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Mauremys annamensis (Siebenrock 1903) – Vietnamese Pond Turtle, Annam Pond Turtle, Rùa Trung Bộ

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Summary. – The Vietnamese Pond Turtle, *Mauremys annamensis* (Family Geoemydidae), is a medium-sized (carapace length to 285 mm in females, 232 mm in males), highly aquatic turtle known only from the lowland wetlands of central Vietnam. Field records are limited and the natural history of *M. annamensis* is poorly known, in part due to the difficulty in conducting research within the species' native range as a result of conflict and political isolation during much of the period since its description. Recent work has delimited the historical distribution and gathered evidence for the historical abundance of *M. annamensis*, but also indicates that the species has largely been extirpated across its range and is now extremely rare in the wild. Over-collection and habitat loss are the greatest contributors to the species' decline, while pollution and interspecific hybridization may represent additional threats. Substantial international trade in *M. annamensis* occurred in the past, and despite national and international protection for the species, surviving populations continue to be threatened by intensive collection efforts. In captivity, the species acclimates well and breeds readily, with females capable of producing several clutches of eggs per year. Current conservation efforts include greater enforcement of trade restrictions, the establishment of a protected habitat area, and planning for future reintroductions from captive stocks. Continued research and conservation measures are required to save this critically endangered species.

Distribution. – Vietnam. Historically ranged across central Vietnam coastal lowlands from the municipality of Da Nang and Quang Nam Province south to Phu Yen Province and west into the low-lying inland areas of Gia Lai and Dak Lak provinces.

Synonymy. – *Cyclemys annamensis* Siebenrock 1903, *Cuora* (*Cyclemys*) *annamensis*, *Cuora annamensis*, *Annamemys annamensis*, *Mauremys annamensis*, *Annamemys annamemys* (ex errore), *Cathaiemys annamensis, Annamemys merkleni* Bourret 1940, *Annamemys mekleni* (ex errore), *Clemmys guangxiensis* Qin 1992 (partim, hybrid), *Mauremys guangxiensis, Ocadia glyphistoma* McCord and Iverson 1994 (partim, hybrid).

Subspecies. – None.

Status. – IUCN 2014 Red List: Critically Endangered (CR A1d+2d, assessed 2000); TFTSG Draft Red List: Critically Endangered (CR, assessed 2011); CITES: Appendix II with zero quota for commercial purpose; Vietnam: Decree No. 32/2006/ND-CP.

Taxonomy. — *Mauremys annamensis* was first described as *Cyclemys annamensis* by Siebenrock (1903) based on a juvenile specimen obtained by H. Fruhstorfer from "Phuc-Son" (= Phuoc Son District, Quang Nam Province, Vietnam). Without reference to Siebenrock's description, Bourret (1940) named the species *Annamemys merkleni* from a series of eight specimens collected at or near "Fai-Fo" (= Hoi An town, Quang Nam Province, Vietnam), about 40 km NE of Phuoc Son. Presumably, Bourret's error was partly due to the fact that Siebenrock's description was based on a single immature individual, while Bourret's specimens were adults (Savage 1953). Further, Bourret (1941) stated that Siebenrock's specimen was lost after deposition, which would have prevented examination. However, the holotype

Figure 1. Captive adult female *Mauremys annamensis*. Photo by Jeffrey E. Dawson.

(NMW 23394) has since been located and is in the Museum of Natural History of Vienna, Austria (Naturhistorisches Museum Wien; Tiedemann and Häupl 1980; Tiedemann et al. 1994). In his later monograph on the turtles of Southeast Asia, Bourret (1941) included accounts for both *C. annamensis* and *A. merkleni*. Bourret presented one of the syntypes of *A. merkleni* to the Natural History Museum of Stanford University (Leviton 1953); this specimen (now in the collection of the California Academy of Sciences; CAS-SU 9142) was designated a lectotype by Savage (1953), who recognized that *A. merkleni* was the adult form of *C. annamensis* and synonymized the taxa. However, Savage (1953) recommended that the species be retained in the genus *Annamemys*, instead of being placed in *Cyclemys*, due to the lack of a transverse plastral hinge in the adult specimens. Subsequently, *Annamemys* has been synonymized with the genus *Mauremys* (McDowell 1964; Iverson and McCord 1994).

Mauremys guangxiensis, first described as *Clemmys guangxiensis* by Qin (1992 [1991]), was recently added to the synonymy of *M. annamensis* (as partim, hybrid) based on the molecular work of Hu et al. (2013); however, the exact relationship of *M. guangxiensis* to *M. annamensis* and other taxa is still unresolved and additional research needs to be undertaken (Turtle Taxonomy Working Group 2014).

Mauremys annamensis is closely related to *M. mutica*; excluding studies containing invalid hybrid species (e.g.,

Figure 2. Captive adult female *Mauremys annamensis*. Photo by Jeffrey E. Dawson.

Figure 3. Captive adult female *Mauremys annamensis*. Photo by Jeffrey E. Dawson.

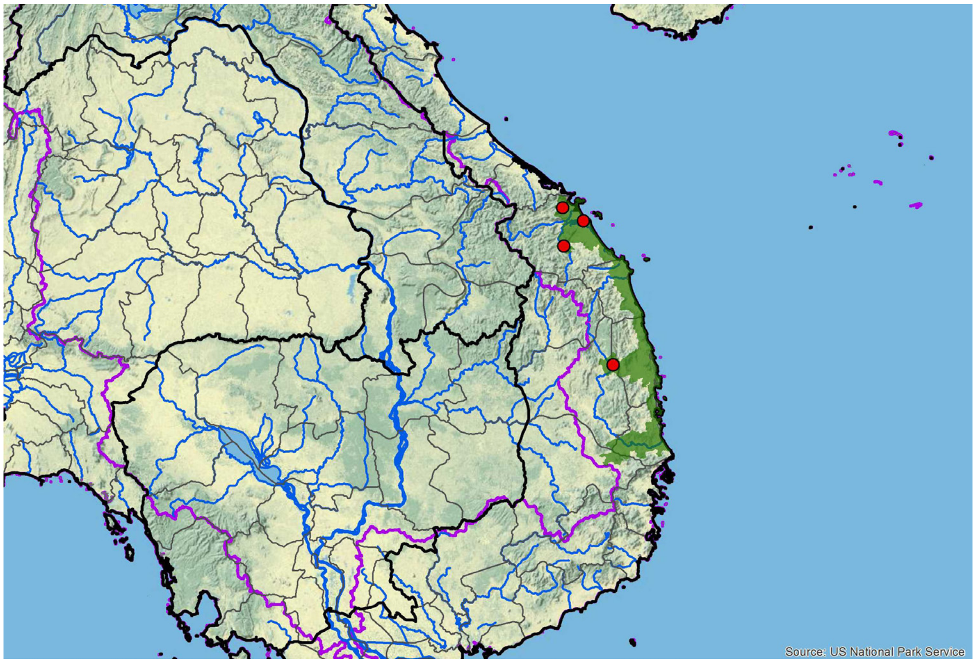

Figure 4. Historic distribution of *Mauremys annamensis* in central Vietnam in southeast Asia. Purple lines = boundaries delimiting major watersheds (level 3 hydrologic unit compartments – HUCs); red dots = museum and literature occurrence records of native populations based on Iverson (1992) plus more recent and authors' data; green shading = projected native historic distribution based on GIS-defined HUCs constructed around verified localities and then adding HUCs that connect known point localities in the same watershed or physiographic region, and similar habitats and elevations as verified HUCs (Buhlmann et al. 2009; TTWG 2014), and adjusted based on authors' subsequent data.

Honda et al. 2002b), both morphological (Iverson and McCord 1994) and molecular phylogenetic (Honda et al. 2002a; Barth et al. 2004; Spinks et al. 2004) analyses have confirmed that the two taxa are each other's closest living relatives. However, the exact taxonomic relationship between *M. annamensis* and *M. mutica* is unclear. McDowell (1964) synonymized *M. annamensis* with *M. mutica* based on their similar morphology, yet later morphometric analyses (Iverson and McCord 1994; Yasukawa et al. 1996) found *M. annamensis* to be distinctive.

Initial molecular studies using mitochondrial DNA (mtDNA) found substantial differences between *M. annamensis* and *M. mutica* (Barth et al. 2004; Spinks et al. 2004). However, a more comprehensive mtDNA study found *M. mutica* to be paraphyletic with respect to *M. annamensis*, with *M. mutica* from eastern China forming one clade and *M. annamensis* from central Vietnam forming another clade with *M.* '*mutica*' from northern Vietnam (Feldman and Parham 2004). Based on the low number of nucleotide differences between *M. annamensis* and Vietnamese *M.* '*mutica*,' Feldman and Parham (2004) suggested several possibilities, including that *M. annamensis* had recently separated from *M. mutica*, that historical or ongoing gene flow occurred between the two species, or that *M. annamensis* might simply represent a geographic phenotypic variant of *M. mutica*.

Incongruences among nuclear DNA (nuDNA), mtDNA, and morphology were also found by Fong et al. (2007). Three distinct clades were recovered from the nuDNA – *M. annamensis*, *M.* '*mutica*' from Hainan Island, China, and *M. mutica* from mainland eastern China. However, only two distinct clades were formed by the mtDNA, with mainland

Figure 5. Captive hatchling *Mauremys annamensis*. Photo by Peter Paul van Dijk.

Figure 6. Captive hatchling *Mauremys annamensis* at Turtle Conservation Centre, Cuc Phuong National Park, Vietnam. Photo by Timothy McCormack, ATP.

Figure 7. Two sections of Co Ni River in Dien Ban District, Quang Nam Province, central Vietnam. Locally caught specimens of *Mauremys annamensis* are still observed in local trade and apparently caught in this habitat. Photos by Timothy McCormack, ATP.

Figure 8. Ha Tre Lake, situated on a seasonally flooded island in the Thu Bon River, Quang Nam Province, central Vietnam, a site at which *Mauremys annamensis* was caught in the wild by an ATP team in 2006. Photos by Timothy McCormack, ATP.

M. mutica being a sister clade to the Hainan Island specimens and two subclades of *M. annamensis*. In both studies, the incongruent *M.* '*mutica*' specimens (northern Vietnam and Hainan Island) were readily distinguishable from *M. annamensis* morphologically and closely resembled the mainland eastern *M. mutica* (Feldman and Parham 2004; Fong et al. 2007).

Unfortunately, a rarity of locality-specific specimens of *M. mutica* and *M. annamensis* has hindered all phylogenetic analyses published to date. Genetic samples have primarily been obtained from specimens acquired from turtle farms or trade seizures; consequently, the specimens could be of anthropogenic hybrid origins, limiting the ability to draw conclusions from these studies (Feldman and Parham 2004; Fong et al. 2007; J. Parham, pers. comm.). As a result, taxonomic uncertainties continue to exist. Stuart and Parham (2007) ascribed the incongruent *M.* '*mutica*' specimens from northern Vietnam and Hainan Island to '*M.* cf. *annamensis*.' However, most authorities have recommended maintaining the current taxonomy until further data are available (Feldman and Parham 2004; Fong et al. 2007). Given the potential significance to conservation efforts of any premature taxonomic changes, we retain *M. annamensis* as a full species and consider *M. mutica* as containing multiple evolutionarily significant units, based on the characteristic morphological differences between the two taxa (Iverson and McCord 1994).

Mechanisms of reproductive isolation appear to be weak among geoemydid turtles, including *M. annamensis*. Human-mediated hybridization has occurred between *M. annamensis* and *Cuora amboinensis* (Fritz and Mendau 2002), *Cuora trifasciata* (Zhou et al. 2008), *M. mutica* (Uhrig and Lee 2006; MAE and JMG, unpublish. data), *M. nigricans* (Ipser 2011), and possibly *M. reevesii* (Spinks and Shaffer 2007) in captivity.

Hybrids have also occurred between *M. annamensis* and *M. sinensis* (Spinks et al. 2004). McCord and Iverson (1994) described "*Ocadia glyphistoma*" based on specimens reportedly from southern China. This species was later shown to be invalid as the specimens were *M. annamensis* x *M. sinensis* hybrids that likely had been acquired from wildlife markets (Spinks et al. 2004; Stuart and Parham 2007). In Vietnam, hybrids have been observed in the wildlife trade, including a male specimen of unknown origin purchased from Dong Xuan Market, Hanoi in July 1999 by one of the authors (DBH) which is currently maintained at the Turtle Conservation Centre (TCC) in Cuc Phuong National Park, Vietnam. Although these hybrids may originate through captive breeding on turtle farms (Spinks et al. 2004), there is also evidence to suggest that natural hybridization may occur in the wild where the distributions of the species overlap; several hybrids seen in Quang Nam province in 2012 were apparently locally wild caught (Pham 2012; Blanck and Braun 2013; McCormack 2013; McCormack et al. 2013).

Description. — *Mauremys annamensis* is a medium-sized turtle; a maximum carapace length (CL) of 170 mm was reported by Ernst and Barbour (1989), but Iverson and McCord (1994) documented a female of 285 mm CL, as do we. A series of mature captive females measured by the current authors (MAE, JBI, JMG) had measurements (mean ± SD) of 212 ± 28 mm in straight CL (range 189–285 mm, n = 12), 184 ± 26 mm in plastron length (PL; range 155–257, n = 12) and 1717 ± 250 g in mass (range 1302–2126 g, n = 8). Adult males are slightly smaller; the largest male known to the authors (JED and REH) is a captive specimen with a CL of 232 mm. Captive males measured by the authors (MAE, JBI, JMG) had a CL of 187 ± 17 mm (range 163–218 mm, n = 16), PL of 153 ± 10 mm (132–176 mm, n = 16), and mass of 1066 ± 352 g (range 687–1744 g, n = 13).

The carapace is moderately depressed, twice as wide as high, with three longitudinal keels. The median keel is best developed, while the dorsolateral keels, which run across the dorsal surfaces of the pleural scutes, are lower. Typically, the color of the carapace is uniformly brown (ranging from chestnut to dark brown), gray, or even nearly black, but rarely, there is slight lightening along the keels to create three faint stripes. Growth annuli are evident on the scutes of young specimens; the scutes are worn smooth in older animals. The first vertebral scute is wider anteriorly than posteriorly; the last vertebral scute is the opposite. The remaining vertebral scutes are roughly as broad as long (Ernst and Barbour 1989). Lateral to the dorsolateral keels, the slope of the carapace dips substantially, and then flares outwardly at the marginals. The marginals also flare anteriorly and posteriorly. Viewed from above, the sides of the carapace are slightly rounded, with a slightly crenate, or upturned, marginal aspect. The widest point of the carapace is in the middle or slightly to the posterior of the middle. The rear of the carapace is unserrated.

Maximum PL is roughly 80 to 95% of maximum CL. The plastron is unhinged and well-developed, but does not completely cover the opening of the shell. The anterior lobe is truncate and slightly upturned at the front; the posterior lobe has a deep anal notch. Ernst and Barbour (1989) gave the typical plastral formula as: abd < pect > fem > an > hum >< gul, but they also noted that the pectoral, abdominal, and femoral seams are often nearly identical in length. The plastron is sutured to the carapace and the length of the bridge is 40 to 50% the length of the plastron (Ernst and Barbour 1989). Internally, the bridge is extensively buttressed (Savage 1953), with thicker bone than is typical of many semi-aquatic species.

All scutes of the bridges, plastron, and undersides of the marginals include black blotches on a background of yellow-orange, horn, or tan. Generally, the bridges and the undersides of the posterior marginals are darker than the undersides of the nuchal and adjacent marginals. The outer margin of the plastron is light colored, while the center of the plastron has a large, contiguous light area which runs across at least the pectoral, abdominal, and femoral scutes. At its widest, the light area is a third to half as wide as the plastron. Between the light edges and light center are dark patches which coalesce posteriorly on the anal scutes and also often at the anterior of the plastron, forming a dark ring across the plastron.

The head is of moderate size in proportion to the body and is somewhat pointed. The temporal arch is complete and the quadratojugal contacts both the jugal and postorbital. Skin on the back of the head is smooth. The background color of the head is slightly lighter to nearly as dark as the carapace but with an olive green cast. Three prominent pairs of pale yellow stripes extend posteriorly from near the tip of the nose on each side of the head. The faintest pair passes dorsolaterally over the orbits and ends in the temporal area. The lateral and most prominent pair runs from the nostrils across the orbit and posteriorly along the neck. The third pair extends from below the nostrils along the dorsal border of the jaw, below the tympanum, and onto the neck. An additional set of stripes begins along the inner border of the lower jaw and passes across the jugular region and onto the neck. The central areas of the chin and the throat sport pale yellow. The alveolar surfaces of the jaws are narrow and unserrated; their external color changes from near-white close to the cutting edges to light gray distally.

The limbs have unremarkable length but are muscular. The toes are not especially long, but are fully webbed. Generally, the neck, limbs, and tail are dark to medium gray dorsally and become lighter gray ventrally. On the forelimbs, the antebrachia have many enlarged and a few sickle-shaped scales, which may be mottled with gray and pale tan. The axillary and inguinal pockets are cream colored, and occasionally mottled with light gray.

Hatchlings (n = 41) from eggs produced by captives and measured by the authors (MAE, REH, JMG) were 37.5 ± 1.9 mm in CL (range 33.8–40.6 mm), 32.5 mm in PL (range 28.8–35.4 mm), 31.2 ± 1.6 mm in carapace width (range 27.9–33.9 mm), and 9.12 ± 1.2 g in mass (range 6.5–11.0 g). The hatchling carapace is tricarinate; however, the median ridge so dwarfs the lateral ones that the overall effect is essentially unicarinate. Hatchlings are colored similarly to adults but more vivid, with sharper demarcations between light and dark. All hatchlings of *M. annamensis* have prominent, light supraobital stripes on their heads, and a few also have short, light, midsagittal stripes.

In addition to being slightly smaller, males differ from females in having distinctly concave rather than flat or mostly flat plastra. The tails of males are appreciably broader at the base and more stoutly tapered than those of females, but are at most only slightly longer. The cloacal opening is also more distally located along the tails of males. As with other *Mauremys* species, hatchlings have long tapering tails.

Iverson and McCord (1994) discussed morphological differences between members of the genus *Mauremys*. Features which distinguish *M. annamensis* from *M. mutica* are: 1) a set of head stripes that pass from the snout to above the orbit (not present in *M. mutica*); 2) a larger maximum size (at least 285 mm versus 188 mm maximum CL, respectively); 3) retention of a moderately tricarinate carapace in adult specimens (smooth to weakly tricarinate in most *M. mutica*); 4) female-dominated sexual size dimorphism (either male-dominated or lacking in most *M. mutica* populations); 5) a wider carapace and longer bridge; 6) narrower and longer gular scutes; 7) a shorter seam between the humeral scutes; and 8) a longer interpectoral seam.

Distribution. — The range of *M. annamensis* appears to be restricted to central Vietnam (Iverson 1992; Nguyen et al. 2009, McCormack 2013). Most published historical records originate from Quang Nam Province (Siebenrock 1903; Bourret 1940, 1941). The species has also been reported from the centrally-controlled municipality of Da Nang (Dawson et al. 2013) and the provinces of Quang Ngai (Turtle Ecology and Conservation Project 2002), Binh Dinh (Le et al. 2004), and Gia Lai (Parham et al. 2006). Since 2006, interviews of local people within 11 provinces that are believed to encompass the species' range have been conducted by the Asian Turtle Program (ATP) of Cleveland Metroparks Zoo. These surveys confirmed the historical presence of *M. annamensis* in the previously listed locations and uncovered other potential sites in Phu Yen and Dak Lak Provinces (McCormack et al. 2007; McCormack 2013).

A specimen of *M. annamensis* in the Toulouse Museum was collected by Bourret in the early 20th century with the locality data of Nha Trang (Khanh Hoa Province) and apparently mislabeled as *M. mutica* (R. Bour, pers. comm.). However, interview surveys in 2011 and 2012 failed to find any information regarding wild *M. annamensis* in Khanh Hoa Province (McCormack 2013). While it is possible that the species once inhabited the area and has since been extirpated, it is more likely that the specimen originated in another location and was then transported to Nha Trang, which was an important regional town situated on the major trade route in Vietnam.

Le and Broad (1995) reported that *M. annamensis* was abundant in the wildlife trade in Ca Mau Province at the extreme southern tip of Vietnam. In 2000, a single *M. annamensis* was observed in a Ho Chi Minh City market (Hendrie 2000a). As recent trade routes of turtles in Vietnam typically move northward (Stuart et al. 2000), these observations suggested that the distribution of *M. annamensi*s might extend into the Mekong Delta. However, Jenkins (1995) proposed that the records of Le and Broad (1995) were based on misidentified specimens, a view supported by Stuart (2004), who found no evidence of *M. annamensis* in southern Vietnam. Three species in southern Vietnam *(Cuora amboinensi*s, *Malayemys subtrijug*a, and juvenile *Heosemys annandalii*) superficially resemble *M. annamensis* (Hendrie et al. 2011) and frequently appear in trade (Hendrie 2000b). The Ca Pass Mountains along the border of Phu Yen and Khanh Hoa provinces likely serve as a southern limit for the distribution of *M. annamensis*. Furthermore, the coastal lowlands near and south of Nha Trang in Khanh Hoa Province have a semi-arid climate (Sterling et al. 2006), which may present an additional barrier to *M. annamensis*.

The range of *Mauremys mutica* does not appear to overlap that of *M. annamensis*. The northernmost field-collected specimens of *M. annamensis* have been reported from Quang Nam Province and the city of Da Nang. *Mauremys annamensis* was not present in any shipments of turtles from northern Vietnam to Germany in the mid-20th century (Petzold 1963). During a visit to northern Vietnam, Petzold (1965) failed to locate any individuals of *M. annamensis* in the wild and found only a single specimen of the species in the museum collection at the University of Hanoi. Although Petzold did not state the origin of this specimen, it seems reasonable to assume that it was collected in central Vietnam during colonial times. In contrast, *M. mutica* has only been verified in Vietnam from northern locations (Bourret 1941; Tien 1957; Petzold 1963, 1965 [as "*Clemmys nigricans*"]; Iverson 1992). The sole record of *M. mutica* in central Vietnam was in error (see above).

The southernmost documented locality for *M. mutica* (= *Annamemys grochovskiae*) is in Quang Tri Province (Tien 1957). However, anecdotal evidence exists for the historical occurrence of *M. mutica* just to the south of Quang Tri in Thua Thien Hue Province. Descriptions provided by local people match this species; these reports likely represent the historical southern limit of *M. mutica* in Vietnam (McCormack 2013). The Hai Van Pass of the Truong Son Range (Annamite Mountains) appears to be a natural physical boundary between the southern extent of *M. mutica* and the northern limit of *M. annamensis* (Le et al. 2004).

In recent years, the range of *M. annamensis* has contracted significantly. Throughout much of its range, local people consider it to be extremely rare (McCormack 2013). Currently, only isolated individuals and a few fragmented relic populations are thought to remain in the wild. Recent interviews of turtle collectors and traders within a few scattered districts in the provinces of Binh Dinh, Phu Yen, Quang Ngai (McCormack 2013), and Quang Nam (Duc and Nguyen 2001; McCormack et al. 2007; McCormack 2013) have indicated that people in these areas continue to be familiar with *M. annamensis*. In 2006, a single wild specimen was caught during an ATP field survey in Quang Nam Province, roughly 10 km from Hoi An, where Bourret's specimens were reportedly obtained in the 1930s (McCormack et al. 2007). Recent reports from Da Nang consist only of specimens in trade and restaurants (Le et al. 2004; Tran Thi An Huong, pers. comm.).

Habitat and Ecology. — *Mauremys annamensis* appears to be restricted to low elevations, less than 200 m above sea level (McCormack 2013). This is most apparent in the mountainous provinces of Gai Lai and Dak Lak, where *M. annamensis* has been reported by local people only from low elevations in the eastern regions of these provinces, and appears to have historically been absent from higher elevations to the west (McCormack 2013). Turtle traders in Quang Nam Province associate *M. annamensis* with "streams, ponds, and swamps" in valleys (Duc and Nguyen 2001).

In central Vietnam, hundreds of streams carry water down from the Truong Son Range and across the lowlands before draining into the South China or East Sea (Sterling et al. 2006). Originally, *M. annamensis* likely inhabited the lowland freshwater marshes and slow-moving waterways connected to these streams. Floore et al. (1971) characterized these wetlands as having sandy, clay soil and abundant floating and submerged vegetation. The margins of the marshes supported ferns, sedges, and grasses, with the surrounding upland habitat consisting of bamboo stands, leading to xeric herbs and shrubs in higher areas (Floore et al. 1971). Most of this lowland habitat has now been converted to agriculture and urban areas (Thuy et al. 2000) and *M. annamensis* currently appears restricted to ponds and fragmented wetlands scattered among rice fields and along riparian corridors (McCormack 2013).

Mauremys sinensis appears to occur sympatrically with *M. annamensis*. Both species have been reported from the same wetland and lake complex during Asian Turtle Program (ATP) surveys in Quang Ngai province (McCormack 2013; McCormack et al. 2013).

Little is known about the biology of *M. annamensis* in the wild. Most observations of behavior, diet, and reproduction are from captivity. The lowlands of central Vietnam experience a monsoon climate with distinct dry (January through September) and wet (October through December) seasons (Sterling et al. 2006; Yen et al. 2011). During the dry season, *M. annamensis* may estivate on land, particularly within bamboo stands. Formerly, when the species was more abundant, hunters would locate *M. annamensis* during the dry season by probing the leaf litter at the base of bamboo stands with bamboo poles tipped with metal, listening for a distinctive sound when the carapace was hit (Asian Turtle Program, unpubl. data). In the wet season, flood events are common, and *M. annamensis* likely disperses during these seasonal floods. Local people recall the capture of turtles clinging to tree branches in gardens and fields during floods in the past (ATP, unpubl. data).

No information is available on the natural predators of *M. annamensis*; however, Iverson and McCord (1994) and Yasukawa et al. (1996) suggested that the shape and heavy buttressing of the shell of *M. annamensis* may have evolved in response to predation pressure by crocodilians. At a number of sites throughout its range, *M. annamensis* has likely occurred sympatrically with the Siamese Crocodile (*Crocodylus siamensis*), as is evident in Song Hinh district, Phu Yen province, where remnant crocodilian populations occur (Nguyen et al. 2005; Simpson and Bezuijen 2010).

Mauremys annamensis is likely a generalist feeder, but the natural diet is unknown. In captivity, the species is omnivorous, but demonstrates a strong preference for carnivory.

The reproductive behavior of *M. annamensis* is known only from captive observations. During courtship, males will often bite and hold females by the nape of the neck, clapping their plastrons against the carapaces of the females before attempting intromission. A receptive female quickly assumes a submissive position with her neck, limbs, and tail fully extended and limp. If the female is unwilling, however, a violent struggle may ensue (Gurley 2003; JED and REH, pers. obs.). These behaviors are very similar to the copulatory behaviors of *M. mutica* (Yasukawa et al. 1996) and unlike those described for *M. japonica* (Yasukawa et al. 2008).

Under semi-natural conditions at the Turtle Conservation Centre (TCC) in Cuc Phuong National Park, Vietnam, nests of *M. annamensis* have been discovered in May and June (McCormack and Bui 2005). Captives in Indiana and Ohio in the United States have been found gravid from the last week of March to the first week of August (MAE and JMG, unpubl. data). The shells of eggs are rigid and brittle. Eggs obtained under captive conditions in the United States and measured by the authors (MAE, REH, JMG) averaged 45.3 ± 3.7 mm in length, 23.6 ± 1.1 mm in width, and 15.5 ± 2.5 g in mass (n = 293). Females (n = 8) laid 1–4 (median 2) clutches of eggs per year, with 5.5 ± 1.6 eggs per clutch (n = 53) and a maximum of 17 eggs per female in a season. Relative clutch mass (clutch mass/spent female mass) varied from 0.033 to 0.104 (MAE and JMG, unpubl. data).

The rate of embryonic development is determined by temperature, with incubation length ranging between 114–131 days at 25°C (n = 11), 93–104 days at 27°C (n = 3), and 80–83 days at 30°C (n = 8) (MAE, unpubl. data). Sex differentiation is controlled by temperature during embryonic development (temperature-dependent sex determination, TSD), with *M. annamensis*, along with other *Mauremys* studied thus far (Ewert and Nelson 1991; Du et al. 2007; Du et al. 2010; Okada et al. 2010), following TSD Pattern Ia, in which males are produced at lower constant incubation temperatures and females at higher constant temperatures (Ewert et al. 2004). The pivotal temperature, the constant temperature which produces an equal sex ratio (1:1), has been estimated to be 28.9°C for *M. annamensis* (Ewert et al. 2004).

Information on growth, maturation, and longevity of *M. annamensis* is scarce and only available from captive individuals. A series of females (n = 16), bred in the United States and continuously provided with adequate growing conditions, reached a mean CL of 157 ± 8 mm (range 145–174 mm), PL of 134 ± 12 mm (range 117–159 mm), and mass of 676 ± 104 g (range 497–834 g) at 4.75 yrs of age (Columbus Zoo and Aquarium, unpubl. data). In captivity, females mature when they reach approximately 180 mm CL at roughly 5–7 years old (MAE, JED, REH, JMG, unpubl. data). The longevity record for this species in captivity is approximately 46 years for an individual currently living at the Columbus Zoo (Dawson et al. 2013); several other individuals in the same collection, received as young adults in the early 1990s, are still alive in 2014 and reproductively active at approximately 25–30 yrs of age.

Population Status. — Bourret (1941) described *M. annamensis* as being abundant in the ponds and streams within the area surrounding Hoi An. However, no quantitative data exist to support this statement. Due to regional warfare and political isolation that subsequently ensued, almost nothing is known about the status of *M. annamensis* during the next several decades; only one individual from this time period is known, collected in 1966 near Da Nang by a U.S. Navy corpsman (Dawson et al. 2013). However, interviews of local people indicate that *M. annamensis* was locally common in many areas throughout its range during the 1970s and early 1980s; in some areas, the species was even considered a pest, as large individuals would flatten trails through rice crops or walk into houses. Some locals report collecting rice sacks full of turtles (likely including both *M. annamensis* and *M. sinensis* in areas where these species occur sympatrically) nightly during the 1980s (ATP, unpubl. data).

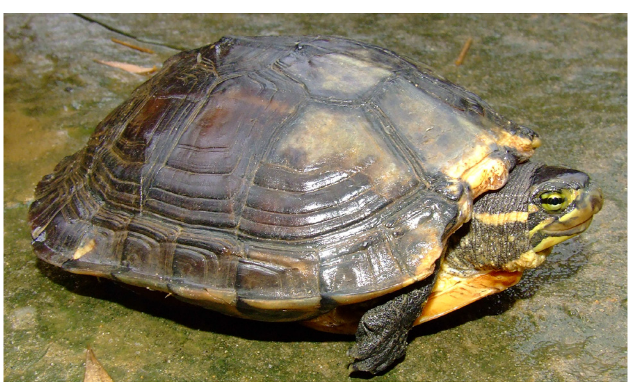

Figure 9. Wild-caught subadult female *Mauremys annamensis* from Dien Ban District, Quang Nam Province, Vietnam, 2006. This animal appeared to have injuries from a fire; bamboo stands are sometimes cleared using fire and the turtles are reported to estivate during the dry season in the base of bamboo. Photo by Timothy McCormack, ATP.

Since that time, only a few specimens have been documented outside of captivity (Parham et al. 2006; McCormack et al. 2007). One wild specimen was caught in Quang Nam Province during a field survey in 2006 (McCormack et al. 2007), but since 2009, additional trapping at other locations with apparently suitable habitat has failed to locate other specimens (McCormack 2013). Today, *M. annamensis* appears to be extremely rare in the wild and is apparently extant only at low densities in a few remaining isolated populations.

Threats to Survival. — The greatest threat to the survival of *M. annamensis* is the so-called Asian Turtle Crisis (Hendrie 2000b) – the expansive international trade in Asian chelonians for food, traditional medicine, and pets (van Dijk et al. 2000). Most *M. annamensis* that entered the international trade were destined for consumption in China. Local people in Vietnam state that collection of this species for trade to China began in the 1980s and increased rapidly (ATP, unpubl. data). Subsequently, the species has been widely observed in the markets of southern mainland China (Wildlife Conservation Society – China Program and China Endangered Species of Wild Fauna and Flora Import and Export Administrative Office 2000; Artner and Hofer 2001; Lee et al. 2004), Hainan Island (de Bruin and Artner 1999), and Hong Kong (Cheung and Dudgeon 2006). Beginning around 1990, *M. annamensis* also appeared in the pet trade in Europe, Thailand, and the United States (Altherr and Freyer 2000; China and Germany 2002; JMG and REH, pers. obs.).

In Vietnam, *M. annamensis* was regularly found in trade seizures headed toward China prior to 1998, but observations in the trade declined afterward (Hendrie 2000b). This decline likely resulted from a reduction in the number of turtles in the wild, which made collection more difficult (Hendrie 2000b) and increased the economic value of M. annamensis in the trade, possibly prompting authorities to permanently confiscate fewer animals; instead, turtles may have been briefly impounded, then sold back into the trade using regulatory loopholes without being reported (ATP, unpubl. data).

In addition to international trade, local consumption for food and purported medicinal benefits has been documented (McCormack et al. 2013). Small numbers of *M. annamensis* continue to be found in the possession of people in central Vietnam; at a single location in Quang Ngai province, 13 turtles were seen in local households between May 2008 and July 2013 (McCormack 2013; McCormack et al.

2013). Currently, the economic incentive for local people to collect turtles continues to exist. Whereas *M. annamensis* previously had a relatively modest value in the trade (Duc and Nguyen 2001), individuals now command a much higher price (McCormack et al. 2013). In particular, the cost appears to have risen dramatically since 2011 (ATP, unpubl. data).

Due to the increased economic value of *M. annamensis*, farming operations targeting this species have now begun (McCormack 2013; McCormack et al. 2013). However, rather than relieve the pressure on *M. annamensis* in the wild, these farms have further increased demand for the species through the need for breeding stock. As a result, most specimens in the trade are now reportedly destined for farms in Vietnam and China (ATP, unpubl. data). While some breeding is reported by farmers, turtles caught from the wild may also be laundered through farms and resold as being captive-bred (McCormack 2013). Farmers have also established 'pyramid schemes' where existing farms sell hatchlings to new farms, promising high returns on investments, but providing little information on how to sell to end consumers (ATP, unpubl. data). Such speculative farming activities have already had negative impacts on other types of wildlife in Vietnam (Wildlife Conservation Society 2008; Brooks et al. 2010).

Another major threat to *M. annamensis* is habitat destruction. The lowlands of central Vietnam have an extended history of human occupation (Sterling et al. 2006). Despite this long period of settlement and the anthropogenic changes to the landscape (such as agricultural conversion) that occurred during this time (Floore et al. 1971), *M. annamensis* has persisted in the wild until relatively recently (McCormack et al. 2013). However, the loss of habitat to intensive rice cultivation and urban areas has increased dramatically as the human population of Vietnam has grown tremendously in the 20th century (Sterling et al. 2006). The area between Da Nang and Hoi An is now a major socio-economic center of Vietnam (Thuy et al. 2000) and Da Nang is currently one of the largest, most highly urbanized, and most densely populated Vietnamese cities (Da Nang Urban Environment Company 2003; Sterling et al. 2006). Many watercourses in the area have been substantially impacted by channelization, filling of low-lying areas, and draining of wetlands (Da Nang Urban Environment Company 2003). Although *M. annamensis* could potentially still inhabit some of these modified habitats (e.g., flooded rice fields or urban canals), turtles in these areas have a greater chance of human contact, leading to an increased potential for collection.

Chemical pollution may pose additional problems for *M. annamensis*. In the 1960s and early 1970s, the entire distribution of *M. annamensis* was located within a war zone. During this conflict, large quantities of herbicides were used to defoliate forests and destroy crops (Stellman et al. 2003). Dioxin, a potent and persistent toxin, was an impurity in some of these chemical defoliants (Schecter et al. 2006). Soil contamination and the subsequent bioaccumulation of dioxin in the tissues of organisms have occurred at some former sites of herbicide handling and application, including in central Vietnam (Dwernychuk et al. 2002).

Following the end of the war, as urbanization within the range of *M. annamensis* has increased, additional pollutants (such as untreated sewage and heavy metals) have been discharged from residential areas and industries into the waterways and soil (Thuy et al. 2000; Danang Urban Environment Company 2003), while pesticide and herbicide usage has also increased. In Quang Ngai Province, an oil refinery and industrial zone has been built in a coastal area near one of the last known remnant *M. annamensis* populations (ATP, unpubl. data).

The possible effects of environmental contaminants on remaining *M. annamensis* populations in the wild are unknown. However, in other turtle species, dioxin and other toxic chemicals have been implicated in developmental abnormalities (Bishop et al. 1998) and reproductive impairment (Shelby-Walker et al. 2009). Bioaccumulated contaminants in *M. annamensis* may also present risks to human consumers, as has been shown in other species of turtles utilized for food and traditional medicine (Green et al. 2010).

The rarity of *M. annamensis* in the wild may hinder the remaining mature individuals from finding suitable mates (McCormack et al. 2013), increasing the potential for genetic bottlenecks, genetic drift, and genetic mixing through interspecific hybridization. In 2012, seven juvenile turtles, apparent hybrids between *M. annamensis* and *M. sinensis*, were reputedly discovered in the wild by local people at a site in Quang Ngai Province (Blanck and Braun 2013; McCormack 2013; McCormack et al. 2013). All of the turtles were reportedly caught when a small pond was drained (Pham 2012; Blanck and Braun 2013).

Conservation Measures Taken. — *Mauremys annamensis* has been listed by the IUCN Red List of Threatened Species as Critically Endangered since 2000 (IUCN 2014) and is included among the world's top 25 most endangered tortoises and freshwater turtles (Turtle Conservation Coalition 2011). A proposal to add *M. annamensis* to CITES Appendix II (China and Germany 2002) was accepted in 2002. At the sixteenth meeting of the Conference of the Parties in 2013, the Socialist Republic of Vietnam (2012) proposed transferring the species from Appendix II to Appendix I. However, an alternate proposal which retained *M. annamensis* on Appendix II but included a zero export quota for commercial purposes (China and United States 2012) was approved instead.

Within Vietnam, *M. annamensis* is listed as Critically Endangered in the Vietnam Red Data Book (Tran et al. 2007).

The species is partially protected by a listing in Group 2B (animals with restricted exploitation and use for commercial purposes) of Decree No. 32/2006/ND-CP (Socialist Republic of Vietnam 2006). However, in a draft revision of this law, *M. annamensis* is recommended for up-listing to Group 1B (animals prohibited from exploitation for economic purposes).

Enforcement of trade regulations has been inconsistent and problematic in the past (Hendrie 2000a, 2000b), but has shown recent improvement (McCormack 2013). Between 2000 and 2009, no confiscations of *M. annamensis* were turned over to conservation organizations. Since then, *M. annamensis* has been seized by officials in Quang Ngai Province (Education for Nature – Vietnam 2009) and Khanh Hoa Province (Hoang and Wahl 2013) and transferred to a captive assurance population for conservation purposes. These confiscations can be partly attributed to increased local awareness about the status and conservation needs of *M. annamensis* in central Vietnam.

Since 2009, the Asian Turtle Program (ATP) of Cleveland Metroparks Zoo has conducted school programs, community activities, and professional training courses (including enforcement training with a focus on tortoise and freshwater turtles for authorities) throughout the species' range (McCormack 2013). Additionally, *ex-situ* captive assurance colonies of *M. annamensis* are held in Vietnam at the Turtle Conservation Centre in Cuc Phuong National Park (McCormack et al. 2013) and internationally in both Europe (Raffel and Meier 2013) and the United States (Schaffer 2006; Turtle Conservation Coalition 2011).

Conservation Measures Proposed. — *Mauremys annamensis* is not currently known to inhabit any protected areas in Vietnam (Turtle Conservation Coalition 2011; McCormack et al. 2013). Existing protected areas within the range of *M. annamensis* include Son Tra Nature Reserve in Da Nang, Phu Ninh Nature Reserve in Quang Nam Province, An Toan Nature Reserve in Binh Dinh Province, A Yun Pa Nature Reserve in Gia Lai Province, Ea So Nature Reserve in Dak Lak Province, and Krong Trai Nature Reserve and Deo Ca Hon Nha Special Use Forest in Phu Yen Province (Tordoff et al. 2004). Although *M. annamensis* could potentially occur in these protected areas, significant numbers of turtles are unlikely to be supported as suitable wetland and pond habitat is in limited availability with mostly rivers and streams occurring there.

In 2010, the ATP, working with the provincial Forest Protection Department (FPD), identified a complex of lakes, wetlands, and other habitat that appears suitable for *M. annamensis* in Binh Son District, Quang Ngai Province (McCormack 2013; McCormack et al. 2013). *Mauremys sinensis* is known to occur at the locality and specimens of *M. annamensis* are still occasionally encountered in local trade surrounding the site (McCormack et al. 2013). ATP, FPD, and the local People's Committee have started working to establish a Species Habitat Conservation Area (SHCA), a proposed area of roughly 100 ha of protected habitat. Formation of the protected area is still being negotiated, as fragmentation of the habitat and usage of the area by local households makes creation of a protected area challenging (McCormack et al. 2013).

In addition to protecting vital habitat for the species, the proposed creation of a Turtle Assurance Colony (TAC) at the SHCA would allow for the housing and breeding of a captive group of *M. annamensis*, with the goal of producing offspring for future release into the SHCA (McCormack et al. 2013). Furthermore, the TAC would permit the quarantine of captive-bred animals transferred to Vietnam from international captive assurance colonies. Already, *M. annamensis* have been relocated from the Kadoorie Farm and Botanic Garden in Hong Kong (Anonymous 2006), the Rotterdam Zoo in the Netherlands, and the Münster Zoo and a private breeder in Germany (Education for Nature – Vietnam 2013) to the TCC in Cuc Phuong National Park. These transfers have greatly boosted the captive assurance population in Vietnam in terms of numbers and genetic lineages (Education for Nature – Vietnam 2013).

Captive Husbandry. — Aspects of the husbandry of *M. annamensis* have been previously described by Gurley (2003), Uhrig and Lee (2006), Artner (2007), and Stern (2014). Overall, *M. annamensis* acclimates well to a range of captive conditions. Individuals may be maintained in groups provided that care is taken to watch for intraspecific aggression (in particular, extremely active courting males may injure or drown other individuals when held together in close quarters for long periods; Gurley 2003; JED and REH, pers. obs.). *Mauremys annamensis* can be successfully housed with other aquatic turtle species (López et al. 2001; Uhrig and Lee 2006; Artner 2007; JED and REH, pers. obs.); however, the frequency with which the species hybridizes with other Asian geoemydids in captivity suggests that assurance colonies should be maintained in isolation from related species.

Outdoor ponds, greenhouses, and indoor enclosures with artificial lighting have all been used successfully. As *M. annamensis* is only a moderately good swimmer, water deeper than 2 m and steep-sided pools should be avoided. An ample land area with both open and sheltered spots should be provided. Captive specimens tend to remain shy and secretive. Although *M. annamensis* is active during both the day and night, there is a trend towards greater nocturnal activity (Uhrig and Lee 2006; Artner 2007; JED and REH, pers. obs.).

Captive *M. annamensis* tolerate a range of environmental temperatures, from 40°C in the summer down to 4–8°C in winter (Uhrig and Lee 2006; Artner 2007). Turtles kept indoors seem to do well in water temperatures between 24–27°C. Use of lighting which provides a natural photoperiod and ultraviolet radiation in basking areas is recommended for indoor enclosures. Captive specimens will accept a wide variety of foods, including earthworms, insects, fish, commercial turtle pellets, aquatic vegetation, green leafy vegetables, leaves, and fruit. Individuals housed outdoors have been observed catching and consuming newly metamorphosed frogs (Uhrig and Lee 2006). Artner (2007) reported feeding almost exclusively a homemade gelatin diet, with good success.

Mauremys annamensis reproduces readily under human care. Successful breeding has occurred in China (Li et al. 2002), Japan (Kawata 2003), the United States (Gurley 2003; Uhrig and Lee 2006; MAE, JED, REH, pers. obs.), Europe (Artner 2007; Raffel and Meier 2013), and Vietnam (McCormack and Bui 2005). At the TCC in Cuc Phuong National Park (roughly 550 km north of the northern distribution limit of *M. annamensis*), natural incubation of nests laid in outdoor enclosures has been successful (McCormack and Bui 2005). However, artificial incubation, with the eggs partially buried in damp substrate (approximately 1:1 mixture of coarse vermiculite to water by weight), is typically utilized in captive breeding operations. Artner (2007) reported that embryos enter diapause in the middle of incubation and described cooling eggs at 20–23°C for 3–4 weeks in order to increase hatching rate. However, Uhrig and Lee (2006) achieved hatching rates of >85% over 5 years without utilizing a cooling period. Similarly, the current authors (MAE, JED, REH, pers. obs.) have used constant incubation temperatures and found no evidence of post-ovipositional arrest in embryos of *M. annamensis*. The reason for this discrepancy between incubation methods is not readily apparent.

Long-term captive and captive-bred *M. annamensis* are hardy and the incidence of disease in these individuals is low. As with other captive reptiles, over-feeding can result in morbid obesity. Occasional episodes of reluctance to nest, leading to dystocia and rapid overcalcification of the egg shell, may occur, but females typically respond well to injections of the hormone oxytocin, as described by Ewert and Legler (1978). Fungal infections can occur in situations when water parameters are unsuitable or basking areas are insufficient (Uhrig and Lee 2006; JED, REH, TEMM, pers. obs.).

A studbook is maintained for specimens of *M. annamensis* held in North American zoological institutions (Stern 2014), but interest in the management of this species within zoos has traditionally been low (Association of Zoos and Aquariums Chelonian Advisory Group 2006). As of August 2013, the Zoological Information Management System (International Species Information System 2013) reported 65 individuals housed in 11 North American zoos and aquariums and 120 individuals in 16 European zoos. A much larger number of *M. annamensis* are held in the private sector in both the United States and Europe (JED, pers. obs.).

Current Research. — An attempt to examine genetic variation within the genus *Mauremys* using genetic material acquired from historical museum specimens of *M. annamensis* through ancient DNA techniques and from a living specimen of known locality is on-going (J. Parham, pers. comm.; B. Stuart, pers. comm.). Additionally, DNA analysis of captive-bred animals is being undertaken in Vietnam to ensure genetic suitability before release (McCormack et al. 2013).

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