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A Review of Epizoic Barnacles Reported from Freshwater Turtles with a New Record from California

Sea turtles are known platforms for colonization of a diverse epibiotic community (Caine 1986; Michael et al. 1998). Epizoic barnacles are widely reported among all sea turtles, which often support obligate and facultative epibiotic barnacles of the genera *Chelonibia*, *Platylepas*, and *Stomatolepas* (Stamper et al. 2005; Zardus and Balazs 2007; Hayashi and Tsuji 2008; Hayashi 2013). In contrast, the occurrence of epizoic barnacles on freshwater turtles appears to be uncommon (Jackson et al. 1973; Frazier 1986). Here, we report and describe the first occurrence of a barnacle (*Amphibalanus subalbidus*) attached to a Western Pond Turtle (*Actinemys marmorata*), from Hill Slough Wildlife Area (HSWA), located in Suisun Marsh at the estuarine reaches of the San Francisco Bay-Delta, California, USA. Our observation is the first report of this barnacle species in the Eastern Pacific since it was first recognized as introduced to Laguna Salada and the Rio Hardy in northernmost Baja California (Van Syoc 1992). In addition, we review and discuss the known records of epizoic barnacles on non-marine turtles.

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The HSWA is a state managed 688-hectare brackish water system, including a mixture of tidal, diked, and managed marshes, located at the northern extent of Suisun Marsh in Solano County, California. The HSWA is a productive and ecologically diverse part of Suisun Marsh (Moyle et al. 2014), where salinity ranges from approximately 0.95–5.5‰ (Watson and Byrne 2009); however, recent intermittent sampling suggests salinities as high as 10‰ (MA, unpubl. data).

On 25 July 2017, MA captured a live adult female Western Pond Turtle in a hoopnet trap in HSWA (38.2316°N, 122.0069°W), as part of a long-term mark-recapture study. The turtle's straight-line carapace length was 16.8 cm and it weighed 900 g. Under the left rear edge of the animal's carapace, adjacent to the tail, there was a relatively large epizoic barnacle (> 20 mm rostro-carinal diameter; Fig. 1). The barnacle was photographed but not removed from the turtle because it was securely attached and removal would have risked removing the scute or harming the turtle. Although the turtle was missing its rear right limb and the end of its tail, it nonetheless appeared in good health, as it had no eye or nasal abnormalities, exhibited normal overall activity and responsiveness, had no skin or cloacal abnormalities, and could fully retract all limbs. There was no obvious connection between the injury and the location

Table 1. All published studies known to the authors that document an epizoic barnacle on a non-marine turtle.

Turtle family	Turtle species	Common name	Barnacle species	Location	Reference
Chelydridae	*Macroclemys temminckii*	Alligator Snapping Turtle	*Amphibalanus improvisus*	Mobile County, Alabama	Jackson & Ross (1971)
Emydidae	*Graptemys kohni*	Mississippi Map Turtle	*Amphibalanus* spp.	Calvert County, Maryland	Schwartz & Dutcher (1961)
	Pseudemys alabamensis	Alabama Red-bellied Cooter	*Amphibalanus improvisus*	Mobile County, Alabama	Jackson & Ross (1972)
	Pseudemys rubriventris	Northern Red-bellied Cooter	*Amphibalanus improvisus*	Salem County, New Jersey	Arndt (1975)
	Pseudemys concinna	River Cooter	Not identified	Levy County, Florida	Carr (1940)
	Trachemys venusta cataspila	Huastecan Slider Turtle	*Amphibalanus venustus*	Tamaulipas, Mexico	Barrios-Quiroz et al. (2013)
	Malaclemys terrapin	Diamondback Terrapin	*Amphibalanus improvisus, Chelonibia patula*	Dixie County, Florida	Ross & Jackson (1972)
			Amphibalanus eburneus	Taylor County, Florida	Jackson et al. (1973)
			Chelonibia manati, Amphibalanus eburneus, Chelonibia testudinaria	Brevard County, Florida	Seigel (1983)
			Not identified	Citrus County, Florida	Boykin (2004)
	Actinemys marmorata	Western Pond Turtle	*Amphibalanus subalbidus*	Solano County, California	Present study
Chelidae	*Chelus fimbriatus*	Matamata	Not identified	Delta Amacuro, Venezuela	Pritchard & Trebbau (1984)
	Hydromedusa tectifera	Argentine Snake-necked Turtle	*Amphibalanus* aff. *improvisus*	Buenos Aires Province, Argentina	Frazier (1986)
Dermatemydidae	*Dermatemys mawii*	Central American River Turtle	Not identified	Belize City, Belize	Neill & Allen (1959)
Testudinidae	*Aldabrachelys gigantea*	Aldabra Giant Tortoise	*Lepas* spp.	Kimbiji, Tanzania	Gerlach et al. (2006)

Fig. 1. Adult female Western Pond Turtle (*Actinemys marmorata*) with probable *Amphibalanus subalbidus* barnacle attached to the underside of its posterior carapace, Hill Slough Wildlife Area, Solano County, California. White arrow points toward the barnacle.

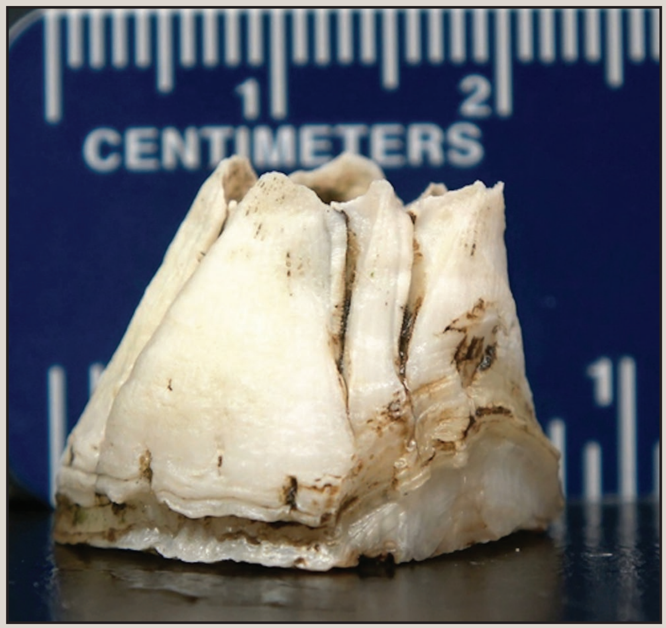

Fig. 2. One of the *Amphibalanus subalbidus* specimens collected from a piling in Hill Slough Wildlife Area, Solano County, California.

of the barnacle. After inspection, the turtle was released at the point of capture and two salinity measurements (3–4‰) were obtained with a refractometer.

To identify the species of barnacle attached to the Western Pond Turtle captured in our study, five barnacles, several comparable in size to that seen on the turtle, were collected on 27 July 2017 from a piling underneath a bridge <1 km southwest of where the study turtle was captured. These specimens were identified as *Amphibalanus subalbidus* (Henry 1973), based on morphological characters and genetic analyses (Fig. 2; Carlton et al., unpubl.). These barnacles (20–25 mm rostro-carinal diameter) represent the first report of the introduction of this species to the San Francisco Estuary (Carlton et al., unpubl.). The native range of *A. subalbidus* is along the Atlantic coast, from Chesapeake Bay to the Gulf of Mexico (Henry and McLaughlin 1975). On the Pacific Coast of North America, *A. subalbidus* has also been reported from Laguna Salada and the Rio Hardy within the Colorado River Delta in northern Baja California, Mexico (Van Syoc 1992), where it was likely introduced from the Gulf of Mexico (Carlton et al. 2011).

Although we were unable to collect the barnacle specimen attached to the turtle, three lines of evidence strongly suggest it was *Amphibalanus subalbidus*, rather than the estuarine *A. improvisus*. The latter, reported from Suisun Marsh before the tidal control facility on Montezuma Slough was established (Newman 1967), is a well-documented barnacle introduced to San Francisco Bay in the 1800s (Carlton et al. 2011). First, the barnacle on the turtle had an estimated rostro-carinal diameter of > 20 mm, whereas *A. improvisus* is not known to reach sizes greater than 17 mm (Henry and McLaughlin 1975; WAN and JTC, pers. observ.). Second, the specimens positively identified as *A. subalbidus* were collected < 1 km from the site of the turtle observation and in a similar habitat type (i.e., brackish-water slough). Third, we captured the turtle in water with 3–4‰ salinity; *A. subalbidus* is more tolerant of low salinity than *A. improvisus*, with the former generally being found at 0.1–3.5‰ (Poirrier and Partridge 1979; Dineen and Hines 1994).

With the addition of the Western Pond Turtle, 12 non-marine turtle species are now known to host epizoic barnacles (Table 1). Barnacle species in the "*eburneus*" group of *Amphibalanus* (*A. amphitrite*, *A. eburneus*, *A. improvisus*, and *A. subalbidus*; Henry and McLaughlin 1975) are wide-ranging and have been introduced to multiple regions around the world (Carlton et al. 2011; Wrange et al. 2016). Many species within this group can tolerate a wide breadth of salinity and thermal conditions (Nasrolahi et al. 2012). It is therefore not surprising that *Amphibalanus* spp. have been recorded on more than half of the presently known non-marine turtles that have been observed with attached barnacles (Table 1). While most reports of barnacles on non-marine turtles do not suggest any harm to the individual, heavy fouling by epizoic barnacles, such as *Amphibalanus* spp., can potentially cause shell deterioration, as well as mating and nesting interference (Seigel 1983).

The Western Pond Turtle is generally regarded as a freshwater species (Ernst and Lovich 2009). However, it does occur in brackish water habitats in the San Francisco Estuary. While it is present in tidal marsh habitat in Suisun Marsh and other nearby areas, we could not find data to illustrate its salinity tolerance and general biology or ecology in brackish water environments. While most freshwater turtles lack functioning salt glands, several species can physiologically or behaviorally maintain homeostasis in brackish water for days or even months (Dunson and Seidel 1986; Bower et al. 2016). However, the degree to which a non-marine turtle's tolerance of brackish waters facilitates the settlement and growth of epizoic barnacles and other organisms remains to be determined.

Given the results of our literature survey (Table 1), only 5% of the 241 species of non-marine turtles with a geographic range that extends along and overlaps a coastline or estuary (i.e., turtle species potentially exposed to brackish water; Rhodin et al. 2017) are known to host epizoic barnacles. In addition, of the 147 Western Pond Turtles captured to date in Suisun Marsh by MA, only the one turtle referenced here was found with an epizoic barnacle. Thus, barnacle settlement and growth on freshwater and estuarine turtles of the world is likely an opportunistic and rare relationship.

At least two factors likely limit the occurrence of barnacles on non-marine turtles. First, most non-marine turtles are restricted to fresh or very low-salinity water (Dunson and Seidel 1986; Ernst and Lovich 2009), whereas few barnacle species can tolerate such conditions (Dineen and Hines 1994). Second, unlike sea turtles, many non-marine turtles spend substantial periods of time out of water (e.g., terrestrial aestivation periods may last an average of 111 days for *Actinemys marmorata*; Ernst and Lovich 2009), and barnacles, especially during juvenile stages, cannot survive extended periods of subaerial exposure. When a barnacle is subaerially exposed, water is lost through the skeletal wall (Newman 1967) and the barnacle becomes increasingly susceptible to desiccation (Foster 1971). For instance, two species in the genus *Amphibalanus* lose up to 70% of their total water weight in less than 48 hours when exposed to dry air (20°C and 45–50% relative humidity; Newman 1967). In ecosystems where barnacles and non-marine turtles co-occur, further research is needed to better understand how climate or habitat type (e.g., intertidal marsh) may support or influence successful barnacle colonization of turtle shells.

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