of monitors have been documented in Florida, including a breeding population of Nile Monitor in Cape Coral, Lee County (Enge et al. 2004), and more recently 2 other breeding populations in Palm Beach and Broward counties (Ketterlin-Eckles et al. 2016). Both the Asian Water Monitor and the Ornate Monitor share similar ecological traits as the Nile Monitor, and the presence of breeding populations of the latter, may indicate the potential for the other 2 monitor species to spread and become established in Florida.

The source of Asian Water Monitor individuals found at various locations in Florida is not known, though it is likely a combination of accidental and intentional introductions (Ferriter et al. 2008). Water monitors are popular in the pet trade, and hatchlings are relatively inexpensive. Given the large size that a water monitor can attain in adulthood combined with a nervous disposition, pet releases/escapes are very likely causes of sightings (Bennett et al. 2010). Numerous accounts of interstate smuggling associated with the pet trade have occurred in multiple Florida counties (Fig. 3; Danielson 2020, Swift 2019, Virata 2020). Illegal releases by reptile dealers, with the intent of establishing breeding populations to be exploited in the future, is a probable source for Nile monitors (Enge et al. 2004). Several water monitor individuals have been observed in multiple locations throughout the state and may indicate multiple release events. The likelihood of the species' expansion throughout Florida's numerous canals, rivers, levees, and many naturally occurring wetlands is of major concern as this may be a reason for the often prolonged searches needed prior to successful capture during removal efforts (Swift 2019). A breeding population of this species has not yet been detected.

Biology

Reproduction

Inhabiting a tropical climate across its native range, the Asian Water Monitor does not have a pronounced reproductive season. Instead, the species is capable of multiple reproductive events per year (Pianka et al. 2004), the timing of which may be influenced by rainfall (Rashid 2004). The species has a mean clutch size of 13 ± 4.46 eggs (Camina et al. 2013, de Buffrenil and Rimblot-Baly 1999) and can produce from 5 to 25 eggs per clutch (Rashid 2004). Wild individuals within the *V. salvator* complex show regional variation not only in their peak breeding seasons but also in clutch sizes, signifying the importance of climate and habitat on the breeding success of the population (Gaulke 1989, Shine et al. 1996). In Singapore, female monitors were gravid or engaged in reproductive activity for the wet season from October to March (Rashid 2004). Captive populations in North America have been shown to experience numerous hormonal peaks (roughly 10-fold higher than baseline levels), indicating ideal periods for reproduction (Long et al. 2005). Given the nature of their reproductive abilities, the fact that there as of yet no known breeding populations in their introduced range of Florida likely indicates the introduced individuals are more sparsely distributed than other invasive monitor lizards that have established breeding populations in the state.

It has been suggested that the individual's size, rather than its age, is a more important/predictive factor in its ability to reproduce. Female Asian Water Monitors from Sumatra have been shown to reach reproductive maturity at roughly 50 cm SVL (equating to 125 cm TL) or when vitellogenic follicles are >8 mm in diameter, while males reach maturity at 40 cm SVL (100 cm TL); both sexes typically attain these sizes within 2–3 years, depending on resource availability (Shine et al. 1996, 1998). There is a direct correlation between clutch size and female body length, with larger females capable of generating larger clutch sizes (Rashid 2004, Shine et al. 1998). Studies have shown that maternal body size plays a much more important role in reproductive output than phylogeny (Thompson and Pianka 2001). It is noteworthy that parthenogenesis has occurred in the genus, with female Ornate Montiors held in cpativity without access to males reported to produce clutches of 15 and 12 eggs (all of which were infertile), though previous records have documented successful offspring due to parthenogenesis (Hennessy 2010).

Captive individuals within the *V. salvator* species complex have been recorded laying as many as 3 clutches in a single year, with intervals between 3.5 and 5 months (eggs recorded as laid in January, March, April, July, August, September, October, and December; Pianka et al. 2004). Species in the *V. salvator* complex from areas with stable climates have adapted reproductive tendencies of producing small quantities of eggs multiple times a year (de Buffrenil and Rimblot-Baly 1999, Shine et al. 1998).

Asian Water Monitor eggs are reported to weigh 55–78 g and measure 70–80 mm x 35–40 mm, while the relative clutch mass (RCM = 100 * [the clutch mass/net wet body mass]) for the species has been reported as 15% in Singapore, 17.7% in Sumatra (oviductal eggs), 23% in the Philippines, and 29% in captive Indian individuals (Andrews 1995, Auffenburg 1994, Rashid 2004, Shine et al. 1996). However, much larger (92–100 mm x 35–38 mm) as well as much smaller (66.6 mm x 30.5 mm) eggs have been reported within the species complex (Pianka et al. 2004, Shine et al. 1996). Average incubation period was reported as 214.9 ± 6.9 days (n = 7; Rashid 2004).

Age and growth

Newly hatched neonates averaged 135 ± 5.62 mm SVL and 35.32 ± 3.25 g in body weight (n = 15; Rashid 2004). Much of the information regarding growth rates and longevity has been obtained from captive specimens because obtaining such information from wild individuals is difficult. There is a high growth rate in early development, reported as 0.84 mm/day for SVL during the first year (Andrews and Gaulke 1990). Growth rate has also been found to vary significantly between individuals, with the largest individual averaging a growth of 1200 g and 22 cm per year (Andrews and Gaulke 1990). A captive Asian Water Monitor averaged 18.2 cm per year (over a 10-year period, with an average growth of 26.2 cm in the first 5 years of growth and only 6.6 cm the remaining 5 years; Pianka et al. 2004). Longevity records of this species have been documented between 5.1 and 8.7 years, though there are reports of an individual in captivity reaching 10 years 8 months (Pianka et al. 2004).

Diet

The *V. salvator* species complex is known to have a very varied diet across its expansive geographic range. Neonates possess extremely sharp, recurved teeth, which become blunter, crushing teeth in adults (Pianka et al. 2004). Though Water Monitors are classified by some as scavengers feeding mainly on animal carcasses (Kulabtong and Mahaprom 2014, Træholt 1995b, Daniel 2002), studies have indicated that their extensive diets include direct predation on mammals, insects, other invertebrates, reptiles, birds, amphibians, fish, bird eggs, and reptile eggs (Arbuckle 2009, Bennett 1998, De Lisle 2007, Gaulke 1991, Gaulke and Horn 2004, Rashid 2004, Shine et al. 1998) as well as crabs (Cota et al. 2009). This diversity in diet indicates prey availability would not inhibit their ability to grow and function ecologically in Florida, similar to the broad diet of Nile Monitors within Florida (Mazzotti et al. 2020). The Asian Water Monitor has also been known to unearth human bodies from shallow graves in the Philippines (Dryden 1965, Taylor 1922), and has a reputation for preying on domestic pigs, chickens, and dogs in rural areas of their range (Gaulke 1991). Fish have rarely been found in diet analyses of Asian Water Montiors, though most stomach analyses have been done of specimens trapped in palm plantations where the only aquatic habitat available are small streams (Shine et al. 1998). Most people of southeast Asia familiar with this monitor insist it does catch fish (Træholt 1994a). There are a few reports of Asian Water Monitors catching fish (De Lisle 2007) and more recent observations of unusual feeding behavior on the invasive *Hypostomus plecostomus* (L.) (Suckermouth Catfish; Karunarathra 2008, Stanner 2010). Individuals will also opportunistically scavenge human leftovers (Træholt 1994a, 1994b, 1997a, 1997b) and have been found actively searching garbage dump sites for leftover food (Fig. 5). They have been reported as much more abundant in human-inhabited areas (2400 monitors/km^2) vs uninhabited areas (4 monitors/km^2) (Uyeda 2009). In some instances, monitors have appeared on average to be larger and more robust in some areas of incidental human supplementation (Auliya 2003), demonstrating that an adaptation to coexistence with humans could be beneficial to monitor populations (Uyeda 2009).

Figure 5. Subadult *Varanus salvator* at the “garbage hole” on Tinjil Island, Indonesia. From Uyeda (2009).

Parasites and disease

Species within the *V. salvator* complex are susceptible to several different parasites and diseases that vary among locations and among age classes, with juveniles carrying a higher parasite load than adults (Pianka et al. 2004, Shine et al. 1998). Stomach-content analysis of Asian Water Monitors from Sumatra suggested that individuals from this area carry large nematode worms (*Tanqua tiara* (von Linstow) Blanchard; Spirurida) and that certain locations have significantly higher parasite loads than others (mean of 10.6 worms/stomach in Cikampak, as opposed to a mean of 7.5 in Rantauprapat) (Shine et al. 1998). External parasites, such as ticks (*Amblyomma helvolum* Koch and *Aponomma lucasi* Schulze), have also been shown to be prevalent in the species, with most individuals from Taman Negara, Malaysia, having high concentrations of these parasites located on the inner folds of the legs (numbers varied from 3 to 30 between individuals; Auffenberg 1988, Pianka et al. 2004). The African tick *Amblyomma exornatum* Koch has been found on an individual in captivity in Florida (Burridge et al. 2000), and *Amblyomma varanense* Supino (Asian Monitor Lizard Tick) was found on an individual brought from Indonesia to Poland (Nowak 2010).

Other parasites identified within the *V. salvator* complex include: *Sphaerechinorhynchus macropisthospinus* Amin, Wongsawad, Marayong, Saehoong, Suwattanacoupt, & Say; *Sambonia parapodum* Self & Kuntz; *Giardia varani* Lavier; pinworms (Oxyuridae); the families Hexamitae, Ascaridae, and Strongylidae; the cestodes *Acanthotaenia daeleyi* von Listow and *Duthiersia fimbriata* (Diesing); and the nematodes *Hastospicullum macrophallus* Bolette*, Kalicephalus guangdongensis* (Rataj et al.)*, Kalicephalus schadi fotedari* Kalia et Nayital, and *Ophidascaris esa* Yamaguti (Acharjyo et. al. 1970, Amin et al. 2008, Biswas and Acharjyo 1977, Pianka et al. 2004, Self and Kuntz 1966, Upton and Zien 1997).

Disease organisms found within the genus *Varanus* include *Entamoeba invadens* Rodhaim*, Escherichia coli* (Migula) Castellani and Chalmers*,* and the bacteria *Rickettsia* from the spotted fever group. Certain fungal infections have also been identified within the genus (e.g., mouth rot [stomatitis ulcerosa]; Chia et al. 2009, Doornbos et al. 2013, Pianka et al. 2004, Puspitasari et al. 2001).

Behavior

Daily activity

Within the *V. salvator* complex, individuals are active during the day and spend most nights in burrows, tree holes or branches, dense vegetation, and sometimes with their bodies submerged but heads out of the water (Biswa and Acharjyo 1977, Pianka et al. 2004). In most locations, monitors are active from sunrise through sunset (approximately 0600 h through 1800 h), though the peak of activity depends largely on temperature (Uyeda et al. 2013). Basking temperatures vary from 21 °C to 27 °C (preferred basking sites include sand, litter, and tree branches in highly sun-exposed locations), as opposed to foraging activities, which often occur in temperatures of 29–31 °C (Pianka et al. 2004), with peak activity at a body temperature of 31 °C (Træholt 1995a). Studies from multiple locations throughout the range of

Asian Water Monitors have provided evidence indicating peak activity occurs during the warmest time of day (~1300–1500 h; Pianka et al. 2004). In Florida, capture success during removal efforts have been most successful during the mid-morning during basking activity (Ketterlin-Eckles et al. 2016). Thermoregulation by behavioral means includes basking, cooling in water, and reducing heat loss at night by sleeping in burrows (Træholt 1995a, b). When monitors are not basking during the day, they are often moving and foraging for food (Wickramasinghe et al. 2010). Larger individuals travel farther distances, with records of a large male traveling more than 2 km per day in foraging efforts (Gaulke and Horn 2004).

There are widely varying reports of Asian Water Monitor home-range sizes: 1.4–31.7 ha based on radiotelemetry data from Tulai Island, Malaysia (Træholt 1997a, c); 20 ha to 120 ha (De Lisle 1996); and up to >150 ha for an individual living in the Ujung Kulon Nature Reserve in West Java, Indonesia (Gaulke et al. 1999, Vogel 1979). Studies have indicated home-range sizes vary depending on habitat (highly productive habitats, such as mangrove swamps, require smaller activity areas) and age (younger individuals have much smaller home ranges), with home ranges often overlapping, suggesting a lack of territoriality (Pianka et al. 2004). However, specific individuals tended to have preferred burrows which they made use of up to 75% of the days observed (Træholt 1995b). Intra-specific aggression has been observed in water monitors and is likely a result of resource availability (of food, shelter, basking sites, and mates; Earley et al. 2002, Jolley and Meek 2007). There have also been observations of a primarily size-based dominance hierarchy among individuals who frequent areas with human-provided resources (Uyeda et al. 2015).

Seasonal activity

As a result of the tropical climate experienced in the natural range of the Asian Water Monitor, seasonal changes in activity patterns are less pronounced, though in mainland locations during winter (December through February), temperatures can fall to 10 °C, and daily activity patterns start later and end earlier in the day (Pianka et al. 2004). In Sri Lanka, changes in foraging behavior between the wet and dry season have also been observed, with foraging consisting of primarily aquatic activities (brief excursions on the banks of waterways) during the dry, high-temperature season, and primarily terrestrial activities (entering water only to cross waterways) during the rainy season, when there is cooler, overcast weather (Jolley and Meek 2007). The seasonal structure of Florida is comparable or more favorable in some instance for Asian Water Monitors, and very little change would be expected relative to their seasonal behavior observed in their native habitats.

Conservation and Management

Asian Water Monitors are among some of the most popular reptiles in the pet trade. They are hunted and heavily exploited in their native range for their skin and meat as well (Koch et al. 2013). Active capture methods include noosing (though this method requires a high level of approachability in individuals), following tracks to burrows to catch/dig up individuals, and shooting individuals emerging from burrows (Smith 2004). Hunting dogs are also an effective capture method; however, the lizard typically sustains injury and, if not caught, later succumbs to infection from dog-bite wounds (Bennett 2000).

Passive techniques have also been used to capture monitors, though the effectiveness of these methods varies across species. Some of these techniques include pit-fall traps (Smith 2004), nooses set in highly travelled corridors (Sweet 1999), PVC storm-water pipe traps (Smith 2004), Havahart traps (Campbell 2005), and to capture water monitors, floating baited traps ("box traps", to address rising and falling tides; Auliya and Erdelen 1999). A wide variety of bait has been used to attract monitors, including fresh and rotten pork, fish, squid, chicken, bone-in chicken, and eggs, though frozen squid and rotting fish have been most effective (Campbell 2005, Smith 2004).

Several studies used a variety of methods to effectively trap monitors, but none are specific to Asian Water Monitors. Eradication attempts of the Cape Coral, FL, population of Nile Monitors used Havahart traps baited with frozen squid to capture over 100 monitors (Campbell 2005, Enge et al. 2004). In South Florida, a combination of custom USDA model traps, Havahart traps, and Tomahawk traps were baited with chicken and squid (with chicken being more efficient as bait) to capture 4 Nile Monitors; a fifth individual was hand-captured (Scobel et al. 2017). A separate study conducted in Australia used baited arboreal PVC storm-water pipe traps as a capture method of *V. indicus* (Daudin) (Mangrove Monitor; Smith 2004). This method relies on gravity and the smooth surface of the pipes to prevent escape (pipes, sealed on the bottom and drilled with holes to allow drainage and the spread of bait odor, are placed vertically on tree trunks). Trapping efforts took place over a period of 6 days, with 12 traps utilized over a 2-ha area of estuarine mangrove forest, resulting in 36 captures (highest trap day success was 9 captures/day; Smith 2004). Rotting fish proved to be the most effective bait used, and other methods such as hand-noosing was less effective with average catch per day of less than 1 individual (Smith 2004).

Although previous studies have provided efficient trapping methods, the most effective methods are those observed in the species' native range. In these areas, it has been estimated 1.5 million skins are traded annually for use in the leather trade (Horn et al. 2007). Hunters in these locations actively seek monitors and depend on the capture of individuals not only for profit but also for meat and traditional medicines (Uyeda et al. 2014, Welton et al. 2013a). The manpower and time spent hunting these animals in their native range is highly unlikely to be attained in introduced ranges, and more passive methods provide the most efficient way of controlling these species.

Water monitors (in the *V. salvator* complex) are known to thrive in mangrove swamps, salt/freshwater marshes, coastal shores, and on the banks of rivers, lakes, and canals (Ferriter et al. 2008). They are often found within proximity of water, and some species stay within 200 m of water throughout their lifespan (Koch et al. 2013), indicating wetland habitats, as well as adjacent terrestrial habitats, are at risk of establishment (Enge et al. 2004). Their ability to successfully establish populations in these areas results in much of peninsular Florida representing suitable habitat. As monitors are also known to inhabit savannahs and disturbed areas in their native range, pastures, old fields, agricultural, and suburban areas represent potentially hospitable habitats as well. The presence of humans does not deter these species, and they are often found inhabiting human settlements and foraging on waste and debris, further illustrating their ability to colonize residential areas (Pianka et al. 2004, Uyeda et al. 2015). The extensive canal systems present in the Florida areas represent an efficient dispersal network evident through the recent population expansion of Nile Monitors throughout Cape Coral and adjacent areas (Enge et al. 2004). By using underground refugia, monitors can survive cold weather, such as that experienced in north Florida (evident through populations in temperate African regions), though areas in the southern part of the state such as Big Cypress National Preserve, Ten Thousand Islands, Everglades National Park, and Lake Okeechobee represent ideal habitats for expansion (Enge et al. 2004).

Invasion impacts

There are no ecologically similar species to Asian Water Monitors native to Florida; however, the non-native *Ctenosaura similis* (Gray) (Black Spiny-tailed Iguana) and *Tupinambis merianae* A.M.C. Duméril & Bibron (Argentine Black and White Tegu) share some similar traits. These species are relatively large and live in burrows, though the Argentine Black and White Tegu is a much more terrestrial species (Fitzgerald 1994). The Black Spiny-tailed Iguana has more similar habits, though the species experiences a change in diet; as a juvenile, it is primarily insectivorous (like monitors), and as an adult it is omnivorous (primarily herbivorous) (Fitch and Henderson 1978).

The most ecologically similar species present in Florida is the Nile Monitor. The establishment and spread of the species throughout Florida is a prime example of the genus' ability to colonize habitats. There are no records indicating the source of any of the Florida populations of Nile Monitors in Cape Coral, West Palm Beach, Southwest Ranches, and Homestead Air Force Base, though genetic analyses indicate low haplotype diversity within these populations with a West Africa origin (Dowell et al. 2016). These data match the trade data of Nile Montiors legally imported from West Africa for the pet trade between 1999 and 2013, mostly from Togo and Benin (Dowell et al. 2016). The 4 populations are most likely 3 separate introductions (Dowell et al. 2016, Ketterlin-Eckles et al. 2016) either by accident or by intention (Ferriter et al. 2008). As popular pets, monitors are often intentionally released after they become too sick/damaged to sell, outgrow their cages/enclosures (hatchlings are relatively small, though adults can easily attain sizes >2 m), or become too difficult to handle (because of size or temperament), become too expensive to maintain/feed, or once their owners lose interest (Enge et al. 2004; Ketterlin-Eckles et al. 2016). They are also able to tear through enclosure screens and push off terraria lids and can also escape following hurricane damage to holding facilities (Enge et al. 2004).

Due to popularity and high demand for monitors as pets, many individuals have been imported in the past. Trading of live Asian Water Monitors accounted for 1.3%

of trade in live CITES Appendix II reptiles between 1996 and 2012, which includes animals that were captive-bred, ranched, and wild-caught (Robinson et al. 2015). There has been an increase in ranched Asian Water Monitors from southern and southeastern Asia by 22%, and exports of this species from Indonesia and Malaysia make up 14.3% of the countries' total reptile exports (Robinson et al. 2015). The incidental importation of monitors is highly unlikely, due to their size and temperament (tend to run when disturbed; Enge et al. 2004). From first sighting of Asian Water Monitors in Florida in 1978, a total of 58 individual sightings have been made in the state and span numerous counties, but these appear to be isolated cases and not of an established breeding population (EDDMapS 2021).

Varanus salvator and its associated species complex have an extremely high potential for affecting native species in Florida, and because monitors have a generalist/opportunistic diet, an expansive variety of taxa are at risk of predation. Throughout their range, Asian Water Monitors are known to forage on the eggs and juveniles of numerous species (Luiselli et al. 1999). Their ability to locate and scavenge nests poses a direct threat to native species, many of which are extremely vulnerable to predation. For example, due to their nesting in mangrove habitats (preferred locations of many monitor species), colonial water birds (e.g., *Pelecanus occidentalis* L. [Brown Pelican]) and wading birds have heightened susceptibility to predation by *Varanus* spp.; non-ground–nesting bird species are also at risk, as monitors are exceptional climbers (Enge et al. 2004, Ketterlin-Eckles et al. 2016, Rodgers et al. 1999).

In their native range, water monitors are known to be voracious predators of sea turtle nests, further indicating a direct threat to native Florida species including *Caretta caretta,* (L.) (Loggerhead Sea Turtle), *Chelonia mydas* (L.) (Green Sea Turtle), *Dermochelys coriacea* (Vandelli) (Leatherback Sea Turtle), *Lepidochelys kempii* (Garman) (Kemp's Ridley Turtle), and *Eretmochelys imbricat* (L.) (Hawksbill Sea Turtle), as well as native freshwater turtle species (e.g. *Malaclemys terrapin* (Schoepff) [Diamondback Terrapin] and *Pseudoemys nelson,* Carr [Florida Red-bellied Cooter]) (Enge et al. 2004, Spawls et al. 2001). Monitors also possess the ability to locate buried eggs of semi fossorial and even fossorial species (Koch et al. 2007). The nests of *Alligator mississippiensis* (Daudin) (American Alligator) and *Crocodylus acutus* Cuvier (American Crocodile) are also at risk from predation, as monitors in their native range have been known to forage on the eggs and juveniles of similar species (e.g., *Crocodylus porosus* Schneider [Estuarine Crocodile] and *Osteolaemus tetraspis* Cope [Dwarf Crocodile]) The ecological relationship existing between sympatric monitors and crocodiles is not fully understood (Luiselli et al. 1999, Ng and Mendyk 2012).

Monitors not only threaten native species through predation but also pose a threat through competition for habitat and food. Monitors often occupy and modify the burrows of other species and easily displace and prey upon burrow inhabitants (Edroma and Ssali 1983, Enge et al. 2004). Adult monitors have few predators in their native range, though Estuarine Crocodiles (Ng and Mendyk 2012), *Lutrogale perspicillata* (Geoffroy Saint-Hilaire) (Smooth-coated Otter; Goldthorpe et al.

2010) and *Haliaeetus leucogaster* Gmelin (White-bellied Sea Eagle; Iqbal et al. 2013) have been documented as predators of the species. As a result of this dearth of predators, and of the monitors' opportunistic diet, the *V. salvator* species complex poses serious threats to native Florida wildlife.

Monitors have a high rate of range extension and high population growth rates (Wood et al. 2016). As noted earlier, at least some monitor species also possess the ability to undergo parthenogenesis (Hennessey 2010), though this form of reproduction might well be a rare occurrence and it is unclear to what extent it factors in to the success of these species. Monitors could impact many species in Florida on multiple levels. *Gopherus polyphemus* Daudin (Gopher Tortoise), currently listed as "vulnerable" by the IUCN, is threatened not only with predation but also with displacement from burrows (and consumption of eggs and juveniles if present). Larger monitors have been found with tortoise carapaces in their stomachs (indicating individual monitors could lower genetic variation of entire populations within short periods of time; Losos and Greene 1988). Similarly, *Athene cunicularia* (Molina) (Burrowing Owl), a species of high concern, faces predation as well as displacement (Enge et al. 2004). Lee County has the highest density of Burrowing Owls in Florida, with Cape Coral closely following. The "Ding" Darling Refuge on Sanibel Island is an important bird sanctuary in Florida, and the population of monitors currently established in the state poses serious threats to the species of birds inhabiting this area (Ferriter et al. 2008).

Nearly all invertebrates and smaller vertebrates in Florida, including mammals and fish, are potentially impacted by the presence of monitors, most commonly through predation (Cota and Sommerlad 2013). Smaller mammals such as *Oryzomys palustris sanibeli* Hamilton (Sanibel Island Rice Rat), *Podomys floridanus* (Chapman) (Florida Mouse), and *Sylvilagus palustris hefneri* Lazell (Lower Keys Marsh Rabbit) are at high risk of predation if monitor populations continue to establish (Losos and Greene 1988). Monitors also prey on shrub/tree-nesting birds such as *Aphelocoma coerulescens* (Bosc) (Florida Scrub-Jay) and have been recorded chasing ducks in the Cape Coral population (Enge et al. 2004). Additionally, habitat disturbance and damage to water-management structures such as berms and levees may result from monitors digging for prey and constructing burrows.

Anthropocentric impacts

Monitors do not pose direct threats to humans unless they are cornered or captured (Enge et al. 2004, Ketterlin-Eckles et al. 2016). Some species will become aggressive just prior to egg-laying and when defending a nest, though this behavior is most often observed in captive individuals and individuals acclimated to human presence (Horn and Visser 1997). Monitors use a combination of vigorous biting, clawing, and tail-whipping when defending themselves, though individuals often flee when encountered and will use a series of warning hisses when threatened (Enge et al. 2004, Pianka et al. 2004).

Due to the insectivorous/carnivorous diet of Asian Water Monitors, their direct impacts to agricultural/cultured crops are minor (though they can disturb crops when digging for food). They may, however, positively impact these crops through the consumption of pests (e.g., insects and rodents; Træholt 1994a). Asian Water Monitors have also been known to prey on *Gallus domesticus* (L.) (Domestic Chicken; Gaulke 1991). Since many monitor species are popular in the pet trade, if tighter regulations are placed on the genus, many pet shops and breeders will experience negative economic effects.

Monitors propensity to inhabit human settlements (e.g., villages, towns, cities) and forage on leftover food (Uyeda et al. 2013) can lead to financial loss in newly developed areas (e.g., decrease in property value) and deter people from locations. Reports have indicated monitors in and around people's yards, although there have been no major reports of damage to houses/landscape/agriculture. If the number of monitors continues to increase in these areas, the probability of damage reports will also likely increase as human–wildlife interactions become more common. In Cape Coral, a report indicated multiple Nile Monitors were responsible for stealing bait (squid) out of a fisherman's cooler while he was fishing in Charlotte Harbor (Campbell 2005). The highly variable diet of *Varanus* species means that if species continues to increase in residential areas, pets (e.g., dogs, cats, birds, fish, and lizards) kept outside are also in danger of becoming prey.

Monitors are, however, some of the most exploited species on the planet, particularly Asian Water Monitors (Horn et al. 2007). This species is mainly hunted for its skin (highly sought after in the leather trade and traded on a commercial scale; Koch et al. 2013), though its meat and fat are also utilized. *Varanus salvator* is listed on Appendix II of CITES and is protected in India and Sri Lanka (Daniel 1969, Karunarathna et al. 2008b). In the species' native countries, export quotas and annual allowable catches are in place, though the latter is apparently frequently ignored as annual catches often surpass the allowable values (Koch et al. 2013). Indonesia has high export quotas, with an estimated 6.2 million skins from wild-caught Asian Water Monitors and another 11,500 confiscated skins from 2000–2010 (Koch et al. 2013). During this same time, it is believed over 10 million skins from Malaysia were traded on a global scale (Koch et al. 2013). Import of live specimens of these species from Indonesia have been suspended into the European Union since 2001 to prevent population decline, though many individuals are still imported from Indonesia into several countries in the European Union (i.e., Germany, Spain, Czech Republic, France and Great Britain) through secondary countries such as the United States (Camina et al. 2013).

Research needs

The taxonomic uncertainty regarding Varanidae needs to be addressed to completely understand diversity and distribution of the genus as well as management of and regulations on specific species. In native ranges, the Asian Water Monitor continues to be heavily exploited, and the once-common lizard is unlikely to sustain current rates of exploitation. The Nile Monitor is currently the only monitor species listed as a reptile of concern in Florida (requiring a valid reptile of concern license), and has established breeding populations in Cape Coral, West Palm Beach, Southwest Ranches, and Homestead Air Reserve. The Nile Monitor could serve as a case study for how the Asian Water Monitor would disrupt habitats ecologically should it spread and become established (Dowell et al. 2016). The generalist nature of the Asian Water Monitor shows it has the potential to impact a wide range of native species and could be detrimental to endangered sea turtles, ground-nesting birds, endemic mammal populations, and the native crocodilians, much like the Nile Monitor (Mazzotti et al. 2020, Wood et al. 2016). The larger size of Asian Water Monitors could enable their impacts to reach higher up the trophic level. As a result of the relationships that monitors have with each other and the shared characteristics among the Asian Water Monitor , the Nile Monitor, and the Ornate Monitor, these species should be re-assessed, and a proper risk assessment should be conducted. The continued monitoring of known Nile Monitor populations could lead to developing management plans preventing the establishment of the larger Asian Water Monitor and minimize potential introduction impacts through early detection and rapid-response measures. The high risks of establishment call for an effective eradication program aimed at target locations with breeding potential to prevent the Asian Water Monitor from becoming an established introduced species in Florida, which could serve as the gateway for the species to invade the Caribbean and Central America.

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