Aquatic Nuisance Species Research Program

ANSRP Bulletin, Vol-04-1 February 2004

Suckermouth Catfishes: Threats to Aquatic Ecosystems of the United States?

by Jan Jeffrey Hoover, K. Jack Killgore, and Alfred F. Cofrancesco

Introduction

In appearance and in habits, the suckermouth catfishes or "plecos" of South and Central America (*Loricariidae*) are markedly different from the bullhead catfishes of North America (*Ictaluridae*). Bullhead catfishes are terete and naked, with a terminal mouth and a spineless adipose fin. They are free-swimming predators that feed on invertebrates and other fishes. Suckermouth catfishes, in contrast, are flattened ventrally, their dorsal and lateral surfaces covered with rough, bony plates forming flexible armor (Figure 1). Because of this armor, suckermouth catfishes are sometimes referred to as "mailed" catfishes (Norman 1948). The mouth is inferior and the lips surrounding it form a sucking disc (Figure 2). The adipose fin has a spine. The caudal fin is frequently longer ventrally than dorsally. Pectoral fins have thick, toothed spines which are used in male-to-male combat and locomotion (Walker 1968). Suckermouth catfishes are benthic, adhering to streambeds and rocks with their mouths. They are vegetarians feeding on detritus and algae. Feeding is done by plowing along the substrate and using the thick-lipped, toothy mouth to scrape plant materials (filamentous algae, diatoms) from hard surfaces or to

*Figure 1. Suckermouth catfishes from the San Antonio River at Lone Star Boulevard, San Antonio, Texas. These are sailfin catfishes and are believed to represent three species: **Pterygoplichthys anisitsi** (foreground), **P. disjunctivus** (middle), **P. multiradiatus** (background)*

Figure 2. Mouth of a sailfin catfish. The thick, fleshy lips form a sucking disc for attaching to rocks and grazing on algae

In this Issue:

suck up fine sediments. Specimens in aquaria may live more than 10 years. Suckermouth catfishes are capable of breathing air by swallowing it and extracting oxygen through the gut lining (Norman 1948).

With more than 550 species, suckermouth catfishes constitute the largest family of catfishes in the world (Robins et al. 1991). Popular with home aquarists because of their distinctive appearance, hardiness, and propensity for cleaning algae from all submerged surfaces (including vascular plants), suckermouth catfishes have been commonly imported into the United States since the mid-20th century (Innes 1948) and the number of taxa imported has increased during recent decades (Robins et al. 1991). Consequently, it is not easy, at present, to precisely identify specimens of suckermouth catfishes when they are found in U.S. waters.

Taxonomy of this group has been described as "relatively primitive" and for some genera as "a mess" (Page and Burr 1991; Armbruster 2000). As a result, species-level identifications are tenuous. Forums exist for identifying specimens from photographs (e.g., *http://www.planetcatfish.com*) and some taxonomic resources are available on the Web, such as those for Loricariidae at the Auburn University Website (Armbruster 2000), but comprehensive taxonomic keys to species are not yet readily available to resource managers. Also, taxonomists working with sucker-mouth catfishes are themselves divided into two different camps: "splitters," principally Europeans, who divide the group into multiple genera and numerous species, and "lumpers," principally Americans, who divide the group into fewer genera and fewer species.[1] Confounding the problem of taxonomic resolution is the co-occurrence of multiple species in a single location and the possibility of interspecific hybridization. For example, three recognizably distinct forms occur at a single location in the San Antonio River in Texas (Figure 1). These conform to characteristics of three of the species known to exist in the United States, but their close abundance and co-occurrence suggest the possibility of future hybridization.[2] At present, several species, in two genera, are known to be well-established in U.S. waters (Page and Burr 1991). Some specimens, however, have unusual pigmentation suggesting hybridization (e.g., Nico and Martin 2001).

Hypostomus spp. Armadillo del Rio

Armadillo del rio (Figure 3) were introduced to Texas and Florida rivers in the mid-1950s/early-1960s and other locations shortly thereafter (Nico and Fuller 1999). Reproductive populations exist in Nevada and Hawaii and isolated specimens have been reported from at least five other states (Arizona, Colorado, Connecticut, Louisiana, and Pennsylvania). In Texas, the San Antonio River population was apparently established after individuals escaped from the San Antonio Zoo in 1962. Armadillo del rio were used in the zoo as a biological control for nuisance growths of hair algae (Barron 1964). Other populations in the United States resulted from fish farm escapees or aquarium releases.

Fishes in the genus *Hypostomus* (*Plecostomus* in older references)

Figure 3. Armadillo del rio from the San Antonio River at the San Antonio Zoo. The small dorsal fin has a single spine and seven rays

---

[1] Personal Communication. 2003. Pete Liptrot, Bolton Museum , Art Gallery, and Aquarium; United Kingdom.

[2] Personal Communication. 2003. Larry Page, Florida Museum of Natural History, University of Florida.

are readily distinguished by their comparatively small dorsal fin with fewer than nine (usually seven) rays, a snout with a smooth margin, and fused opercular bones (Burgess 1989). They frequently have patterns of spots and they range in size from 14-50 cm depending on age and species. Texas specimens have been collected that approach the maximum known size for the taxon. There are approximately 116 species (Burgess 1989), but one, *Hypostomus plecostomus*, is the most geographically widespread, occurring in tropical South America, Panama, and Trinidad; *H. plecostomus* is also the most frequently imported species (Walker 1968). At least six other species, however, have been used as ornamental fishes and can be distinguished (and putatively identified) based on pigmentation (Walker 1968). Taxonomic status of populations in the United States has not been determined definitively, but three morphologically distinct species are established (Page and Burr 1991).

These fishes construct branching, horizontal burrows in stream or pond banks that are 120-150 cm deep (Burgess 1989). Burrows are used as nesting tunnels and are guarded by the males until free-swimming larvae leave the burrow. Some species are salt-tolerant. Although salinities in which they have been collected are not reported, waters have been described as "quite brackish." Introduced populations can become locally abundant in a short period of time. Prior to 1989, the estimated number of individuals in U.S. waters was 7 million.

Pterygoplichthys spp. Sailfin Catfishes

Sailfin catfishes were confirmed from waters in Texas, Florida,and Hawaii after 1970 (e.g., Ludlow and Walsh 1991; Page 1994; Edwards 2001). Early introductions may have gone unnoticed because of superficial similarities to armadillo del rio. Most populations of sailfin catfishes were probably started from aquarium releases.

Fishes of the genus *Pterygoplichthys* (*Liposarcus* in some literature) are readily distinguished from the armadillo del rio by their comparatively wide dorsal fin with more than 10 rays (Figure 4), their snout with a granular margin, and an articulated interopercular bone with evertable spines (Burgess 1989). There are approximately 22 species (Armbruster 1997). Pigmentation, within and among species, is highly variable. Four species are known from U.S. waters (Table 1). A fifth species, *P. gibbiceps*, the leopard pleco or acari pedra, is frequently imported but has not yet been collected in North America (Smith 1981; Burgess 1989; Sandford and Crow 1991).

Like armadillo del rio, these fishes construct burrows in the banks of the rivers and lakes in which they live (Figure 5). Burrow width approximates that of the occupant fish (i.e., width between extended pectoral fins), burrow length is typically 0.5 to 1.0 m, and shape is variable although the tunnel usually extends downward into the bank (Devick 1988). These burrows are

Figure 4. Sailfin catfish from Espada Lake, Texas. The large dorsal fin has a single spine and 11 rays.

Table 1
Sailfin Catfishes (*Pterygoplichthys* spp.) in North America[1]

Scientific name	Common Name	Native Range	Records in the United States
P. anisitsi (= *P. ambrosettii ?*)	Sailfin catfish, snow pleco, snow king	Tropical America	Texas
P. disjunctivus	Vermiculated sailfin catfish	Amazon Basin	Texas, Florida
P. multiradiatus	Butterfly sailfin catfish, radiated ptero	Venezuela	Puerto Rico (Bunkley-Williams et al. 1994), Florida, Hawaii, Texas (pers.obs.)
P. pardalis	acari-bodo	Amazon Basin	South Carolina (single specimen)

[1] Common names are those recommended by Burgess (1989), Robins et al. (1991), and other authorities. Information from Nico (1999a, 1999b, 2000a, and 2000b) unless otherwise indicated.

used for reproduction but also allow survival during drought (Figure 6). Eggs are laid in the burrow and are guarded by males; fish can survive in the moist microhabitat even when water levels fall far below the opening to the chambers (Burgess 1989; Sandford and Crow 1991). The authors have observed San Antonio River fish that are, for all appearances, "dead" in the dry burrows above de-watered reaches of the river, but which are, in fact, very much alive (Figure 7). Such fish, when returned to the water, recover after a short time and swim away. Burrows may also be used as refugia during cold weather (Nico and Martin 2001). These traits enable sailfin catfish to thrive in their natural and in unnatural habitats.

Dense populations of sailfin catfishes (hundreds to thousands per water body) have been observed in natural parts of their range (Burgess 1989) and in Hawaii, Puerto Rico, and Florida (Devick 1988; Nico 1999a; Bunkley-Williams et al. 1994).[1] Growth is rapid during the first two years of life (more than 35 cm) and fecundity high (472-1283 mature eggs/female) especially in larger individuals (Devick 1988, 1989). Consequently, introduced populations can become abundant in a very short period of time. The population of *Pterygoplichthys multiradiatus* in Wahiawa Reservoir (Oahu, Hawaii) was established in 1986 (or shortly before), was characterized by


Figure 5. Burrows of sailfin catfishes in the San Antonio River, Texas


Figure 6. Sailfin catfish in de-watered burrow

---

[1] Personal Communication. 2003. Joe Gallo, Southwind Lakes Homeowners Association, Boca Raton, FL.

more than 2,000 burrows at three locations in 1987, and more than 10,000 burrows at those same locations in 1988 (Devick 1989). In 1989, it was one of the more abundant fish species in the impoundment, and by 1991 had spread throughout nearby streams and reservoirs (Devick 1991).

Environmental Effects

The distinctive feeding and reproductive behaviors of suckermouth catfishes, coupled with large size and high population densities, constitute significant threats to native fish communities and to aquatic habitats of the United States. Potential and documented impacts of suckermouth catfishes include:

Disruption of aquatic food chains

Grazing on benthic algae and detritus by suckermouth catfishes alters and reduces food and physical cover available for the aquatic insects eaten by most North American stream fishes. Feeding on mud and silt (Walker 1968) could result in resuspension of sediments and/or changes in substrate size. In addition, nutrients are prematurely diverted from the "consumer" components of food webs and transformed into feces available only to scatophags and decomposers (i.e., bacterial, fungi). Food chain disruption is not limited to stream channels, as some species (e.g., *P. gibbiceps, P. pardalis*) also forage on floodplain detritus (Smith 1981).

Impacts to native species

Native herbivorous North American fishes, like the central stoneroller (*Campostoma anomalum*) and the Florida flagfish (*Jordanella floridae*), are small (less than12 cm) minnows or minnow-like fishes, with comparatively short lifespans (less than 4 years), low fecundity, and limited resistance to hypoxia and desiccation (Figure 8). Consequently, they are at a competitive disadvantage when confronted by larger (greater than 15 cm), longer-lived, highly productive, environmentally tolerant species that feed on the same foods that they do. Because they are bottom feeders, suckermouth catfishes may incidentally ingest eggs of native fishes. Because they are benthic and large, they may displace smaller or less aggressive benthic fishes (e.g., darters, madtoms, bullhead catfishes). Declining abundance and restricted occurrences of the central stoneroller in the San

Figure 7. Sailfin catfish extracted from de-watered burrow. Eyes are sunken into the sockets and surface is dry to touch indicating prolonged aerial exposure. Specimen recovered, however, when returned to the river, ventilating and moving almost immediately, and swimming off into deep water several minutes later

Figure 8. Central stoneroller, Campostoma anomalum, *a native herbivore threatened by suckermouth catfishes. The ventrally positioned (inferior) mouth has a cartilaginous ridge on the lower jar used to scrape off attached algae on which the fish feeds. The hooked horns on the dorsal surface of the head are breeding tubercles of the male, which will be lost shortly after spawning*

Antonio River system, for example, were coincident with increasing abundance and expanding distributions of suckermouth catfishes believed to threaten the native minnow (Hubbs et al. 1978).

Mortality of endangered shore birds

Suckermouth catfishes, because they are large, sedentary, and palatable, are attractive prey to fish-eating birds. Their defensive erection of dorsal and pectoral spines, however, poses mortal danger to birds attempting to swallow whole fish. Twenty brown pelicans (*Pelecanus occidentalis*) are known to have strangled after feeding on *P. multiradiatus* but many more deaths are suspected (Bunkley-Williams et al. 1994).

Changes in aquatic plant communities

Suckermouth catfishes "plow" the bottoms of streams, occasionally burying their heads in the substrate and lashing their tails (Walker 1968). These behaviors can uproot or shear aquatic plants. This would impact native plant species by reducing their abundance in beds of submersed aquatic vegetation and creating mats that could shade them from sunlight. Making "cuttings" at the water's surface available for dispersal by water movement, boat propellers, and aquatic birds would benefit non-native nuisance plant species.

Bank erosion

The nesting burrows of suckermouth catfishes sometimes form a large group or "spawning colony" in which several dozen occur in very close proximity to each other (Nikolsky 1963). These colonies can compromise shoreline stability, increasing erosion and suspended sediment loads (Nico 2000a). Siltation, bank failure, head-cutting, and elevated turbidity are likely impacts. In Wahiawa Reservoir, burrows excavated in 1988 were estimated to have displaced 150 tons of silt (Devick 1989). In one south Florida community, erosion of catfish-infested shorelines is estimated at 0.6-1.3 m following each substantial rainfall or 4 m/yr.[1]

Systems at Risk

Based on their biology and commercial appeal, the likelihood of continued dispersal of suckermouth catfishes in North American waters is high. They are tolerant of (and likely to benefit from) eutrophication and other forms of aquatic disturbance, as evidenced by their occurrence in nutrient-rich Lake Thonotosassa and Lake Maggiore, Florida (Page 1994; Nico 1999b). Armadillo del rio are highly resistant to high water velocities. In laboratory swim tunnels, they can maintain station and move freely in water velocities greater than 1 m/s (personal observation). Cold tolerance is unknown but movements into thermal refugia (i.e., springs and seeps during winter) seem likely based on seasonal disappearances in the spring-fed San Antonio River, Texas (personal observation) and apparent utilization of sewage outflows in Houston area (Nico and Martin 2001). Also, the variety of species in each of the genera suggests that certain taxa (or hybrids) in successive generations will acclimatize to subtropical and mild-temperate climates, becoming more cold tolerant over time.

It is probable then that suckermouth catfishes will readily disperse through eutrophic waters (including those that are hypoxic and turbid), through high water velocities, and through brackish water. Overland travel has been reported anecdotally when environmental conditions are extreme and short terrestrial excursions seem likely if ground is sufficiently moist (Walker 1968).[2] Inter-drainage dispersal via upland stream cross over and coastal or inter-coastal waterway migration is inevitable. Suckermouth catfishes are commercially valuable for their tasty flesh, their roe (suitable for caviar), and as live specimens for aquaria. Consequently, the risk of deliberate, anthropogenic introductions of fish into other uncontaminated drainages exists and is likely to increase as more people become aware of the species.

Several geographically disparate ecosystems are at immediate risk from recent (after 1990) introductions (or discoveries) of sucker-mouth catfishes:

- Kissimmee River, Florida – under restoration by the Army Corps of Engineers.
- Lake Okeechobee, Florida – the perimeter of which is contained by earthen levees.
- San Antonio River, Texas – under restoration by the Army Corps of Engineers.
- Reservoirs, Puerto Rico and Hawaii – operated by the Army

---

[1] Personal Communication. 2003. Joe Gallo, Southwind Lakes Homeowners Association, Boca Raton, FL.

2 Personnal Communication. 2003. Leo Nico, USGS Geological Survey, Gainesville, FL.

Corps of Engineers or other governmental resource agencies.

Unprecedented Levels of Threat

Suckermouth catfishes present a cumulative series of threats to aquatic ecosystems unprecedented in recent history. Previously introduced fishes have had significant effects on a limited number of ecosystem characteristics. Some species degrade physical habitats (e.g., common carp via turbidity, grass carp via aquatic vegetation removal). Others compete directly with native fishes for space (e.g., round goby with sculpins) or for food (e.g., bighead carp with paddlefish). A few prey on native fishes (e.g., pike killifish on native topminnows, sea lamprey on several Great Lakes fishes). Suckermouth catfishes, however, affect all of these ecosystem components and processes. They degrade physical habitats (i.e., removing algal cover, uprooting aquatic plants, altering bank topography), compete directly with native fishes (i.e., small herbivorous fishes, larger crevice-dwelling fishes), and could prey on native fishes (i.e., via incidental ingestion of demersal eggs). However, they also affect ecosystems at lower and higher trophic levels. By ingesting mud and grazing, they impact primary productivity (e.g., via changes in sediment size and algal standing crops) and secondary productivity (e.g., bypassing consumer levels of food webs). By serving as prey for aquatic birds, they threaten endangered populations of keystone predators (e.g., pelicans). Multi-level impacts of this variety and magnitude from a single group of introduced fishes have not yet been seen in this country.

Recommendations

In the early 1990s, bighead and silver carps were viewed largely as a localized and innocuous phenomenon of the lower Mississippi Basin. Little effort was made to study, contain, and manage those species. Today they threaten the upper Mississippi Basin and the Great Lakes. In recent years, suckermouth catfishes have appeared in a greater number of locations and in greater taxonomic diversity than ever before. Failure to promptly contain and manage them could result in a similar range expansion with potential for disastrous environmental consequences.

To effectively control these species, innovative barriers, management techniques, and public awareness programs are required. Electrical barriers, effective at containment of some other fishes (Stokstad 2003), may not be effective on suckermouth catfishes, the adults of which are capable of sudden bursts of speed carrying them substantial distances in seconds (personal observation). Hydraulic barriers provide natural containment of many fishes and can be used to contain some exotic species (Hoover et al. 2003), but may be difficult to create for this group of fishes. Suckermouth catfishes are specially adapted for resisting high water velocities, both behaviorally (via substrate appression and rapid swimming) and morphologically (via suctorial mouths, winglike pectoral fins, rough surfaces, and flattened bellies).

Turbulence, bubbles, or sound, however, may provide some level of containment due to the fishes' sensitivity to underwater vibrations and sounds. Suckermouth catfishes, like all catfishes and minnows, possess a series of bones (i.e., the Weberian apparatus or Weberian ossicles) connecting the inner ear to the swim bladder and providing better sound discrimination and perception than other fishes (Burgess 1989). Pulses or curtains of such disruptive stimuli will be avoided by fish, but the threshold levels and habituation responses of suckermouth catfishes have not been determined.

Bank stabilization (e.g., to minimize nesting), water diversion (to minimize contamination of uninfested waters), population augmentation of native herbivores, and removal of suckermouth catfishes can also be implemented proactively or as damage control techniques. Burrows of sailfin catfishes in south Florida are sometimes clumped, suggesting that certain substrates, or locations within water bodies are preferred. If these areas were stabilized (e.g., bank armor), erosion would be reduced and nesting discouraged simultaneously. Likewise, if infested water bodies could be isolated during periods of fish movement (e.g., flap gate culverts), some level of containment could be achieved. Native fish communities could be enhanced by stocking waterways with native herbivores (minnows, killifishes, tadpoles). They could also be enhanced by the promotion of fishing for suckermouth catfishes. Suckermouth catfishes are larger than most species of native freshwater fishes and in some streams (e.g., San Antonio River), they may be the largest fishes present. Commercial fishermen could be contracted (and could generate additional revenue for contractors from the sale of meat and eggs). Recreational fishermen could participate in fund-raising "rodeos" or "roundups" sponsored by local governments (and could be eligible for cash prizes or bounties).

Educational materials (e.g., CDs, Webpages, flyers, posters), similar to those used for other aquatic nuisance species and for endangered species, could be developed to inform people of the dangers posed by these seemingly innocuous fishes. The United States Geological Survey produces detailed species "fact sheets" for all exotic fishes in U.S. waters (e.g., Nico 1999a, 1999b, 2000a, 2000b) and the U.S. Army Corps of Engineers has a Web-page devoted to its own Aquatic Nuisance Species Research Program (*http://www.wes.army.mil/el/ansrp/ansrp.html*). These, or similar materials, could be incorporated into public outreach programs (e.g., for schools, youth groups), news coverage (e.g., in newspapers, local publications), and in science-oriented events (e.g., at nature centers and natural history museums, at meetings of aquarium societies).

Acknowledgments

Neil Douglas, Steven George, Bradley Lewis, and Catherine Murphy provided assistance in the field. Tyler Strange assisted in the laboratory. Bob Edwards and Larry Page suggested identifications for San Antonio River specimens based on the authors' photographs. Joe Gallo provided information on suckermouth catfish populations and their impacts on shorelines in Boca Raton, Florida. Preliminary research on sailfin catfishes was funded by the U.S. Army Engineer District, Fort Worth, and by the Aquatic Nuisance Species Research Program. Permission to publish this document was granted by the Chief of Engineers.

Literature Cited and Internet Sources

Armbruster, J. W. (1997). "Phylogenetic relationships of the sucker-mouth armored catfishes (Loricariidae) with particular emphasis on the Ancistrinae, Hypostominae, and Neoplecostominae," Unpubl. Ph.D. dissertation, University of Illinois, Urbana-Champaign.

Armbruster, J. W. (2000). Loricariid Home Page. Auburn University Museum. *http://george.cosam.auburn.edu/usr/key_to_loricariidae/lorhome/lorhome.html*

Barron, J. C. (1964). "Reproduction and apparent overwinter survival of the suckermouth armor catfish, *Plecostomus* sp., in the headwaters of the San Antonio River," *Texas J. Sci.* 16(4), 449-450.

Bunkley-Williams, L., Williams, E. H., Jr., Lilistrom, C. G., Corujo-Flores, I., Zerbi, A. J., Aliaume, C., and Churchill, T. N. (1994). "The South American sailfin catfish *Liposarcus multiradiatus* (Hancock), a new exotic established in Puerto Rican fresh waters," *Carrib. J. Sci.*, 1-2: 90-94.

Burgess, W. E. (1989). *An atlas of freshwater and marine catfishes – A preliminary survey of the Siluriformes.* TFH Publications, Neptune City, NJ.

Devick, W. S. (1988). "Disturbances and fluctuations in the Wahiawa Reservoir ecosystem," Project F-14-R-12, Job 4, Study I. Division of Aquatic Resources, Hawaii Department of Land and Natural Resources.

Devick, W. S. (1989). "Disturbances and fluctuations in the Wahiawa Reservoir ecosystem," Project F-14-R-13, Job 4, Study I. Division of Aquatic Resources, Hawaii Department of Land and Natural Resources.

Devick, W. S. (1991). "Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats." *New directions in research, management and conservation of Hawaiian freshwater stream ecosystems. Proceedings of the 1990 symposium on freshwater stream biology and fisheries management.* Division of Aquatic Resources, Hawaii Department of Land and Natural Resources, 189-213.

Edwards, R. J. (2001). "New additions and persistence of the introduced fishes of the upper San Antonio River, Bexar County, Texas," *Texas J. Sci.* 53(1), 3-12.

Hoover, J. J., Adams, S. R., and Killgore, K. J. (2003). "Can hydraulic barriers stop the spread of the round goby?," *ERDC/TN ANSRP-03-1*, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Hubbs, C., Lucier, T., Garrett, G. P., Edwards, R. J., Dean, S. M., and Marsh, E. (1978). "Survival and abundance of introduced fishes near San Antonio, Texas," *Texas J. Sci.* 30(4), 369-376.

Innes, W. T. (1948). *Exotic aquarium fishes*. Innes Publishing Co., Philadelphia, PA.

Ludlow, M. E., and Walsh, S. J. (1991). "Occurrence of a South American armored catfish in the Hillsborough River, Florida," *Fla. Sci.* 54, 48-50.

Nico, L. (1999a). "*Pterygoplichthys anisitsi*. Nonindigenous aquatic species fact sheet 766," United States Geological Survey. *http://nas.er.usgs.gov.queries/SpfactSheet.asp?speciesID=766*

Nico, L. (1999b). "*Pterygoplichthys disjunctivus*. (Weber 1991). Nonindigenous aquatic species fact sheet 766," United States Geological Survey. *http://nas.er.usgs.gov.queries/SpfactSheet.asp?speciesID=767*

Nico, L. (2000a). "*Pterygoplichthys multiradiatus* (Hancock 1828). Nonindigenous aquatic species fact sheet 766," United States Geological Survey. *http://nas.er.usgs.gov.queries/SpfactSheet.asp?speciesID=768*

Nico, L. (2000b). "*Pterygoplichthys pardalis* (Castelnau 1855). Nonindigenous aquatic species fact sheet 766," United States Geological Survey.

http://nas.er.usgs.gov.queries/SpfactSheet.asp?speciesID=769

Nico, L., and Fuller, P. (1999). *"Hypostomus* sp. Nonindigenous aquatic species fact sheet 766," United States Geological Survey. *http://nas.er.usgs.gov.queries/SpfactSheet.asp?speciesID=762*

Nico, L. G., and Martin, R. T. (2001). "The South American suckermouth armored catfish, *Pterygoplichthys anisitsi* (Pisces: Loricariidae), in Texas, with comments on foreign fish introductions in the American southwest," *Southwestern Naturalist* 46, 98-104.

Nikolsky, G. V. (1963). *The ecology of fishes.* (translation by I. Birkett). Academic Press, London [1978 Edition, TFH Publications, Inc., Neptune Ciuty, NJ].

Norman, J. R. (1948). *A history of fishes.* A. A. Wyn, Inc., New York.

Page, L. (1994). "Identification of sailfin catfishes introduced to Florida," *Fla. Sci.* 57(4), 171-172.

Page, L. M., and Burr, B. M. (1991). *A field guide to freshwater fishes – North America North of Mexico.* Houghton Miflin Company, Boston, MA.

Robins, C. R., Bailey, R. M., Bond, C. E., Brooker, J. R., Lachner, E. A., Lea, R. N., and Scott, W. B. (1991). "World fishes important to North Americans exclusive of species from the continental waters of the United States and Canada," American Fisheries Society, Bethesda, MD.

Sandford, G., and Crow, R. (1991). *The manual of tank busters.* Tetra Press, Morris Plains, NJ.

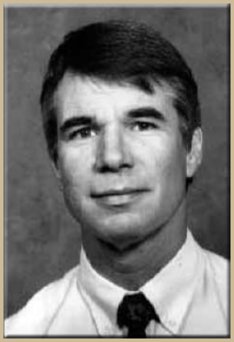
Smith, N. J. H. (1981). *Man, fishes, and the Amazon.* Columbia University Press, New York.

Stokstad, E. (2003). "Can well-timed jolts keep out unwanted exotic fish?" *Science* 301, 157-158.

Walker, B. (1968). "The fish with the folded mouth," *The Aquarium Series II* 1(10), 4-5, 36-43.

About the Authors:

Jan Jeffrey Hoover** is a research fishery biologist in the Environmental Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS. He holds a B.S. degree in biology from Florida Atlantic University, an M.A. degree in zoology from Florida Atlantic University and a Ph.D. in zoology from the University of Oklahoma. Dr. Hoover's research expertise is in the natural history of fishes. His professional experience includes fish surveys in bottomland hardwood systems reflecting variable anthropogenic impact.* ***Contact: *601-634-3996, Jan.J.Hoover@erdc.usace.army.mil.*



K. Jack Killgore** is a research fishery biologist in the Environmental Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS. He holds a B.A. degree in zoology from the University of Arkansas, an M.S. degree in fishery biology from Sam Houston State University, and a Ph.D. in fish ecology from the University of Mississippi. Dr. Killgore has been involved in research concerning fish ecology of large river systems.* ***Contact: *601-634-3397, Jack.Killgore@erdc.usace.army.mil.*

***Dr. Alfred F. Cofrancesco** is a research entomologist and Branch Chief, Aquatic Ecology and Invasive Species Branch, Environmental Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS. His studies focus on integrated pest management, in particular, biological control of noxious and nuisance plants. Dr. Cofrancesco holds B.S. and M.S. degrees and a Ph.D. in Biology from the University of Southern Mississippi. Contact: 601-634-3182, Al.F.Cofrancesco@erdc.usace.army.mil.*

Risk Assessment, Decision Analysis, and Invasive Species

Barry S. Payne and Andrew C. Miller

Introduction

The world is much more interconnected now than just a few decades ago. Consequently, the frequency of biological invasions worldwide has increased. Such invasions have threatened biodiversity, ecosystem structure and function, national economies, and even human health (Simberloff et al. 2000). International and national priorities have made invasive species an urgent issue. Risk assessment and decision-making methods allow systematic yet rapid consideration of invasive species management options.

Risk assessments of invasive species are emerging in several forms. The Aquatic Nuisance Species Task Force, under the authority of the Nonindigenous Aquatic Nuisance Species Act of 1990 and the National Invasive Species Act of 1996, recently developed a qualitative screening protocol for application to species of interest (Risk Assessment Management Committee 1996). This qualitative procedure considers seven elements (pathway, survival in pathway, establishment, spread, etc.), and then guides both the assignment of a risk level (high, medium, low) to each element and a confidence statement concerning each risk level estimate. Detailed species profiles subsequently have been published for a few invasive species that incorporate brief risk assessments that have relied on this qualitative approach (e.g., Nico et al. 2001; Courtenay and Williams 2002). Although comprehensive and standardized, the method is purely qualitative.

More quantitative approaches are being developed that explicitly combine theoretical ecology and invasive species management (e.g., Bartell and Nair, *in press*). However, rigorously quantitative and data-rich approaches tend to be less accessible to managers making invasive species decisions. Furthermore, most issues cannot be resolved using scientific information alone. Data are never as comprehensive or clear as desired, yet invasive species management decisions still must be made. Experts' opinions always remain part of the process. Also, public and social values play important roles. Tools of formal decision analysis offer ways of combining scientific information, opinion, and values in risk assessments of invasive species (e.g., Maguire, *in press*).

This bulletin combines the use of risk assessment and decision analysis with existing information and approaches, which should yield more objectively structured and quantitative evaluations than those presently guided by the qualitative screening procedure recommended by the Aquatic Nuisance Species Task Force.

Improving Invasive Species Risk Assessment and Management

The process of environmental impact assessment often overemphasizes the need for new data. Risk assessment (e.g., Bartell et al. (1992); U.S. Environmental Protection Agency (USEPA) 1998) and decision-making methods (e.g., Clemen and Reilly 2001) can be used to maximize existing data and strategically guide new data acquisition. Existing information and knowledge always should be used to the maximum extent possible. Higher levels of uncertainty accompany less data-rich aspects of risk assessment and decision analysis. However, decisions, uncertainty, and preferences still can be modeled. Certainly, such methods can point data acquisition at those aspects of a decision that are least clear, most important, and can be improved with new or more information. Too often additional studies are poorly aimed at critical aspects of uncertainty that, if better elucidated, can improve decision-making.

With respect to invasive species issues, a great deal of existing knowledge and understanding of life history mechanisms, control methods and strategies, can be applied without delay. This is not to suggest that all details of the problem are known, but simply that there is a relevant collective wisdom. Formal risk or decision analysis methods begin not with a search for new data, but rather systematic organization of existing information and knowledge in a fashion directly tied to management decisions that must be made (e.g., Maguire, *in press*). Probabilities can be assigned to areas of knowledge that are poorly understood. Ultimately, decisions are made that are transparent (nothing is hidden in the process) and repeatable. Uncertainties are fully displayed.

Decisions about management of invasive species are difficult for reasons typically addressed by formal decision analysis: uncertain outcomes, multiple and conflicting objectives, and many interested parties with differing views on both facts and values (Maguire, *in press*). Decision analysis involves modeling of decisions, uncertainty, and preferences (Clemen and Reilly 2001). Tools of formal decision analysis (e.g., decision trees, influence diagrams, probability trees, values structuring, uncertainty propagation, and additive utility functions) offer much for invasive species risk assessment and management. For example, probability modeling integrates scientific information into the decision process. Nevertheless, expert judgments often remain necessary. However, opinions can vary unacceptably among different groups of experts using essentially the same information. Structured methods of eliciting expert opinion allow limited objective information to be used in a more defensible way than unstructured use of such opinion (Maguire, *in press*).

Improvements that aim at making qualitative assessments of invasive species issues more quantitative fall mostly in the area of probability modeling. Various approaches or tools hold considerable promise for application to invasive species predictions. For example, stochastic matrix models, widely used for viability analyses of rare or endangered species (e.g., Akcakaya 1991, 2000a; Cox and Engstrom 2001; Maguire et al. 1995; Root 1998) also can be applied to invading populations, and can address influential factors such as life history parameters, catastrophes and environmental fluctuation, and habitat spatial patterns and connectivity. Neutral landscape models and percolation theory (Gardner et al. 1987) may provide greater insight into thresholds for species establishment. Discrete-time versions of classic PDE models are applicable to quantitative predictions of spread rates (Henson 1998). Spatial scales of assessment are probably crucial to estimates of the risk of establishment and management options to reduce risk. Metapopulation models (e.g., Akcakaya 2000b; Litvaitis and Villafuerte 1996; Kindvall 2000) and exposure-response models (e.g., Pastorok et al. 2001; Bartell and Nair, *in press*) might help quantify risk and uncertainty in relation to spatial scale. Retrospective analysis of life history and physiological ecology of successful and unsuccessful invaders has allowed recognition of attributes that might predict success of future invaders (Kolar and Lodge, *in press*).

Table 1 summarizes approaches that are especially relevant to invasive species risk assessments and management plans and have potential to make such assessments and plans more thorough, clear, and quantitative.

ANSRP Initiative

The Corps of Engineers Aquatic Nuisance Species Research Program (ANSRP) is developing risk assessment and decision-making methods for invasive species. These methods

Table 1
Useful Methods for Improved Invasive Species Risk Assessments

Methods/Tools	Pertinence to Invasive Species
Formal decision analysis methods	An overarching framework for modeling decision alternatives, uncertainties, and preferences or social values
Stochastic matrix models used in viability analysis	“Reverse application” of models widely used to predict viability of rare and endangered species
Neutral landscape models/percolation theory	Landscape structure and disturbance patterns affecting spread
Gravity and PDE models	Prediction of invasive species’ rates of spread
Metapopulation models/spatially sensitive exposure-response models	Quantification of risk and uncertainty at different spatial scales and in fragmented landscapes
Retrospective evaluation of life history and physiological ecology of successful versus unsuccessful invaders	Predictions of potential invasive success of related species

will structure the analysis of management alternatives, data, assumptions, and uncertainties, and result in species management plans that can be both clearly communicated and rapidly implemented. The success of this research depends on development of methods that are:

- Accessible by managers.
- Coherent, transparent, and easily reproduced or modified.
- Able to quantify ecological, economic, and social risks and rewards of management options.

Future bulletins and technical notes will present specific applications of risk assessment and decision analysis tools, relying on the methods listed in Table 1, to invasive species management issues and decisions. These will tend to address particular taxa, yet provide examples applicable to commonly encountered invasive species issues.

Future Directions

It is noteworthy that governments, agencies, and the public tend to deal with biological invasions at the species level. Thus, development of more structured and quantitative risk assessment procedures for one or a few high priority species is sensible.

Three important and recent approaches to species-specific approaches have been reviewed that are especially instructive. The first is represented by biological profiles with risk assessments that were recently developed for the Snakehead Fish (Courtenay and Williams (2002)) and Black Carp (Nico et al. 2001)). This approach to risk assessment strictly follows the reasonably comprehensive yet purely qualitative approach suggested by the the Aquatic Nuisance Species Task Force (Risk Assessment Management Committee 1996). This approach is suitable mainly for screening or early planning studies and is not especially rigorous. In contrast is a highly rigorous and quantitative approach such as that applied in a recent risk assessment of the Asian Longhorn Beetle (Bartell and Nair, *in press*). Such a risk assessment is difficult to communicate and may be difficult for managers to readily use, but admirably aspires to a more objective and quantitative assessment. A third approach, exemplified by Maguire's (*in press*) application of formal decision analysis to feral pigs in Hawaii represents an intermediate option. Decision analysis tools offer a means of achieving clarity of communication and ease of use while still incorporating rigorous quantitative modeling components.

During the next few years, relatively qualitative approaches are likely to continue to dominate invasive species risk assessments. The coherence of relatively qualitative assessments can be substantially improved using some of the tools of formal decision analysis. However, those aspects of decision analysis that relate to decision, uncertainty, and preference or value modeling are also accommodated by quantitative methods. When existing data are plentiful, decision analysis can accommodate rigorously quantitative methods. When supporting data are scarce and expert judgement increases in importance, decision analysis can also accommodate less rigorous quantification. The value structuring aspects of decision analysis may allow different groups of experts, with different values and biases, to follow the same procedure to approximately the same outcome. Tools of decision analysis are now applied mostly to business, legal, and industrial efficiency or quality control issues, but have great potential for ecological risk assessments, including those needed to improve invasive species management.

These tools are not constrained to qualitative assessments. Applied to either approach they offer means of clarifying choices, highlighting crucial considerations and uncertainties, and concisely summarizing consequences of different alternatives. The discipline of formal decision analysis offers much to ecologists and engineers dealing with invasive species risk assessment and management.

Literature Cited

Akcakaya, H. R. (1991). "A method for simulating demographic stochasticity." *Ecological Modelling* 54, 133-136.

Akcakaya, H. R. (2000a). "Population viability analyses with demographically and spatially structured models," *Ecological Bulletins* 48, 23-38.

Akcakaya, H. R. (2000b). "Viability analyses with habitat-based metapopulation models," *Population Ecology* 42, 45-53.

Bartell, S. M., Gardner, R.H., and O'Neill, R. V. (1992). *Ecological risk estimation.* Lewis Publishers, Chelsea, MI.

Bartell, S. M., and Nair, S. K. "The establishment of invasive species: An interface between risk analysis and theoretical population ecology," *Risk Analysis* (in press).

Clemen, R. T., and Reilly, R. (2001). *Making Hard Decisions with Decision Tools.* Duxbury Press, Belmont, CA.

Courtenay, W. R., and Williams, J. D. (2002). *Snakeheads (Pisces: Channidae): A biological synopsis* *and risk assessment.* USGS Florida Integrated Science Centers, Centers for Aquatic Resource Studies, Gainesville, FL.

Cox, J., and Engstrom, R. T. (2001). "Influence of the spatial pattern of conserved lands on the persistence of a large population of red-cockaded woodpeckers," *Biological Conservation* 100, 137-150.

Gardner, R. H., Milne, B. T., Turner, M. G., and O'Neill, R. V. (1987). "Neutral models for the analysis of broad-scale landscape pattern," *Landscape Ecology* 1(1), 19-28.

Henson, S. M. (1998). "Leslie matrix models as "stroboscopic snapshots" of McKendrick PDE models," *Journal of Mathematical Biology* 37, 309-328.

Kindvall, O. (2000). "Comparative precision of three spatially realistic simulation models of metapopulation dynamics," *Ecological Bulletins* 48, 101-110.

Kolar, C. S., and. Lodge, D.M. "Ecological predictions and risk assessments for alien species," *Science* (in press).

Litvaitis, A. J., and Villafuerte, R. (1996). "Factors affecting the persistence of New England cottontail metapopulations: The role of habitat management," *Wildlife Society Bulletin* 24, 686-693.

Maguire, L. A. "What can decision analysis do for invasive species management?" *Risk Analysis* (in press).

Maguire, L. A., Wilhere, G. F., and Dong, Q. (1995). "Population viability analysis for red-cockaded woodpeckers in the Georgia Piedmont," *Journal of Wildlife Management* 59, 533-542.

Nico, L. G., Williams, J. D., and Herod, J. J. (2001). *Black Carp (Mylopharyngodon piceus): A Biological synopsis and updated risk assessment.* USGS Florida Carribbean Science Center, Gainesville, FL.

Pastorok, R. A., Bartell, S. M., Ferson, S., and Ginzburg L. R., ed. (2001). *Ecological modeling in risk assessment: Chemical effects on populations, ecosytems, and landscapes.* Lewis Publishers, Boca Raton, FL.

Risk Assessment Management Committee. (1996). "Generic nonindigenous aquatic organisms risk analysis review process (for estimating risk associated with the introduction of nonidigenous aquatic organisms and how to manage for that risk)," Report to the Aquatic Nuisance Species Task Force, U.S. Government Printing Office: 1998-693-132/62087 Region No. 10. Dated October 1996.

Root, K. V. (1998). "Evaluating the effects of habitat quality, connectivity and catastrophes on a threatened species," *Ecological Applications* 8(3), 854-865.

Simberloff, D., Mack, R.N., Lonsdale, W.M., Evans, H., Clout, M., and Bazzaz, F. (2000). "Biotic invasions: Causes, epidemiology, global consequences and control," *Issues in Ecology* No. 5, Ecological Society of America.

USEPA. (1998). "Final Guidelines for Ecological Risk Assessment," EPA/630/R-95/002F, April 1998.

About the Authors:

Dr. Barry Payne *is a research biologist in the Environmental Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS. He holds a B.S. degree from The University of Texas at Arlington and a Ph.D. from Syracuse University. Dr. Payne leads a research team that focuses on the physio-logical ecology of freshwater invertebrates in relation to environmental issues associated with water resource projects. His research focuses on the life history, population dynamics, and physiological ecology and stress tolerance of freshwater molluscs, aquatic habitat and bioassessment procedures, and aquatic ecosystem sustainability and restoration.* ***Contact:*** *601-634-3837, Barry.S.Payne@erdc.usace.army.mil.*

Dr. Andrew Miller *is a research limnologist in the Environmental Laboratory at the U.S. Army Engineer Research and Development Center (ERDC) in Vicksburg, MS. He holds a B.A. degree from Olivet College in Michigan, an M.S. degree from Central Michigan University, and a Ph.D. from the University of Louisville. Dr. Miller's research interests include freshwater molluscs, endangered species, techniques for creating aquatic habitats, and methods for measuring effects of water resource projects.* ***Contact:*** *601-634-2141, Andrew.C.Miller@erdc.usace.army.mil.*

US Army Corps of Engineers®
Engineer Research and Development Center

Aquatic Nuisance Species Research Program

This bulletin is published in accordance with AR 25-30 as one of the information dissemination functions of the Environmental Laboratory of the Engineer Research and Development Center at the Waterways Experiment Station. It is principally intended to be a forum whereby information pertaining to and resulting from the Corps of Engineers' nationwide Aquatic Nuisance Species Research Program (ANSRP) can be rapidly and widely disseminated to Corps District and Division offices and other Federal and State agencies, universities, research institutes, corporations, and individuals. Contributions are solicited, but should be relevant to the management of aquatic nuisance species, providing tools and techniques for the control of problem aquatic nuisance species in the Nation's waterways. These management methods must be effective, economical, and environmentally compatible. The contents of this bulletin are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. This bulletin will be issued on an irregular basis as dictated by the quantity and importance of information to be disseminated. Communications are welcomed and should be addressed to the Environmental Laboratory, ATTN: Mr. Glenn G. Rhett, U.S. Army Engineer Research and Development Center (CEERD-EM-W), 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, or call 601-634-3717.

James R. Houston

JAMES R. HOUSTON, PhD
Director

DEPARTMENT OF THE ARMY
ENGINEER RESEARCH AND DEVELOPMENT CENTER
WATERWAYS EXPERIMENT STATION, 3909 HALLS FERRY ROAD
VICKSBURG, MS 39180-6199

OFFICIAL BUSINESS
CEERD-EV-E

BULK RATE
U.S. POSTAGE PAID
Vicksburg, MS
Permit No. 85