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A Review of Recent Introductions of Aquatic Invertebrates in Puerto Rico and Implications for the Management of Nonindigenous Species

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ABSTRACT.—The Asian clam, *Corbicula fluminea* (Bivalvia); Florida applesnail, *Pomacea paludosa* (Gastropoda); and Australian redclaw, *Cherax quadricarinatus* (Crustacea) have recently become established or possibly established in Puerto Rico. The giant floater, *Anodonta grandis* (Bivalvia); giant freshwater prawn, *Macrobrachium rosenbergii* (Crustacea); and red swamp crawfish, *Procambarus clarkii* (Crustacea), have been introduced but not released. This paper presents the history of these introductions, their potential ecological consequences, and the loopholes that allowed each one to happen. Among the latter were: the danger inherent in *C. fluminea* was apparently not advertised, very similar snails (*P. paludosa* and South American applesnails, *Pomacea cumingii*) were not distinguished, existing enforcement systems were not designed to prevent package-delivery shipments and mass shipments of *C. quadricarinatus* to individuals, and *P. clarkii* and *A. grandis* were introduced by the aquarium industry and transferred to aquaculture.

INTRODUCTION

Three important nonindigenous aquatic invertebrates; the Asian clam (*Corbicula fluminea*), the Florida applesnail (*Pomacea paludosa*), and the Australian redclaw (*Cherax quadricarinatus*) have recently become established or possibly established in Puerto Rico. Red swamp crayfish (*Procambarus clarkii*) and giant floater (*Anodonta grandis*) have been introduced but not released. We provide an overview of these five introductions, compare them to similar Caribbean cases, and try to define the weaknesses in the regulatory system that allowed them to occur.

These potentially dangerous introductions occurred despite laws restricting and regulating nonindigenous species. The following distinct weaknesses in the system allowed the introductions: 1. The danger inherent in *C. fluminea* was apparently not known by the local aquarium industry; 2. Very similar snails [*P. paludosa* and South American applesnails, *Pomacea cumingii*] were not distinguished in mass shipments; 3. Existing enforcement systems were designed to regulate shipments to large business and failed to detect package-delivery shipments and mass shipments of *C. quadricarinatus* to individuals; and 4. The introduction of *P. clarkii* and *A. grandis* as aquarium industry animals and their subsequent transfer to aquaculture. These weaknesses involved lack of regulating or properly informing the aquarium, package delivery, and aquaculture industries, and require better training and information for inspectors. These lessons are valuable for evaluating other nonindigenous management systems.

INTRODUCED SPECIES

Asian clam, Corbicula fluminea

Corbicula fluminea (Bivalvia: Verneroida: Corbiculidae), was imported by Chi-

nese immigrants into the west coast of Canada and continental USA sometime in the late 1800s (Eldredge, 1994). Beginning in the 1960s, *C. fluminea* spread from the west coast of North America throughout much of temperate and subtropical North America (Eldredge, 1994). The clam is considered an undesirable species because it can out compete and replace native clams in freshwater and brackish habitats. It is also considered a pest because it clogs water pipes, screens, and other submerged structures. Chinese immigrants valued the purported medicinal properties of eating the raw clam, but it carries parasites that can infect humans with echinostomiasis (Huffman and Fried, 1990). Some fish species eat at least the smaller specimens of *C. fluminea*, but reservoir fish populations in California have declined because of competition with the clam (Devick, 1991).

In May 2000, we found adult *C. fluminea* in Cidra and La Plata Reservoirs in Puerto Rico. These reservoirs are found in separate, but largely parallel drainages (La Plata and Bayamón) in northeastern Puerto Rico. The high densities ($10/m^2$) of *C. fluminea* that we found are much greater than those of the native freshwater Puerto Rican bivalves (Puerto Rican fingernail clam, *Eupera portoricensis*, and ubiquitous peaclam, *Pisidium casertanum*). *Eupera portoricensis* is endemic, while *P. casertanum* is widespread in the Caribbean and North America. Both species are considered endangered by the Puerto Rico Department of Natural and Environmental Resources (DNER) but they are not included in federal endangered species lists. *Corbicula fluminea* attains a much larger size (>4 cm) than either native clam (<1 cm). We deposited samples of *C. fluminea* in the Invertebrate Collections of the Department of Biology, UPRM, and Biology Department, University of Puerto Rico at Humacao (UPRH). These collections do not assign accession numbers.

We attempted to trace the origin of this introduction but found only one record. In 1998, Cortes (pers. comm.) collected small specimens of *C. fluminea* in the Cayey River near Cayey, Puerto Rico, Loiza Drainage. He stored the specimens in his laboratory and gave them to us after we inquired about the species. Although these specimens may have originated from an aquarium release of *C. fluminea* or water containing their larvae, we have had great difficulty in obtaining information from the aquarium fish industry (Williams et al., 1996).

With three river systems now supporting *C. fluminea*, control of this species seems very unlikely. We anticipate that the clam will spread throughout the fresh and brackish waters of Puerto Rico and will ultimately cause the extinction of *E. portoricensis* and the extirpation of *P. casertanum*. *Corbicula fluminea* has caused intense biofouling problems in North America and in parts of the tropical Pacific (Eldredge, 1994). It will likely cause the same problems in hydroelectric power systems, reservoir management, and aquaculture facilities in Puerto Rico.

Florida applesnail, Pomacea paludosa

Applesnails, *Pomacea* spp.(Gastropoda: Architaenioglossa: Ampullariidae), have a long history of invading habitats as nonindigenous introductions and out competing native snails (Mochida, 1991). For years, the local aquarium fish industry has imported millions of South-American applesnails, *P. cumingii.* This species is native to northeastern South America but has been introduced into many Caribbean islands. The snails have been released into the environment, become established in high densities (10-$30/m^2$), and may have displaced and replaced local species of mollusks in some parts of Puerto Rico (Ortiz-Corps, unpubl. data).

Several years ago, distributors supplying *P. cumingii* to local aquarium fish retailers substituted the Florida applesnail, *P. paludosa.* This snail is native to the southeastern USA, especially Florida (Eldredge, 1994). Eventually DNER questioned the identity of a shipment of 3000 of these snails, confiscated the animals, and sent us a subsample for identification. We identified them as *P. paludosa* and deposited samples in the Invertebrate Collections of the Department of Biology, UPRM, and Biology Department, UPRH. We evaluated 10

specimens of *P. paludosa* for parasites and diseases but found none.

Some *P. paludosa* may have been introduced into Puerto Rican fresh waters, but we have not been able to confirm this. As a result of our efforts, importation of this species has been banned to prevent the establishment of a second applesnail in Puerto Rico (DNER, in press). Importation of additional *P. cumingii* should be discouraged in favor of harvesting the locally abundant stocks. This would decrease the number of locally established *P. cumingii*, support a local collection industry for this and other aquarium nonindigenous species (Bunkley-Williams et al., 1994), and stop importation of additional nonindigenous snails that may harbor parasites and diseases.

Australian redclaw, Cherax quadricarinatus

This crayfish, *Cherax quadricarinatus* (Malacostraca: Decapoda: Parastacidae), has been cultured in the Caribbean and continental USA (Rubino et al., 1990). The closely related marron, *Cherax tenuimanus*, has also been cultured in Barbados (Alston, 1991). In 1990, at the request of an aquaculture company, DNER evaluated *C. quadricarinatus* for possible culture in Puerto Rico. It was rejected as an approved introduction at that time because its culture was still experimental and its impact on tropical ecosystems had not been evaluated. A summary of diseases, parasites, and commensals was compiled during the evaluation (Bunkley-Williams and Williams, unpubl. data).

A shipment of 3000 *C. quadricarinatus* was sent to Puerto Rico in 1997, at least partially via a well-known commercial package service, without inspection or knowledge of the local government. These animals were stocked in earthen ponds on a farm in northeastern Puerto Rico. Only after adult *C. quadricarinatus* escaped as a result of Hurricane Georges, 22 September 1998, was the unauthorized introduction discovered. Subsequent investigation suggested that several other farms had received shipments of *C. quadricarinatus* and stocked these animals in various amounts.

Cherax quadricarinatus has become established in the Loiza River and Carraizo Reservoir due to this mass escape (possibly multiple mass escapes). Sporadic sampling by DNER suggested that *C. quadricarinatus* have maintained their numbers and appear to be expanding their range (Lilyestrom, unpubl. data).

We examined samples of escaped animals for parasites and disease but only found harmless commensals. Some of these animals were held for experimental purposes by the Aquaculture Project, UPRM. We also deposited samples of *C. quadricarinatus* in the Invertebrate Collection of the Department of Marine Sciences, UPRM.

Red Swamp Crayfish, Procambarus clarkii

The red swamp crayfish, *Procambarus clarkii* (Malacostraca: Decapoda: Cambaridae) is native to the southern USA, but has been introduced throughout the world (Hobbs et al., 1989). We saw many specimens in east African lakes in 2000. The species is destructive and undesirable for introduction on at least two counts: 1. it carries a deadly fungal disease caused by *Aphanomyces astaci* that devastated European freshwater crustaceans and almost totally eliminated European crayfishes in the late 1800s and early 1900s, and still causes problems (Johnson, 1977); (2) it is physically destructive, burrowing holes through earthen dams and dikes (Eldredge, 1994). *Procambarus clarkii* should be banned from introduction everywhere (Eldredge, 1994). This highly dangerous animal has been held experimentally in Puerto Rico (Williams, unpubl. data). It was apparently obtained from aquarium industry sources (where it should have been illegal, but was not), and used in aquaculture experiments. Specimens were exposed to all native species of Puerto Rican freshwater crustaceans for several weeks without causing disease signs in the native species (Williams, unpubl. data). Fortunately all experimental animals were destroyed and neither *P. clarkii* or *Aphanomyces astaci* were released into the environment.

We have continued to see specimens of *P. clarkii* in aquarium shops in Puerto Rico. Two or three specimens were obtained

from an aquarium shop two years ago and released into an earthen pond in northeastern Puerto Rico, but fortunately died before reproducing (Lilyestrom, unpubl. data). This is clearly another example of the danger of having undesirable aquatic organisms imported by the aquarium trade. As a result of our efforts, *P. clarkii* has been added to the list of species prohibited from importation into Puerto Rico (DNER, in press).

We know of one other nonindigenous clam species (see *Anodonta grandis* below) and two nonindigenous fish species that have similarly been imported as aquarium industry species and then used for aquaculture experiments or production. While this mechanism has not resulted in the establishment of a nonindigenous invertebrate, it is another loophole in the regulation and management of nonindigenous species.

Giant Floater, Anodonta grandis

The giant floater, *Anodonta grandis* (Bivalvia: Unionidea: Unionidae) is native to the southeastern USA and was introduced into the Dominican Republic in the 1970s. This represented a "biological loophole" in their exotic regulations because the clam entered the country as a glochidial stage encysted in the gills of common carp, *Cyprinus carpio*. The larval stages of this mussel cannot survive without passing though a parasitic stage in the gills of a fish and this makes it an additional threat because the glochidia damage the gills. *Anodonta grandis* is economically valuable because its flesh is edible and shell fragments are used as nuclei for the Japanese cultured pearl industry. These aspects led aquaculturalists in Puerto Rico to illegally import specimens from the Dominican Republic, probably as aquarium animals, for use in aquaculture experiments (Bunkley-Williams and Williams, 1994).

All species of native and established exotic freshwater fishes in Puerto Rico were exposed to *A. grandis* shedding glochidial infective stages. None of the hosts became infected, which is at odds with Fuller (1974) and Trdan and Hoeh (1982), who found that glochidia infect a wide variety of host species, including many of those found in Puerto Rico. In an attempt to clarify this discrepancy, in 1998 we visited a mussel re-establishment project operated in cooperation with the Chattanooga Aquarium. We were informed that they had raised *Anodonta grandis* extensively and found that its glochidia infected a wide range of freshwater fishes. Thus, *A. grandis* should be considered a threat to local freshwater fishes and it should not be imported into Puerto Rico. The local experiments were supposedly conducted in closed culture systems and all the animals were destroyed.

Management Implications

Many mass releases of the widely-cultured giant freshwater prawn, *Macrobrachium rosenbergii*, have occurred in Puerto Rico and throughout the Caribbean without ill effects. This prawn was originally distributed in the Indo-Pacific, from northwest India and Vietnam to the Philippines, New Guinea, northern Australia, and Palau (Eldredge, 1994), but has been introduced throughout the tropical and subtropical world as a very popular aquaculture animal. *Macrobrachium rosenbergii* is generally considered an ecologically harmless nonindigenous species because of its well-documented non-aggressive behavior (Alston, 1991). This trait was expected to prevent its survival in the wild because it would not be able to compete with native species of shrimp. Indeed, *M. rosenbergii* became established in Dominica only in areas where native freshwater shrimps had been eliminated (Alston, 1991). However, *M. rosenbergii* may have more potential for competing with native freshwater shrimps than has been suspected; in Venezuela it has spread from aquaculture to a river system where it has out competed a smaller, native shrimp over a large geographic area (Pereira, pers. comm.).

Cherax quadricarinatus is more aggressive than *M. rosenbergii* and possibly constitutes a greater threat to local freshwater shrimps. By inadvertedly releasing many *C. quadricarinatus*, Puerto Rico is conducting the first

large-scale "experiment" on the effect of this species in a new tropical environment. We need to carefully follow the results. Preliminary results suggest that *C. quadricarinatus* may out compete and replace local freshwater shrimps.

Puerto Rico has been fortunate in being damaged by few nonindigenous aquatic animals and relatively few aquatic parasites and diseases (Bunkley-Williams and Williams, 1994). Puerto Rico has rules, regulations, and enforcement personnel that function relatively well in protecting the island's aquatic environments against nuisance species. However, recent introductions of three aquatic invertebrates have exposed loopholes in the regulatory system: 1. not informing the aquarium industry of the danger of *Corbicula fluminea*, 2. inability to distinguish very similar snail species, 3. not informing or regulating the small-package delivery companies concerning smaller shipments of nonindigenous species to individuals, and 4. not restricting aquarium industry animals for use in aquaculture. Exposing these problems should help us improve our system and may be instructive to those responsible for such regulation in other localities.

In most countries the aquarium fish industry is only restricted from importing the most obviously dangerous species because their imports are not intended for release into the local environment. This freedom should be accompanied by a certain amount of responsibility. Any organisms possibly dangerous or damaging to local environments should be avoided by the industry. Replacement of *Pomacea cumingii* with *P. paludosa* could have been an inadvertent error with unanticipated results. However, *Corbicula fluminea* is so well documented as a highly destructive pest that it should have never been brought to Puerto Rico. The species is not considered a problem in the North American aquarium fish trade because it is already widely established in inland waters.

The Asian clam may have been shipped to Puerto Rico without explanation or concern. A similar situation occurred with largemouth bass, *Micropterus salmoides* (Lacepède), infected with the bass tapeworm, *Proteocephalus ambloplitis*). This parasite is ubiquitous in North America and is thus an unimportant contaminant, but it does not exist in Puerto Rico and its introduction was potentially disastrous (Bunkley-Williams and Williams, 1994).

Commercial package delivery companies are not generally considered a live animal delivery service. Hence, one of these package services could be used to deliver shipments of an aquatic animal such as *Cherax quadricarinatus* (illegal in Puerto Rico) without question or comment. Hopefully this loophole in the information/regulatory system has been closed by informing these companies about the applicable regulatory clearances for shipments of nonindigenous species.

The following control measures have been or should be established in Puerto Rico to avoid further introductions of nonindigenous species:

1. An updated list of nonindigenous species potentially dangerous to Puerto Rico has been prepared and will be published (DNER, in press).
2. Inspectors should receive better training for identifying nonindigenous species, especially those similar to native or previously established nonindigenous species.
3. An illustrated checklist and a diagnostic key for identifying these species should be prepared and published.
4. The various package-delivery companies in Puerto Rico have been informed of existing regulations concerning nonindigenous species.
5. Aquaculture organizations should be informed that only approved nonindigenous species obtained from approved sources can be cultured.
6. A checklist of species currently approved for aquaculture should be prepared and published.
7. A list of the regulations and laws governing nonindigenous species and the supporting materials described above should be made available in a packet or brochure. This will partially be accomplished by the DNER educational effort regarding new fisheries regulations

(DNER, in press). Four booklets will be prepared containing the pertinent articles and rules for: recreational marine fishermen, commercial fishermen, aquaculturalists, and those applying for special permits regarding prohibited issues.

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