Giant Applesnail (*Pomacea maculata*)
Ecological Risk Screening Summary

U.S. Fish and Wildlife Service, January 2024
Revised, February 2024
Web Version, 7/24/2024

Organism Type: Mollusk
Overall Risk Assessment Category: High

Photo: C.R. Morningstar, USGS. Public domain. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2633 (January 2024).

1 Native Range and Status in the United States

Native Range

From Hayes et al. (2012):

"The southernmost extent of the [native] range of *P. maculata* is the lower Paraná River basin in the La Plata region of Argentina, with the most northern records in the Amazon basin of Brazil, north of Manaus; it also occurs in Uruguay and Paraguay […]"

"Both species [*Pomacea canaliculata* and *P. maculata*] occur sympatrically in the Paraná and Uruguay river basins of Argentina and Uruguay […] (Martín, Estebenet & Cazzaniga, 2001). *Pomacea maculata* has a much larger range, occurring throughout much of western Brazil, from the border of Paraguay in the south to the Amazon Basin in the north, and it is a significant component of the freshwater molluscan biodiversity of the Pantanal wetlands. Based on habitat similarities it is also likely to occur in the eastern portions of Bolivia, Ecuador, and Peru, although we have not confirmed its presence in these regions."

Status in the United States

According to Morningstar and Jordon (2024), nonindigenous occurrences of *Pomacea maculata* have been reported in the following U.S. States and territories, with range of years, hydrologic units, and establishment status within the State or territory given in parentheses:

- Alabama (2003–2023; Escatawpa, Lower Tallapoosa, Mobile-Tensaw, Upper Choctawhatchee; established)
- Arizona (2011–2021; Agua Fria, Lower Salt, Lower Verde, Middle Gila; established)
- Florida (1989–2023; Alafia, Apalachee Bay-St. Marks, Big Cypress Swamp, Caloosahatchee, Cape Canaveral, Charlotte Harbor, Crystal-Pithlachascotee, Daytona-St. Augustine, Everglades, Florida Southeast Coast, Hillsborough, Kissimmee, Little Manatee, Lower Ochlockonee, Lower St. Johns, Manatee, Myakka, Northern Okeechobee Inflow, Ochlockonee, Oklawaha, Peace, Pensacola Bay, Santa Fe, Sarasota Bay, St. Andrew-St. Joseph Bays, St. Marys, Tampa Bay, Upper St. Johns, Upper Suwannee, Vero Beach, Western Okeechobee Inflow, Withlacoochee; established)
- Georgia (2005–2023; Cumberland-St. Simons, Kinchafoonee-Muckalee, Lower Flint, Lower Ogeechee, Lower Savannah, Satilla, St. Marys, Upper Ochlockonee, Withlacoochee; established)
- Louisiana (2006–2023; Amite, Atchafalaya, Bayou Sara-Thompson, Bayou Teche, Calcasieu-Mermentau, East Central Louisiana Coastal, Eastern Louisiana Coastal, Lake Maurepas, Lake Pontchartrain, Liberty Bayou-Tchefuncta, Lower Calcasieu, Lower Grand, Lower Ouachita, Lower Pearl, Lower Sabine, Mermentau, Tangipahoa, Upper Calcasieu, Vermilion, West Central Louisiana Coastal; established)
- Mississippi (2008–2022; Lower Pearl, Mississippi Coastal, Pascagoula; established)
- Puerto Rico (2006–2009; Eastern Puerto Rico, Southern Puerto Rico; established)
- North Carolina (2023; Lumber; established)
- South Carolina (2008–2020; Bulls Bay, Coastal Carolina, Cooper, Lake Marion, Middle Savannah, South Carolina Coastal, Waccamaw; established)
- Texas (2000–2023; Aransas Bay, Austin-Oyster, Austin-Travis Lakes, Buffalo-San Jacinto, East Fork San Jacinto, Elm Fork Trinity, Lower Angelina, Lower Brazos, Lower Brazos-Little Brazos, Lower Colorado-Cummins, Lower Neches, Lower Sabine, Lower Trinity, Lower West Fork Trinity, North Laguna Madre, North Wichita, San Fernando, San Gabriel, South Laguna Madre, Spring, Upper San Antonio, West Fork San Jacinto, West Galveston Bay; established)

From Morningstar and Jordon (2024):

"Established in the U.S. in most southeastern states as well as Puerto Rico, […]."

This species may be available in the aquarium trade in the United States.

From PickFish LLC (2022):

"Apple Snails (*Pomacea maculata*) – 5 small mixed colors
This is for 5 small apple mystery snails

This product is currently out of stock and unavailable."

From Ghesquiere (2021):

"The giant *Pomacea maculata*, rarely [sic] makes its way into aquaria. With tropical fish expeditions, sometimes other apple snail species are collected and offered for sale.
Apple snails are often sold under the name Golden mystery snail and are given incorrect names like *Ampullarius* for the genus instead of *Pomacea* and species names like *gigas* instead of *maculata*."

Regulations

The following U.S. States regulate the possession, transport, or sale of species in the genus *Pomacea* (sometimes with exception for *P. bridgesii*): Arizona (Arizona Office of the Secretary of State 2013), Georgia (State of Georgia 2023), Hawaii (Hawaii Department of Agriculture 2020), Louisiana (Louisiana State Legislature 2019), North Carolina (North Carolina Office of Administrative Hearings 2019), and Texas (Texas Parks and Wildlife 2020).

There are federal regulations on interstate transport and importation of applesnail species within the genus *Pomacea*.

From USDA-APHIS (2024):

"[…] aquatic snails in the family Ampullaridae (e.g., *Pomacea canaliculata*, channeled apple snail), with one exception, may not be imported or moved interstate except for research purposes into an APHIS inspected containment facility. One species in the family Ampullaridae*, Pomacea diffusa* (formerly *bridgesii*) may move interstate without a permit because these snails are not known to be agricultural pests but are primarily algae feeders. […] Diseased snails that carry or vector human or livestock diseases only may be imported with only a CDC (Centers for Disease Control) permit."

While effort was made to find all applicable regulations, this list may not be comprehensive.

Means of Introductions within the United States

From Morningstar and Jordon (2024):

"Although the mechanisms of introduction are not certain, the species was likely introduced via the aquarium trade (Karatayev et al. 2009), and the source of the southeastern U.S. populations was genetically traced back to populations native to Argentina and Brazil (Rawlings et al. 2007). The timeline of introduction of this species in the southeastern U.S. is unclear due to the initial misidentification of the species as *P. canaliculata* (Rawlings et al. 2007). However, the earliest record in the NAS database is an egg clutch deposited in the University of Florida museum in 1989 by Fred Thompson as *P. canaliculata*, though it is now known this specimen is likely *P. maculata* […]. There is also evidence that the snail can be transported by flood waters (Advocate staff report 2018)."

Remarks

A previous version of this ERSS was published in 2018. Revisions were done to incorporate new information and conform to updated standards.

This species is commonly confused with its congeners *Pomacea canaliculata* and *P. diffusa*.

From Hayes et al. (2012):

"Molecular data confirm that *P. maculata* and *P. canaliculata* are two distinct species, each with an average of 2.71–2.81% sequence divergence at *COI* within populations, and as much as 4.80 and 6.87% sequence divergence between distantly separated populations of *P. maculata* and *P. canaliculata*, respectively. Despite not being closely related within the genus, their shells are highly similar, their biogeographic distributions overlap, and both are frequently introduced pests. Until recently, representatives of both were typically referred to *P. canaliculata*, with published information sometimes ascribed to the incorrect species (e.g. data for *P. maculata* ascribed to *P. canaliculata*; Hylton Scott, 1958; Neck & Schultz, 1992; Carlsson & Lacoursière, 2005), or conflating the two (e.g. Naylor, 1996; Lowe et al., 2000; Cowie, 2002)."

From EPPO (2024):

"The name *Pomacea insularum* was widely used for one of the South American apple snails that invaded South-East Asia and Southern North America but Hayes *et al.* (2012) synonymized *P. insularum* and *Pomacea gigas* with *P. maculata* and established it as a different species from *P. canaliculata* […]"

"[…] the taxonomic situation in South-East Asia and other invaded regions may be more complicated than previously thought since a new species (*Pomacea occulta*), not known in the native range of the genus, has been described in China (Yang & Yu, 2019). Hybridization between *P. canaliculata* and *P. maculata* may be locally frequent in the native range (up to 30% of the snails analysed; Glasheen *et al.*, 2020) but may reach up to 53% in South-East Asia where pure *P. canaliculata* snails are common but pure *P. maculata* are extremely rare (Yang *et al.*, 2020, 2022)."

From Cowie (2015):

"[…] the algae-eating 'spike-topped' apple snail, *Pomacea diffusa* (formerly identified as the different species *Pomacea bridgesii*) is not perceived as a threat to agriculture and so *P. diffusa* remains freely available in the aquarium trade. Without any requirement or practice of inspection, small *P. maculata* may be mistaken for *P. diffusa* and unintentionally sold to the public. *P. maculata* does not perform well in an aquarium, however, and so pet owners will often release the illegally acquired snail 'back' into the environment without any awareness of the consequences."

2 Biology and Ecology

Taxonomic Hierarchy and Taxonomic Standing

From MolluscaBase editors (2024):

"Animalia (Kingdom) > Mollusca (Phylum) > Gastropoda (Class) > Caenogastropoda (Subclass) > Architaenioglossa (Order) > Ampullarioidea (Superfamily) > Ampullariidae (Family) > Pomaceinae (Subfamily) > *Pomacea* (Genus) > *Pomacea maculata* (Species)"

According to MolluscaBase editors (2024), *Pomacea maculata* is the current valid name for this species.

Size, Weight, and Age Range

From Hayes et al. (2012):

"[…] ranging in size from ~35 to >165 mm in adult shell length […]"

From Cowie (2015):

"Fully grown females are larger than males and can achieve a weight of over 200 g (Kyle et al., 2009)."

"Anecdotal estimates suggest *P. maculata* can live for up to 8 years."

From Morningstar and Jordon (2024):

"Sexual maturity has been documented at around three months of age (Bernatis 2014), and it is thought to live up to three years, although average lifespan has not been confirmed (Arnold et al. 2014)."

Environment

From Cowie (2015):

"*P. maculata* occurs in shallow parts of slow-moving bodies of fresh water, close to riverbanks, at the edges of lakes and in ponds, in wetlands and irrigated wetland croplands and in drainage/irrigation ditches. It has been reported from estuaries (EFSA Panel on Plant Health, 2012) but its salinity tolerance probably prevents its extensive penetration into such brackish habitats (Ramakrishnan, 2007), although eggs remain viable when exposed to periodic inundations typical of a tidal regime and modest, albeit reduced, growth and survival occurs at moderate salinities (5 and 10‰) (Martin and Valentine, 2014). […] Ramakrishnan (2007) […] examined tolerance to environmental temperature (15.2-36.6°C), salinity (0-6.8‰) and pH (4.0-10.5). Ramakrishnan (2007) also showed that the maximum desiccation tolerance of *P. maculata* was loss of 58% of total corporeal plus extracorporeal water and that it is a moderate regulator of oxygen consumption when subjected to progressive hypoxia, maintaining a normal oxygen uptake rate down to a critical PO_2 of 80-120 Torr depending on temperature, and suggested that *P. maculata* would be most successful in oxygenated, flowing-water (but only slow-flowing) habitats."

From EPPO (2024):

"Water temperature is of major importance in apple snail biology and ecology (Hayes *et al*., 2015). *P. maculata* feeds between 15 and 35°C and grows between 20 and 35°C but the highest rates are attained at 30°C (Gettys *et al*., 2008). After ten days at 15 °C, *P. maculata* remains active and showed no mortality but at 10 °C and 5 °C activity is reduced and mortality increases to 50 and 60 %; no snail survived after five days at 0 °C; nevertheless, *P. maculata* has established in locations where freezing temperatures occur in winter (Burks *et al.* 2017). Upper lethal limits are around 35-36.6 °C. *P. maculata* snails often live in ephemeral habitats and are able to aestivate during the dry season. Adults may survive for a year on moist sand if air relative humidity is higher than 80% but only for 22 weeks if the sand is dry and the relative humidity lower than 60 %. Even though adult *P. maculata* survive for three days at salinities of 10 psu [practical salinity units], activity and feeding rates are almost null above 6 psu (McAskill & Douglass, 2017). They are able to crawl over dry land for three hours at a speed of 3 m per hour (Mueck *et al*., 2018), if water conditions are too stressful or if the waterbody dries up."

Climate

From Cowie (2015):

"The most northern latitude at which *P. maculata* populations occur is the Ebro River delta in Spain (EFSA Panel on Plant Health, 2012; Horgan et al., [2014]; Andre and Lopez, 2013), where it has been introduced. The southernmost latitude at which it occurs appears to be near Buenos Aires, Argentina (Hayes et al., 2012; Byers et al., 2013). Buenos Aires is one the [sic] coldest areas in the native range of the species, with average temperatures of 4-6 °C in the coldest months. In Houston, Texas, USA, where many populations of introduced *P. maculata* exist, temperatures can reach highs of 33 °C. Populations of *P. maculata* in Charleston, South Carolina, USA, probably experience the coldest temperatures in the introduced range, although climatic modelling indicates suitability of areas a little further north (Byers et al., 2013)."

"Latitude North (°N) […] 40.8000"

"Latitude South (°S) […] 31.6036"

Cowie (2015) also states that its preferred habitat is in wetter tropical climates, but it can tolerate temperate and dry savanna climates.

Distribution Outside the United States

Native

From Hayes et al. (2012):

"The southernmost extent of the [native] range of *P. maculata* is the lower Paraná River basin in the La Plata region of Argentina, with the most northern records in the Amazon basin of Brazil, north of Manaus; it also occurs in Uruguay and Paraguay […]."

"Both species [*Pomacea canaliculata* and *P. maculata*] occur sympatrically in the Paraná and Uruguay river basins of Argentina and Uruguay, although *P. canaliculata* extends further south (Martín, Estebenet & Cazzaniga, 2001). *Pomacea maculata* has a much larger range, occurring throughout much of western Brazil, from the border of Paraguay in the south to the Amazon Basin in the north, and it is a significant component of the freshwater molluscan biodiversity of the Pantanal wetlands. Based on habitat similarities it is also likely to occur in the eastern portions of Bolivia, Ecuador, and Peru, although we have not confirmed its presence in these regions."

Introduced

Cowie et al. (2017) report the nonnative range of *P. maculata* to include the following countries: Cambodia, China, Israel, Japan, Malaysia, Pakistan, the Philippines, Singapore, South Korea, Spain, Thailand, and Vietnam. This list excludes records from captivity and artificial thermal outflows.

From Cowie et al. (2017):

"Roll et al. (2009) reported […] *P. maculata* (as '*insularum*') […] associated with human dominated habitats in Israel, but the identifications need verification."

Cowie (2015) states that this species has also been introduced to Belgium (only in pet trade, not in the wild), Indonesia, and New Zealand. Similarly, EPPO (2024) includes New Zealand within the introduced range.

From Cowie (2015):

"Although it is clear that *P. canaliculata* was first introduced to the region (to Taiwan) in about 1979 or 1980, *P. maculata* has not been demonstrated rigorously as ever having been present in Taiwan (Hayes et al., 2008)."

Means of Introduction Outside the United States

From Yang et al. (2018):

"[…] *P. maculata* was introduced to Asia from Brazil and Argentina independently [Hayes et al. 2008]."

From Cowie (2015):

"Due to the confusion in species identification, it is impossible to determine exactly when *P. maculata* was initially introduced to Asia, much less into individual countries."

"The primary mode of spread has probably been deliberate introduction to new areas by people who see it as a potential source of food, generally not distinguishing it from *P. canaliculata*. Although usually confined initially to aquaculture facilities, the snails either escape or are deliberately released into agricultural or natural wetlands. This has happened despite knowledge of the serious pest status of *Pomacea* spp. in areas already invaded. It has also been reported as having been introduced by the pet trade, perhaps more commonly than *P. canaliculata*, although the main ampullariid in the pet trade is *P. diffusa*. Once introduced, it is further possible that it spreads naturally by floating downstream, to a limited extent by crawling upstream, during flooding, and even attached to birds, as has been reported for *P. canaliculata* in Hawaii (Levin et al., 2006). People may also move it around accidentally; for instance, eggs can be transported on boats (EFSA Panel on Plant Health., 2012) […]"

Short Description

From Hayes et al. (2012):

"Shell: Shell globose, thick, yellowish brown, occasionally malleate (predominantly in Brazilian specimens), but generally smooth with fine axial growth lines and frequent periodic growth arrests, […]; spiral bands variable in colour (reddish to green–brown or dark brown) and thickness, when present; periostracum thick, variable in colour from yellow–green to greenish brown, or dark chestnut; shell comprising five or six whorls on average, increasing rapidly in size, separated by deep suture; shoulder angulate; spire height generally low, variable, with ratio of spire height to overall shell height ranging from 0.026 to 0.114; umbilicus narrow, moderately deep; aperture large, width variable, generally ovoid; inside of pallial lip of shell light yellow to reddish orange."

"External anatomy: Operculum corneous, evenly thick, inflexible, dark brown, tightly sealing entire aperture; sexually dimorphic, uniformly concave in females, concave at nucleus becoming convex toward margins in males; nucleus eccentric, displaced towards columellar edge, with concentric growth lines; inner surface smooth, attachment scar ovoid, near columellar […]. Foot oval, elongate, flattened, with squarish anterior edge, slight constriction separating propodium from mesopodium; anterior pedal gland running along anterior edge of propodium, opening to deep groove. Cephalic tentacles long, tapering, highly extensible, with large ocular peduncles at outer bases. Snout short, squarish, with lateral, anterior tips elaborated into long tapering labial palps. Neck modified on right into broad, short, slightly concave nuchal lobe, on left into long, enrolled, extensible siphon […]."

Biology

From Cowie (2015):

"*P. maculata* has separate sexes with female size typically exceeding male size. Fertilization occurs internally, followed by oviparous development. Barnes et al. (2008) described the reproductive behaviour and fecundity of *P. maculata* (referred to as *P. insularum*). Female and male snails copulate for several minutes, if not hours. The time needed for egg development is uncertain. The female crawls out of the water onto an emergent substrate and lays a clutch of pink eggs. Burks et al. (2010) noted that *P. maculata* in Texas laid a disproportional number of clutches on riparian vegetation, specifically taro (*Colocasia esculenta*). In laboratory experiments eggs were laid on natural substrates (i.e. plants and wood) in preference to artificial substrates (Kyle et al., 2011). Nonetheless, egg clutches are laid on all sorts of substrates that can support the weight of the female snail (emergent plants, rocks, bridge supports, etc.). Kyle et al. (2011) found no clear relationship between female size and clutch size."

"In Texas, with a warm temperate climate, females tend to start laying clutches near the end of spring or start of summer and continue throughout summer and the warmer months of autumn. Seasonal patterns have not been studied in the native range of *P. maculata*. No study has yet documented the potential or limitations for reproduction in the species but anecdotal observations suggest that mature female snails can lay one clutch every 7-10 days, with clutch size ranging widely but averaging over a thousand eggs per clutch (Barnes et al., 2008; Burks et al., 2010). Their reproductive capacity certainly exceeds that reported for other *Pomacea* species (Cowie, 2002). Viable clutches usually take 10-14 days to hatch (Barnes et al., 2008; Horn et al., 2008). The colour of the eggs starts off as a vibrant pink and then fades to light pink, grey and then eventually white as the oxidative proteins break down and the clutches start to hatch. Eggs are laid noticeably above the water line, from a few centimetres but generally higher and up to ~2 metres. Immersion of the eggs, especially for extensive periods, reduces hatching success. Even without water stress, not all clutches hatch fully and some fail to hatch at all, perhaps indicating incomplete fertilization. However, given its success as an invasive alien species it is not surprising that the majority of clutches display high hatching success, often 70% or more (Barnes et al., 2008). Hatchlings (~1 mm in width) then fall into the water and attempt to adhere to some type of substrate. Hatchlings are likely to rely on detritus and algal-based resources for food, although they also readily consume lettuce in the laboratory. They may also use leftover egg material as an initial resource."

"Burlakova et al. (2010) best described the invasive populations of *P. maculata* in a study conducted in southeastern Texas. In permanent habitats, such as ponds and lakes, they observed low densities (fewer than two snails per square meter), stable populations, and the same size structure through the year. […] In contrast, ephemeral agricultural habitats contained extremely high densities (>130 snails per square meter), and furthermore, snail size and numbers varied through time, both peaking in autumn."

From Morningstar and Jordan (2024):

"This species is not cold tolerant and will burry [sic] themselves in sediment to overwinter in temperate climates where they are introduced (Matsukura et al. 2016). *Pomacea maculata*, like all applesnails (Ampullridae [sic]), have an operculum, which they can use to seal their shells (Hayes et al 2012; Thompson 1999)."

"This species feeds mainly on vegetation but has been shown to be an opportunistic omnivore in laboratory settings (Carter, unpublished in Burks et al. 2017)."

Human Uses

From Cowie (2015):

"The aquaculture industry first transported apple snails, both *P. maculata* and *P. canaliculata*, from South America to Asia as potential human food sources (Mochida, 1991; Naylor, 1996)."

"In general, *Pomacea* were not well liked as a food in Asia and markets did not develop (e.g. Wada, 1997; Cheng and Kao, 2006; Preap, 2006; Wada, 2006; Yang et al., 2006; Yin et al., 2006) […] However, once these aquaculture efforts generally failed, snails were released or escaped, leading to the spread of apple snails throughout much of Southeast Asia. Deliberate introduction for food may therefore now be rare."

"*P. maculata* has been detected in the pet trade in Belgium (Hayes et al., 2008) and its presence in both Israel (Roll et al., [2009]) and Spain (EFSA Panel on Plant Health, 2012) is thought to have been due to introductions via the aquarium trade."

Cowie (2015) reports the following list of human uses for *P. maculata*: botanical garden/zoo, pet/aquarium trade, research model, human food, bait/attractant, and use of shell material.

Diseases

No information was found associating *Pomacea maculata* with any diseases listed by the World Organisation of Animal Health (2024).

From Teem et al. (2013):

"This species can serve as a host for the rat lungworm, *Angiostrongylus cantonensis* [Chen 1935], a parasite that can cause disease in people who consume infected mollusks."

From Pinto et al. (2015):

"For a survey of parasites of *Pomacea maculata*, snails were collected from the municipality of São Vicente Férrer, state of Maranhão, northeastern Brazil. In the present study, the xiphidiocercariae shed from these snails were used in the experimental infection of the water bug *Belostoma plebejum*. The insect mortality was observed 30 days post-infection, and the metacercariae recovered in the body cavity of *B. plebejum* were identified as *Stomylotrema* *gratiosus*. This is the first report of an ampullariid snail as intermediate host of stomylotrematid trematodes."

Threat to Humans

From Teem et al. (2013):

"This mollusk serves as an intermediate host of the rat lungworm parasite (*Angiostrongylus cantonensis*), which can cause eosinophilic meningitis in humans who consume infected mollusks. A PCR-based detection assay was used to test nonindigenous apple snails for the rat lungworm parasite in Louisiana, Texas, Mississippi, and Florida. Only apple snails obtained from the New Orleans, Louisiana, area tested positive for the parasite. These results provide the first evidence that *Angiostrongylus cantonensis* does occur in nonindigenous apple snails in the southeastern United States."

From Cowie (2015):

"*P. maculata* can impact many plant species. It can directly affect two aquatic crops: taro (*Colocasia esculenta*) and rice (*Oryza sativa*), but probably others."

From Arfan et al. (2015):

"[*Pomacea* spp.] are also vectors of parasitic *Angiostrongylus* nematodes and cause infection of rice workers through cuts on their feet from the sharp edges of shells killed by pesticides (Horgan et al., 2014; Nghiem et al., 2013)."

3 Impacts of Introductions

From Lucero and Wilson (2023):

"It [*Pomacea maculata*] has emerged as an agricultural pest in rice production regions of invaded territory. Its presence in rice production systems causes estimated economic losses of up to US$2.1 billion per year in the Philippines, Thailand, and Vietnam combined (Arfan et al., 2015). Over the last two decades, *P. maculata* has established itself in Louisiana, but has only been infesting rice and crawfish farms in the state since 2018 (Wilson et al., 2020). In rice, apple snails can consume seedlings and cause significant decreases in total production (Litsinger and Estano 1993). In production of crawfish, *Procambarus clarkii* (Decapoda: Cambaridae), large apple snails may block crawfish trap entrances, and smaller snails can accumulate inside the traps in large quantities reducing crawfish capture (Wilson et al., 2020). The dry planting of rice in Louisiana has limited the snails' impact to rice production relative to other regions. However, crawfish production has been severely disrupted in snail-infested farms as some farmers have been forced to stop fishing and drain their ponds."

From O'Neil et al. (2023):

"*Pomacea maculata* (previously known as *P. insularum*), a widespread invader, is the most fecund and potentially destructive apple snail species given its body size, reproductive capacity, and plasticity in life history traits (Barnes et al., 2008). For years, *P. maculata* was misidentified as *P. canaliculata* and thus research is needed to distinguish *P. maculata*'s unique ecological effects on wetlands (Howells et al., 2006). For example, in laboratory feeding trials, *P. maculata* and *P. canaliculata* had similar plant preferences and total biomass consumption, but *P. maculata* had much higher growth and conversion efficiencies with lower mortality, and thus presumably greater destructive ecological effects (Morrison and Hay, 2011)."

"In this research, we conducted a mesocosm experiment to investigate ecological consequences of *P. maculata* invasion in subtropical wetlands in Florida, USA (Swain et al., 2013)."

"Our study demonstrates that *P. maculata* exerted direct and cascading ecological effects across the plant-water-soil interface […] by altering plant communities and nutrient cycling. While most snail effects were consistent across wetland types, certain responses (e.g., chla [chlorophyll a concentration]) were divergent, suggesting that management strategies may mediate how invasive apple snails impact wetland ecosystems. In tandem, our findings are relevant for managed and natural wetlands that are experiencing similar apple snail invasions across the globe and imply that *P. maculata* invasion may also compromise vital wetland ecosystem services."

From Monette et al. (2016):

"This study examined the differences between adult life-stage native *Pomacea paludosa* (Florida Applesnail) and adult non-native *Pomacea maculata* (Giant Applesnail) grazing behavior and rates on *Vallisneria americana* (Tapegrass), a plant of restoration importance, to assess the potential ecological impact. […] The observed grazing behavior of adult life-stage specimens of the 2 species differed substantially, with Florida Applesnail grazing along blade edges and Giant Applesnail completely cutting off blades from their bases. These results also show that Giant Applesnail consumed and removed more Tapegrass biomass at a faster rate than the native Florida Applesnail. The introduction of Giant Applesnail, with its greater herbivory and total biomass damage rates over the native apple snail and behavior that removes leaf blades, may shift competitive interactions in Tapegrass communities under pressure from non-native plant invaders such as *Hydrilla verticillata* (Waterthyme)."

From Cattau et al. (2010):

"Despite acknowledging that exotic species can exhibit tremendous influence over native populations, few case studies have clearly demonstrated the effects of exotic prey species on native predators. We examined the effects of the recently introduced island apple snail (*Pomacea insularum* [synonym of *P. maculata*]) on the foraging behavior and energetics of the endangered snail kite (*Rostrhamus sociabilis plumbeus*) in Florida. […] When foraging for *P. insularum*, snail kites dropped a greater proportion of snails, and they experienced increased handling times and decreased consumption rates; however, kites foraging for *P. insularum* also spent a smaller proportion of the day in flight. Estimates of net daily energy balances between kites feeding on *P. insularum* versus [native] *P. paludosa* were comparable for adults, but juveniles experienced energetic deficiencies when feeding on the exotic snail. Due to this discrepancy, we hypothesize that wetlands invaded by *P. insularum*, such as Lake Tohopekaliga, may function as ecological traps for the snail kite in Florida by attracting breeding adults but simultaneously depressing juvenile survival."

The following sources describe potential negative impacts of *Pomacea maculata* tested in a laboratory setting:

From Dodd et al. (2016):

"Avian vacuolar myelinopathy (AVM) is a neurologic disease causing recurrent mortality of Bald Eagles (*Haliaeetus leucocephalus*) and American Coots (*Fulica americana*) at reservoirs and small impoundments in the southern US. […] Previous studies link the disease to an uncharacterized toxin produced by a recently described cyanobacterium, *Aetokthonos hydrillicola* gen. et sp. nov. that grows epiphytically on submerged aquatic vegetation (SAV). The toxin accumulates, likely in the gastrointestinal tract of waterbirds that consume SAV, and birds of prey are exposed when feeding on the moribund waterbirds. *Aetokthonos hydrillicola* has been identified in all reservoirs where AVM deaths have occurred and was identified growing abundantly on an exotic SAV [submerged aquatic vegetation] hydrilla (*Hydrilla verticillata*) in Lake Tohopekaliga (Toho) in central Florida. Toho supports a breeding population of a federally endangered raptor, the Florida Snail Kite (*Rostrhamus sociabilis*) and a dense infestation of an exotic herbivorous aquatic snail, the island applesnail (*Pomacea maculata*), a primary source of food for resident Snail Kites. We investigated the potential for transmission in a new food chain and, in laboratory feeding trials, confirmed that the AVM toxin was present in the hydrilla/*A. hydrillicola* matrix collected from Toho. Additionally, laboratory birds that were fed apple snails feeding on hydrilla/*A. hydrillicola* material from a confirmed AVM site displayed clinical signs (3/5), and all five developed brain lesions unique to AVM. This documentation of AVM toxin in central Florida and the demonstration of AVM toxin transfer through invertebrates indicate a significant risk to the already diminished population of endangered Snail Kites."

From Posch et al. (2013):

"The Florida apple snail, *Pomacea paludosa* (Say, 1829), is the only native *Pomacea* species in North America. Due to alterations in wetland hydrologic conditions, populations have been declining for several years (Darby, Bennetts & Percival, 2008). This reduction has had a negative impact on the federally endangered snail kite, *Rostrhamus sociabilis*, which feed predominately on apple snails (Stevens et al., 2002). […] In July 2011, 10 *P. maculata* egg clutches were collected from a drainage canal in Indian River County, Florida and 30 native snail egg clutches were collected from the Fort Drum Wildlife Management Area, Florida. Eggs from both species were allowed to hatch naturally in the laboratory, and hatching occurred within 1–2 weeks of collection. […] Snails were randomly selected and stocked into one of five treatment ratios […] Increased presence of *P. maculata* resulted in lower growth rates in native [*P. paludosa*] snails, especially in treatments where exotic snails were dominant. Suppressed growth has also been recorded when juvenile native snails were stocked with adult *P. maculata* at varying densities (Conner et al., 2008). These results suggest that native snails may be susceptible to interspecific competition with the exotics, as has been demonstrated before with other snail species (Riley, Dybdahl & Hall, 2008). It is thought that enhanced feeding rates and higher conversion efficiencies may give the exotic *Pomacea* snails a competitive edge (Morrison & Hay, 2011). In our study, it is unknown whether or not the exotic snails consumed a greater proportion of the food. However, there is currently no evidence that *P. maculata* is displacing *P. paludosa* through resource competition (Pomacea Project, Inc., 2013)."

From Carter et al. (2018):

"Even when snails were provided with an alternative preferred food item from their regular diet, they still ate frog eggs. We have demonstrated that Giant Apple Snails will eat frog eggs under laboratory conditions. It remains to be demonstrated, but it is very likely that Giant Apple Snail depredate amphibian egg in natural settings, […]"

The following U.S. States regulate the possession, transport, or sale of species in the genus *Pomacea* (sometimes with exception for *P. bridgesii*): Arizona (Arizona Office of the Secretary of State 2013), Georgia (State of Georgia 2023), Hawaii (Hawaii Department of Agriculture 2020), Louisiana (Louisiana State Legislature 2019), North Carolina (North Carolina Office of Administrative Hearings 2019), and Texas (Texas Parks and Wildlife 2020). The U.S. Department of Agriculture regulates species within the genus *Pomacea* at the federal level (USDA-APHIS 2024). A more detailed description of regulations can be found in Section 1.

4 History of Invasiveness

The History of Invasiveness for *Pomacea maculata* is classified as High. This species has become widely established outside of its native range where released. Its foraging behavior has contributed to substantial economic losses for rice agriculture in Southeast Asia. In mesocosm experiments, it disrupts wetland plant communities, nutrient cycling, and other wetland ecosystem services. *P. maculata* has been implicated in disrupting foraging behavior of the federally endangered Florida Snail Kite and is also capable of passing a natural environmental neurotoxin to birds when consumed. This species is also an intermediate host for a meningitis-causing parasite in humans. Where introduced, *P. maculata* rapidly consumes native plants, leading to ecosystem alterations. *P. maculata* has a long history of introduction through aquaculture use and aquarium release.

5 Global Distribution

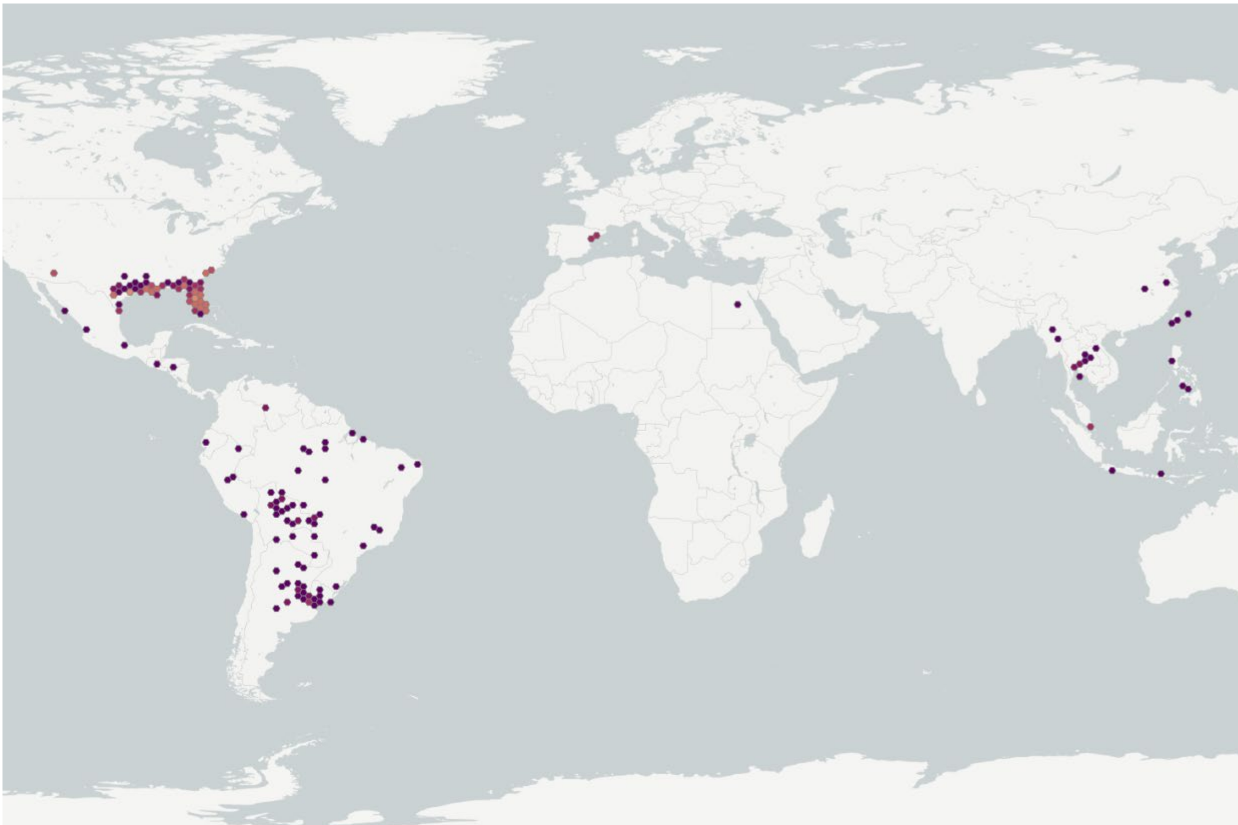

Figure 1. Reported global distribution of *Pomacea maculata*. Map from GBIF Secretariat (2024). Observations are reported from Argentina, Bolivia, Brazil, China, Ecuador, Egypt, El Salvador, Honduras, Indonesia, Japan, Mexico, Paraguay, Peru, Philippines, Singapore, Spain, Taiwan, Thailand, Uruguay, the United States, and Colombia. Occurrences in Taiwan, Myanmar, Egypt, Mexico, El Salvador, Honduras, Colombia, Ecuador, and Peru could not be verified as established populations of *P. maculata* and were excluded from the selection of source points for climate matching. Occurrences in Argentina, Bolivia, and Brazil were also excluded from the selection of climate matching source points if they were located outside the boundaries of the range of *P. maculata* depicted in Hayes et al. (2012).

No georeferenced occurrences were available for parts of the established range of *P. maculata* in Cambodia, New Zealand, Pakistan, South Korea, or Vietnam.

6 Distribution Within the United States

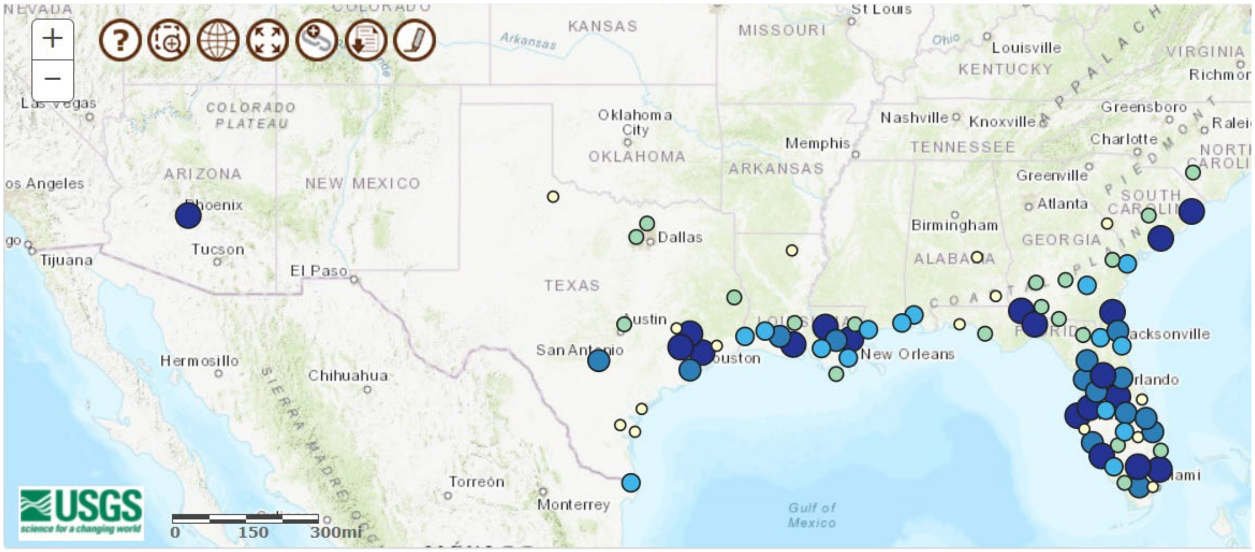

Figure 2. Reported distribution of *Pomacea maculata* in the United States. Map from Morningstar and Jordon (2024). Observations are reported from Alabama, Arizona, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas.

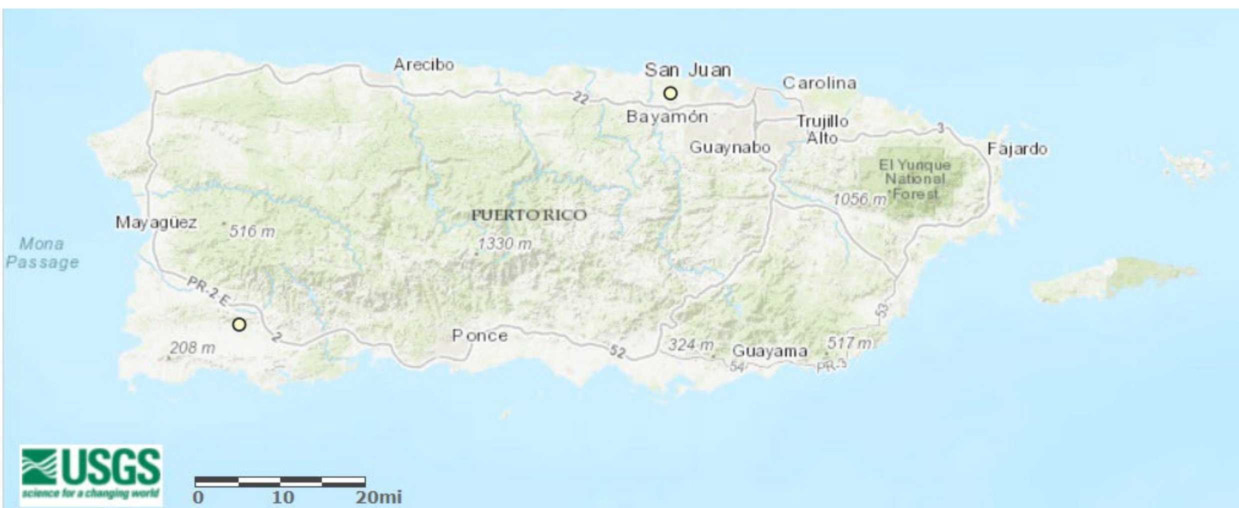

Figure 3. Reported distribution of *Pomacea maculata* in Puerto Rico. Map from Morningstar and Jordon (2024). Observations are in the southwestern and northeastern regions of Puerto Rico.

7 Climate Matching

Summary of Climate Matching Analysis

The highest climate match scores for *Pomacea maculata* in the contiguous United States occurred where this species is already established and in surrounding areas. These areas include parts of Arizona, Nevada, and southeastern California, and from eastern Texas to the southern Mid-Atlantic region along the Gulf of Mexico and Atlantic coasts. The southeastern United States had a high climate match in general. The lowest scores were found in the Pacific Northwest, especially on the Olympic Peninsula of Washington and along the Cascade and Sierra-Nevada mountain ranges. Other areas of low match were found along the rest of the northwest Pacific Coast, in the Rocky Mountains, and along the border with Canada in the north-central and northeast regions of the country. The rest of the contiguous United States recorded medium matches in general. The overall Climate 6 score (Sanders et al. 2023; 16 climate variables; Euclidean distance) for the contiguous United States was 0.589 indicating that Yes, there is establishment concern for this species. The Climate 6 score is calculated as: (count of target points with scores ≥ 6)/(count of all target points). Establishment concern is warranted for Climate 6 scores greater than or equal to 0.002 based on an analysis of the establishment success of 356 nonnative aquatic species introduced to the United States (USFWS 2024).

Projected climate matches in the contiguous United States under future climate scenarios are available for *Pomacea maculata* (see Appendix). These projected climate matches are provided as additional context for the reader; future climate scenarios are not factored into the Overall Risk Assessment Category.

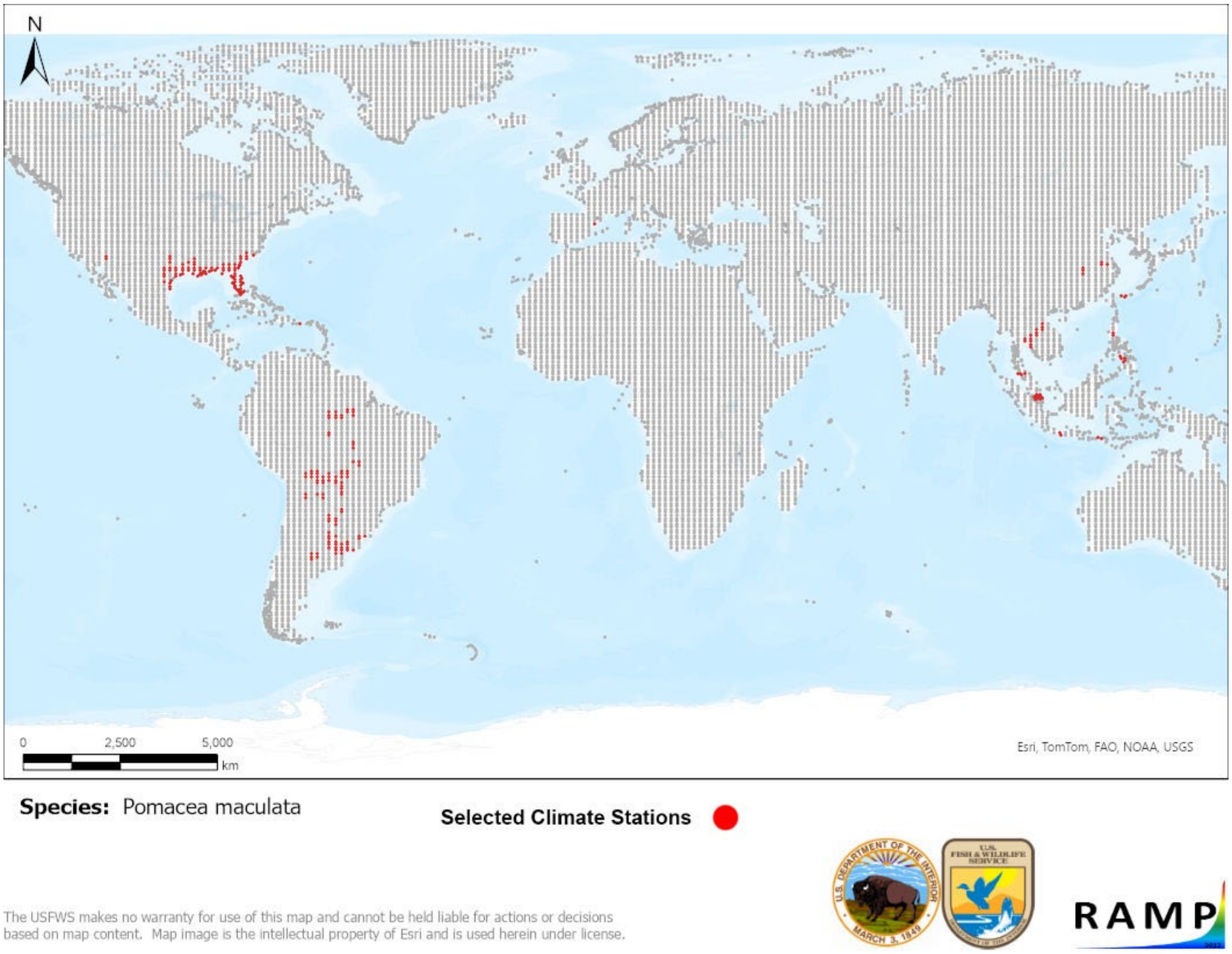

Figure 4. RAMP (Sanders et al. 2023) source map showing weather stations throughout the world selected as source locations (red; Argentina, Bolivia, Brazil, Japan, Paraguay, Singapore, Spain, Thailand, Uruguay, the continental United States, China, Philippines, Indonesia, Malaysia, and Puerto Rico) and non-source locations (gray) for *Pomacea maculata* climate matching. Source locations from GBIF Secretariat (2024) and Morningstar and Jordon (2024). Selected source locations are within 100 km of one or more species occurrences, and do not necessarily represent the locations of occurrences themselves.

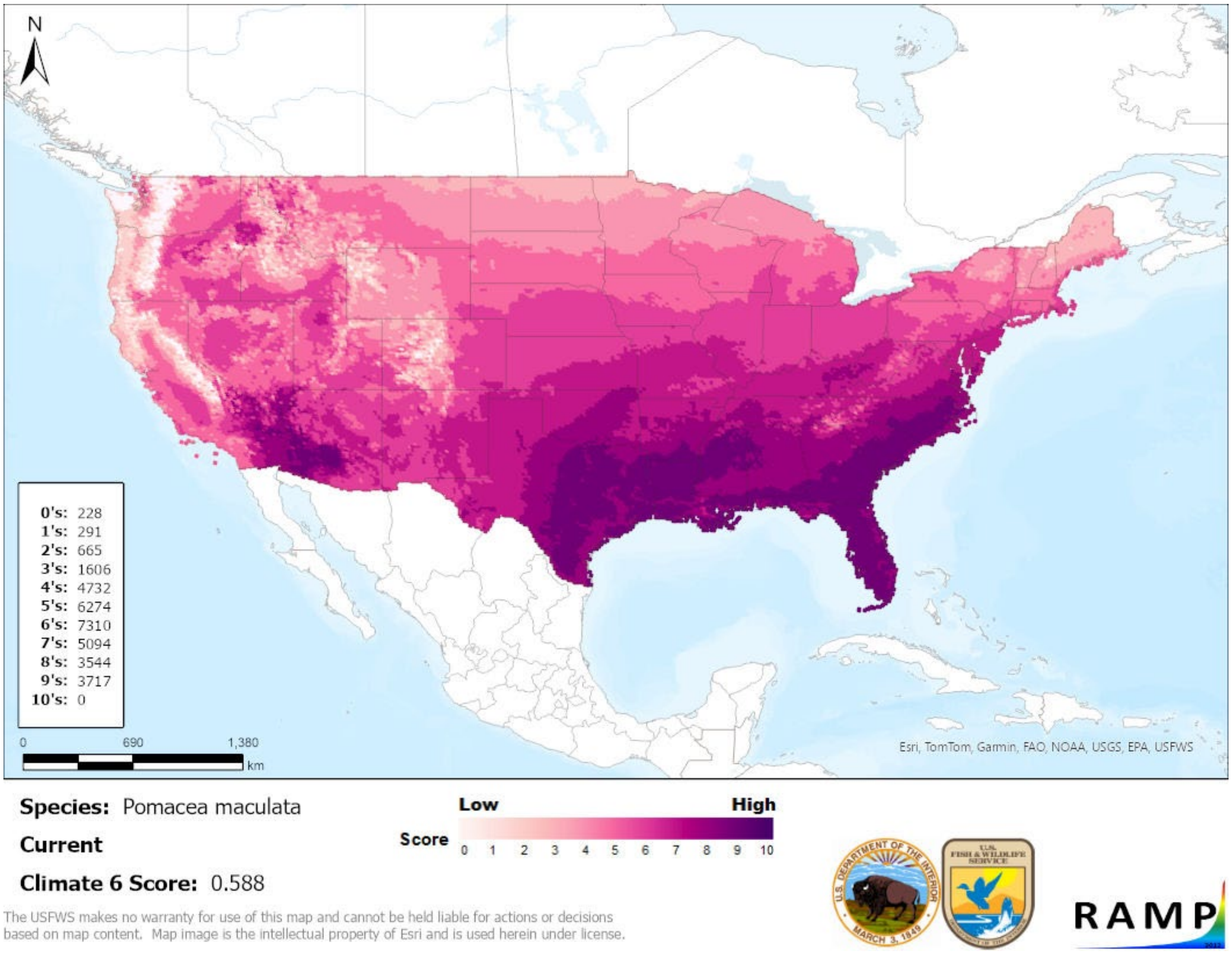

Figure 5. Map of RAMP (Sanders et al. 2023) climate matches for *Pomacea maculata* in the contiguous United States based on source locations reported by GBIF Secretariat (2024) and Morningstar and Jordon (2024). Counts of climate match scores are tabulated on the left. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

8 Certainty of Assessment

The Certainty of Assessment for *Pomacea maculata* is classified as High. There is quality information available about the biology and ecology of *Pomacea maculata*. Multiple reliable records of introduction and establishment were found. Information on negative impacts and History of Invasiveness were from peer-reviewed sources. Although there have been misidentifications of *P. maculata* in literature, recent genetic studies have clarified the native and introduced range of this species to give this ERSS a High certainty.

9 Risk Assessment

Summary of Risk to the Contiguous United States

Pomacea maculata, Giant Applesnail, is an aquatic snail species that is native to the La Plata and Amazon basins in Argentina, Paraguay, Uruguay and Brazil. It has been used in the aquaculture and aquarium industries, which has led to its introduction in Asia and the Southeastern United

States. *P. maculata* is also established in Spain and New Zealand. This species has been commonly misidentified with a congener, *Pomacea canaliculata*, a similar species with an overlapping distribution range, but recent genetic work has clarified the distinctiveness of these two species. The genus *Pomacea* is regulated in Arizona, Georgia, Hawaii, Louisiana, North Carolina, and Texas, which results in this species being prohibited or requiring a license or permit to be obtained in these states. The U.S. Department of Agriculture has also placed federal regulations on the genus *Pomacea*. Peer-reviewed literature reports that *P. maculata* has become invasive in the United States and has negative impacts in some introduced locations. The species is damaging to crayfish aquaculture in the United States and to rice agriculture in Southeast Asia. In mesocosm experiments, *P. maculata* disrupts wetland plant communities, nutrient cycling, and other wetland ecosystem services. It decreases feeding efficiency of juvenile Snail Kites (*Rostrhamus sociabilis plumbeus*), a federally endangered bird species. It can transfer a deadly toxin to birds, potentially including the Snail Kite. *P. maculata* is also a host for *Angiostrongylus cantonensis*, a nematode parasite capable of infecting humans. Competition with *P. maculata* is associated with decreased growth rates of *P. paludosa,* the native Florida Applesnail. The climate matching analysis for the contiguous United States indicates establishment concern for this species, especially in areas close to where it is already established in the Southeast and in Arizona. The Certainty of Assessment for this ERSS is classified as High due to a large amount of reliable scientific information showing negative impacts of this species' introduction. The Overall Risk Assessment Category for *P. maculata* in the contiguous United States is High.

Assessment Elements

- **History of Invasiveness (see Section 4): High**
- **Establishment Concern (see Section 7): Yes**
- **Certainty of Assessment (see Section 8): High**
- **Remarks, Important additional information: Host of the rat lungworm, which can be transferred to and infect humans.**
- **Overall Risk Assessment Category: High**

10 Literature Cited

Note: The following references were accessed for this ERSS. References cited within quoted text but not accessed are included below in section 11.

Arfan AG, Muhamad R, Omar D, Nor Azwady AA, Manjeri G. 2015. Comparative life cycle studies of *Pomacea maculata* and *Pomacea canaliculata* on rice (*Oryza sativa*). Pakistan Journal of Agricultural Science 52(4):1075–1079.

Arizona Office of the Secretary of State. 2013. Live wildlife. Arizona Administrative Code, Game and Fish Commission, Title 12, Chapter 4, Article 4.

Carter J, Johnson D, Merino S. 2018. Exotic invasive *Pomacea maculata* (giant apple snail) will depredate eggs of frog and toad species of the southeastern US. Southeastern Naturalist 17(3):470–475.

Cattau CE, Martin J, Kitchens WM. 2010. Effects of an exotic prey species on a native specialist: example of the snail kite. Biological Conservation 143(2):513–520.

Cowie R. 2015. *Pomacea maculata*. In CABI Compendium. Wallingford, United Kingdom: CAB International. Available: https://www.cabidigitallibrary.org/doi/10.1079/cabicompendium.116486 (January 2024).

Cowie RH, Hayes KA, Strong EE, Thiengo SC. 2017. Non-native apple snails: systematics, distribution, invasion history and reasons for introduction. Pages 3–32 in Joshi RC, Cowie RH, Sebastian LS, editors. Biology and management of invasive apple snails. Science City of Muñoz, Philippines: Philippine Rice Research Institute.

Dodd SR, Haynie RS, Williams SM, Wilde SB. 2016. Alternate food-chain transfer of the toxin linked to avian vacuolar myelinopathy and implications for the endangered Florida snail kite (*Rostrhamus sociabilis*). Journal of Wildlife Diseases 52(2):335–344.

[EPPO] European and Mediterranean Plant Protection Organization. 2024. *Pomacea maculata*. EPPO datasheets on pests recommended for regulation. Paris: European and Mediterranean Plant Protection Organization. Available: https://gd.eppo.int/taxon/POMAIN/datasheet (June 2024).

GBIF Secretariat. 2024. GBIF backbone taxonomy: *Pomacea maculata*. Copenhagen: Global Biodiversity Information Facility. Available: https://www.gbif.org/species/7532642 (January 2024).

Ghesquiere S. 2021. Apple snails. Available: https://www.applesnail.net/ (January 2024).

Hawaii Department of Agriculture. 2020. Animal guidelines. Honolulu, Hawaii: Hawaii Department of Agriculture, Plant Industry Division. Available: http://hdoa.hawaii.gov/pi/pq/import-program/animal-guidelines/ (November 2020).

Hayes KA, Cowie RH, Thiengo SC, Strong EE. 2012. Comparing apples with apples: clarifying the identities of two highly invasive Neotropical Ampullaridae (Caenogastropoda). Zoological Journal of the Linnean Society 166(4):723–753.

Louisiana State Legislature. 2019. Exotic fish; importation, sale, and possession of certain exotic species prohibited; permit required; penalty. Louisiana Revised Statutes, Title 56, Section 319.

Lucero JM, Wilson BE. 2023. Regional expansion and chemical control for invasive apple snails (*Pomacea maculata*) in Louisiana rice and crawfish production systems. Crop Protection 164:106–127.

MolluscaBase editors. 2024. *Pomacea maculata* Perry, 1810. World Register of Marine Species. Available: https://www.marinespecies.org/aphia.php?p=taxdetails&id=737473 (January 2024).

Monette D, Ewe S, Markwith SH. 2016. Effects of the consumption behavior of adult *Pomacea maculata* and *Pomacea paludosa* on *Vallisneria americana*. Southeastern Naturalist 15(4):689–696.

Morningstar CR, Jordon A. 2024. *Pomacea maculata* (giant applesnail). Nonindigenous Aquatic Species Database. Gainesville, Florida: U.S. Geological Survey. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2633 (January 2024).

North Carolina Office of Administrative Hearings. 2019. Possession of certain fishes. North Carolina Administrative Code, Title 15A, Chapter 10, SubChapter C, Section 211.

O'Neil CM, Guo Y, Pierre S, Boughton EH, Qiu J. 2023. Invasive snails alter multiple ecosystem functions in subtropical wetlands. Science of The Total Environment 864:160939.

PickFish LLC. 2022. Apple Snails (*Pomacea maculata*) – 5 small mixed colors. PickFish Pets. Available: https://www.pickfishpets.com/product/apple-snails-pomacea-maculata-5-small-mixed-colors/ (January 2024).

Pinto HA, Cantanhede SP, Thiengo SC, de Melo AL, Fernandez MA. 2015. The apple snail *Pomacea maculata* (Caenogastropoda: Ampullariidae) as the intermediate host of *Stomylotrema gratiosus* (Trematoda: Stomylotrematidae) in Brazil: the first report of a mollusc host of a stomylotrematid trematode. The Journal of Parasitology 101(2):134–139.

Posch H, Garr AL, Reynolds E. 2013. The presence of an exotic snail, *Pomacea maculata*, inhibits growth of juvenile Florida apple snails, *Pomacea paludosa*. Journal of Molluscan Studies 79:383–385.

Sanders S, Castiglione C, Hoff M. 2023. Risk Assessment Mapping Program: RAMP. Version 5.0. U.S. Fish and Wildlife Service.

State of Georgia. 2023. Wild animals. Rules and Regulations of the State of Georgia subject 391-4-8.

Teem JL, Qvarnstrom Y, Bishop HS, da Silva AJ, Carter J, White-Mclean J, Smith T. 2013. The occurrence of the rat lungworm, *Angiostrongylus cantonensis*, in nonindigenous snails in the Gulf of Mexico region of the United States. Hawai‘i Journal of Medicine & Public Health 72(6 Supplement 2):11–14.

Texas Parks and Wildlife. 2020. Invasive, prohibited and exotic species. Austin, Texas: Texas Parks and Wildlife. Available: https://tpwd.texas.gov/huntwild/wild/species/exotic/prohibited_aquatic.phtml (November 2020).

[USDA-APHIS] U.S. Department of Agriculture- Animal and Plant Health Inspection Service. 2023. Snails and slugs. Available: https://www.aphis.usda.gov/aphis/ourfocus/planthealth/sa_import/sa_permits/plant-pests/sa_snails_slugs/ct_snails_slugs (January 2024).

[USFWS] U.S. Fish and Wildlife Service. 2024. Standard operating procedure: how to prepare an "Ecological Risk Screening Summary." Version 3.

World Organisation for Animal Health. 2024. Animal diseases. Paris: World Organisation for Animal Health. Available: https://www.woah.org/en/what-we-do/animal-health-and-welfare/animal-diseases/ (January 2024).

Yang QQ, Liu SW, He C, Yu XP. 2018. Distribution and the origin of invasive apple snails, *Pomacea canaliculata* and *P. maculata* (Gastropoda: Ampullariidae) in China. Scientific Reports 8:1–8.

11 Literature Cited in Quoted Material

Note: The following references are cited within quoted text within this ERSS, but were not accessed for its preparation. They are included here to provide the reader with more information.

Advocate staff report. 2018. Invasive snail found in Acadiana crawfish pond; pest also poses threat to rice plants. Baton Rouge, Louisiana: The Acadiana Advocate. Available: http://www.theadvocate.com/acadiana/news/article_a44e0de0-1039-11e8-ab97-efed1305c5da.html.

Andre KB, Lopez MA. 2013. Species identification from archived snail shells via genetic analysis: a method for DNA extraction from empty shells. Molluscan Research 3:1–5.

Arnold TE, Brenner M, Curtis JH, Dutton A, Baker SM, Escobar JH, Ortega CA. 2014. Application of stable isotopes (δ18O) to determine growth patterns of the invasive gastropod *Pomacea maculata* in Florida Lakes. The Florida Scientist 77:126–143.

Barnes MA, Fordham RK, Burks RL, Hand JJ. 2008. Fecundity of the exotic applesnail, *Pomacea insularum*. Journal of the North American Benthological Society 27:738–745.

Bernatis JL. 2014. Morphology, ecophysiology, and impacts of nonindigenous *Pomacea* in Florida. Doctoral dissertation. Gainesville: University of Florida.

Burks RL, Bernatis J, Byers JE, Carter J, Martin CW, McDowell WG, Van Dyke J. 2017. Identity, reproductive potential, distribution, ecology and management of invasive *Pomacea maculata* in the southern United States. Pages 293–333 in Joshi RC, Cowie RH, Sebastian LS, editors. Biology and management of invasive apple snails. Science City of Muñoz, Philippines: Philippine Rice Research Institute.

Burks RL, Kyle CH, Trawick MK. 2010. Pink eggs and snails: field oviposition patterns of an invasive snail, *Pomacea insularum*, indicate a preference for an invasive macrophyte. Hydrobiologia 646:243–251.

Burlakova LE, Padilla DK, Karatayev AY, Hollas DN, Cartwright LD, Nichol KD. 2010. Differences in population dynamics and potential impacts of a freshwater invader driven by temporal habitat stability. Biological Invasions 12(4):927–941.

Byers JE, McDowell WG, Dodd SR, Haynie RS, Pintor LM, Wilde SB. 2013. Climate and pH predict the potential range of the invasive apple snail (*Pomacea insularum*) in the southeastern United States. PLoS ONE 8(2):e56812.

Carlsson NOL, Lacoursière JO. 2005. Herbivory on aquatic vascular plants by the introduced golden apple snail (*Pomacea canaliculata*) in Lao PDR. Biological Invasions 7:233–241.

Chen H. 1935. A new pulmonary nematode of rats, *Pulmonema cantonensis* ng, nsp from Canton. Annals of Parasitology 13:312–317.

Cheng EY, Kao C. 2006. Control of golden apple snail, *Pomacea canaliculata* (Lamarck), in Taiwan. Pages 155-167 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute.

Conner SL, Pomory CM, Darby PC. 2008. Density effects of native and exotic snails on growth in juvenile apple snails *Pomacea paludosa* (Gastropoda: Ampullariidae): a laboratory experiment. Journal of Molluscan Studies 74(4):355–362.

Cowie RH. 2002. Apple snails (Ampullariidae) as agricultural pests: their biology, impacts and management. Pages 145-192 in Barker GM, editor. Molluscs as crop pests. Wallingford, United Kingdom: CABI Publishing.

Darby PC, Bennetts RE, Percival HF. 2008. Dry down impacts on apple snail demography. Implications for wetlands water management. Wetlands 28:204–214.

EFSA Panel on Plant Health. 2012. Scientific opinion on the evaluation of the pest risk analysis on *Pomacea insularum*, the island apple snail, prepared by the Spanish Ministry of Environment and Rural and Marine Affairs. EFSA Journal 10:2552.

Gettys LA, Haller WT, Mudge CR, Koschnick TJ. 2008. Effect of temperature and feeding preference on submerged plants by the island apple snail, *Pomacea insularum* (d'Orbigny, 1839)(Ampullariidae). Veliger 50:248–254.

Glasheen PM, Burks RL, Campos SR, Hayes KA. 2020. First evidence of introgressive hybridization of apple snails (*Pomacea* spp.) in their native range. Journal of Molluscan Studies 86:96–103.

Hayes KA, Burks RL, Castro-Vazquez A, Darby PC, Heras H, Martín PR, Cowie RH. 2015. Insights from an integrated view of the biology of apple snails (Caenogastropoda: Ampullariidae). Malacologia 58:245–302.

Hayes KA, Joshi RC, Thiengo SC, Cowie RH. 2008. Out of South America: multiple origins of non-native apple snails in Asia. Diversity and Distributions 14:701–712.

Horgan FG, Stuart AM, Kudavidanage EP. 2014. Impact of invasive apple snails on the functioning and services of natural and managed wetlands. Acta Oecologica 54:90–100.

Horn KC, Johnson SD, Boles KM, Moore A, Siemann E, Gabler CA. 2008. Factors affecting hatching success of golden apple snail eggs: effects of water immersion and cannibalism. Wetlands 28(2):544–549.

Howells RG, Burlakova LE, Karatayev AY, Marfurt RK, Burks RL. 2006. Native and introduced Ampullariidae in North America: History, status, and ecology. Pages 73–112 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute.

Hylton Scott MI. 1958. Estudio morfologico y taxonomico de los ampullaridos de la Republica Argentina. Revista del Museo Argentino de Ciencias Naturales ‘Bernardino Rivadavia’ e Instituto Nacional de Investigacion de las Ciencias Naturales. Ciencias Zoológicas 3:233–333.

Joshi RC, Sebastian LS, editors. 2006. Global advances in ecology and management of golden apple snails. Muñoz, Nueva Ecija, Philippines: Philippine Rice Research Institute.

Karatayev AY, Burlakova LE, Karatayev VA, Padilla DK. 2009. Introduction, distribution, spread, and impacts of exotic freshwater gastropods in Texas. Hydrobiologia 619:181–194.

Kyle CH, Trawick MK, McDonough JP, Burks RL. 2009. Population dynamics of an established reproducing population of the invasive apple snail (*Pomacea insularum*) in suburban southeast Houston, Texas. Texas Journal of Science 61(4):323–327.

Kyle CH, Kropf AW, Burks RL. 2011. Prime waterfront real estate: apple snails choose wild taro for oviposition sites. Current Zoology 57(5):630–641.

Levin P, Cowie RH, Taylor JM, Hayes KA, Burnett KM, Ferguson CA. 2006. Apple snail invasions and the slow road to control: ecological, economic, agricultural, and cultural perspectives in Hawaii. Pages 325–335 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute (PhilRice).

Litsinger JA, Estano DB. 1993. Management of the golden apple snail *Pomacea canaliculata* (Lamarck) in rice. Crop Protection 12(5):363–370.

Lowe S, Browne M, Boudjelas S, De Poorter M. 2000. 100 of the world's worst invasive alien species: a selection from the global invasive species database. Auckland, New Zealand: The Invasive Species Specialists Group of the Species Survival Commission of the World Conservation Union.

Martin CW, Valentine JF. 2014. Tolerance of embryos and hatchlings of the invasive apple snail *Pomacea maculata* to estuarine conditions. Aquatic Ecology 48(3):321–326.

Martín PR, Estebenet AL, Cazzaniga NJ. 2001. Factors affecting the distribution of *Pomacea canaliculata* (Gastropoda: Ampullariidae) along its southernmost natural limit. Malacologia 43:13–23.

Matsukura K, Izumi Y, Yoshida K, Wada T. 2016. Cold tolerance of invasive freshwater snails, *Pomacea canaliculata*, *P. maculata*, and their hybrids helps explain their different distributions. Freshwater Biology 61:80–87.

McAskill S, Douglass J. 2017. Salinity and temperature alter *Pomacea maculata* herbivory rates on *Vallisneria americana*. Journal of Molluscan Studies 83:481–483.

Mochida O. 1991. Spread of freshwater *Pomacea* snails (Pilidae, Mollusca) from Argentina to Asia. Micronesica Supplement 3:51–62.

Morrison W, Hay M. 2011. Feeding and growth of native, exotic and non-exotic alien apple snails (Ampullariidae) in the United States: exotics eat more and grow more. Biological Invasions 13:945–955.

Mueck K, Deaton LE, Lee A, Guilbeaux T. 2018. Physiology of the apple snail *Pomacea maculata*: aestivation and overland dispersal. The Biological Bulletin 235:43–51.

Naylor R. 1996. Invasions in agriculture: assessing the cost of the golden apple snail in Asia. Ambio 25:443–448.

Neck RW, Schultz JG. 1992. First record of a living channeled applesnail, *Pomacea canaliculata* (Pilidae), from Texas. Texas Journal of Science 44:115–116.

Nghiem LTP, Soliman T, Yeo DCJ, Tan HTW, Evans TA, Mumford JD, Keller PR, Baker, Corlett RT, Carrasco LR. 2013. Economic and Environmental Impacts of Harmful Non-Indigenous Species in Southeast Asia. PLoS ONE 8:e71255.

Pomacea Project, Inc. 2013. Literature review of Florida apple snails and snail kites, and recommendations for their adaptive management. Final Report. National Park Service, Everglades National Park. Pensacola, Florida: The Pomacea Project.

Preap V, Chanty P, Bunnarith K, Hin K. 2006. The golden apple snail situation in Cambodia. Pages 267–274 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute.

Ramakrishnan V. 2007. Doctoral dissertation. Arlington: University of Texas at Arlington. [Source material did not give full citation for this reference.]

Rawlings TA, Hayes KA, Cowie RH, Collins TM. 2007. The identity, distribution, and impacts of non-native apple snails in the continental United States. BMC Evolutionary Biology 7:97.

Riley LA, Dybdahl MF, Hall BO. 2008. Exotic species impact: asymmetric interactions between exotic and endemic freshwater snails. Journal of the North American Benthological Society 27:509–520.

Roll U, Dayan T, Simberloff D, Meinis HK. 2009. Non-indigenous land and freshwater gastropods in Israel. Biological Invasions 11:1963–1972.

Stevens AJ, Welch ZC, Darby PC, Percival HF. 2002. Temperature effects on Florida applesnail activity: implications for snail kite foraging success and distribution. Wildlife Society Bulletin 30:75–81.

Swain HM, Boughton EH, Bohlen PJ, Lollis LO. 2013. Trade-offs among ecosystem services and disservices on a Florida ranch. Rangelands 35(5):75–87.

Thompson FG. 1999. An identification manual for the freshwater snails of Florida. Available: https://www.floridamuseum.ufl.edu/iz/resources/florida-snails/.

Wada T. 1997. Introduction of the apple snail *Pomacea canaliculata* and its impact on rice agriculture. Tsukuba, Japan: Proceedings of International Workshop on Biological Invasions of Ecosystems by Pests and Beneficial Organisms.

Wada T. 2006. Impact and control of introduced apple snail, *Pomacea canaliculata* (Lamarck), in Japan. Pages 181–197 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute.

Wilson et al. 2020. [Source material did not give full citation for this reference.]

Yang P-S, Chen Y-H, Lee W-C, Chen Y-H. 2006. Golden apple snail management and prevention in Taiwan. Pages 169–179 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute.

Yang QQ, He C, Liu GF, Yin CL, Xu YP, Liu SW, Yu XP. 2020. Introgressive hybridization between two non-native apple snails in China: widespread hybridization and homogenization in egg morphology. Pest Management Science 76:4231–4239.

Yang QQ, Ip JCH, Zhao XX, Li JN, Jin YJ, Yu XP, Qiu JW. 2022. Molecular analyses revealed three morphologically similar species of non-native apple snails and their patterns of distribution in freshwater wetlands of Hong Kong. Diversity and Distributions 28:97–111.

Yang QQ, Yu XP. 2019. A new species of apple snail in the genus *Pomacea* (Gastropoda: Caenogastropoda: Ampullariidae). Zoological Studies 58:e13.

Yin Y-P, Jiang H, Guo D-J, Wang Z-K. 2006. Golden apple snails in China. Pages 299–314 in Joshi RC, Sebastian LS, editors. Global advances in ecology and management of golden apple snails. Los Baños, Philippines: Philippine Rice Research Institute.

Yusa Y, Sugiura N, Wada T. 2006. Predatory potential of freshwater animals on an invasive agricultural pest, the apple snail *Pomacea canaliculata* (Gastropoda: Ampullariidae), in southern Japan. Biological Invasions 8:137-147.

Appendix

Summary of Future Climate Matching Analysis

Future climate projections represent two Shared Socioeconomic Pathways (SSP) developed by the Intergovernmental Panel on Climate Change (IPCC 2021): SSP5, in which emissions triple by the end of the century; and SSP3, in which emissions double by the end of the century. Future climate matches were based on source locations reported by GBIF Secretariat (2024) and Morningstar and Jordon (2024).

Under the future climate scenarios (figure A1), on average, high climate match for *Pomacea maculata* was projected to occur in the Appalachian Range, Gulf Coast, Mid-Atlantic, Southeast, and Southwest regions of the contiguous United States. The areas of highest match were predicted to contract noticeably over time, from 2055 to 2085, and to contract slightly from SSP3 to SSP5, while areas of slightly lower but still high match expanded northward out of the Southeast into the Great Lakes, Mid-Atlantic, and Northeast regions. The Climate 6 scores for the individual future scenario models (figure A2) ranged from a low of 0.607 (model: MPI-ESM1-2-HR, SSP5, 2085) to a high of 0.803 (model: UKESM1-0-LL, SSP5, 2085). All future scenario Climate 6 scores were above the Establishment Concern threshold, indicating that Yes, there is establishment concern for this species under future scenarios. The Climate 6 score for the current climate match (0.588, figure 5) falls below the range of scores for future projections. The time step and climate scenario with the most change relative to current conditions was SSP5, 2085, the most extreme climate change scenario. Under most time step and climate scenarios, and particularly under the 2085 time step, areas within the Great Lakes and Northeast saw a large increase in the climate match relative to current conditions. Additionally, areas within the Appalachian Range, Colorado Plateau, Great Basin, Mid-Atlantic, Northern Pacific Coast, Northern Plains, Southern Plains, Southwest, and Western Mountains saw a moderate increase in the climate match relative to current conditions. Under multiple time step and climate scenarios, and particularly under the 2085 time step, areas within California, the Gulf Coast, Southeast, Southern Plains, and Southwest saw a moderate decrease in the climate match relative to current conditions. In general, no large decreases were observed regardless of time step and climate scenarios. Additional, very small areas of large or moderate change may be visible on the maps (figure A3). The difference in climate match relative to the current climate match was more extreme for the SSP5 scenarios relative to the SSP3 scenarios, and for the 2085 time step relative to the 2055 time step.

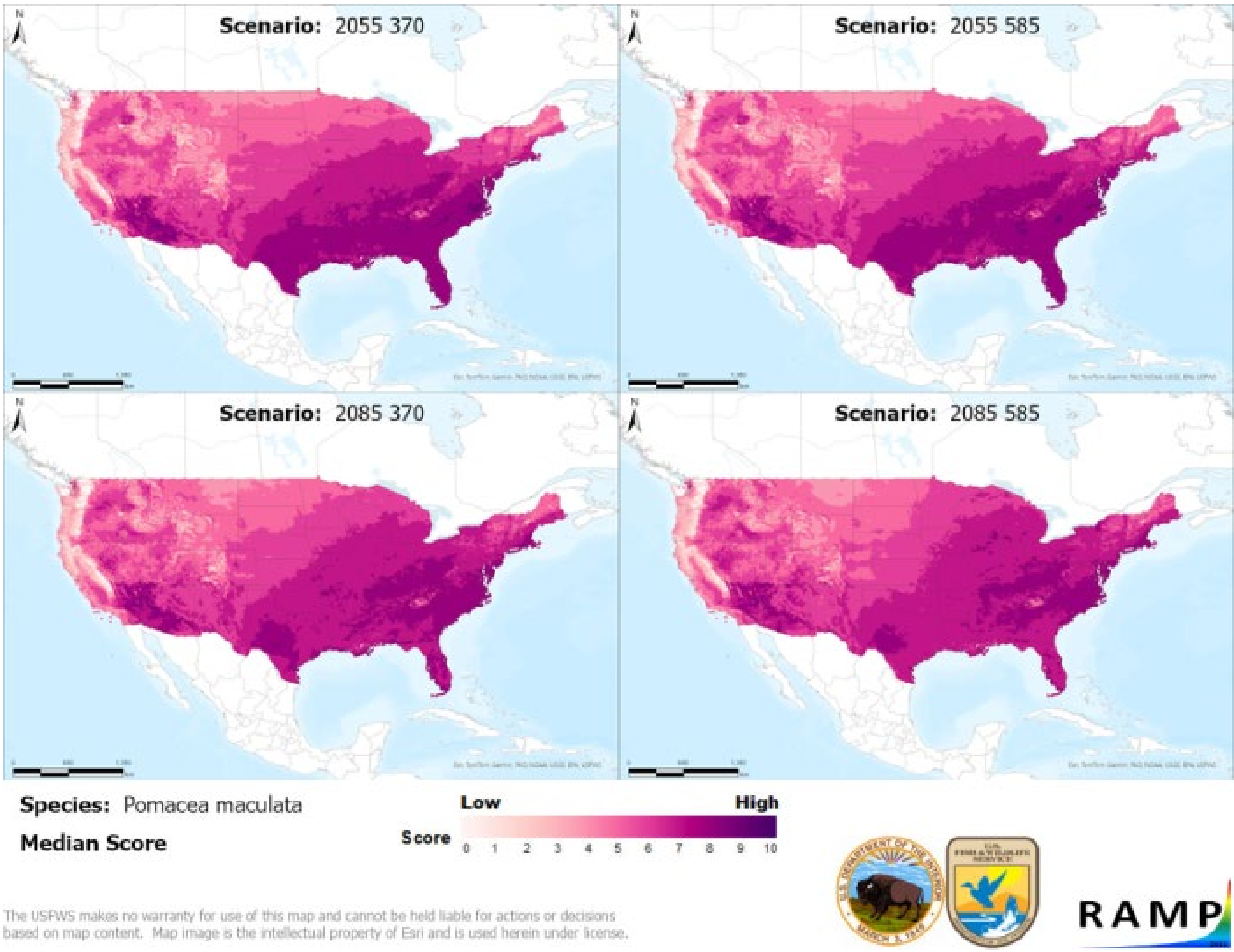

Figure A1. Maps of median RAMP (Sanders et al. 2023) climate matches projected under potential future climate conditions using five global climate models for *Pomacea maculata* in the contiguous United States. Climate matching is based on source locations reported by GBIF Secretariat (2024) and Morningstar and Jordon (2024). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global climate models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. 0/Pale Pink = Lowest match, 10/Dark Purple = Highest match.

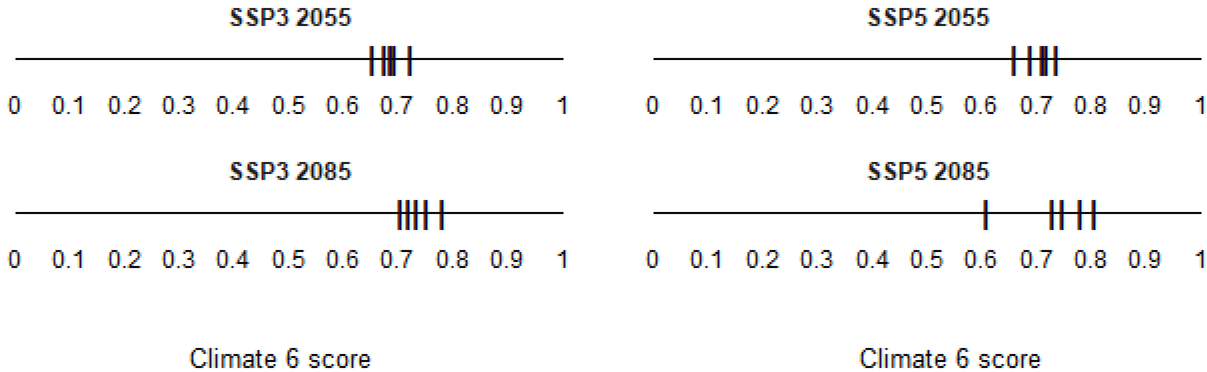

Figure A2. Comparison of projected future Climate 6 scores for *Pomacea maculata* in the contiguous United States for each of five global climate models under four combinations of Shared Socioeconomic Pathway (SSP) and time step. SSPs used (from left to right): SSP3, SSP5 (Karger et al. 2017, 2018; IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global climate models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0.

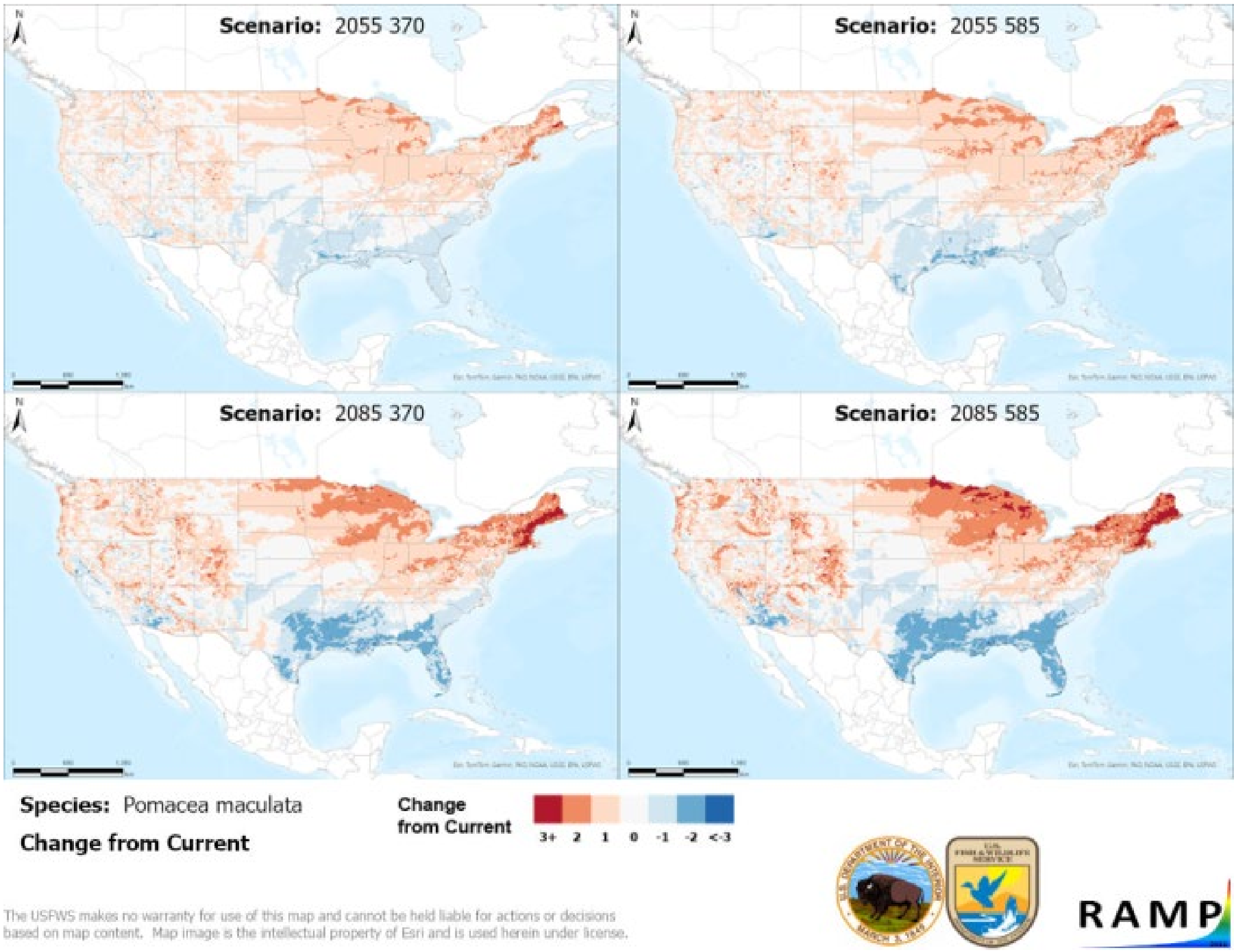

Figure A3. RAMP (Sanders et al. 2023) maps of the contiguous United States showing the difference between the current climate match target point score (figure 4) and the median target point score for future climate scenarios (figure A1) for *Pomacea maculata* based on source locations reported by GBIF Secretariat (2024) and Morningstar and Jordon (2024). Shared Socioeconomic Pathways (SSPs) used (from left to right): SSP3, SSP5 (IPCC 2021). Time steps: 2055 (top row) and 2085 (bottom row). Climate source data from CHELSA (Karger et al. 2017, 2018); global models used: GFDL-ESM4, UKESM1-0-LL, MPI-ESM1-2-HR, IPSL-CM6A-LR, and MRI-ESM2-0. Shades of blue indicate a lower target point score under future scenarios than under current conditions. Shades of red indicate a higher target point score under future scenarios than under current conditions. Darker shades indicate greater change.

Literature Cited

GBIF Secretariat. 2024. GBIF backbone taxonomy: *Pomacea maculata* Perry, 1810. Copenhagen: Global Biodiversity Information Facility. Available: https://www.gbif.org/species/7532642 (January 2024).

[IPCC] Intergovernmental Panel on Climate Change. 2021. Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP, Kessler M. 2018. Data from: Climatologies at high resolution for the earth's land surface areas. EnviDat. Available: https://doi.org/10.16904/envidat.228.v2.1.

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder P, Kessler M. 2017. Climatologies at high resolution for the Earth land surface areas. Scientific Data 4:170122.

Morningstar CR, Jordon A. 2024. *Pomacea maculata* (giant applesnail). Nonindigenous Aquatic Species Database. Gainesville, Florida: U.S. Geological Survey. Available: https://nas.er.usgs.gov/queries/FactSheet.aspx?SpeciesID=2633 (January 2024).

Sanders S, Castiglione C, Hoff M. 2023. Risk Assessment Mapping Program: RAMP. Version 5.0. U.S. Fish and Wildlife Service.