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A Synthesis and Review of the Expanding Range of the Asian Freshwater Mussel *Anodonta woodiana* (Lea, 1834) (Bivalvia: Unionidae)

by

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Abstract. The freshwater mussel *Anodonta woodiana* is native to eastern Asia. In recent years, it was discovered in fish hatcheries in Romania, Hungary, France, and several Indonesian islands. It also was collected in the wild in the Dominican Republic and Costa Rica. These occurrences are believed to be the result of the incidental introduction of exotic fishes imported for food, as foraging fishes, or for mosquito control, which bore parasitic glochidia of the mussel. These hosts are grass, common, bighead, and silver carp; Nile tilapia; and mosquitofish. Because these fishes are imported throughout the world, *Anodonta woodiana* may eventually be found in additional countries. It has the potential to escape and compete with native freshwater mussels wherever it is introduced.

INTRODUCTION

Accidental introductions of aquatic mollusks have become more common with the increase in traffic and speed of transoceanic crossings. Transport in ballast water has been implicated in the North American invasion by the zebra mussels *Dreissena polymorpha* (Pallas, 1771) and *D. bugensis* (Andrusov, 1897) from Europe (Hebert et al., 1989; Rosenberg & Ludyanskiy, 1994), and the marine gastropod *Philine auriformis* Suter, 1909, from New Zealand (Gosliner, 1995). The brackish-water bivalve *Mytilopsis leucophaeta* (Conrad, 1831) was introduced from North America to the Netherlands, France, and Belgium; and the Caribbean *Mytilopsis sallei* (Récluz, 1849) was introduced to Visakhapatnam in India, and Fiji (Marelli & Gray, 1983). Numerous marine exotics in Hawaii were traced to Barge YO–146, which carried mollusks on its hull from Guam; other Hawaiian exotics may have arrived on other ships during World War II (Burgess, 1995). The estuarine bivalves *Corbicula largillierti* (Philippi, 1811), *C. fluminea* (Müller, 1774), and *Limnoperna fortunei* (Dunker, 1857) were introduced to Argentina as food items (Darrigran & Pastorino, 1993). *Corbicula fluminea* was similarly introduced to North America as a food item, and has since spread throughout much of the continent (Mills et al., 1993). Exotic thiarid freshwater gastropods were introduced repeatedly to North America through the aquarium trade, and many have escaped to the wild (Murray, 1971).

Unionacean bivalves, "freshwater mussels," also were transported to areas outside their normal range by the activities of man. The Indonesian *Pseudodon vondembuschianus* (Lea, 1840) was introduced to Singapore, presumably as glochidia on exotic fishes (Ng et al., 1993). *Anodonta anatina* (Linnaeus, 1758) may be a recent arrival in Ireland (Ross & McCarthy, 1991; Lucey, 1995). The eastern North American *Pyganodon grandis* (Say, 1829) was found in Arizona, probably as the result of the release of infected fishes (Taylor, 1966). But no unionacean has been introduced as widely as *Anodonta woodiana* (Lea, 1834).

DISCUSSION

Biology

Anodonta woodiana is a native of southeastern Russia, China, Cambodia, Thailand, Malaysia, and Taiwan (Dudgeon & Morton, 1983; Chang, 1991). A form or subspecies also occurs in Japan and has been given the subspecific name *japonica* Martens, 1874. Other subspecific taxa have been proposed, such as *calipygos* Kobelt,

1879, and *lauta* Martens, 1877, but the status of these is unclear. Dudgeon & Morton (1983) discussed the taxonomy of this variable species, which also has been placed in *Cristaria, Pletholophus,* and *Sinanodonta.* Considering the changing status of anodontine higher taxa, this species is referred to here conservatively as an *Anodonta.* It is a large species, reaching lengths of 26 cm. Like most anodontines, it grows quickly and can tolerate a variety of habitats (Dudgeon & Morton, 1983; Kiss & Pekli, 1988; Kiss, 1990b). Most anodontines that have been investigated were able to parasitize a wide range of host fishes (Trdan & Hoeh, 1982), including exotics. Kiss (1990a) believed *A. woodiana* could parasitize any freshwater fish. The potential thus exists for anodontines, and *A. woodiana* in particular, to become established outside their native range if given the opportunity.

Reported potential fish hosts for *Anodonta woodiana* include *Metzia takakii, Puntius semifasciolatus, Rhinogobius brunneus, Rhodeus tabira, Zacco platypus, Z. temmincki,* and *Acheilgnathus moriokae.* More importantly, the following commercially exported species are suspected as hosts: black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idella*), silver or mud carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), common carp (*Cyprinus carpio*), western mosquitofish (*Gambusia affinis*), and Nile tilapia (*Oreochromis niloticus*) (Habe, 1975; Dudgeon & Morton, 1983, 1984; Pétro, 1984; Girardi & Ledoux, 1989; Kondo, 1987, 1989; Sárkány-Kiss, 1986). These fishes were, and still are being introduced outside their native range for food, control of aquatic vegetation, hatchery water quality maintenance, mosquito control, or as aquarium fishes.

Introductions

Anodonta woodiana was introduced in Hungary to the Szarvas hatchery on exotic food and foraging fishes imported from the Amur River, and later from Krasnodar, Russia, between 1963 and 1965 (Petró, 1984; Kiss, 1990a). The Amur River is part of the natural range of *A. woodiana.* The origin of the Russian fishes was not determined. The imported fishes included grass, silver, and bighead carp. *Anodonta woodiana* has since been recorded from the Szazhlombatta hatchery as well. Mussels or infested fishes have escaped the hatcheries, and *A. woodiana* was established in six localities in Hungary as of 1988, including the Tisza River at Szeged and Szentes, the Körös River at Biharugra, and the Danube River (Kiss & Petró, 1992).

In 1982, *A. woodiana* appeared in a hatchery at l'Etang des Gravières à Fonvieille near Arles, France (Girardi & Ledoux, 1989). Introduced common and grass carp were procured that year from Hungarian hatcheries in Hortobagy, Szazhlombatta, and Szarvas. As described above, the latter two hatcheries were infested at that time with the mussels carried by fishes imported from the Amur River (Pétro, 1984; Kiss & Pétro, 1992). *Anodonta woodiana* therefore had survived through at least several generations in these Hungarian hatcheries to infest fishes exported to France 19 years later.

Sárkány-Kiss (1986) documented the introduction of *A. woodiana* into Romania. In 1959, 54,000 young-of-year, and in 1960, 22,555 larvae of grass carp were imported from the Yangtze River basin via Moscow into the Experiment Station at Nucet. Like the Amur, the Yangtze River is part of the natural range of this mussel. A similar import took place in 1962 into Cefa-Oradea and Nucet, again. Adult *A. woodiana* were collected in fish ponds in 1979 at Cefa-Oradea. Grass, silver, and bighead carp were introduced, all hosts for *A. woodiana.* It is likely that *A. woodiana* was or is present at the Moscow hatchery as well, but there was no information available.

Anodonta woodiana was introduced from Taiwan into the Inland Fisheries Research Institute at Bogor, West Java, in 1969 on silver carp and/or Nile tilapia. Mussels themselves were released in 1972 into the Bogor Botanical Garden ponds. This species subsequently was introduced on fishes into other sites in Java, Sumatra, Manado in North Sulawesi, Kendari in Southeast Sulawesi, Lombok Island in the Nusa Tenggara Islands, and Moluccas (Djajasasmita, 1982; Dharma, 1992).

In 1994, E. Keferl collected *A. woodiana* at Laguna de Arenal, a hydroelectric impoundment at San Luis, Costa Rica. The mussel did not occur there until blue tilapia, *Oreochromis aureus,* and Nile tilapia, *Oreochromis niloticus,* were introduced as food fishes (Keferl, 1995; in litt., 1996). The fishes were imported from an agriculture project in the Guanacaste region near Lomas Barbudal Reserve, which in turn may eventually have received the fishes from Taiwan.

Hispaniola has no native unionids (Johnson, 1981). In 1982, Padre J. Cicero and G. Grullón P. (1982) first recognized that an exotic anodontine occurred in the Dominican Republic in a hatchery at Nigua near Santo Domingo, but identified it as *Anodonta* [=*Pyganodon*] *grandis* Say, 1829, a North American species. Gomez et al. (1986) also reported that an *Anodonta* sp. was "recently introduced" into the Dominican Republic and was present in these carp and tilapia ponds at the Ministry of Agriculture in Nigua. Subsequently, G. Duffy and M. Kohl independently collected specimens of this species in the wild in Santo Domingo (Watters & Kohl, 1995). Specimens sent to the author were identified as *A. woodiana* based upon comparisons with material from China and Sulawesi. Additional specimens also were identified as this species by malacologists R. Johnson, Museum of Comparative Zoology, Cambridge, Massachusetts, and H. Lee, Jacksonville, Florida (Duffy, written communication, 1995). The mussel was recorded from several places: Rio Yuna in the El Seibo region; the impoundment of Presa de Rincón near Bonao (Duffy, written communication, 1995); and Byaguana (F. Richardson, written communication, 1995). Numerous exotic fish species have been introduced into the Dominican Republic, including species believed to host *A. woodiana:* common, grass, and silver carp, Nile tilapia,

and mosquitofish. It is likely that these fishes were imported via Panama from Taiwan. Unfortunately, the original import manifests for the Dominican Republic were destroyed in a fire in 1994 (F. Richardson, written communication, 1995). The import of these fishes, whatever their source, resulted in the introduction of *A. woodiana* to the Dominican Republic, where it has escaped to the wild.

There is no doubt that *A. woodiana* is being accidentally translocated to new areas outside its normal range by the shipping of host fishes. Saline solutions used for transporting fishes, usually 0.5% or less, may be insufficient to destroy attached glochidia. Bruno et al. (1988) treated Atlantic salmon infested with *Margaritifera margaritifera* (Linnaeus, 1758) glochidia with saline water at 5.4, 10.1, and 24.3% for 1, 3, and 9 hours, and at 33.3% for 24 hours. No significant glochidial mortality was observed in any treatment. Bathing fishes in 0.5 mg/l^{-1} $CuSO_4$ for 1 hour, or 5 mg/l Nuvan® for 1 hour followed by 1 mg/l Roccal® for 1 hour, also did not significantly affect glochidial mortality. Because *A. woodiana* may require several weeks to metamorphose, depending on water temperature, there is ample time to move infested fishes great distances. The fact that *A. woodiana* has colonized hatcheries and successfully infested exported fishes years after its initial introduction indicates that hatcheries can act as sources of repeated release of this exotic mussel.

Similar Species

Presently there are no records of *A. woodiana* in North America, which has a diverse but imperiled unionid fauna. However, it may exist undetected in hatcheries or adjacent rivers, confused with native species. *Anodonta woodiana* resembles *Utterbackia suborbiculata* (Say, 1831) from the Mississippi River system, and *Anodonta* sp. from the Pearl River of Louisiana (Vidrine, 1993: pl. 1, fig. M). The latter appears to represent an undescribed species. It differs from those species in the following ways: the umbo protrudes above the hinge line, whereas in *U. suborbiculata* it is flush; the beak sculpture consists of coarse, linear or slightly concentric ribs without prominent nodules, whereas in *U. suborbiculata* and *Anodonta* sp. the sculpture is fine, concentric but nodulous. It is often more brightly colored, with dark green rays, whereas *U. suborbiculata* and *Anodonta* sp. are typically tan or yellowish, rayless, or with very fine brown or green rays. *Utterbackia suborbiculata* and *Anodonta* sp. are consistently round in profile, whereas *A. woodiana* is variable in outline, from round to elongate. *Pyganodon grandis* has very different beak sculpture composed of fine double loops. The European unionids *Anodonta anatina* (Linnaeus, 1758) and *Pseudanodonta complanata* (Rossmässler, 1835) also have double-looped beak sculpture, and *Anodonta cygnea* (Linnaeus, 1758) has fine concentric beak sculpture (Fechter & Falkner, 1990). The glochidium of *A. woodiana* was illustrated by Inaba (1941) and Bykhovskaya-Pavlovskaya (1962), but consistent differences from other anodontine glochidia (Wiles, 1975; Rand & Wiles, 1982) have not been identified.

Implications for Native Freshwater Mussels

Where introduced, it is believed that *A. woodiana* is using native fishes as hosts (Djajasasmita, 1982; Dudgeon & Morton, 1983, 1984). However, its natural hosts, grass and common carp are found as exotics, wild throughout much of North America, including nearly all of the contiguous United States; and silver and bighead carp, and Nile tilapia, occur wild in several southern states. Common carp was introduced into the United States in 1831 (Page & Burr, 1991). Grass carp was introduced to Arkansas and Alabama in 1963, silver carp to Arkansas in 1973, and bighead carp to Arkansas in 1972. Culture of Nile tilapia is allowed by permit, and triploid grass carp are stocked by several states in the United States (Howells, 1992; S. Ross, personal communications 23 August 1994). Blue tilapia is annually stocked in Alabama ponds (Page & Burr, 1991). If *A. woodiana* enters North America, it may therefore use not only native hosts, but wild exotic hosts as well.

It is suspected that unionids compete for hosts (Rashleigh, 1995). So far, *A. woodiana* has been introduced to areas having few or no native unionids. It is not known what impact an introduction would have on North America's several hundred native species. The introduction of an anodontine capable of infesting native and exotic fishes may diminish the chances of native unionids' survival, many of which are already rare or endangered. Simulations have shown that such an exotic may locally drive some types of native mussels to extirpation by monopolizing suitable hosts, both native or exotic. Populations of the exotic may become larger than those of the native species by orders of magnitude (Watters, in press). Given the history of this species' invasion elsewhere, and the continued farming and exporting of its hosts, it is likely that *A. woodiana* eventually will invade North America and other countries.

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