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CHAPTER 3

Armored Catfish (*Loricariidae*) Trinational Risk Assessment

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INTRODUCTION

This chapter assesses the known and potential ecological and economic risks associated with the North American aquarium trade in several fish species of the family *Loricariidae*, otherwise known as the "armored" or "suckermouth" catfishes. Because the taxonomy of the *loricariid* catfishes is not fully resolved, this assessment primarily considers the risks from a subset of the species of *Loricariidae* that are currently known in the aquarium trade in North America. Subsequent chapters focus on detailed case studies addressing the socioeconomic impacts of these fishes in Mexico and the United States, respectively.

Background of the Armored Catfish Families

The armored catfishes include two South American families of fishes, the *Callichthyidae* and *Loricariidae*. A brief background of their distinguishing characteristics follows.

Callichthyidae

The callichthyids are characterized by two rows of spineless plates extending along each side of the body, above and below the lateral line. They have an adipose fin that may also contain a spine. Nearly all species in the family possess a pair of short barbels on the upper jaw and two or more on the chin, and the fishes' air bladder is divided into two compartments enclosed in a bony casing. Over a dozen species of the genus *Corydoras* are popular with the aquarium trade (Migdalski and Fichter 1989). They can breathe air and, thus, are tolerant of waters with low oxygen content. All of the species are small, rarely exceeding 10 cm, but *Callichthys callichthys* (cascarudo, or armored catfish) may attain lengths of approximately 18 cm (Migdalski and Fichter 1989). One species of callichthyid, *Hoplosternum littorale*, is known to have become established in the Indian River lagoon system in Florida (Nico *et al*. 1996), and one recent report suggests that this population has spread throughout many parts of southern and central Florida (Nico and Muench 2004).

Loricariidae

The *Loricariidae* is the largest family of catfishes, including approximately 825 nominal species, 709 of which are considered valid, and 83 genera that are considered valid as of January 2006.[3] Taxonomic studies are ongoing to address uncertainties in the systematic relationships of the species as new species are discovered almost annually (Nelson 2006). A distinguishing characteristic of this South American fish family is their bony plate armoring that extends along three rows across their entire dorsal surface. The body is ventrally flattened, with the ventral surface of the fish wider than the height of the fish, such that in cross-section they appear somewhat triangular. All species possess a subterminal sucking mouth that is developed for sucking organic matter and algae from the substrate; hence the term, "suckermouth" is commonly used to name these fishes. The suckermouth is also useful to the fish in maintaining station in the strong currents of their native habitats. Table 3.1 lists some loricariid species common to the aquarium trade and Figures 3.1 to 3.11 illustrate some of the morphologic similarities and differences among them.

Assessment of Probability of Loricariid Establishment

Assessment of Loricariids in Pathway

Live Food Trade

Although several species of loricariids are consumed for food within their native ranges and efforts have been made to utilize problem populations as a food source for humans and animals elsewhere (see Chapter 5), no such substantial trade in loricariids is thought to occur. Specimens were recently observed, however, in the Vancouver, BC, fish market in 2007 but the dispensation anticipated for these specimens could not be determined (B. Cudmore, personal communication). Notwithstanding, this recent observation suggests the live food trade pathway cannot be completely discounted as an additional mechanism for the spread of loricariid catfish into North American waters.

Aquarium Trade

Loricariids are considered a 'bread and butter' fish of the aquarium trade in all three countries of North America (Table 3.1). Thus, there is strong potential for introduction of fishes in this family to come from the aquarium trade pathway. Most species of loricariid catfish brought into North America for the aquarium trade originate in Colombia, Peru or Brazil, with the proportions differing among the importing countries. However, both the United States and Mexico also produce loricariids domestically for distribution through aquarium stores and other outlets. In both cases, the industry is supported by non-native populations that have been established in the wild. Significant amounts of the imports into Canada also originate from the United States.

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[3] See J. Armbruster's taxonomic key at http://www.auburn.edu/academic/science_math/res_area/loricariid/fish_key/key.html.

Table 3.1. Simplified Taxonomy of Selected Genera and Species of *Loricariidæ* Catfishes Known to the Aquarium Trade

Subfamily/Tribe	Scientific Name	Common Name
Pterygoplichthys	*Pterygoplichthys* anisitsi* (formerly *Liposarcus*)	
	Pterygoplichthys disjunctivus (formerly *Liposarcus*)	Vermiculated sailfin catfish
	Pterygoplichthys gibbiceps* (formerly *Glyptoperichthys*)	Leopard plecos
	Pterygoplichthys joselimaianus* (formerly *Glyptoperichthys*)	Gold spot plecos
	Pterygoplichthys lituratus* (formerly *Glyptoperichthys*)	
	Pterygoplichthys multiradiatus (formerly *Liposarcus*)	Orinoco sailfin catfish
	Pterygoplichthys pardalis (formerly *Liposarcus*)	
	Pterygoplichthys parnaibæ* (formerly *Glyptoperichthys*)	
	Pterygoplichthys punctatus* (formerly *Glyptoperichthys*)	Yogi, Trinidad, Guimares silver, or Imperial Ranger plecos
	Pterygoplichthys scrophus* (formerly *Glyptoperichthys*)	Rhino, Alligator or Chocolate plecos
	Pterygoplichthys undecimalis	
	Pterygoplichthys xinguensis (formerly *Glyptoperichthys*)	
Loricariinæ	*Farlowella acus*	Twig catfish
	Farlowella gracilis	
	Rineloricaria filamentosa	
	Rineloricaria parva	Whiptail catfish
Ancistrini	*Ancistrus cirrhosus*	Bristlemouth catfish
	Ancistrus spp.	
	Ancistrus dolichoptera* (formerly *Xenocara*)	Blue chin xenocara
Acanthicus	*Pseudacanthicus* leopardus* (formerly *Stoniella*)	
Hypoptopomatinæ	*Otocinclus affinis*	Dwarf sucker catfish
Hypostomini	*Hypostomus plecostomus*	Plecostomus, Pleco
	Hypostomus spp.	Suckermouth catfishes

*Based on Armbruster 1997, 2004 and Armbruster and Sabaj 2002, with additional annotations by Armbruster (in correspondence, December 2008).

Loricariid catfish are highly sought by aquarists because of their distinctive appearance, hardiness, and propensity for consuming algae from all submerged surfaces. However, several species grow to large sizes, outgrowing their confined space, and are apparently released by aquarists into surrounding waters. Such introductions are thought to be one of the mechanisms responsible for the populations currently established in portions of Mexico (see Chapter 4), Texas (Nico and Martin 2001; López-Fernández and Winemiller 2005) and Florida (Nico *et al.* 1996; Ludlow and Walsh 1991). It is thought that loricariid catfish were first introduced into American waters in the 1950s (Burgess 1958) but did not reach problematic population levels until the 1990s (Hoover *et al.* 2007). The presence of *Pterygoplichthys* in southeastern Florida was first reported in 1971 (Courtenay *et al.* 1984) and establishment was later confirmed (Courtenay *et al.* 1986). Recent reports have also identified the presence of *Pterygoplichthys pardalis* in the Sepulvida Basin and Los Angeles River in Los Angeles (personal communication from Camm Swift to Walt Courtenay, 20 June 2007), and a population of the Orinoco sailfin catfish (*P. multiradiatus*) was recently reported by the NAS alert system from Horse Creek in Desoto and Hardee Counties in Florida. In these latter cases, the release of the catfish by aquarists is presumed the likely source of the introduction.

The following text summarizes elements of the aquarium trade pathway for each country that have relevance to the risk assessment of loricariids.

CANADA

In Canada, 145 of 243 importers bringing live fishes into Canada from 1 October 2004 to 30 September 2005 imported species of loricariid catfish (Cudmore and Mandrak, unpub. data). A total of 140,362 of these imported fish were listed as 'plecos,' and 11 species were represented, including: (*1*) *Pterygoplichthys anisitsi*, (*2*) *P. gibbiceps*, (*3*) *P. multiradiatus*, (*4*) *P. joselimaianus*, (*5*) *Peckoltia brevis*, (*6*) *P. vermiculata*, (*7*) *Panaque nigrolineatus*, (*8*) *Hypostomus plecostomus*, (*9*) *H. punctatus*, (*10*), *Beaufortia levereti*, (*11*) *B. kweichowensis*. The countries of origin for these fishes included Malaysia, Hong Kong, United States (California. Florida, Michigan), Singapore, Sri Lanka, Colombia, Vietnam, Czech Republic, Taiwan, Cuba, Thailand, Trinidad and Tobago, Brazil, Peru, Venezuela and Ecuador.

MEXICO

In Mexico, it is estimated that there are approximately 10 million fish imported by the aquarium trade (INEGI 2005a). Of these, twenty

Figure 3.1. *Pterygoplichthys gibbiceps* (formerly *Glyptoperichthys*)

Source: FishBase/JJPhoto 2006

Figure 3.2. *Pterygoplichthys joselimaianus* (formerly *Glyptoperichthys*)

Source: FishBase/JJPhoto 2006

Figure 3.3. *Pterygoplichthys lituratus* (formerly *Glyptoperichthys*)

Source: Amazon Exotic Imports 2005

Figure 3.4. *Pterygoplichthys punctatus* (formerly *Glyptoperichthys*)

(Source: FishBase/JJPhotos 2004

Figure 3.5. *Pterygoplichthys scrophus* (formerly *Glyptoperichthys*)

Source: FishBase/JJPhotos 2004

Figure 3.6. *Pterygoplichthys multiradiatus*

Source: FishBase/JJPhotos 2006

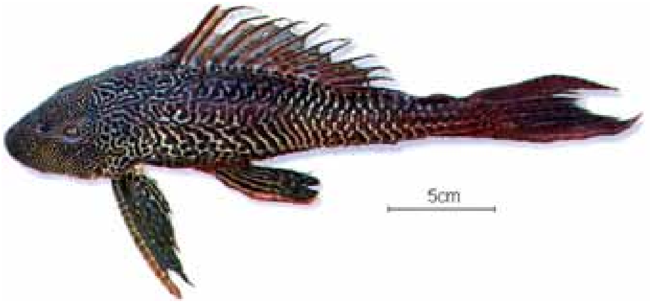
Figure 3.7. *Pterygoplichthys anisitsi*

Source: FishBase/JJPhotos 2006

Figure 3.8. *Pterygoplichthys disjunctivus*

Source: FishBase/JJPhotos 2006

Figure 3.9. *Pterygoplichthys pardalis*



Source: FishBase/JJPhotos 2002

Figure 3.10. *Pterygoplichthys undecimalis*

(Source: FishBase/JJPhotos 2005)

Figure 3.11. *Pterygoplichthys xinguensis*

(Source: FishBase/JJPhotos 2004-)

species belong to the loricariid family and are estimated to represent five percent of total imports, or roughly 500,000 fish annually (Álvarez-Jasso 2004).

UNITED STATES

The United States trade in ornamental fishes is monitored, to some extent, through the USFWS Law Enforcement Management Information System (LEMIS). Records of all legally imported and exported plants and animals from the United States are maintained in this database, and data fields include: taxonomic information, country of importation/exportation, port of arrival, purpose and the number and/or mass of individuals. A recent review of this database identified some 26,469 records of freshwater fishes for the year 2005, with total imports amounting to 171,865,168 individuals and exports of 21,029,694 (J. Olden, University of Washington, personal communication). Figures 3.12 through 3.14 reflect the general breakdown of the most traded species (Figure 3.12) and the pathways for distribution into the United States (Figures 3.13 and 3.14), as recorded in LEMIS. LEMIS does not maintain records of loricariid introductions, so the "propagule pressure" of loricariid catfish imported into the United States is not fully understood at present. Furthermore, the full extent of the domestic industry remains to be determined, and quantitative estimates in the US of the loricariid trade in the US remains a 'work in progress.'

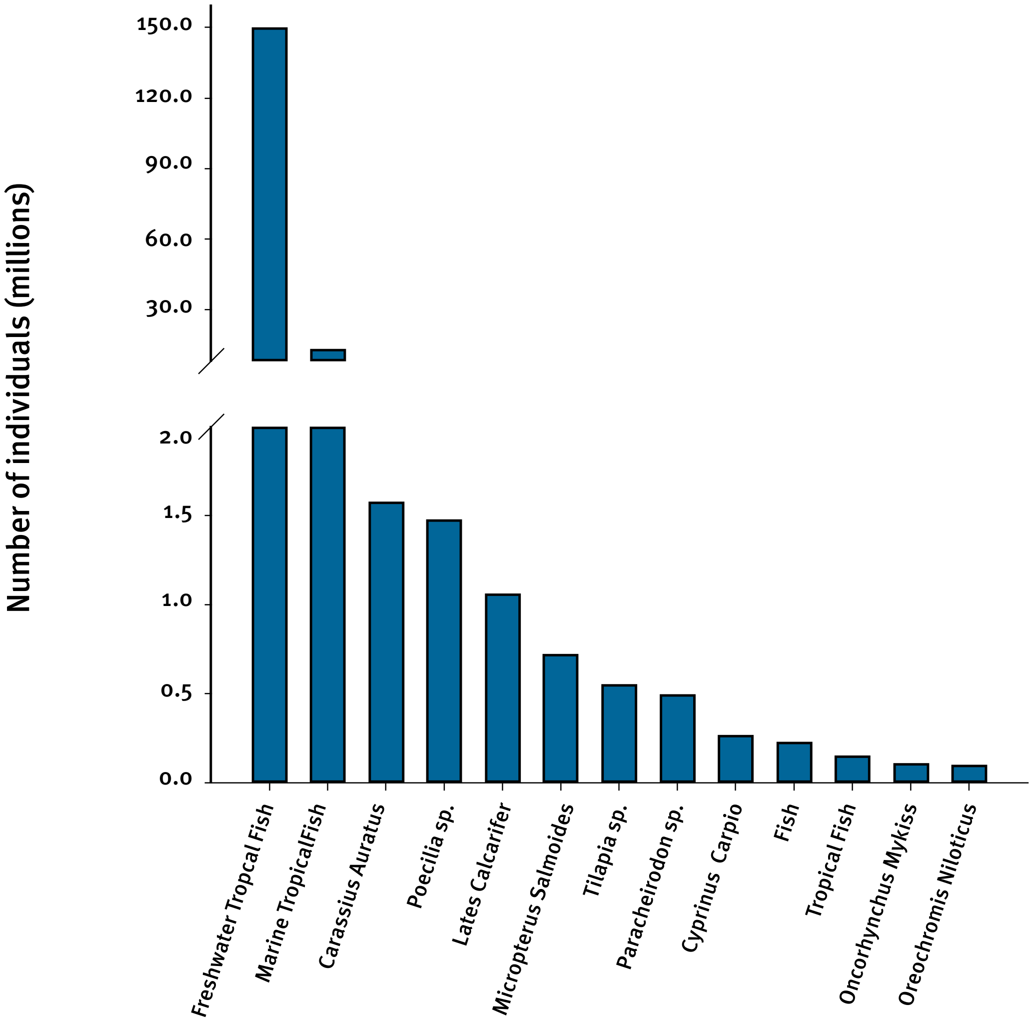
Hill and Martinez (2006), in a recent workshop sponsored by the US Army Corps of Engineers, have provided some perspective on the cottage industry that has developed around these species in Florida. According to these authors, there are currently about 170 farms where loricariids are cultured to supply the domestic demand for common varieties (e.g., *Ancistris spp.*, *Hypostomus spp.*, *Pterygoplichthys disjunctivus*, and *P. multiradiatus*). Roughly 80 percent of this production occurs in Hillsborough County (FL), notably one of the locations where wild populations have become established (Ludlow and Walsh 1991). As a result of the establishment of viable populations in the wild, the Florida industry is shifting away from brood stock maintenance toward the collection of egg masses deposited in the wild, and the subsequent incubation and grow-out of fry from these egg masses (Figures 3.15 and 3.16). The more "fancy" (colorful and unusual) species of suckermouth catfish, however, are still imported from South America.

Entry Potential

The entry potential considers the probability of the species' surviving in transit through the pathways of introduction, as well as the probability of survival if deliberately or inadvertently released into the environment. An analysis of entry potential should consider what drives the demand for the species' in trade such that other sources of entry are not overlooked.

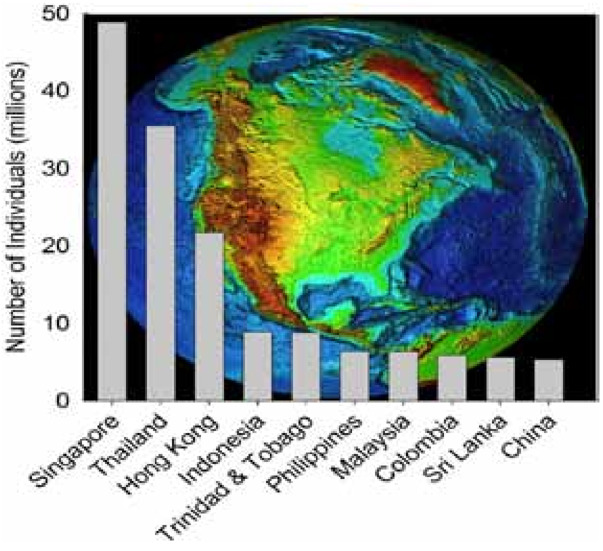
The long history of the successful transport of loricariid species from their countries of origin into CEC-member countries through the aquarium trade is well established. Thus, it can be assumed that the probability for survival through the transit process is essentially 100 percent. The probability of survival if released is less studied, but examples throughout many regions of the world indicate there is sufficient probability for survival in many tropical and subtropical regions. For example, populations have become established in the Philippines (Chávez *et al.* 2006), Taiwan (Liang *et al.* 2005); Puerto Rico, Panama, Trinidad, Guyana, Japan and Peru (FishBase); Singapore, Sumatra, Malaysia and Java (Page and Robins 2006). Given the broad occurrence of these species in

Figure 3.12. Trade of Freshwater Fish Species in the United States (for 2005), as Recorded in LEMIS



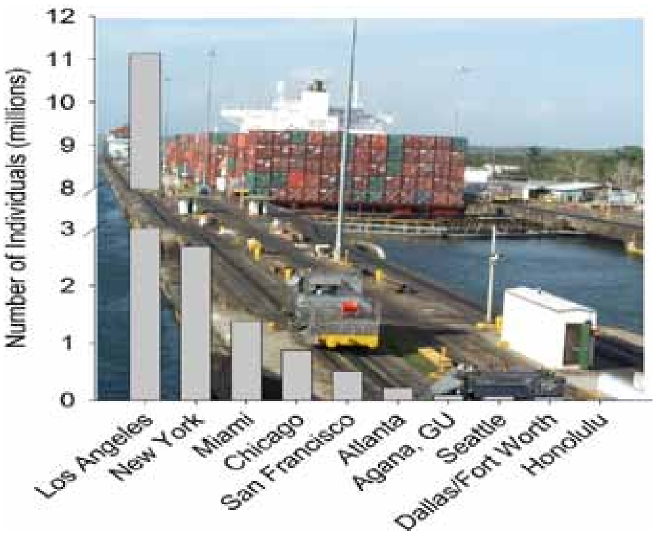
Source: Olden 2006, by permission

Figure 3.13. Principal Sources of Freshwater Fish Imported into the United States (for 2005), as Recorded in LEMIS



Source: Olden 2006, by permission

Figure 3.14. Principal Ports of Entry for Freshwater Fish Entering the United States and US Territories (for 2005), as Recorded in LEMIS



Source: Olden 2006, by permission

Figure 3.15. Loricariid Egg Collection in the Wild

Source: J.E. Hill and C.V. Martinez 2006. Culture of Loricariid Catfishes in Florida. Gainesville, FL 30–31 May 2006.

the aquarium fish trade, populations not yet identified in other countries are conceivable.

Other potential sources of entry that may be ancillary to the aquarium fish trade of these species exist as well. Possibilities include:

- escape from commercial tropical fish importers and fish farmers,
- dispersal of adults from established populations,
- intentional release for biological control of unwanted snails or plants (e.g., as occurred in Puente de Ixtla, Morelos, Mexico)

Natural events, such as hurricanes (as occur regularly in the southeastern United States and Mexico) or typhoons (as happened in the Philippines) may substantially increase the likelihood for entry into uncolonized waters from adjacent colonized waters (see Hubilla and Kis 2006).

CANADA

No records have confirmed that populations of loricariids have become established in Canadian waters. However, several records of loricariids caught in the wild are documented by the Canadian Biodiversity Information Facility and by the Royal British Columbia Museum. The species captured and recorded by these sources include: *Pterygoplichthys spp.* (Lake Erie, western basin), *Liposarcus* (*Pterygoplichthys*) *pardalis* (Duffins Creek, Ontario), *Panaque nigrolineatus* (Sydenham River, Ontario), and *Panaque suttonarum* (Shawingan Creek, Vancouver Island). These occurrences are thought to have resulted from aquarium releases.

MEXICO

Within Mexico, a significant population of loricariid catfishes has established itself in the Infiernillo Reservoir (Chapter 5). The species' distribution elsewhere in the country is increasing, and expanding populations of *Pterygoplichthys anisitsi*, *P. disjunctivus*, *P. multiradiatus*, and *P. pardalis* have also become established in the Grijalva-Usumacinta River; at least one species has spread through this watershed into Guatemala (Valdez-Moreno and Salvador Contreras, *pers. comm.* 2006). Another population has colonized the small basins surrounding Laguna de Terminos (Wakida-Kusunoki 2007).

UNITED STATES

In the United States, populations of loricariid catfishes have established in Hawaii (Sabaj and Englund 1999), Texas (Nico and Martin 2001; López-Fernández and Winemiller 2005), Florida (Ludlow and Walsh 1991, Nico *et al.* 1996;) and Nevada (Courtenay and Deacon 1982). It is unknown if the recent finding of a population in the Los Angeles River is reproducing, but large burrows found in the banks of the Sepulveda basin in Los Angeles suggest reproduction may be occurring there.

Colonization Potential

Colonization potential is the probability that an organism can establish self-sustaining population(s) once it has been released into the environment—by whatever mechanism. Numerous biotic and abiotic factors are involved in determining colonization potential and, with the loricariids, the lack of information on numerous ecologically relevant parameters makes predicting colonization potential challenging for many species that are in the aquarium trade. The following text summarizes the biotic and abiotic factors that may influence colonization potential as currently understood. Biotic information relevant to

Figure 3.16. Loricariid Egg Mass Incubation

Source: Hill and Martinez 2006

Figure 3.17. Male loricariid catfish guarding burrow

Source: Hill and Martinez 2006

understanding the potential for colonization includes information on physical characteristics of each species (size, morphology, etc.), physiological tolerances, life span, age to sexual maturity, spawning and agonistic behaviors, migratory requirements, fecundity, prey preferences, and biotic interactions. Abiotic factors reflect the physical conditions of the habitat that are preferred and tolerated by the species in question. Thus, factors such as minimum temperatures, hydrology, turbidity, substrate, salinity and stream velocity can all be important at predicting colonization potential.

Biotic Factors Potentially Influencing Colonization Potential

Most species within the *Loricariidae* family are generally nocturnal fishes that inhabit streams, lakes, and weedy, mud-bottomed channels. Bottom detritus and benthic algae are commonly their major food sources, but they also feed on worms, insect larvae, and various bottom-dwelling aquatic animals (Gestring *et al.* 2006). Loricariid catfishes often show high digestibility rates for organic matter (Yossa and Araujo-Lima 1998).

Loricariids, particularly the species that can grow to larger sizes, can be aggressive about defending territory and can compete for food. However, the mutability of these behaviors is poorly understood with respect to population size. In the Infiernillo Reservoir, the subject of Chapter 5, extensive schooling behavior of loricariids has been documented, suggesting that at high population densities, when resources are less limited, such agonistic behaviors may be reduced.

Most species of loricariids are burrow spawners (Figure 3.17). These fishes construct horizontal burrows in stream or pond banks that are 120–150 cm deep and shape is variable although the tunnel usually extends downward into the bank. Burrows are used as nesting tunnels and eggs are guarded by the males until free-swimming larvae leave the burrow, but sometimes also permit survival during drought. Fish can survive in the moist microhabitat even when water levels fall below the opening to the chambers.

Growth is rapid during the first two years of life, with total lengths of many sailfin catfishes exceeding 300 mm by age 2 (Hoover *et al.* 2007). Specimens in aquaria may live more than 10 years. The size range for most of the adult species in the Loricariid family is 30–50 cm, but individuals have been observed to reach 70 cm. Fecundity of loricariids is on the order of 500 to 3,000 eggs per female, depending on species and size. High fecundity may facilitate establishment, and female-biased sex-ratios may facilitate expansion of newly introduced populations (Liang *et al.* 2005; Page and Robbins 2006).

Liang *et al.* (2005) determined that females had significantly different external features from males in all but 2 of 13 morphometric characteristics they examined (e.g., body depth, predorsal length, eye diameter). However, the distinctions were very minor and statistical differences identified were only discernible through the large sample sizes they collected; gender distinction using morphometry in the field remains difficult to all but the most experienced taxonomists. The most assured way to differentiate the sexes is by the extrusion of eggs from gravid females during spawning seasons; measurement of plasma vitellogenin can also be used if laboratory facilities are available. In addition, certain similar growth patterns are documented in both sexes (Rapp Py-Daniel and Cox Fernandes 2005). However, Moodie and Power (1982) reported sexual dimorphism based on the mobility of pectoral fins.

The overall sex ratio of loricariid catfishes is often found to be female-biased. This finding may simply represent a sampling bias from males practicing parental care during the reproductive season, and thereby escaping capture more easily during collections. The reproductive season peaks during the summer (based on GSI values) but lasts several months and in some places it takes place during the whole year (see Chapter 5). They start reproducing at approximately 25 cm, and fecundity is moderately high. Hoover (2004) reported fecundity ranging from 472 to 1283 mature eggs/female. Gestring *et al.* (2006) quantified 1,983 eggs/ripe female in *P. multiradiatus* (Gestring *et al.* 2006). Escalera Barajas (2005) reported 975 eggs in females averaging 245 mm and 280 g. Mazzoni and Caramaschi (1997) reported a fecundity of 912 eggs in *Hypostomus spp.* The range in fecundity reported by these researchers may be associated with variations in the degree of parental behavior exhibited by the representative species in the loricariid family. Many loricariids exhibit male parental care for eggs and early fry. While males of some species carry eggs under large flaps of their lower lip, most loricariid fathers guard eggs and hatchlings in protected nests cavities. The degree to which these behaviors alter fecundity, relative to other factors such as size, has not been explored.

Suckermouth catfishes are capable of breathing air by swallowing it and extracting oxygen through the gut lining (Armbruster

1998). This characteristic allows them to withstand drought conditions in stagnant water or humid burrows (as well as long trips, like those from the Amazon Basin to North America). Loricariid catfish possess large-sized blood cells and large amounts of DNA per cell—factors that relate to their low metabolic rate and capacity to tolerate changes in body fluid composition (Fenerich *et al.* 2004). These cellular characteristics may enable their tolerance of challenging physiological stressors that may occur during drought periods (Brauner and Val 1996; McCormack *et al.* 2005). Collectively, these aspects of their physiology have provided them with a physiological advantage over other less tolerant fishes (Stevens *et al.* 2006).

Because they have evolved heavy external bony plates, and potential endemic predators in North American waters have little or no experience with this species, predation pressure on juveniles may be less intense in places where they have invaded than in their native range. Schooling behavior evidenced in several locations where they have become established may also reduce predation pressures.

Abiotic Factors Potentially Influencing Colonization Potential

Loricariid catfishes can be found in a wide variety of habitats, ranging from relatively cool, fast-flowing and oxygen-rich highland streams to slow-flowing, warm lowland rivers and stagnant pools poor in oxygen. Based on an evaluation of all species reported in FishBase, the thermal range preferred by the loricariids is approximately 20–28ºC. What likely plays the most significant role in restricting their range is the lower lethal temperature. Gestring (2006) reported lower lethal temperatures for *P. multiradiatus* as 8.8ºC and 11.1ºC for *Hypostomus spp.*; work is ongoing to establish these limits in a broader array of species.

Some species prefer rocky habitats and rapids, others shallow sandy lagoons or habitats with abundant woody debris (e.g., trees, branches, rootwads). Still others prefer shallow jungle creeks or deeper regions of larger rivers. The diversity of habitats potentially occupied or sought by *Loricariidae* species would suggest that nearly all types of freshwater environments within North America that provide temperature conditions suitable for the species' year-round survival could support some species of loricariids. Thus, when the thermal regime is suitable, other habitat adaptations, such as responses to water velocity or abundance of food supply, may play equally or more-important roles in shaping the distribution and spread of loricariid catfishes in new environments.

Like many fishes, loricariids exhibit differences in habitat use between large and small individuals. Smaller fish are generally collected only from the tributaries, whereas larger fish are generally collected from the mainstem (Power 1984; Liang *et al.* 2005). These findings suggest that early development occurs in smaller channels of streams. Power (1984) suggests that juveniles may select the smaller stream channels to avoid high velocity mainstem channel habitat, to avoid predators, and/or to improve their feeding opportunities.

Loricariids are highly tolerant of polluted waters and can adapt readily to varying water quality conditions (Nico and Martin 2001). They are often found in soft waters, but can adapt very quickly to hard waters. They can thrive in a range of acidic to alkaline waters (pH 5.5 to 8.0). Furthermore, some species are salt-tolerant. Although salinities in which they have been collected are not reported, waters have been described as "quite brackish." Table 3.2 summarizes species of loricariids that have become established in Mexico and the United States, and some of their physiological and habitat preferences. Based on the wide array of conditions tolerated by the loricariid catfishes and their inherent biological characteristics (e.g., high fecundity, territoriality), introduced populations may become locally abundant (colonized) in a short period of time (Hoover *et al.* 2007).

Table 3.2. *Loricariidae* **Species Reported in Mexico and the United States and Some Biological and Niche Preference Data**

LORICARIIDAE SPECIES	TEMP (ºC)	dH*	pH	SIZE (cm)
*Pterygoplichthys*** *gibbiceps*	23–27	4–20	6.5–7.8	50
P. joselimanianus	24–29	4–8	6.5–7	30
P. lituratus				37
P. parnaibae				29
P. punctatus	22–26			28.5
P. scrophus				27.5
P. xinguensis				27
P. anisitsi	21–24	25	6.5–8.2	42
P. disjunctivus				70
P. multiradiatus	22–27	4–20	6.5–7.8	70
P. pardalis	23–28	10–20	7–7.5	70
P. undecimalis				50
TOTAL	**21–29**	**4–20**	**6.5–8.2**	

*Degrees of water hardness (as mg/L calcium)

**Synonymized as per Armbruster 2004 and personal communication (December 2008)

Spread Potential

Analyzing the potential for the spread of loricariids assumes that a population has colonized. Considering the probability for spreading requires an assessment of the environmental characteristics in the areas vulnerable to future colonization based on hydrological connectivity and other human-based and natural factors.

Environmental Characteristics of Vulnerable Receiving Waters

Environmental factors in receiving waters that prevent colonization or spread of introduced loricariid populations remain little studied. As discussed, loricariids have exhibited tolerance to a wide variety of water quality conditions and, therefore, have potential to invade both polluted and unpolluted waters. Loricariid catfishes are equipped to tolerate polluted environments through their air breathing ability. They have evolved several modifications of the digestive tract that allow it to function as an accessory respiratory organ. Air breathing increases at night, regardless of dissolved oxygen concentration. They also exhibit substantial cardiac hypoxia tolerance that allows them to survive in hypoxic and polluted waters. However, they may move from polluted waters to cleaner waters upstream.

They are also highly adapted to high water velocities. In laboratory swim tunnels, they can maintain station and move freely in water velocities greater than 1 m/s.[4] Such characteristics could enable the loricariid catfishes to ascend gradients impassable to most other fishes, such as earthen dam spillways or other near-vertical structures such as natural cascades and waterfalls.

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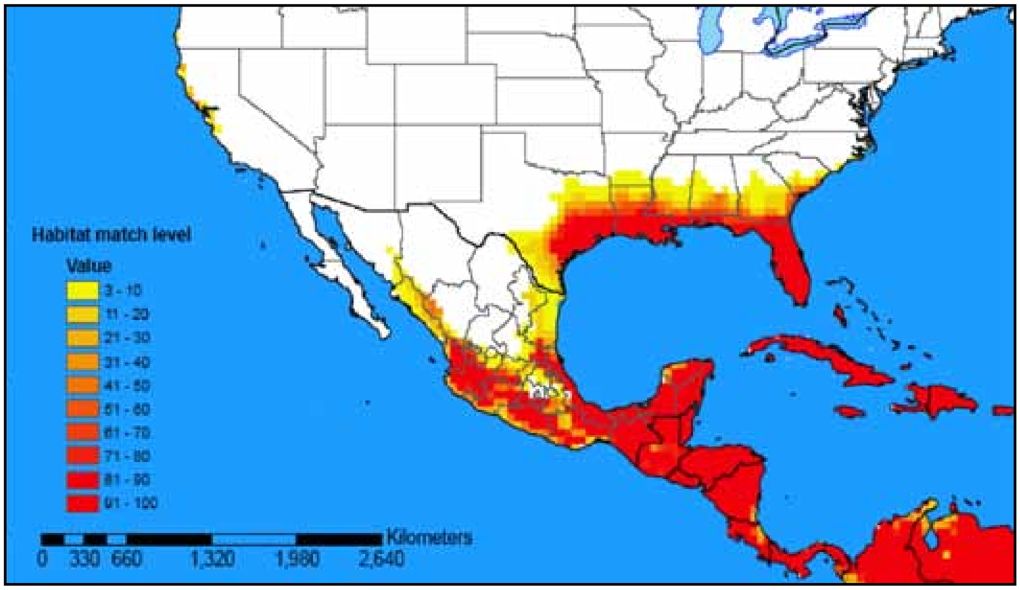
[4] Hoover *et al.* 2004.

Figure 3.18. Potential distribution of *Loricariidae* in North America using GARP modeling



As discussed, the absolute thermal thresholds for cold tolerance are not known for many loricariid catfish species, but movement into thermal refugia (e.g., springs and seeps during winter) seems likely, and the utilization of thermally enriched sewage outflows has been demonstrated in Houston (Nico and Martin 2001). The acclimation of some introduced populations to cooler subtropical and temperate climates over time must be considered a possibility.

The spread potential of the loricariids is therefore related to a variety of the distinctive features exhibited by this fish family: moderately high reproduction rate, spawning behavior in deep burrows (reducing the ability to eradicate populations effectively), parental care, territoriality, resistance to desiccation, protected by a heavy armor, rasping teeth and dorsal spines used for defense, and the ability to utilize atmospheric oxygen somewhat—thus having the possibility to survive out of water much longer than other fishes. Data are not sufficient to ascertain which among these factors may play the greatest role in determining spread potential, but all likely play a role. It is worth noting, however, that the *Loricariidae* have been found to have an 80% rate of establishment for introduction events outside their geographic range worldwide and are thus given the highest risk score in other risk assessments (Bomford and Glover 2004).

GARP Modeling

To further estimate the potential distribution of loricariid species in North America, a Genetic Algorithm for Rule Set Production (GARP) analysis was used, similar to that applied for the snakehead (Chapter 2) and others to predict the potential distribution of invasive species (e.g., Drake and Lodge 2006). Information on nine environmental variables (maximum, mean and minimum air temperatures, wet day index, annual river discharge, precipitation, compound topographic index, slope, and frost frequency) from the native ranges of three loricariid species was used to estimate the potential spread of the *Loricariidae* family collectively. The nine variables were chosen as they are the only variables for which we have global information. The GARP modeling results for the *Loricariidae* family is projected in Figure 3.18 below. While these results should be considered preliminary, they conform generally with empirical findings to date from the United States and Mexico where loricariids have been introduced.

As demonstrated below, large parts of Mexico and the southeastern United States appear vulnerable to the spread of loricariids. Definitive modeling at the watershed scale is needed to consider the potential spread of specific species and GARP modeling does not support resolution at this finer scale.

CONSEQUENCES OF ESTABLISHMENT

Economic Impact Potential

Both positive and negative economic impacts of the loricariids in the aquarium trade must be considered. Full economic analyses at the national level of each country have not been conducted. The following text summarizes the current knowledge.

CANADA

There is no evidence that loricariids are having a negative socioeconomic impact on Canadian waters, as no established populations have been identified.

MEXICO

The first record of these fishes in Mexico was *Liposarcus* (=*Pterygoplichthys*) *multiradiatus* in the Río Balsas in 1997. Three years ago the first invasive status was registered in the basin. At present, the problem has become severe, as some species have already established themselves in the Infiernillo Reservoir, one of the largest bodies of freshwater in the country (120 km in length and 40,000 ha superficies, 2.250 billion m^3). This reservoir was the site of the largest freshwater fishery in the country (several tilapia species constituted 90 percent of the fish population, accounting for 20 percent of the nation's production in continental waters). Before the invasion, fishermen captured 20,000 tons of tilapia per year, more recently they have been catching between 13,000 to 15,000 tons of sailfin catfish. These fishes have been affecting the fishing gear and boats of fishermen, and thus their way of living. Overall, nearly 43,000 jobs have been lost in this one location. The loss of incomes from either directly from fishing or indirectly through fishery support services has affected fishers and their dependants, creating a difficult socioeconomic situation.

The invasion is not restricted to this reservoir but has expanded to the whole Balsas basin, one of the most important in the country: draining a number of important rivers in the south of Mexico. In 2003, other invasions were registered, this time at the Usumacinta River (one of the largest of the country) draining into the Atlantic Ocean, mainly in the state of Tabasco, where fishermen have started requesting the state government to take immediate action on the matter.

Because the loricariid fishes do not have any economic value to the community associated with the Infiernillo Reservoir and are not accepted as food by the general population, ongoing research is being directed to obtaining a byproduct, such as fishmeal. Unfortunately, the quality is not very good due to the bone structure of these fish (the ash content is quite high in the final fish meal, resulting in low digestibility if it is intended as a feed ingredient). However, there is a possibility of using this fishmeal as a natural fertilizer. Studies to understand how loricariids have affected the fish community are being performed. As has been the case with other species introduced from South America, when these fish have been caught in the wild and then released in a region with similar characteristics, they are more prone to become established.

UNITED STATES

The United States can identify both positive and negative economic impacts from loricariid populations that have established in the wild and from the aquarium trade in loricariids (Chapter 4). As previously discussed, the impacts of the species may be watershed-specific and dependent on the local socioeconomic factors. Florida's cottage industry for egg mass collection to support the aquarium trade creates positive economic impacts, as does the aquarium trade in loricariids. Negative impacts have not been fully accounted, but might include costs of shoreline armoring in localized areas, loss of fishing opportunities and damage to commercial gear (e.g., Lake Okeechobee), and the possibility of losses from out-competition and harassment caused by the catfishes (e.g., effects on native darter species in Texas and manatee harassment in Blue Springs, Florida). Table 3.3 summarizes the perceptions of eight researchers in the United States who have had first-hand experience studying the introduced loricariid populations. As reflected in the table, opinions on the economic and environmental impacts of introduced loricariids are not uniform.

Table 3.3. Summary Responses from Professional Inquiry on the Environmental and Economic Impacts of Introduced Loricariid Populations in the United States

Question 1: What species and in what regions do you study introduced suckermouth catfish?	
Respondent	**Response**
(#1)	*Pterygoplichthys multiradiatus*, *P. disjunctivus*, *Hypostomus spp.* in southeastern Florida fish communities
(#2)	*P. disjunctivus*, *P. pardalis*, *P. anisitsi*, *P. multiradiatus*
(#3)	*P. disjunctivus*, *P. pardalis*, *P. anisitsi*, *P. multiradiatus* in Florida
(#4)	*Hypostomus spp.* in San Felipe Creek, Del Rio, Texas
(#5)	*Hypostomus spp.* and *Pterogoplichthys spp.* in the San Marco, Comal and San Antonio rivers
(#6)	Principally populations of loricariids in Florida
(#7)	*P. disjunctivus*, east-central Florida
(#8)	*P. disjunctivus* in Volusia Blue Springs and Gemini Springs, Florida
Question 2: Do you believe that population control or environmental management is possible? If so, at what level?	
(#1)	The most critical environmental limiting factor for loricariids in Florida is coldwater temperature, but as a group they already occupy most of their potential Florida range. Therefore, unless there is a complete freeze-over in Florida waters, or a viable commercial market develops for this species, there will be no major impact to loricariid species abundance. Commercial fishermen do not assert population control, where such freshwater fisheries exist.
(#2)	Prevention should be the first barrier. It may be possible to reduce abundance in some locations, but based on the Hillsborough River studies, eradication is not feasible. Environmental management would only be useful in highly modified habitats located in urban areas.
(#3)	Doubtful that it is possible to control populations over large areas. Shoreline hardening/barriers are effective, but expensive.
(#4)	Hopefully population suppression since eradication does not seem possible.
(#5)	Difficult at best. Currently unknown.
(#6)	Eradication is unlikely, except maybe in localized areas. Population suppression and damage reduction may be possible.
(#7)	Unlikely except in small areas where shoreline armoring could be incorporated.
(#8)	Probably only damage control is possible, as the population densities (in Blue Springs) are too large

Table 3.3. Summary Responses from Professional Inquiry on the Environmental and Economic Impacts of Introduced Loricariid Populations in the United States (continued)

Question 3: What measures of control and management are being practiced in your region?	
(#1)	Relative abundance monitoring and standing crops estimates of Orinoco sailfin, vermiculated sailfin, and suckermouth catfish in SE Florida to assess effects on native fish. Some upscale private companies are installing erosion barriers to reduce effects exacerbated by loricariids.
(#2)	None beyond abundance monitoring.
(#3)	There are no direct control programs, but there are considerable egg collecting programs for ornamental fish trade in Florida. Despite this, there is not likely a negative effect on catfish abundance.
(#4)	Work under the State Wildlife Grant to determine effective measures. The objective is to quantify the dietary preferences and degree of overlap between the Devil's River minnow and the loricariid catfish, and to investigate the efficacy of eradication techniques. Stomach content analysis is done monthly, and an exclusion chamber experiment will be used to assess food preferences.
(#5)	Minimal to none.
(#6)	None in Florida.
(#7)	None to date.
(#8)	None.
Question 4: What measures do you think would be effective?	
(#1)	Measures include permanent barriers along the shoreline; heavy liners with rip-rap overburden; and native plant fringes—which are likely less effective due the burrowing action of the species'. All measures are expensive.
(#2)	The measures depend on population size and ecosystem characteristics. In central Florida, I would restrict access to nesting sites and over fish the loricariid populations. In the Grijalva-Usumacinta basin (Mexico) trapping during the dry season could reduce the populations in pristine basins where other species have to be protected.
(#3)	Perhaps a larger commercial market coupled with intense egg collection could reduce abundance (likely only effective in isolated circumstances.)
(#4)	A variety of passive capture techniques are being investigated for their effectiveness, including hoop nets, trammel nets, catfish trap nets, frame nets and a variety of baits.
(#5)	Educating the public, especially aquarists, to avoid putting their unwanted fishes into open waters. Movies such as "Finding Nemo" have actually hurt the cause dramatically.
(#6)	Systematically visit nesting colonies during the breeding season and capture and remove adults and any eggs and young. This may be mostly effective in areas where breeding habitats are limited. Prevention will likely require added educational programs and law enforcement.
(#7)	Harvesting of adults and egg masses in small ponds and urban lakes. In rivers and canals no method would be effective, as too labor intensive and costly.
(#8)	Unclear if any method would help.
Question 5: Do you believe that suckermouth catfishes pose significant environmental impacts to local biota? If so, are the impacts high, moderate or low?	
(#1)	No. Researcher has examined stomach contents of more than four hundred *P. multiradiatus* over a 12-month period in a Florida canal and 94 percent of the stomach volume was composed of detritus, algae, sand and decomposing plant matter. Microcrustaceans and native fish eggs constituted 1 percent or less of the total stomach volume. Because detritus, algae and decaying plant matter are underutilized as a food by native fishes, this researcher considers risks to native Floridian fishes to be low.
(#2)	Loricariids are having moderate impacts on local biota of the Hillsborough River. There are some hypothetical negative impacts that should be studied in less modified habitats than the canals of southern Florida, including: predation on demersal fish eggs (shad) in St. John River, changes to the trophic chain of alligator, pelican and other birds, and impacts on invertebrate communities.
(#3)	Suckermouth catfish are not having a major negative impact on native fishes in Florida. Indirect effects might be mediated through invertebrates. However, if these effects are important to native fish dynamics then there might be a higher effect on fish populations. There may be impacts on native fish that use cavities for nesting- although the catfish burrows may increase the abundance of nesting sites for these fish. The question has not been thoroughly investigated, but existing evidence of native fish populations does not indicate loricariids are causing major negative effects.

Table 3.3. Summary Responses from Professional Inquiry on the Environmental and Economic Impacts of Introduced Loricariid Populations in the United States (continued)

(#4)	Impacts are high. There is a documented decline in Devil's River minnow and its congener, manatial roundnose minnow. Current hypotheses include: 1) competition over food resources 2) direct predation of minnow eggs by catfish.
(#5)	In addition to competition problems identified among native algivores such as the threatened *Dionda diaboli*, significant habitat competition and interference has been identified between *Hypostomus spp.* and the native San Felipe gambusia, *Gambusia clarkhubbsi*.
(#6)	Largely unknown and not sufficiently studied.
(#7)	Impact is low to moderate, primarily due to their burrowing activities creating low water quality conditions (sedimentation, eutrophication).
(#8)	Yes. Population density and harassment to manatees is a significant impact, as are the burrowing actions and catfish droppings that are adding nutrients to the water systems.

Source: J.J. Hoover, by permission

Environmental Impact Potential

Several authors assert that environmental impacts to endemic species from Loricariid introductions are possible through direct competition for food and space (Nico and Martin 2001; Flecker 1996; Devick 1989; Hubbs *et al.* 1978; Hoover *et al.* 2004). Other authors contend that loricariid catfishes can also have negative indirect impacts on endemic species through incidental ingestion of substrate-attached eggs (Hoover *et al.* 2004), snails or other aquatic benthos (Bunkley-Williams *et al.* 1994). As opportunistic benthic feeders, these mechanisms for impact are plausible, whether or not evidence has shown them to be expressed in all locations where introductions of loricariids have occurred. Their burrowing behavior and habitat selection for breeding may also create significant impacts, but the severity and interpretation of those impacts appears to be determined, at least in part, by the characteristics of the waters where they invaded (Table 3.3). Evidence for these impact pathways is discussed below.

Suckermouth catfishes "plow" the bottoms of streams and lakes while foraging, occasionally burying their heads in the substrate and lashing their tails. These behaviors can uproot or shear aquatic plants and reduce the abundance of beds of submersed aquatic vegetation, creating floating mats that shade the benthos from sunlight. As highly efficient algivores and detritivores (Power et al., 1989; Armbruster 2003), loricariids may compete directly with other fishes such as *Dionda diaboli* (Garrett *et al.* 2002, in López-Fernández and O. Winemiller 2005). By grazing on benthic algae and detritus, loricariids may alter or reduce food availability and the physical cover available for aquatic insects eaten by other native and non-native fishes where they are introduced (Page and Robbins 2006; Liang *et al.* 2005). Cohen (2008) quantified gut contents of suckermouth catfishes from the San Marcos River in central Texas and assessed the degree of dietary overlap between the suckermouth catfish and native herbivorous fishes by comparing gut contents and through stable isotope analysis and concluded that gut content assessments of Guadalupe roundnose minnow *Dionda nigrotaeniata* and two additional *Dionda* species suggest high dietary overlap between the *Dionda* complex and suckermouth catfish. These data indicate introduced suckermouth catfishes in spring-influenced streams are potential direct competitors with native taxa in spring-influenced streams of central and west Texas.

The potential effects on altering insect community assemblages was demonstrated by Flecker (1992), under controlled conditions in simulated neotropical artificial streams with the loricariid *Chaetostoma milesi*. Flecker concluded that the effect of grazers such as *C. milesi* is principally to change the distribution and abundance of resources important to neotropical stream insects, rather than through the direct predation on the insects. Feeding on mud and silt can re-suspend sediments, causing turbidity and reduced depth of the photic zone, and/or could result in changes in substrate size. In addition, nutrients can be prematurely diverted from the "consumer" components of food webs and transformed into feces available only to scatophags and decomposers (i.e., bacterial, fungi).

Because they are benthic feeders and may attain large sizes, loricariids may displace smaller, less aggressive or otherwise less resilient North American benthic fishes (e.g., darters, madtoms, and bullhead catfishes). For example, Stevens *et al.* (2006) reported that typical estuarine fish assemblages in the mouth of the Peace River and upper Charlotte Harbor were replaced with a simpler fish community, including the introduced brown hoplo (*Hoplosternum littorale*) and sailfin catfish (*Pterygoplichthys spp.*) after hurricane Charley. According to the US Fish and Wildlife Service (2005), the Devils River minnow is threatened by the presence of armored catfish. Fish collections by G. Garrett in 1997 from San Felipe Creek revealed for the first time the presence of armored catfish (*Hypostomus spp.*). Collections in 2001 to 2003 confirmed that armored catfish are reproducing and are abundant in San Felipe Creek (López-Fernández and Winemiller 2003). Established breeding populations of *Hypostomus spp.* also exist in the San Antonio River, Texas, and have been cited as potentially competing with *Dionda episcopa* in this system due to its food habitats (Hubbs *et al.* 1978, Hoover *et al.* 2004). Although Dionda species are common in spring runs in Central Texas, they are now absent from these habitats in the San Antonio River, further suggesting possible displacement by the armored catfish (Hubbs *et al.* 1978).

Most species of loricariids are relatively sedentary and may be attractive prey to fish-eating birds. Their defensive erection of dorsal and pectoral spines has been cited as posing a potential danger to birds, such as pelicans, that attempt to swallow whole fish, although other researchers contest this (Bunkley-Williams *et al.* 1994). Loricariids may also compete for space through their habitat selection for breeding. The nesting burrows of loricariids sometimes form a large "spawning colony" in which several dozen occur in very close proximity. These colonies can compromise shoreline stability, increasing erosion and suspended sediment loads. Siltation, bank failure, head-cutting, and elevated turbidity can occur as a result (Hoover *et al*. 2007). In Florida, sailfin catfish tunneling is believed to damage canals and levees and result in increased siltation (Ferriter *et al*. 2006), although as demonstrated in Table 3.3, not all researchers agree with this interpretation of the environmental impact. Goodyear (2000) suggests that *Pterygoplichthys multiradiatus* competes directly with and impedes successful spawning of native fish. In Lake Okeechobee, it feeds and burrows at the bottom and destroys submerged vegetation, essentially displacing native fishes that would otherwise use the aquatic vegetation for spawning and refuge (Fox 2002).

Finally, as with all non-native species introductions, loricariids can host infectious pathogens to which native species are not adapted or resistant. Loricariids are generally resistant to diseases but many harbor parasites, including flukes, roundworms and protozoans. Some loricariids have been associated with the protozoan, *Trypanosoma danilewskyi* (*carassii*), known to afflict cold freshwater cyprinid fishes (e.g., carp, goldfish, tench) with anaemia, likely resulting in death (Kailola 2004). Epizotic commensal chironomid larvae have been found among the oral bristles of different species (not present in species lacking bristles). An unidentified dinoflagellate occurred on the skin, fins and gills of *Pterygoplichthys gibbiceps*. Mortality rates were up to 100 percent in some consignments after 7 to 14 days, and the parasite was not treatable with malachite green, formalin or affected by changes in salinity, due to the formation of cysts (Pearson 2005).

Summary of Risks from the Loricariids

Loricariid risks are summarized in Attachment 2A, the Organism Risk Assessment Form for the *Loricariidae* family. This exercise has highlighted how biotic and abiotic factors in the environment where loricariid species have been introduced govern the severity of their impact. In neotropical Mexico, introductions appear to be at the root of environmental and socioeconomic effects that have not yet been controlled. Temperate conditions throughout Canada will likely prevent loricariids from ever becoming significant pest fishes, although the vulnerability of portions of western Canada requires further study. In the United States, significant effects on native fish fauna have been identified in Texas ecosystems, but are less equivocal in Florida, where several researchers believe the species has extended to its maximum range.

GARP modeling suggests, however, that there is significant possibility for the spread of the family into waters of the states adjacent to Florida and Texas. Based particularly on the Mexican experience, the propagule pressure from aquarist release and/or intentional distribution into these as-yet un-colonized waters is cause for concern. The ecological and socioeconomic effects of a further spread of loricariids in these waters cannot be determined from existing data, but would likely be significant, costly, and damaging in many of the potentially vulnerable aquatic systems in the American southeast.