BioInvasions Records (2012) Volume 1, Issue 3: 179–200
doi: http://dx.doi.org/10.3391/bir.2012.1.3.04

Research Article

Discovery of South American suckermouth armored catfishes (Loricariidae, *Pterygoplichthys* spp.) in the Santa Fe River drainage, Suwannee River basin, USA

Leo G. Nico[1]*, Peter L. Butt[2], Gerald R. Johnston[3], Howard L. Jelks[1], Matthew Kail[4] and Stephen J. Walsh[1]

1 *U.S. Geological Survey, Southeast Ecological Science Center, 7920 NW 71st Street, Gainesville, Florida 32653 USA*
2 *Karst Environmental Services, Inc., 5779 NE County Road 340, High Springs, Florida 32643 USA*
3 *Department of Natural Sciences, Santa Fe College, 3000 NW 83rd Street, Gainesville, Florida 32606 USA*
4 *Teaching Zoo, Santa Fe College, 3000 NW 83rd Street, Gainesville, Florida 32606 USA*

E-mail: LNico@usgs.gov (LGN), kes@atlantic.net (PB), jerry.johnston@sfcollege.edu (JRJ), hjelks@usgs.gov (HLJ), swalsh@usgs.gov (SJW)

**Corresponding author*

Received: 30 May 2012 / Accepted: 31 July 2012 / Published online: 22 August 2012

Abstract

We report on the occurrence of South American suckermouth armored catfishes (Loricariidae) in the Suwannee River basin, southeastern USA. Over the past few years (2009-2012), loricariid catfishes have been observed at various sites in the Santa Fe River drainage, a major tributary of the Suwannee in the state of Florida. Similar to other introduced populations of *Pterygoplichthys*, there is high likelihood of hybridization. To date, we have captured nine specimens (270-585 mm, standard length) in the Santa Fe River drainage. One specimen taken from Poe Spring best agrees with *Pterygoplichthys gibbiceps* (Kner, 1854) or may be a hybrid with either *P. pardalis* or *P. disjunctivus*. The other specimens were taken from several sites in the drainage and include seven that best agree with *Pterygoplichthys disjunctivus* (Weber, 1991); and one a possible *P. disjunctivus* × *P. pardalis* hybrid. We observed additional individuals, either these or similar appearing loricariids, in Hornsby and Poe springs and at various sites upstream and downstream of the long (> 4 km) subterranean portion of the Santa Fe River. These specimens represent the first confirmed records of *Pterygoplichthys* in the Suwannee River basin. The *P. gibbiceps* specimen represents the first documented record of an adult or near adult of this species in open waters of North America. *Pterygoplichthys disjunctivus* or its hybrids (perhaps hybrid swarms) are already abundant and widespread in other parts of peninsular Florida, but the Santa Fe River represents a northern extension of the catfish in the state. *Pterygoplichthys* are still relatively uncommon in the Santa Fe drainage and successful reproduction not yet documented. However, in May 2012 we captured five adult catfish (two mature or maturing males and three gravid females) from a single riverine swallet pool. One male was stationed at a nest burrow (no eggs present). To survive the occasional harsh Florida winters, these South American catfish apparently use artesian springs as thermal refugia. In the Santa Fe River, eradication might be possible during cold periods when catfish congregate in spring habitats. However, should *Pterygoplichthys* increase in number and disperse more widely, the opportunity to eliminate them from the drainage will pass.

Key words: invasive fishes; Loricariidae; Suwannee River; Florida springs

Introduction

Suckermouth armored catfishes (Siluriformes: Loricariidae) are a large and diverse family (about 90 genera and 846 described species) native to South America and Central America (Berra 2001; Eschmeyer and Fong 2012). The loricariid genus *Pterygoplichthys* is a group consisting of perhaps 15 valid species naturally distributed in South America from the Parana River basin, north to the Orinoco River basin, ranging in latitude from about 34°30' S to 11°11'30"N (Weber 1992; Armbruster and Page 2006). Over the past few decades, several *Pterygoplichthys* species and putative hybrids have been widely introduced outside their native ranges. To date, established (reproducing) or possibly established non-native populations have been documented in inland waters of North and Central America, southern and eastern Asia, and various islands of the Indo-Pacific and Caribbean regions (Fuller et al. 1999; Nico et al. 2009a; Ng and Tan 2010). In places where *Pterygoplichthys* are established, they tend to become abundant and disperse rapidly (Hubilla et al. 2007; Nico et al. 2009a; Capps et al. 2011; Chaichana et al. 2011).

Loricariids are typically bottom-dwelling fishes, characterized by a depressed body covered by large bony plates, a unique pair of maxillary barbels, and a ventral suctorial mouth (Covain and Fisch-Muller 2007). The sucker mouth enables adherence to the substrate even in fast-flowing water and, in combination with specialized teeth, is an adaptation for feeding by scraping submerged substrates to consume attached algae, small invertebrates, organic sediments, and even wood (Nico et al. 2009a). *Pterygoplichthys* have a number of attributes that increase the risk that individuals introduced into the wild will survive and reproduce. For example, they are air breathers and able to survive in anoxic waters and extended periods out of water if kept moist. Loricariid catfishes almost exclusively inhabit fresh water environments, but some *Pterygoplichthys* and a few others have been shown to tolerate mesohaline conditions (Capps et al. 2011). Adult *Pterygoplichthys*, presumably the male, excavate burrows in river and lake banks, which are then guarded and used as spawning and nest sites (Nico et al. 2009a).

As many as 15 different *Pterygoplichthys* species are recognized as valid taxa (Armbruster and Page 2006). The number of *Pterygoplichthys* taxa established in Florida (USA) is unclear. Published accounts for Florida typically include *Pterygoplichthys disjunctivus* (Weber, 1991) and *P. multiradiatus* (Hancock, 1828); however, some populations reported as *P. disjunctivus* may actually be *P. anisitsi* (Eigenmann and Kennedy, 1903) and recent reexamination of *P. multiradiatus* specimens indicates many are apparently *P. pardalis* (Castelnau, 1855). Moreover, some wild populations in Florida and Mexico (and elsewhere) include hybrids or likely hybrids (Capps et al. 2011; Wu et al. 2011). Indeed, some introduced *Pterygoplichthys* populations show such extensive variation among individuals that they might best be described as "hybrid swarms." A preliminary analysis examining the genetics of certain introduced North American populations yielded unclear results (T. Collins and L. G. Nico, unpublished data).

In this paper we document the recent discovery of *Pterygoplichthys* in the Santa Fe River drainage (Suwannee River basin), north-central Florida, USA. We describe the Santa Fe environment and what has been ascertained about the distribution and status of *Pterygoplichthys* in the drainage. We also speculate on the origin of the Santa Fe River population and discuss potential impacts and management options, including the possibility of eradication.

Study Area

The Suwannee is a major blackwater river (396-km long), slow-flowing and deep, draining about 28,540 km^2 of the southeastern USA (Figure 1). It originates in the Okefenokee Swamp of southern Georgia then meanders southwest into the northern part of peninsular Florida. The river receives substantial groundwater input along its length, and eventually empties into the Gulf of Mexico near the town of Suwannee. The Suwannee is one of the few large river systems in the USA with largely unregulated, free flow. In Florida, the Suwannee is bounded by several river basins, including the St. Marys (northeast), St. Johns (east and southeast), Waccasassa (south) and the Aucilla and other small coastal drainages (west).

The Santa Fe River (~113-km long) in north Florida is a major eastern tributary of the lower Suwannee River, draining about 3,500 km^2 of land and parts of six Florida counties (Figures 1 and 2A). The river originates in swamps near Lake Santa Fe and Lake Alto of the Northern Highlands physiographic province (elevation 50-60 m) then meanders westward toward the Suwannee (Hellier 1967; Kincaid 1998; Martin et al. 2006). Under the United States Geological Survey's (USGS) watershed classification scheme, the 8-digit Hydrological Unit Code (HUC) for the drainage is 03110206. The Santa Fe's major tributaries include the Ichetucknee River, New River, Olustee Creek, and Cow Creek.

A thorough descriptive overview of the Santa Fe River and its many aquatic environments has never been published, even though the drainage is hydrologically and ecologically quite unique and knowledge about its environmental characteristics are important in understanding and assessing the system's non-native fauna. The Santa Fe River is in a region of karst geology, resulting in unusual hydraulic features, including numerous artesian springs (karst springs), seeps, sinkholes and swallets (e.g., siphons), and complex cave systems that together create an intricate relationship between the river's surface waters and the Floridan aquifer (Kincaid 1998; Scott et al. 2004; Martin et al. 2006; Butt et al. 2007). Of particular note is the swallet known as the River Sink, within O'Leno State Park, where all surface water of the Santa Fe River disappears into an extensive cave system. The river then reemerges, augmented by groundwater from the regional aquifer, as a resurgence

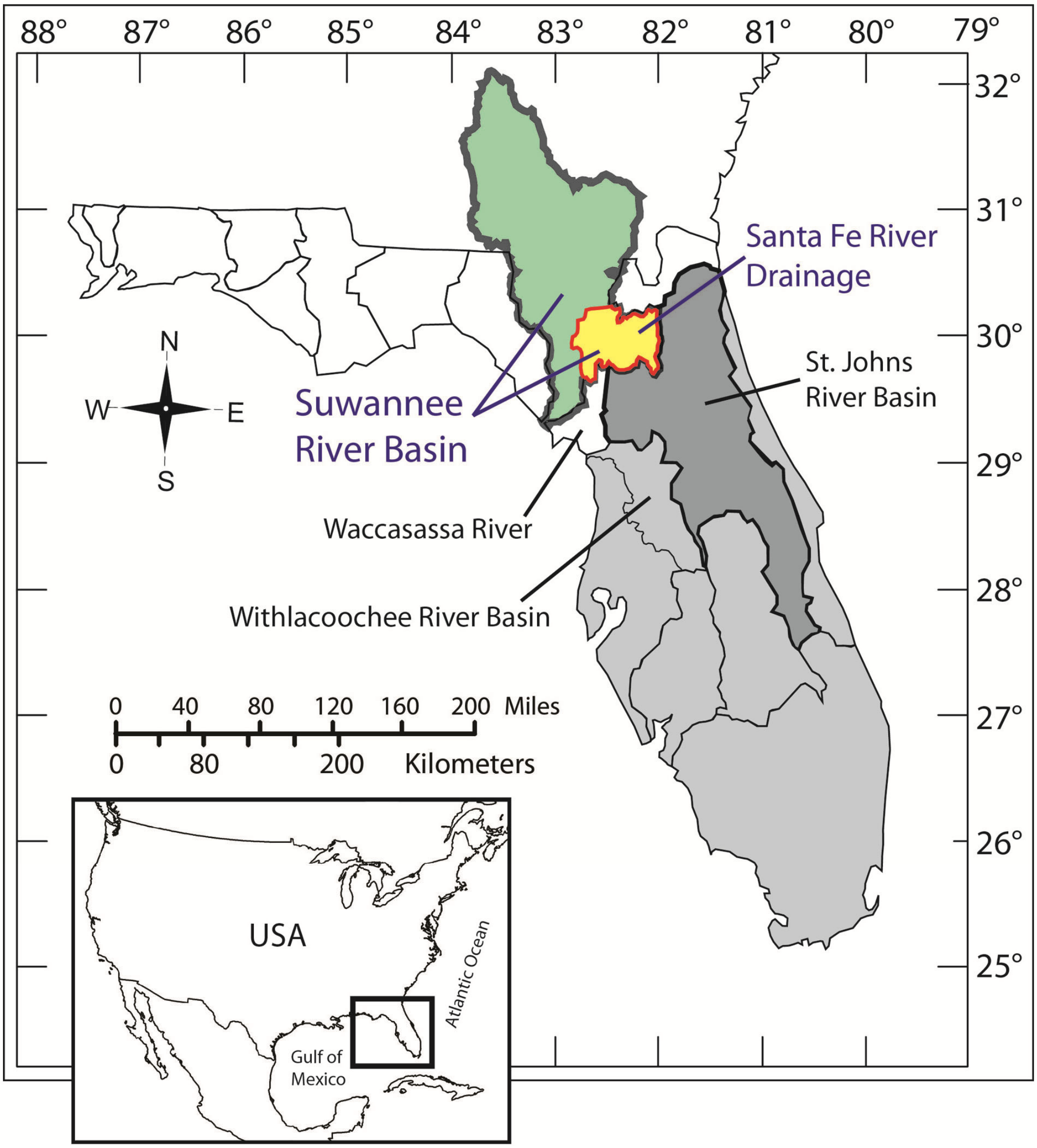

Figure 1. Map of Florida and southeastern Georgia (USA) depicting extent of the Suwannee River basin (green/yellow) and its tributary, the Santa Fe River drainage (yellow). Gray shaded areas in the Florida peninsula represent the major drainages in the state where members of the invasive catfish genus *Pterygoplichthys* are known to have established (reproducing) populations. The St. Johns River basin (dark gray) is the only basin adjacent to the Suwannee basin where *Pterygoplichthys* is known to be established.

equivalent to a first-magnitude spring (i.e., mean discharge >2.8 m^3/sec) at the River Rise within River Rise Preserve State Park, about 4.6 km southwest of the sinkhole (Scott et al. 2004).

The landscape of the Santa Fe River drainage is a mosaic of mainly forest, agricultural lands, and wetlands (Grubbs and Crandall 2007). The river proper is a meandering stream incised on the underlying geology and flowing through bottomland hardwood swamps, mixed hardwoods, and pine uplands. The river's gradient is 0.36 m/km and average discharge is approximately 46 m^3/sec (Nordlie 1990); however, discharge varies widely and, due to drought conditions over recent years, flows have been generally low. Average base flow over the

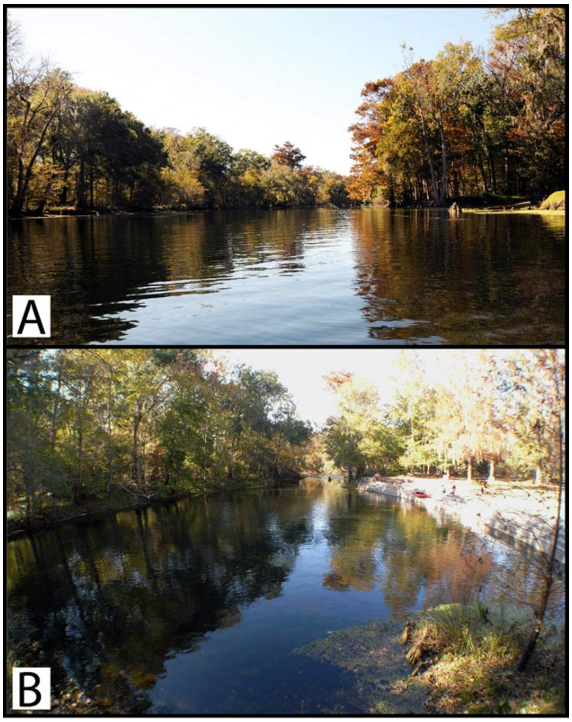

Figure 2. Sites in the lower Santa Fe River drainage, Suwannee River basin, Florida, 24 November 2010: (A) main channel of the Santa Fe River between Rum Island and Ginnie Springs; and (B) Poe Spring main pool with spring run and river channel in distant background. Photographs by Leo G. Nico.

past decade (at the US Hwy 47 bridge) is about 18 m^3/sec. Riverine habitats are very diverse, showing variations in canopy cover, instream vegetation, woody debris, substrate composition, flows, depths, pH, water temperature and clarity, all depending on location (Johnston et al. 2011).

During normal and low flows, the main channel includes moderately straight runs alternating with deep pools in the sharper bends. There are several long stretches consisting of shallow riffles and exposed limestone. In some reaches, the river's channel bottom is incised by canyons from 4 to 5 m deep, some of these extending for lengths up to about 50 meters or more.

Most of the upper river above the River Sink is relatively narrow and shallow, more creek than river, with minimal flow dependent largely on rainfall. In contrast, the Santa Fe below River Rise transforms into a moderate-sized stream, averaging about 40-m wide, although width varies from about 12 to over 70 m. Water depth in the lower reaches ranges from about 0.2 m in riffles to over 10 m in some of the deeper pools. Bottom type of the lower channel is predominantly limestone bedrock, with portions adorned with algae and rooted vascular plants. Large beds of submerged native aquatic vegetation, mainly *Vallisneria americana* Michx and *Sagittaria kurziana* Glück, are common over mixed patches of bedrock and sand. Recently large portions of the river have been colonized by the non-native aquatic plants *Hydrilla verticillata* Royle and *Hygrophila polysperma* (Roxb.). Algae colonize large portions of the bottom during low flow periods (Johnston et al. 2011). Other common substrates include gravel, cobble, mud, and detritus. Fallen trees, submerged logs, and other woody debris are common throughout the system.

The Santa Fe is commonly classified as a blackwater river; however, water clarity and coloration ranges from murky or darkly tannic to crystal clear depending on location, season, rainfall, and water flow (Scott et al. 2004; Butt et al. 2006; Kornilev 2008; Kornilev et al. 2010). The swamp water input predominates in the upper reaches and these waters are colored with high concentrations of dissolved organic matter, mainly acidic tannins. However, the river tends to become progressively clearer as the water moves downstream and receives ever increasing volumes of clear, nearly colorless, water from springs. There is a strong seasonal pattern. During high flow periods, the river receives substantial amounts of water from swamp habitats and water in the main channel is dark. In contrast, during periods of low flow most, sometimes all, of the water carried in the main channel originates from groundwater sources, which reduces the tannin load and greatly increases water transparency (Butt et al. 2006; Kornilev et al. 2010). During extended dry seasons, water in the main channel below Poe Spring is similar in clarity and temperature to that of water flowing in the local spring runs (P. Butt, personal observation).

Although much of peninsular Florida is in the humid subtropical climate zone, north Florida, including the Santa Fe drainage, has temperate characteristics since it is located in the transition zone between tropical and temperate circulation patterns (Myers 1986; Chen and Gerber 1990). Although winter temperatures in the state of Florida tend to be moderate, the lows vary greatly year to year, and in some years severe winter freezes occur that result in major fish kills (Myers 1986). In the Santa Fe River drainage, water temperature varies among sites, influenced by a combination of air temperature, solar heating, and groundwater contributions. Water in the springs remains about 22°C year round (Katz et al. 1999; Martin and Dean 1999), but river temperatures distant from springs may fluctuate monthly and even daily (Kornilev 2008). For example, river water temperatures recorded over the period January to November 1998 at Santa Fe River Sink ranged from a low of about 11°C in February to a high of about 28°C in July (Martin and Dean 1999).

In Florida, the rainfall pattern consists of a summer wet season (about June-September) and a winter dry season (about October-May), with occasional tropical storms and hurricanes (Chen and Gerber 1990). Rainfall in the Santa Fe River drainage averages about 1372 mm (Rumenik and Grubbs 1996; Grubbs and Crandall 2007). Typical of other Florida sites, onset and duration of wet and dry seasons is quite variable, with the large seasonal variation in precipitation in the Santa Fe area rendering the drainage susceptible to occasional flooding (Kincaid 1998). Recent major inundations in the Santa Fe River drainage included a long-duration flood event during the hurricane season of 2004 (Verdi 2005) and a brief, but intense flood in June 2012.

Most springs in the Santa Fe River are in the lower reaches of the river downstream of the River Rise. The springs are morphologically and hydrologically diverse. Included are springs classified as first-magnitude (>2.8 m^3/sec), second-magnitude (0.28-2.8 m^3/sec), third-magnitude (0.028-0.28 m^3/sec) or smaller (Katz et al. 1999). A large number of springs are within or immediately adjacent to the main river channel. However, others (e.g., Ichetucknee, Hornsby, and Gilchrist Blue springs) are situated in the floodplain some distance from the river, their water transported to the river proper via small natural creeks or spring runs. Of the more than 75 springs that discharge to the lower Santa Fe River, the two of importance in this study are Poe and Hornsby springs:

Poe Spring (29°49'32.58"N, 82°38'56.30"W) is located within Poe Springs County Park, Alachua County, about 5 km west of the town of High Springs (Figure 2B). The spring pool is circular (36.6 m diameter) and the vent is 5.7 m deep and situated in a conical depression. The spring run is swift and short, flowing approximately 23 m northwest into the Santa Fe River. Poe Spring is a second-magnitude spring, with recorded discharge rates as high as 2.6 m^3/sec (Scott et al. 2004). Water temperature remains about 22.3°C throughout the year (Katz et al. 1999) and the water is typically clear with some green coloration (Butt et al. 2006).

Hornsby Spring (29°51'01.3"N, 82°35' 35.5"W) is located in the privately-owned Camp Kulaqua, Alachua County, just north of the town of High Springs (Katz et al. 1999, Scott et al. 2004). The spring pool is circular (47 m × 45 m) and depth at the vent is 10.5 m, surrounded by limestone ledges. The spring is fed by a network of cave passages that have been explored and mapped by divers (Butt et al. 2006). The spring run (about 1.5-km long, 4.6 m wide, and up to 1.5 m deep) flows west through bottomland swamp towards Santa Fe River although some of the water is diverted into swallets (Butt et al. 2006). Hornsby Spring is classified as a first magnitude spring, with discharge measurements as high as 7.1 m^3/sec (Scott et al. 2004). However, according to data available from Florida's Suwannee River Water Management District, in recent years Hornsby Spring has experienced low flow conditions, zero flow, and, during river floods, even reverse flows. Water temperature in the spring is near constant 22.2°C (Katz et al. 1999). The water is clear, but tends to be greenish and sometimes dark-brown in color (Butt et al. 2006).

In addition to stable temperatures, water emerging from springs tends to be very hypoxic. In an unpublished report to Alachua County, US Geological Survey hydrologists reported dissolved oxygen readings at Poe Spring ranged from 0.31 to 1.35 mg/L and in Hornsby Spring from 0.27 to 0.50 mg/L based on measurements taken over the period 2003-2004. During the past century widescale development in Florida watersheds has led to increased levels of nutrients in groundwaters discharging from springs (Brown et al. 2008). In addition, over recent decades many of the larger springs show increasing abundance of nonindigenous aquatic vascular plants (e.g., *Hydrilla verticillata*, *Myriophyllum spicatum* Mart. (Solms), and *Eichhornia crassipes* L.) and several nuisance algae, mainly filamentous mat-forming cyanobacteria of the genus *Lyngbya* and the green alga *Vaucheria* (Stevenson et al. 2007; Brown et al. 2008; Sickman et al. 2009). Historically, areas immediately surrounding spring vents consisted of bare sand. However, largely due to increased nutrient input from development of the drainage, macroalgae have proliferated in many springs and cover large portions of spring pool bottoms (Stevenson et al. 2007; Brown et al. 2008).

Swallets or siphons are an important component of the Santa Fe ecosystem. In addition to the River Sink at O'Leno State Park, a large swallet in the study area pertinent to the present research is Big Awesome Suck (29°51'12.65"N, 82°43'09.7"W), a large siphon located in a small side channel of the Santa Fe River between Ginnie Springs and the Highway 47 bridge in Columbia County (Butt et al. 2007). The pool formed by Big Awesome Suck is roughly oval (about 20 × 25 m) and deep (about 15 m). Underwater, the pool is framed on the downstream side by steep limestone walls (formed by two fracture planes) and on its upstream side by a high-gradient slope of mostly sand and soft silt. The two or three cave entrances at the bottom of the pool conduct river water underground at an estimated rate of about 4.3 m^3/sec (Butt et al. 2007).

The springs, seeps, and caves of Florida's karst habitats harbor unique and diverse faunal assemblages and many are biologically important, especially because of the presence of endemic species (Walsh 2001). Florida springs and spring runs have a particularly rich and diverse molluscan fauna (Thompson 1968). Although much of the Santa Fe River region is sparsely populated (Grubbs and Crandall 2007), the river and its springs are heavily used by locals and tourists for recreational purposes. Typical activities include boating (e.g., canoes, kayaks and small motorized boats), rubber rafting and tubing, swimming, occasional airboats and jet skis, snorkeling, SCUBA diving (including cave diving), sport fishing, sight-seeing and nature photography.

Material and methods

Field surveys and detection

Since 2006, biologists have been conducting regular snorkeling surveys of river turtles in the Santa Fe River (Kornilev et al. 2010; Johnston et al. 2011). The field investigations have included day and night surveillance. Surveys cover the lower river and typically focus on the 7-km stretch between Poe Spring and a point about 1 km below Ginnie Springs (Figure 3). Preliminary sightings of *Pterygoplichthys* and some captures occurred during these surveys. Initial sightings by the turtle research group spurred us to begin a search of the river and springs in the Santa Fe system for loricariid catfish or their sign. This included periodic reconnaissance by snorkeling and also visual scans of the water while walking the shore and traveling by canoe. Our approach to search was based largely on our many years of surveying and collecting *Pterygoplichthys* in other parts of Florida (Nico et al. 2009a; Nico et al. 2009b; Nico 2010).

Where *Pterygoplichthys* are common, especially in spring habitats and other clearwater sites, the adults are large and active, generally easy to detect. They can often be observed resting on the bottom or grazing on logs and other surfaces during the day, although juveniles tend to be more secretive and nocturnal (Nico 2010). *Pterygoplichthys* also will frequently and explosively swim upwards, break the surface with their snout to gulp air, and then quickly turn tail and dive back to the bottom. This behavior is likely related to air breathing or to obtain air for maintaining buoyancy (Armbruster 1998; Nico et al. 2009b; Nico 2010). Because water is usually clear in springs and in some parts of the main Santa Fe River, it enables relatively unobstructed observation of fishes by snorkelers and persons stationed on the shore or boats.

In lieu of direct observation, presence of *Pterygoplichthys* or related loricariids may be inferred by certain signs. One of the more reliable is the existence of nest burrows excavated and maintained by adult catfish (Nico et al. 2009a). These burrows often occur in aggregates along shoreline slopes and are generally highly visible, especially in clear water or during low-water periods when many of the holes become exposed to air. Active burrows are usually just beneath or within a few meters of the water line, have a triangular-shaped or oval entrance (about 21-cm wide), and a tunnel length of about 1 m long. Abandoned burrows are commonly degraded and may be mistaken for the burrow of another creature or an eroded cavity (Nico et al. 2009a).

Another sign indicating the possible presence of *Pterygoplichthys* or other large loricariids is the combination of cleaned bedrock surfaces with the presence of their feces. This is because loricariid catfish typically feed by grazing or scraping, removing large quantities of periphyton and other attached materials from flat surfaces (Power 1990; Ludlow and Walsh 1991). Feeding *Pterygoplichthys* also evacuate lots of feces and the green or brownish, worm-like feces are often fairly conspicuous, scattered over the substrate (Power 1990; Ludlow and Walsh 1991; L.G. Nico, personal observations). After periods of

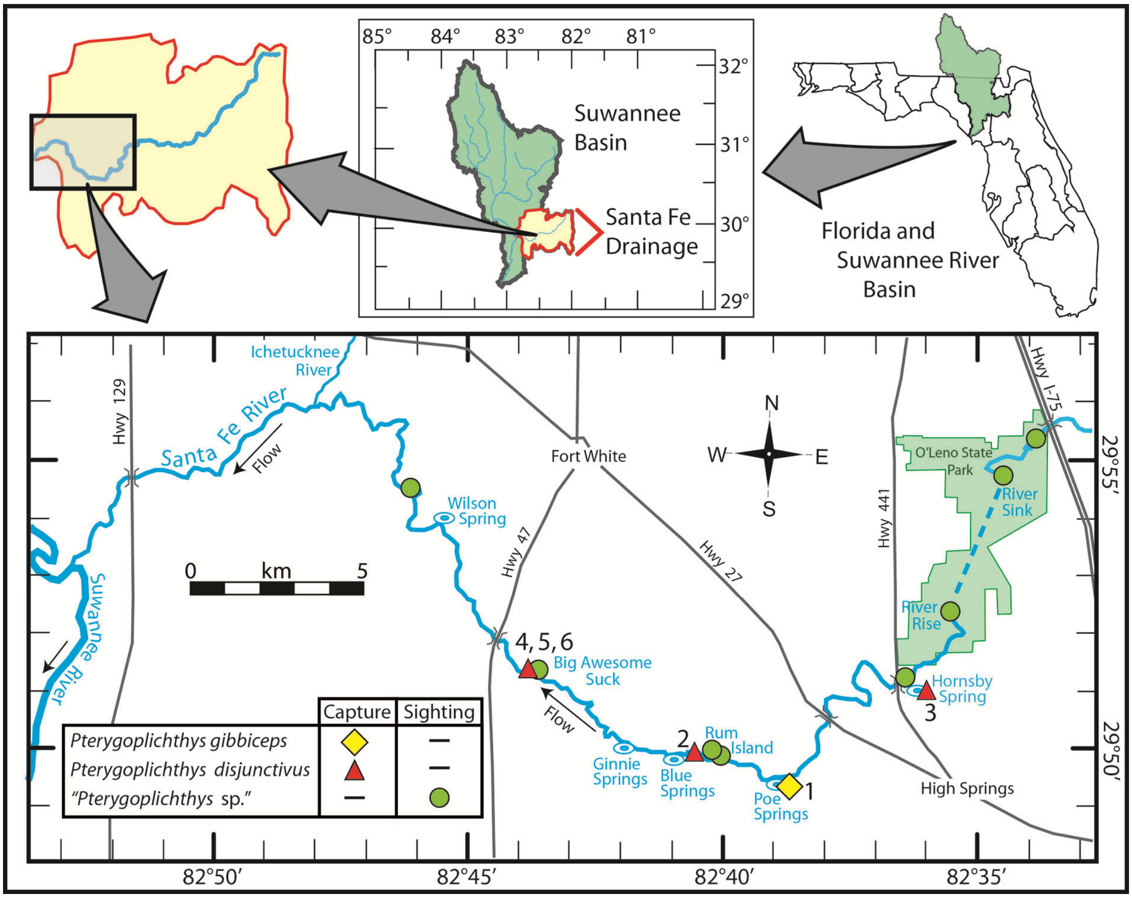

Figure 3. Map of the lower Santa Fe River drainage, northern Florida peninsula, showing the four *Pterygoplichthys* capture sites and multiple sites where suckermouth armored catfish were sighted over the period from 2009 to 2012. Numbers next to symbols correspond to accounts in the Appendix. See text for detailed description of the river system and its habitats.

extremely cold winters in Florida, the rotting carcasses of *Pterygoplichthys* can often be found floating in the water or washed to the shore (L. G. Nico, personal observations).

During surveys, we typically attempted to capture any *Pterygoplichthys* encountered. Captures were carried out by snorkel divers or SCUBA divers, sometimes both working cooperatively. Catfish were grabbed directly by hand or by use of hand-held nets, and both methods required pinning the catfish to the substrate. SCUBA divers also used spears. Any armored catfish captured were photographed, and the specimens were later preserved by freezing. Total length (TL) and standard length (SL) were measured to the nearest mm, and whole body weight to the nearest gram. Specimens were dissected and gonads examined to determine gender, reproductive status, and stage of maturity. The more recent specimens were measured and weighed live and then the catfish were sacrificed and we recorded gonad mass prior to their preservation. For these specimens, we measured gonad dimensions and calculated gonado-somatic index: (GSI) = $M_g/M_t \times 100$, where M_g is the weight of both gonads, M_t is total body mass. Diameter of largest eggs of maturing and mature females were measured with digital calipers.

A piece of muscle tissue was removed from each specimen and preserved in 95% ethanol for use in future genetic analyses. Following dissection, the catfish were preserved in 10% formalin and after several weeks transferred to

70% ethanol. The preserved voucher specimens are cataloged and deposited in the Florida Museum of Natural History Ichthyology Collection (UF: museum catalog numbers from 184196 to 184200 and 184202).

Identification of Pterygoplichthys

Members of the genus *Pterygoplichthys* (subfamily Hypostominae) are distinguished from most other loricariids by a large dorsal fin with 9 or more (usually 10+) dorsal fin rays (Armbruster and Page 2006). They are moderately large catfish, with adults ranging from about 30 to 55 cm total length (Liang et al. 2005; Nico et al. 2009a), although maximum size likely exceeds 70 cm. An identification key to *Pterygoplichthys* appeared in Weber (1992), and was subsequently updated and expanded by Armbruster and Page (2006). Although available keys are useful, positive identification of certain species remains problematic because the primary distinguishing traits are subtle differences in body pigmentation pattern. Indeed, our examination of large numbers of juvenile and adult specimens from drainages in central Florida where *Pterygoplichthys* are abundant revealed wide intra-population variations in color patterns, with some pigmentation patterns apparently age related.

It is also likely that some, perhaps most, introduced populations are composed of hybrids. For instance, large numbers of *Pterygoplichthys* examined by us from some Florida populations (e.g., Peace River) include a diverse mix of color patterns. Some individuals have a spotted ventral pattern (similar to *P. multiradiatus*), some a vermiculated ventral pattern (similar to *P. disjunctivus*), and others display patterns falling anywhere within the gradient between spotted and vermiculated. Researchers studying non-native *Pterygoplichthys* populations in such places as Texas, Mexico, and Taiwan also have noted similar wide variations in color forms and suggested that hybridization was the likely cause (Nico and Martin 2001; Chavez et al. 2006; Liénart 2009; Nico et al. 2009b; Wu et al. 2011).

During examination of loricariids captured in the Santa Fe drainage, we recorded the pigmentation pattern of each specimen and noted other morphological and meristic characteristics useful for identification. For verification of specimen identification, we consulted the loricariid expert Dr. Jonathan Armbruster of Auburn University.

Results

Over the past few years (2009-2012), a total of nine loricariid catfish specimens (270-585 mm, standard length) have been collected in the Santa Fe River drainage (Figures 3; Appendix 1). One specimen taken from Poe Spring best agrees with *Pterygoplichthys gibbiceps* or may, in fact, be a hybrid with either *P. pardalis* or *P. disjunctivus* (Figures 4 and 5). The other specimens were taken from several sites in the drainage and include seven that best agree with *Pterygoplichthys disjunctivus* (Figures 6 and 7); and one a possible *P. disjunctivus* × *P. pardalis* hybrid (Figure 7D). The possibility of some degree of introgressive hybridization among any of the specimens cannot be ruled out. Each of the nine specimens had a dorsal fin ray count of I,12.

Appendix 1 includes information on date and location of capture, specimen body length and mass, gender and reproductive stage, and for selected individuals, their gonad mass and calculated GSI value. All nine specimens captured appeared to be healthy and contained substantial amounts of coelomic fat stores.

Pterygoplichthys gibbiceps (Kner, 1854)

This species is native to the Amazon and Orinoco basins of South America (Weber 1992). The single *P. gibbiceps* taken in the Santa Fe system was captured at Poe Spring on 26 August 2009 just after dawn (Figures 3 to 5). The specimen measured 270 mm TL; 198 mm SL, and weighed 189 g. Primary diagnostic characteristics included: large dorsal fin covered with large dark spots; large, dark spots on the ventral side; and a prominent supraoccipital process forming elevated median crest in the nuchal region of head, anterior to dorsal fin origin. Unlike *P. disjunctivus*, as *P. gibbiceps* grow the individual spots do not coalesce to form larger or elongated markings. According to J. Armbruster (personal communication), who examined the specimen, it has various traits typical of *P. gibbiceps* (i.e., large ventral spots, supraoccipital crest, and light upper caudal fin ray), but a few other traits appear rather uncharacteristic of the species (i.e., general body coloration and the relatively short dorsal fin) which indicate the possibility that the specimen may be a hybrid. Dissection revealed the catfish was an immature female, containing white, underdeveloped eggs.

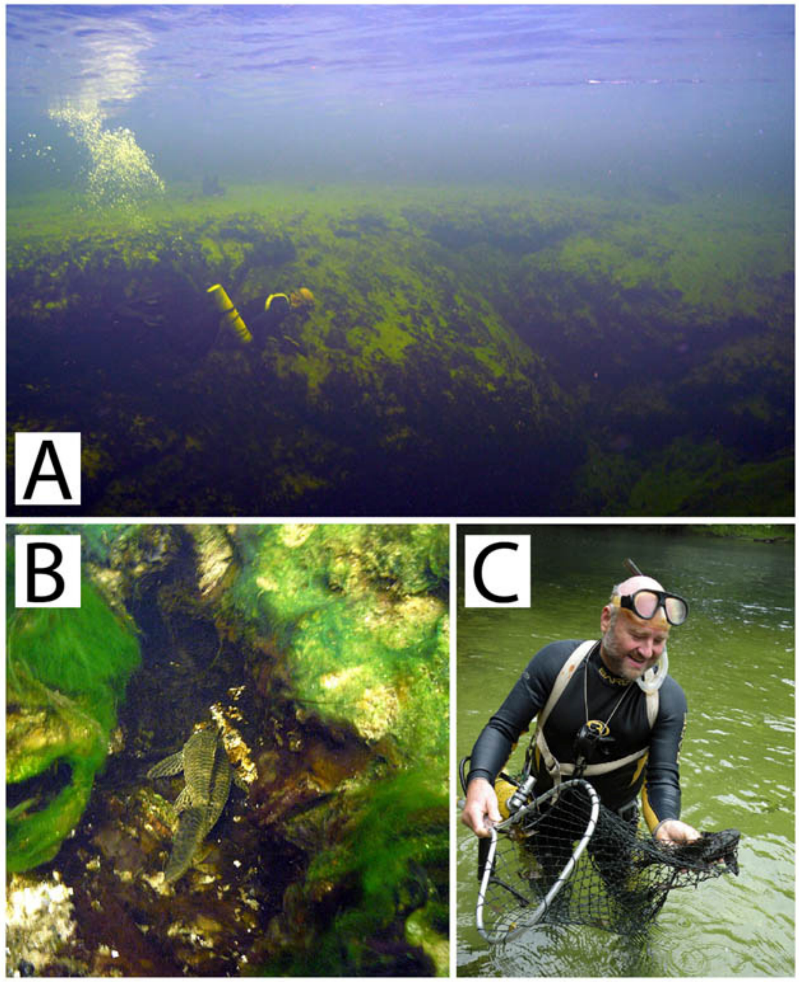

Figure 4. Search for armored catfish at Poe Spring, Santa Fe River drainage, Florida: (A) SCUBA Diver Pete Butt entering the deeper portion of spring leading toward spring vents; (B) *Pterygoplichthys gibbiceps* entering a crevice in spring pool; and (C) Pete Butt with the *P. gibbiceps* that was corralled and captured in Poe Spring on 26 August 2009. Photographs by Leo G. Nico and Georgia Shemitz.

The *P. gibbiceps* taken from Poe Spring was initially observed resting in a crevice a few meters below the surface within the main spring vent. One SCUBA diver and two snorkelers were able to drive the catfish out of the vent into shallows where it was pursued, corralled, and then trapped against the bottom with a hand net in water about 1 m deep. During the same morning, two or three additional loricariids, presumably this species, were also observed deep in the spring vent mouth. The catfish usually remained hidden, occasionally surfacing during air-breathing bouts.

Pterygoplichthys disjunctivus (Weber, 1991)

Pterygoplichthys disjunctivus is native to the Amazon River basin of South America (Weber 1992). The seven specimens taken in the Santa Fe River system were identified as *P. disjunctivus* based primarily on the following diagnostic characteristics: large dorsal fin; abdomen color pattern consisting of light and dark vermiculations (dark vermiculations resulting from coalescence of spots); dark ventral vermiculations on venter broader or same width as light vermiculations; and absence of a prominent supraoccipital process. An additional specimen was tentatively identified as a *P. disjunctivus* × *P. pardalis* hybrid because its ventral pattern was composed of spots with limited coalescence (Figure 7D). The nine captured specimens ranged in size from 431 to 585 mm TL (321 to 455 mm SL) and in mass from 802 to 2066 g (Appendix 1). Included were adult males and females, some maturing and others considered spawning ready.

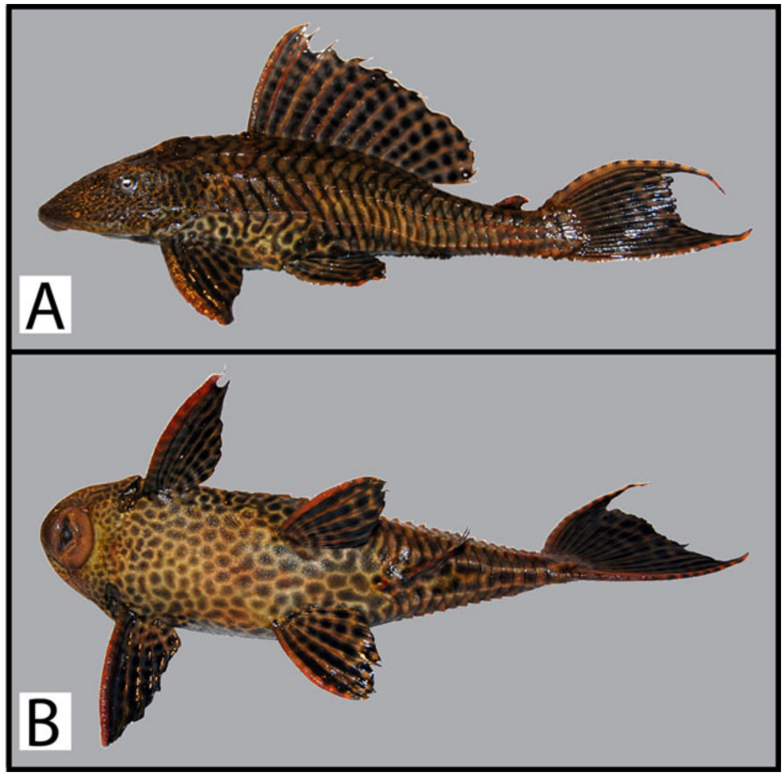

Figure 5. *Pterygoplichthys gibbiceps* (or its hybrid) immature female (198 mm SL), captured at Poe Spring, Santa Fe River drainage, Florida, 26 August 2009: (A) lateral view; and (B) ventral view (Field# LGN09-47; museum catalog no. UF 184196). Photographs by Leo G. Nico.

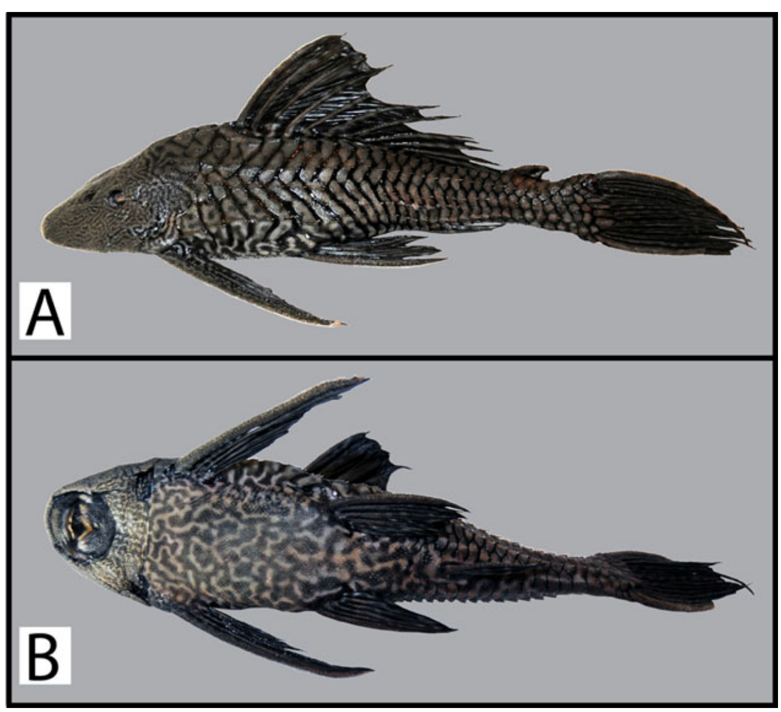

Figure 6. *Pterygoplichthys disjunctivus* (or its hybrid), immature male (321 mm SL), captured in the Santa Fe River main channel between Rum Island and Ginnie Springs, Florida, 11 November 2010: (A) lateral view; and (B) ventral view (Field# LGN10-73; museum catalog no. UF 184197). Photographs by Leo G. Nico.

Basic information on the nine *P. disjunctivus* or putative hybrids is as follows:

Specimen #1 was captured in the main river channel in a reach between Rum Island and Ginnie Springs, 11 November 2010 (Figure 6). The catfish was an immature male measuring 431 mm TL; 321 mm SL, and weighed 802 g. In gross appearance, testes were opaque white and fimbriate.

Specimen #2 was captured in Hornsby Spring on 13 March 2011. It measured 505 mm TL; 390 mm SL, and weighed 1480 g. This catfish died before it could be adequately preserved; consequently the internal organs were already partially decomposed prior to dissection. The body cavity included pieces of white tissue, probably from the testes, indicating the fish was a putative male. In addition, the specimen had thickened and greatly elongated pectoral and pelvic spines, which are probably characteristic of some nuptial males. Although one of the pectoral spines was broken and lost during capture, the remaining pectoral spine was adorned with numerous odontodes (dermal teeth) over most of its length, and the spine was curved at the distal tip.

Specimens #3 to 8 were all captured in the large pool associated with Big Awesome Suck (Figure 3; Appendix 1). The first was an adult female (585 mm TL; 455 mm SL, and weighing 2066 g) taken on 2 March 2012 (Figures 7A and 7B). It contained non-vitellogenic oocytes, amber colored and ranging in size from about 1.4 to 1.7 mm diameter.

Five additional specimens, all adults, were collected from Big Awesome Suck over the period 11-13 May 2012 (Figures 7C to 7F; Appendix 1). These included two adult males, 429 and 444 mm SL, with one of the males found at the entrance of a recently excavated nest burrow, the first such burrow observed by us in the Santa Fe River drainage (Figure 8). The other three armored catfish taken from Big Awesome Suck during May were gravid females, ranging in size from 402 to 432 mm SL (Figures 7D, 7F and 9). The ovaries of the three females were paired and large, each containing numerous yolked, yellow-orange eggs, the largest measuring about 3.4 to 3.5 mm diameter (Figure 9). The GSI of the three females ranged from 4.9 to 10.7 (mean = 7.9) (Appendix 1). One of the gravid females was the putative *P. disjunctivus* × *P. pardalis* hybrid (Figures 7D and 9). The testes of the two males examined from Big Awesome Suck were paired and fairly small relative to catfish body mass; GSI values of the males were 0.1 and 0.3.

The nest burrow found in the pool of Big Awesome Suck had a tunnel length of 1.2 m and height at entrance about 8 cm (Figure 8). The burrow was located in water 5.8 m deep on a sandy-silt slope of the large pool formed by the swallet. The slope surrounding the burrow fairly soft and slight disturbance by SCUBA divers resulted in clouds of suspended silt. The burrow had been excavated immediately below a small submerged log, which was embedded in the substrate and provided stability to the burrow. The entrance of the burrow was somewhat oval and wide, but narrowed within. The burrow did not contain eggs. A second, smaller burrow (< 0.3 m tunnel length), incompletely excavated by the catfish, was located about one meter above the larger burrow (Figure 8). Water temperature at Big Awesome Suck on 12 May 2012 (15:10 h) was 23.5°C. Dissolved oxygen levels were not measured, but presumed to be high because of the rapid flow of water from the main channel being diverted into the side channel habitat.

Other field observations

On the same dates and at each of the locations where *Pterygoplichthys* specimens were captured, we also observed as many as one to five additional armored catfish in the immediate vicinity. In addition, over the period 2009-2012, we have observed adult-sized armored catfish at other sites within the Santa Fe River drainage, including the main channel, side channels or oxbows, sinkholes and at both Hornsby and Poe springs (Figure 3; Appendix 1). Presumably all observations were of *Pterygoplichthys***,** likely the same species as those captured. In many cases, the armored catfish were seen to swim periodically to the surface (i.e., air breathing).

To date, all confirmed records of *Pterygoplichthys* within the Suwannee River basin are from within the lower Santa Fe River drainage (Figure 3). The most upstream sighting was at a point several kilometers above the River Sink (~29°55'18.92"N, 82°33'50.53"W) and the most downstream sighting was about 2 km below Wilson Spring (~29°54'14.77"N, 82°46'0.76"W) (Figure 3). The downstream sighting is about 8 km above the Santa Fe's confluence with the Ichetucknee River and about 19 km from its confluence with the main channel of the Suwannee River. The distance between the uppermost and lowermost sightings is 33 km of

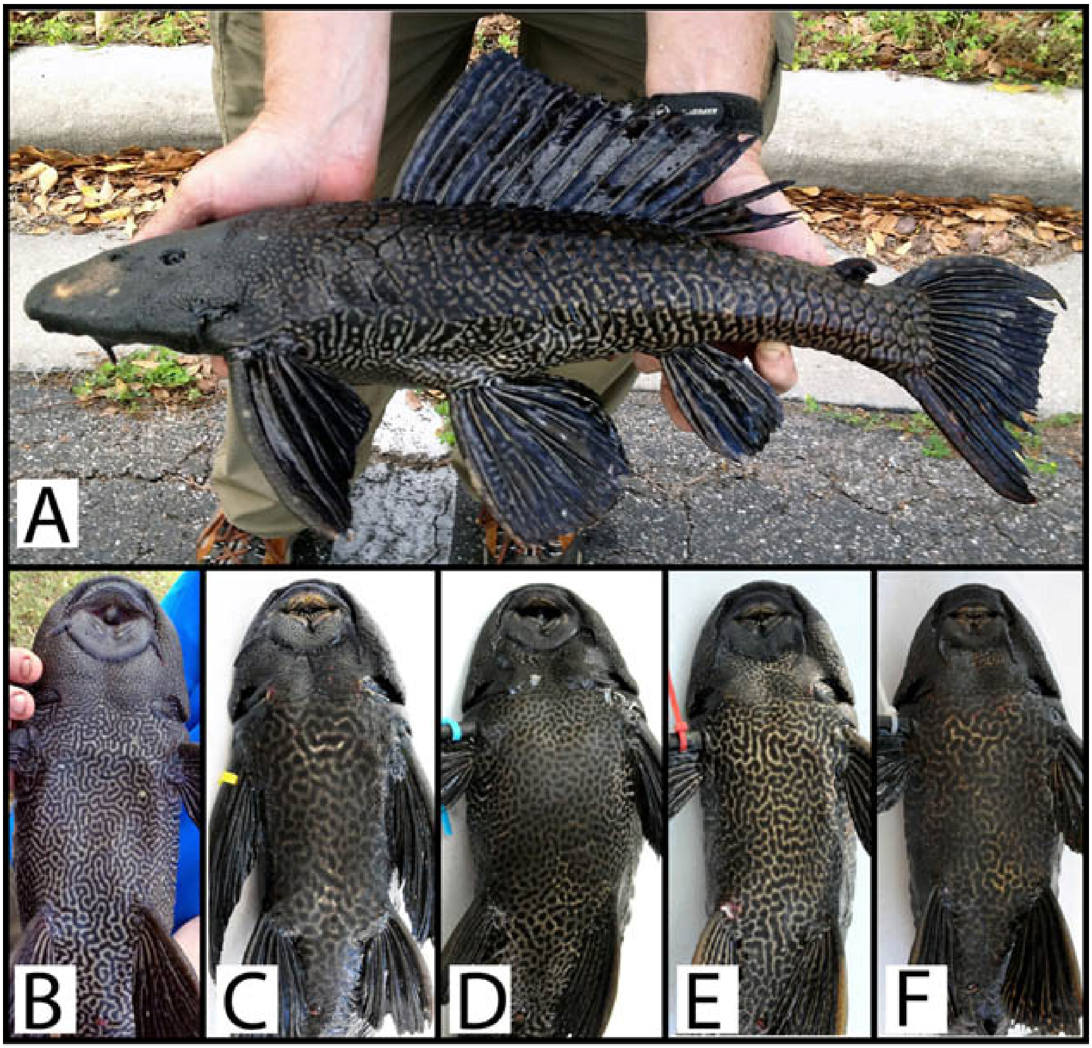

Figure 7. Photos of five of the seven *Pterygoplichthys disjunctivus* (or hybrids) captured at Big Awesome Suck, Santa Fe River drainage, Florida: (A-B) lateral and ventral views of adult female (455 mm SL; with non-vitellogenic eggs) captured 2 March 2012 (Field# LGN12-06, museum catalog no. UF 184199); (C-F) ventral views of four adults (402 to 444 mm SL) captured on 11 May 2012 (Field# LGN12-15, museum catalog no. UF 184200). Specimens D and F were gravid females; and C and E adult males. Images show diversity of ventral patterns and based on its pattern, specimen D may be a *P. disjunctivus* × *P. pardalis* hybrid. See Appendix for more information on the specimens. Photographs by Leo G. Nico.

surface river channel (excluding the subterranean reach of the river within O'Leno State Park).

Since July 2009, we have visited Poe Spring on seven separate days but have only observed *Pterygoplichthys* during two occasions. One of the visits included a night dive during which no catfish were seen. Although submerged bank holes and undercuts are scattered throughout the Santa Fe drainage, none of these other cavities were thought to be created by armored catfish, nor have we observed small juvenile *Pterygoplichthys* in the drainage.

Discussion

Our discovery of *Pterygoplichthys* in the Santa Fe drainage represents the first confirmed records of this invasive group of catfishes in the Suwannee River basin. *Pterygoplichthys disjunctivus* or its hybrids are already abundant and widespread in other parts of peninsular Florida (Figure 1); but the Santa Fe represents a northwestern extension of its population in the state. In contrast, the *P. gibbiceps* specimen is the first documented record of an adult-sized

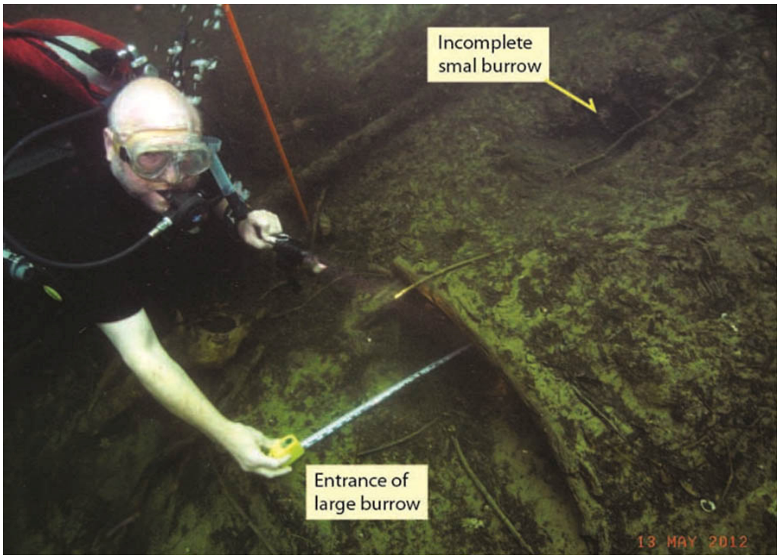

Figure 8. The first confirmed *Pterygoplichthys* nest burrow observed in the Santa Fe River drainage, Florida, was discovered at Big Awesome Suck on 11 May 2012. The newly excavated burrow, with a tunnel length of 1.2 m, was located in water 5.8 m deep on a sandy-silt slope of the large pool formed by the swallet. An adult male *P. disjunctivus* was positioned in the entrance of burrow tunnel and was immediately captured (see Figure 7C). The burrow did not contain eggs. A smaller, incomplete burrow (< 0.3 m long), is shown just above the larger burrow. Additional mature adult male and female *P. disjunctivus* were taken from the same pool during visits to Big Awesome Suck during 11-13 May 2012. Photograph by Leo G. Nico.

Figure 9. Image of dissected gravid adult female *Pterygoplichthys disjunctivus* showing large paired ovaries, ripe yellow-orange eggs, and wide strands of coelomic fat running along intestines. This catfish was captured in the large pool of Big Awesome Suck, Santa Fe River drainage, 11 May 2012 (Field # LGN12-15). (Same specimen is shown in Figure 7D.) Photograph by Leo G. Nico.

member of this species in open waters of North America. The only other records of *P. gibbiceps* (or its hybrids) confirmed for North America, that we are aware of, are two small juvenile specimens (48 and 82 mm SL) taken from Horse Creek in Florida's Peace River drainage in 2005-2006. Those two specimens are deposited in the Florida Museum of Natural History (cataloged as UF 163726 and UF 175923).

In the Santa Fe system, positive sightings of armored catfishes are scattered and infrequent, and limited to the lower drainage (Figure 3; Appendix 1). In addition, only a few armored catfish individuals (five or less) have been observed at any one location. The limited sightings and their small numbers is evidence that *Pterygoplichthys* are not abundant in the Santa Fe and their establishment somewhat uncertain. If these non-native catfish were more abundant and widespread, it is likely the information would be reported since many thousands of recreationists visit the area's springs and travel the river each year. Moreover, biologists and other scientists commonly work in the drainage, including teams of experienced snorkelers who periodically survey the river and springs in search of turtles. The small numbers of *Pterygoplichthys* in the Santa Fe are in sharp contrast to the huge numbers of these catfishes found in most Florida drainages to the south (Nico et al. 2009a; Nico et al. 2009b).

Pterygoplichthys in other parts of Florida appear to be fairly active, some apparently move regularly between springs and river channel habitats (Nico et al. 2009b). It is conceivable that sightings of armored catfish at different locations in the Santa Fe drainage are based on observations of a small group of highly mobile catfish. However, although some repeat sightings may be of the same individuals, we suspect the population in the Santa Fe is more than just a few dozen. Even when present, the catfish may go undetected. During multiple visits to Poe Spring, we only observed armored catfish during half the visits. Although the catfish may have been absent on certain occasions, it is also possible they were present but responded to the presence of humans by hiding in the many cracks and crevices in deep water near the spring vent. Also, although we have only detected one complete nest burrow, we suspect *Pterygoplichthys* sometimes use natural limestone crevices or other natural holes as spawning sites, particularly in habitats where the soil may not be suitable for excavation (e.g., canals of south Florida).

Origin and distribution of Pterygoplichthys in the Santa Fe River drainage

The origin of the two *Pterygoplichthys* species in the Santa Fe drainage is uncertain. *Pterygoplichthys* are common in the aquarium trade and most introductions in Florida (and other parts of the world) are presumed to be linked to the ornamental fish industry. The mode of introduction is typically speculated as being attributed to either escapes from aquaculture farms or aquarium releases (Fuller et al. 1999). As many as 170 fish farms in Florida culture or maintain loricariid catfishes (Mendoza-Alfaro et al. 2009), but we are unaware of any such farms in the Suwannee River basin. We can also only speculate as to whether the presence of these non-native catfish in the Santa Fe resulted from just one or multiple point introductions.

If *P. gibbiceps* is indeed restricted to the vicinity of Poe Spring (Figure 3), then the presence of this species is likely the result of an aquarium release at or near the spring. The appearance of *P. disjunctivus* in the Santa Fe is more difficult to explain. Our collections indicate this species is moderately widespread in the lower drainage. Moreover, *P. disjunctivus* may be the armored catfish observed upstream of the subterranean passage (i.e., above River Sink). Assuming a widespread distribution, we can speculate that this species may have been introduced at one or more locations, possibly by aquarists or anglers.

Alternatively, *P. disjunctivus* may have entered the drainage as a result of dispersal of populations already established elsewhere in Florida. Much of Florida is low elevation and some adjacent drainages are briefly connected during flood periods (e.g., hurricanes). Such connections have probably aided in the dispersal of non-native fishes. The brown hoplo, *Hoplosternum littorale* (Hancock, 1828), may have moved from the St. Johns River basin into the Kissimmee River in this manner (Nico 2005).

Pterygoplichthys disjunctivus or its hybrid has been established in Florida waters more than two decades, being first reported (as *P.* cf. *multiradiatus*) from the Hillsborough Canal system of central Florida near Tampa (Ludlow and Walsh 1991; Fuller et al. 1999). Over the years it has dispersed (perhaps with the aid of humans) throughout a large part of the Florida peninsula and it is extremely abundant in many of the major drainages, such as the Kissimmee, St. Johns, Withlacoochee, and Peace (Nico 2005, 2010; Figure 1).

The only drainage immediately adjacent to the Santa Fe and Suwannee systems known to have an established population of *Pterygoplichthys* is the St. Johns River basin, the large drainage bounding the Santa Fe drainage to the southeast (Figure 1). Along most of the eastern boundary, the Santa Fe drainage is separated from the St. Johns basin by Trail Ridge, a broad, elongated sand ridge extending some 200 km from Georgia southward into central Florida (Burgess and Franz 1978; Gilbert 1987). Our examination of topographic maps and discussions with locals indicate there may be occasional, brief surface water connections between the two basins during floods, but no documented records exist to confirm such links. The St. Johns and Santa Fe share some native aquatic faunal elements, but zoogeographers consider the species overlap to be a result of connections that likely only existed during an earlier geological epoch (Burgess and Franz 1978). Given that native fishes apparently have had few opportunities for cross-drainage movement, then modern-day introduced fish also likely face substantial surface and subterranean barriers preventing cross-drainage movement.

In April 2012, we conducted a brief survey of the landscape along parts of the boundary between the Santa Fe drainage and St. Johns River basin, including the area between Lake Newnan (St. Johns basin) and lakes Alto and Santa Fe. We could find no likely connector between the drainages. Admittedly, major flood events over the past few decades may have created temporary connections. Still, natural dispersal of *Pterygoplichthys* from the St. Johns basin would have been into the far upper Santa Fe system and there have been no reports of these catfish in that part of the drainage.

Pterygoplichthys is also known from the nearby Withlacoochee River system to the south (Figure 1). The Withlacoochee discharges into the Gulf of Mexico and is separated from the lower Suwannee and Santa Fe rivers by the Waccasassa River system, a small, lowland coastal drainage. Based on current maps, it is conceivable that *Pterygoplichthys* in the lower Withlacoochee face few barriers to penetrating into the Waccasassa system and then dispersing north via lowland swamps and marshes into the lower Santa Fe. To date, we have not surveyed the Waccasassa and so do not know if *Pterygoplichthys* is present in that drainage.

Where *Pterygoplichthys* have been introduced and become established they tend to disperse naturally and colonize new areas. However, in Florida it is probable that fishermen and others have augmented armored catfish dispersal by transporting armored catfish from one water body to another. A unique situation has also arisen in Florida because of the widespread establishment and abundance of viable populations of armored catfishes in the wild. Florida's ornamental fish industry has shifted away from brood stock maintenance toward the collection of eggs directly from the nest burrows of wild *Pterygoplichthys*; after obtaining the wild-collected eggs, the fish farmers incubate the eggs and grow out the hatched fry (Mendoza-Alfaro et al. 2009). Some of the individuals responsible for harvesting the eggs are traditional commercial fishermen. Whether the egg harvesters are enticed to also transport adult armored catfish to previously uncolonized sites - such as the Santa Fe system - is unknown.

Our sightings of armored catfish both downstream and upstream of the Santa Fe River Sink/Rise subterranean system is of special interest (Figure 3). This underground passage probably acts as a barrier to migration by some fishes (Hellier 1967). If armored catfish were not independently introduced above and below the subterranean portions of the Santa Fe, then these catfish dispersed through the subterranean passage. In South America, several loricariid catfishes have been described as troglobitic or possibly troglobitic, including *Isbrueckerichthys alipionis* (Gosline, 1947), various *Ancistrus* species, and at least one species of *Hypostomus* (Trajano et al. 2008). The genus *Hypostomus* is closely related to *Pterygoplichthys* (Armbruster 2004). Admittedly, all of our upstream records are based on sightings and we cannot yet confirm that *P. disjunctivus* is the taxon present above the Santa Fe Sink until a specimen is captured.

Whether *Pterygoplichthys* or any other loricariid catfish are present in parts of the Suwannee River basin outside the Santa Fe drainage remains uncertain. We have received reports of possible sightings from at least two sites along the lower Suwannee River mainstem, both below the river's confluence with the Santa Fe River, including near Troy Springs, 12 March 2009 (Bruce Jaggers, personal communication), and at Manatee Spring, August 2012 (Thomas Hewlett, personal communication). Until additional documentation, we are treating these records as unconfirmed.

Are Pterygoplichthys established in the Santa Fe River drainage?

Successful reproduction of *Pterygoplichthys* depends on suitable water temperature and other habitat characteristics of the invaded environment. Given the diversity and extent of habitats in the Santa Fe River and the artificially high biomass of periphyton in the drainage, space and food are not limiting. Consequently, temperature is most likely the main determining factor. The natural distribution of most *Pterygoplichthys* species in South America is within the tropical climate zone, the main exception being *P. anisitsi* whose native range extends to about 34°30' S latitude (Weber 1992; Armbruster and Page 2006). Laboratory tests have shown that adult-sized *P. disjunctivus* (252–373 mm TL) stop feeding at about 10°C and death occurs at about 4°C (Gestring et al. 2010). Based on those findings, the approximate 22°C year-round temperature characteristic of Santa Fe drainages springs is not an impediment to survival.

Volusia Blue Spring in the St. Johns River basin appears to be an important thermal refugium. Researchers investigating *Pterygoplichthys* at that site have witnessed the catfish moving into the spring run in large numbers when river water temperature is lower than spring water temperature, typically between October and April (Gibbs et al. 2008). During a recent visit to Volusia Blue Spring, one of us (LGN) observed a long evening procession of several hundred *Pterygoplichthys* moving up the spring run a few hours prior to the advance of a winter cold front (Nico 2010). During winter

Figure 10. A few of the many thousands of *Pterygoplichthys* carcasses discovered in the St. Johns River basin, Florida, during the unusually cold winter of December 2009-January 2010. Dead catfish shown in this image were found in near-shore shallows along the St. John River main channel immediately upstream (south) of the mouth of the Econlockhatchee River, 19 January 2010. Photograph by Jay Holder.

months, we have also observed large numbers of *Pterygoplichthys* occupying the main vents and pools of other springs in the St. Johns River basin, including Alexander Springs, Wekiwa Springs, and Rock Springs. *Pterygoplichthys* in Florida that do not access springs may suffer extensive mortality during extremely cold winter events (Figure 10), although, the continued abundance of these catfish throughout much of the peninsula is evidence that populations rebound rapidly.

Although *Pterygoplichthys* may tolerate a somewhat broad temperature range, the temperature range suitable for successfully spawning and survival of young is most certainly narrower. However, the precise limits have not been determined. Females taken from Volusia Blue Spring (St. Johns River basin) commonly contained mature oocytes throughout the extended warmer months, May to September or, depending on the year, into October (Gibbs et al. 2008). However, no nest burrows have ever been observed in Volusia Blue Spring or its run.

We suspect that most Florida springs are not suitable as spawning sites for *Pterygoplichthys*, probably because the water temperatures in these habitats are too cold and oxygen levels too low for development of eggs and young. In the St. Johns River basin, all nest burrow excavations and spawning apparently occurs in the river proper or other non-spring habitats. If *Pterygoplichthys* in the Santa Fe system are successfully breeding, they likely follow a similar pattern of behavior to populations in the St. Johns River, using the springs as thermal refugia during colder months and using non-spring habitats as spawning sites during warmer months. However, because of the Santa Fe River system's more northerly latitude, the spawning time period would likely be more constricted.

Admittedly, we found no eggs in the nest burrow at Big Awesome Suck, but the river water during early May was perhaps still too cool (23.5°C) for spawning. However, water at the site would be expected to become progressively warmer over the following weeks as summer approached. Indeed, the GSI values of two of the three gravid females that we captured at Big Awesome Suck in May 2012 were within the range of the higher GSI values reported by Gibbs et al. (2008) for gravid female *Pterygoplichthys* from Florida's Volusia Blue Springs. Overall, the presence of both mature males and gravid females and their recent excavation of a nest burrow at Big Awesome Suck were evidence that spawning appeared imminent.

Potential impacts

The present small population of *Pterygoplichthys* in the Santa Fe drainage is probably not having much of an impact on the environment. However, if these non-native catfishes increase in number, they may have a negative effect. Currently, it is not known whether the population in the Santa Fe drainage are selectively feeding on the nuisance algae that is proliferating in the system or, conversely, if their feeding is contributing to the loss of desirable plants and benthic invertebrates. Research on invasive *Pterygoplichthys* in Mexico has revealed that their grazing reduces the quality and quantity of benthic resources and also cause marked changes in the nutrient dynamics of the invaded river systems (Capps 2012). Adverse impacts have also been associated with their burrowing activities, contributing to bank instability and erosion (Nico et al. 2009a). Indeed, recent news stories from south Florida report that lake-front home owners are increasingly alarmed that catfish burrowing activities are causing substantial erosion, contributing to loss of shoreline and a decline in property values, as well as safety concerns because of crumbling terrain along the banks (Wolford 2012).

Other types of impacts have been noted but also not well quantified. For example, in parts of Florida and Mexico where *Pterygoplichthys* are abundant, commercial fishermen complain that these non-native catfish damage fishing gear and lower the catch rate of more desirable species (Gestring et al. 2010; Capps et al. 2011). In addition, interactions between introduced *Pterygoplichthys* and certain native species are a concern. For example, in the St. Johns basin, *Pterygoplichthys* and native Florida manatees, *Trichechus manatus latirostris* (Harlan, 1824), both congregate in spring habitats during winter months, and large numbers of catfish commonly attach to the manatees and graze the biofilm on the large mammal's skin (Nico et al. 2009b; Gibbs et al. 2010; Nico 2010). The Florida manatee is a federally endangered taxon and populations are especially vulnerable during the winter, but it is still unclear if the presence of *Pterygoplichthys* is a substantial threat.

Much of peninsular Florida south of the Suwannee River basin is considered a "hot spot" for invasive fishes The region's subtropical climate supports a broad diversity of non-native foreign fishes (>30 species established) and many introduced fish taxa are widespread and abundant (Nico and Fuller 1999). In contrast, only three foreign fish species have been reported as occurring in the Suwannee River basin: grass carp *Ctenopharyngodon idella* (Valenciennes, 1844); guppy *Poecilia reticulata* Peters, 1849; and red-bellied pacu *Piaractus brachypomus* (Cuvier, 1818) (Fuller et al. 1999; US Geological Survey Nonindigenous Aquatic Species Database). There is no evidence that any of the three are established and only grass carp has been observed recently in the basin, perhaps as a result of repeated stockings or escapes from ponds.

Fishes native to other parts of the continental USA that have been introduced to the Suwannee basin include: American shad *Alosa sapidissima* (Wilson, 1811); green sunfish *Lepomis cyanellus* Rafinesque, 1819; blue catfish *Ictalurus furcatus* (Lesueur, 1840); flathead catfish *Pylodictis olivaris* Rafinesque, 1818; and hybrid striped bass (*Morone chrysops* × *M. saxatilis*) (Fuller et al. 1999).

Because the Santa Fe and Suwannee rivers have few non-native fishes and no established foreign fishes, the presence of *Pterygoplichthys* represents a marked change in the fish fauna and a unique ecological threat.

Management options

In a few sites in Florida where *Pterygoplichthys* have long been established and are abundant, there have been periodic attempts to control their numbers. The focus has been largely on a few spring habitats in the St. Johns River basin, mainly Volusia Blue Spring and Wekiwa Springs, sites managed by the Florida State Parks system, and Rock Springs, a county park. Data in resource management annual reports released by the Florida Park Service indicate as many as 8,558 *Pterygoplichthys* were captured and removed from park units in the St. Johns basin during the period 2005 to 2011.

In Florida, managers have relied entirely on physical removal. According to state biologists working in Wekiwa Spring, removal efforts occurred rather irregularly, usually a few times each year (Graham Williams and Paul Lammardo, Florida Park Service, personal communications). Gaining experience over the years, they found that the most effective way to remove large numbers of armored catfish was to opportunistically wait for cold fronts to move in, since during sharp drops in temperature the catfish began congregating in the spring. Also, because catfish were most numerous at night, removal work generally began near sunrise. At Wekiwa Spring, the removal team typically consisted of several individuals who entered the water with mask, snorkel, and fins, using spears (e.g., Hawaiian slings) and gigs to capture the catfish. Other participants remained on shore, assisting by taking any impaled catfish off the spears and disposing of the carcasses. In some instances large nets were strategically placed to block the spring run during removals, preventing the catfish from escaping into the river proper.

Unfortunately, due to the widespread abundance of *Pterygoplichthys* in the St. Johns River and its tributaries, the removal of a few thousand armored catfish from a few locations is probably having little effect on the overall catfish population in the basin and appears to only temporarily reduce the numbers of these catfish in the few targeted springs. Indeed, park biologists at Wekiwa Spring informed us they no longer conduct removal efforts, partly because the work is labor intensive and also because the catfish no longer seem to regularly congregate in especially large numbers in the spring habitat. However, removal work is still performed at Volusia Blue Spring. We are unaware if removal work is still conducted at Rock Springs.

The situation in the Suwannee River basin, at present, is radically different than that of the St. Johns River basin and other basins to the south. In the Suwannee River basin, *Pterygoplichthys* are still few in number and possibly limited to the Santa Fe drainage. If the catfish are taking refuge in only a few spring habitats during cold winter periods, then it might be possible to design a removal plan that can successfully remove all individuals before the catfish spread. However, because there are numerous springs and spring outlets throughout the basin, even in the main channel, a wide range of potential winter thermal refugia may be available to *Pterygoplichthys*.

Some springs in the Santa Fe drainage are deep (>8 m) and *Pterygoplichthys* commonly evade snorkelers by diving into deep crevices or the spring vents. Consequently, physical removal of armored catfish likely necessitates the assistance of SCUBA divers. Capture gear may include combinations of gigs and various nets. Because the waters in Poe and Hornsby springs are usually low in dissolved oxygen, armored catfish inhabiting these sites probably have to periodically access the surface to gulp atmospheric air. During their breathing bouts it may be possible to capture the catfish with entanglement nets placed horizontally over the spring cones. However, nets would have to be continually monitored to prevent harm to turtles and other air-breathing animals. If armored catfish are entering caves, then the chances of eradication are much reduced. Ultimately, the design of a removal plan and development of options will depend on more complete knowledge of their numbers and distribution in the basin, whether they are successfully reproducing, location of suitable or preferred spawning and thermal refugia sites, and confirmation that movement patterns are indeed predictable.

Conclusions

Over the past decade, there have been many new publications reporting the occurrence of *Pterygoplichthys* outside their native range, some denoting sites of new introductions and others documenting expansion of existing populations. Included are a wide range of countries and river systems from around the world. More recent reports are from Turkey (Ozdilek 2007), Bangladesh (Hossain et al. 2008), Vietnam (Levin et al. 2008), the Malaysia Peninsula (Samat et al. 2008), Singapore (Ng and Tan 2010), India (Knight 2010), Poland (Keszka et al. 2008), and Italy (Piazzini et al. 2010). Given their increasingly widespread introduction and frequency of establishment, *Pterygoplichthys* have proven to be highly invasive and should be considered one of the more invasive groups of fishes, joining such infamous taxa as the tilapias (Cichlidae: *Oreochromis* spp.), mosquitofish (Poeciliidae: *Gambusia* spp.), and certain large carps (Cyprinidae: *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix* (Valenciennes, 1844), *H. nobilis* (Richardson, 1845), and *Cyprinus carpio* Linnaeus, 1758).

Acknowledgements

Many people were invaluable by assisting in the field, providing photographs, or otherwise sharing knowledge. For their help, we are especially grateful to Georgia Shemitz, Linda Nico, Joseph Mitchell and other members of the turtle research group. Jon Armbruster examined a specimen and photographs of other specimens, giving his expert opinion on species identification. Our understanding of the Santa Fe drainage was improved by conversations with Robert Hutchinson, Travis Tuten, and Buck Albert. Amy Benson provided records from the USGS aquatic species database and assisted with maps. For access to Hornsby Spring, we thank Phil Younts, Mike Hopkins, and other staff at Camp Kulaqua. For access to Poe Spring, we thank caretakers of Poe Springs County Park. We also appreciate information and assistance provided by Daniel Pearson, Richard Owen, Bruce Jaggers, Anthony Lau, and Thomas Hewlett. Rob Robins of the Florida Museum of Natural History assisted with cataloging and loaning of material. We thank Allen D. Martin and the Florida Fish and Wildlife Conservation Commission for permits to collect catfishes. For commenting on drafts of the manuscript, we thank Amy Benson, Lisa Jelks, and various anonymous reviewers. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

Armbruster JW (1998) Modifications of the digestive tract for holding air in loricariid and scoloplacid catfishes. *Copeia* 1998: 663-675, http://dx.doi.org/10.2307/1447796

Armbruster JW (2004) Phylogenetic relationships of the suckermouth armoured catfishes (Loricariidae) with emphasis on the Hypostominae and the Ancistrinae. *Zoological Journal of the Linnean Society* 141: 1-80, http://dx.doi.org/10.1111/j.1096-3642.2004.00109.x

Armbruster JW, Page LM (2006) Redescription of *Pterygoplichthys punctatus* and description of a new species. *Neotropical Ichthyology* 4: 401-409, http://dx.doi.org/10.1590/S1679-62252006000400003

Berra TM (2001) Freshwater fish distribution. Academic Press, San Diego, California, 604 pp

Brown MT, Reiss KC, Cohen MJ, Evans JM, Reddy KR, Inglett PW, Sharma-Inglett K, Frazer TK, Jacoby CA, Phlips EJ, Knight RL, Notestein SK, McKee KA (2008) Summary and synthesis of the available literature on the effects of nutrients on spring organisms and systems. University of Florida Water Institute, Gainesville, Florida, 376 pp

Burgess GH, Franz R (1978) Zoogeography of the aquatic fauna of the St. Johns River system with comments on adjacent peninsular faunas. *American Midland Naturalist* 100: 160-170, http://dx.doi.org/10.2307/2424786

Butt PL, Boyes S, Morris TL (2006) Mill Creek and Lee Sinks dye trace, Alachua County, Florida, July-December 2005. Karst Environmental Services, Inc., High Springs, Florida. Report prepared for Alachua County Environmental Protection Department, 171 pp

Butt PL, Morris TL, Skiles WC (2007) Swallet/resurgence relationships on the lower Santa Fe River, Florida. Karst Environmental Services, Inc., High Springs, Florida. Report prepared for Water Resources Associates, Inc., 27 pp

Capps KA (2012) Changes in community structure and ecosystem processes in response to armored catfish (Siluriformes: Loricariidae) invasion. Ph.D. dissertation, Cornell University, Ithaca, New York

Capps KA, Nico LG, Mendoza-Carranza M, Arévalo-Frías W, Ropecki AJ, Heilprin SA, Rodiles-Hernández R (2011) Salinity tolerance of non-native suckermouth armoured catfish (Loricariidae: *Pterygoplichthys*) in south-eastern Mexico: implications for invasion and dispersal. *Aquatic Conservation: Marine and Freshwater Ecosystems* 21: 528-540, http://dx.doi.org/10.1002/aqc.1210

Chaichana R, Pouangcharean S, Yoonphand R (2011) Habitat, abundance and diet of invasive suckermouth armored catfish (Loricariidae *Pterygoplichthys*) in the Nong Yai Canal, East Thailand. *Tropical Zoology* 24: 49-62

Chavez JM, de la Paz RM, Manohar SK, Pagulayan RC, Carandang JR (2006) New Philippine record of South American sailfin catfishes (Pisces: Loricariidae). *Zootaxa* 1109: 57-68

Chen E, Gerber JF (1990) Climate. In: Myers RL, Ewel JJ (eds), Ecosystems of Florida. University of Central Florida Press, Orlando, Florida, pp 11-34

Covain R, Fisch-Muller S (2007) The genera of the Neotropical armored catfish subfamily Loricariinae (Siluriformes: Loricariidae): a practical key and synopsis. *Zootaxa* 1462: 1-40

Eschmeyer WN, Fong JH (2012) Species by Family/Subfamily in the Catalog of Fishes. California Academy of Sciences. http://research.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp (Accessed 13 July 2012)

Fuller PL, Nico LG, Williams JD (1999) Nonindigenous Fishes Introduced to Inland Waters of the United States. American Fisheries Society, Bethesda, Maryland, 613 pp

Gestring KB, Shafland PL, Stanford MS (2010) Status of the exotic Orinoco sailfin catfish (*Pterygoplichthys multiradiatus*) in Florida. *Florida Scientist* 73: 122-

Gibbs M, Futral T, Mallinger M, Martin D, Ross M (2010) Disturbance of the Florida manatee by an invasive catfish. *Southeastern Naturalist* 9: 635-648

Gibbs MA, Shields JH, Lock DW, Talmadget KM, Farrell TM (2008) Reproduction in an invasive exotic catfish *Pterygoplichthys disjunctivus* in Volusia Blue Spring, Florida, U.S.A. *Journal of Fish Biology* 73: 1562-1572, http://dx.doi.org/10.1111/j.1095-8649.2008.02031.x

Gilbert CR (1987) Zoogeography of the freshwater fish fauna of southern Georgia and peninsular Florida. *Brimleyana* 13: 25-54

Grubbs JW, Crandall CA (2007) Exchanges of water between the upper Floridan aquifer and the lower Suwannee and lower Santa Fe rivers, Florida. U.S. Geological Survey Professional Paper 1656-C, Reston, Virginia, 83 p

Hellier TR, Jr. (1967) The fishes of the Santa Fe River system. *Bulletin of the Florida State Museum* 2(1): 1-46

Hossain MY, Rahman MM, Ahmed ZF, Ohtomi J, Islam ABMS (2008) First record of the South American sailfin catfish *Pterygoplichthys multiradiatus* in Bangladesh. *Journal of Applied Ichthyology* 24: 718-720, http://dx.doi.org/10.1111/j.1439-0426.2008.01117.x

Hubilla M, Kis F, Primavera J (2007) Janitor fish *Pterygoplichthys disjunctivus* in the Agusan Marsh: a threat to freshwater biodiversity. *Journal of Environmental Science and Management* 10: 10-23

Johnston GR, Lau A, Kornilev YV (2011) Composition of a turtle assemblage in a northern Florida blackwater stream. *Florida Scientist* 74: 126-133

Katz BG, Hornsby HD, Bohlke JF, Mokray MF (1999) Sources and chronology of nitrate contamination in spring waters, Suwannee River Basin, Florida. *U.S. Geological Survey Water-Resources Investigations Report* 99-4252: 54 p

Keszka S, Panicz R, Tanski A (2008) First record of the leopard pleco, *Pterygoplichthys gibbiceps* (Actinopterygii, Loricariidae) in the Brda River in the centre of Bydgoszcz (northern Poland). *Acta Ichthyologica Et Piscatoria* 38: 135-138, http://dx.doi.org/10.3750/AIP2008.38.2.08

Kincaid TR (1998) River water intrusion to the unconfined Floridan Aquifer. *Environmental and Engineering Geoscience* 4: 361-374

Knight JDM (2010) Invasive ornamental fish: a potential threat to aquatic biodiversity in peninsular India. *Journal of Threatened Taxa* 2: 700-704

Kornilev YV (2008) Behavioral ecology and effects of disturbance on the Suwannee cooter (*Pseudemys concinna suwanniensis*) in a blackwater spring-fed river, University of Florida, Gainesville, Florida, 117 pp

Kornilev YV, C. Kenneth Dodd J, Johnston GR (2010) Linear home range, movement, and spatial distribution of the Suwannee Cooter (*Pseudomys concinna suwanniensis*) in a blackwater river. *Chelonian Conservation and Biology* 9: 196-204, http://dx.doi.org/10.2744/CCB-0790.1

Levin BA, Phuong PH, Pavlov DS (2008) Discovery of the Amazon sailfin catfish *Pterygoplichthys pardalis* (Castelnau, 1855) (Teleostei: Loricariidae) in Vietnam. *Journal of Applied Ichthyology* 24: 715-717, http://dx.doi.org/10.1111/j.1439-0426.2008.01185.x

Liang S-H, Wu H-P, Sheih B-S (2005) Size structure, reproductive phenology, and sex ratio of an exotic armored catfish (*Liposarcus multiradiatus*) in the Kaoping River of southern Taiwan. *Zoological Studies* 44: 252-259

Liénart GDH (2009) Reproduction in an invasive exotic suckermouth armored catfish *Pterygoplichthys pardalis* (Siluriformes: Loricariidae) in the lower part of the

Usumacinta Watershed, Chiapas, Mexico. MSc, El Colegio de la Frontera Sur (ECOSUR), San Cristóbal de las Casas, Mexico, 98 pp

Ludlow ME, Walsh SJ (1991) Occurrence of a South American armored catfish in the Hillsborough River, Florida. *Florida Scientist* 54: 48-50

Martin JB, Dean RW (1999) Temperature as a natural tracer of short residence times for groundwater in karst aquifers. In: Palmer AN, Palmer MV, Sasowsky ID (eds), Karst modeling. Karst Waters Institute, Charlottesville, West Virginia, pp 236-242

Martin JM, Screaton EJ, Martin JB (2006) Monitoring well responses to karst conduit head fluctuations: Implications for fluid exchange and matrix transmissivity in the Floridan aquifer. In: Harmon RS, Wicks C (eds), Perspectives on karst geomorphology, hydrology, and geochemistry - A tribute volume to Derek C. Ford and William B. White. Geological Society of America Special Paper 404, pp 209-217

Mendoza-Alfaro RE, Cudmore B, Orr R, Fisher JP, Contreras-Balderas S, Courtenay WR, Osorio PK, Mandrak N, Alvarez-Torres P, Arroyo-Damian M, Escalera-Gallardo C, Guevara-Sanguines A, Greene G, Lee D, Orbe-Mendoza A, Ramirez-Martinez C, Strabridis-Arana O (2009) Trinational risk assessment guidelines for aquatic alien invasive species: test cases for the snakeheads (Channidae) and armored catfishes (Loricariidae) in North American inland waters. Commission for Environmental Cooperation, Montreal, Canada, 98 pp

Myers RL (1986) Florida's freezes: An analog of short-duration nuclear winter events in the tropics. *Florida Scientist* 49: 104-115

Ng HH, Tan HH (2010) An annotated checklist of the non-native freshwater fish species in the reservoirs of Singapore. *Cosmos* 6: 95-116, http://dx.doi.org/10.1142/S0219607710000504

Nico LG (2005) Changes in the fish fauna of the Kissimmee River Basin, peninsular Florida: Non-native additions. In: Rinne JN, Hughes RM, Calamusso B (eds), Historical Changes in Large River Fish Assemblages of the Americas. American Fisheries Society Symposium 45, Bethesda, Maryland, pp 523-556

Nico LG (2010) Nocturnal and diurnal activity of armored suckermouth catfish (Loricariidae: *Pterygoplichthys*) associated with wintering Florida manatees (*Trichechus manatus latirostris*). *Neotropical Ichthyology* 8: 893-898, http://dx.doi.org/10.1590/S1679-62252010005000014

Nico LG, Fuller PL (1999) Spatial and temporal patterns of nonindigenous fish introductions in the United States. *Fisheries* 24: 16-27, http://dx.doi.org/10.1577/1548-8446(1999)024<0016:SATPON>2.0.CO;2

Nico LG, Jelks HL, Tuten T (2009a) Non-native suckermouth armored catfishes in Florida: description of nest burrows and burrow colonies with assessment of shoreline conditions. *Aquatic Nuisance Species Research Program Bulletin* 9: 1-30

Nico LG, Loftus WF, Reid JP (2009b) Interactions between non-native armored suckermouth catfish (Loricariidae: *Pterygoplichthys*) and native Florida manatee (*Trichechus manatus latirostris*) in artesian springs. *Aquatic Invasions* 4: 511-519, http://dx.doi.org/10.3391/ai.2009.4.3.13

Nico LG, Martin TR (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, http://dx.doi.org/10.2307/3672381

Nordlie FG (1990) Rivers and springs. In: Myers RL, Ewel JJ (eds), Ecosystems of Florida. University of Central Florida Press, Orlando, Florida, pp 392-425

Ozdilek SY (2007) Possible threat for Middle East inland water: an exotic and invasive species*, Pterygoplichthys disjunctivus* (Weber, 1991) in Asi River, Turkey (Pisces: Loricariidae). *E.U. Journal of Fisheries and Aquatic Sciences (E.Ü. Su Ürünleri Dergisi)* 24: 303-306

Piazzini S, Lori E, Favilli L, Cianfanelli S, Vanni S, Manganelli G (2010) A tropical fish community in thermal waters of southern Tuscany. *Biological Invasions* 12: 2959-2965, http://dx.doi.org/10.1007/s10530-010-9695-x

Power M (1990) Resource enhancement by indirect effects of grazers: armored catfish, algae, and sediment. *Ecology* 71: 897-904, http://dx.doi.org/10.2307/1937361

Rumenik RP, Grubbs JW (1996) Methods for estimating low-flow characteristics of ungaged streams in selected areas, northern Florida. *U.S. Geological Survey Water-Resources Investigations Report* 96-4124, 28 p.

Samat A, Shukor MN, Mazlan AG, Arshad A, Fatimah MY (2008) Length-weight relationship and condition factor of *Pterygoplichthys pardalis* (Pisces: Loricariidae) in Malaysia peninsula. *Research Journal of Fisheries and Hydrobiology* 3: 48-53

Scott TM, Means GH, Meegan RP, Means RC, Upchurch S, Copeland RE, Jones J, Roberts T, Willet A (2004) Springs of Florida. Florida Geological Survey (Florida Geological Survey Bulletin No. 66), Tallahassee, Florida, 658 pp

Sickman JO, Albertin A, Anderson MW, Pinowska A, Stevenson RJ (2009) A comparison of internal and external supply of nutrients to algal mats in two first magnitude springs in Florida. *Journal of Aquatic Plant Management* 47: 135-144

Stevenson RJ, Pinowska A, Albertin A, Sickman JO (2007) Ecological condition of algae and nutrients in Florida springs: the synthesis report. Report prepared for the Florida Department of Environmental Protection, Tallahassee, Florida, 58 pp

Thompson FG (1968) The aquatic snails of the family Hydrobiidae of peninsular Florida. University of Florida Press, Gainesville, Florida, 268 pp

Trajano E, Secutti S, Pereira EHL, Reis RE (2008) A cave population of *Isbrueckerichthys alipionis* (Gosline, 1947) in the Upper Ribeira karst area, southeastern Brazil (Siluriformes: Loricariidae). *Neotropical Ichthyology* 6: 679-682, http://dx.doi.org/10.1590/S1679-62252008000400017

Verdi RJ (2005) Hydrologic effects of the 2004 hurricane season in northwest Florida. *U.S. Geological Survey, Open-File Report* 2005-1277: 1-18

Walsh SJ (2001) Freshwater macrofauna in Florida karst habitats. In: Kuniansky E (ed), U.S. Geologival Survey Karst Interest Group Proceedings, St. Petersburg, Florida, February 13-16, 2001, U.S. Geological Survey Water-Resources Investigations Report 01-4011, pp 78-88

Weber C (1992) Révision du genre *Pterygoplichthys* sensu lato (Pisces, Siluriformes, Loricariidae*). Revue française d'aquariologie* 19: 1-36

Wolford B (2012) Armored catfish chewing up South Florida lakes, nibbling at homeowners' wallets. Sun Sentinel (Broward and Palm Beach editions, 21 April 2012) 52 (362): 1A. http://articles.sun-sentinel.com/2012-04-20/news/fl-armored-catfish-erosion-20120420_1_armored-catfish-lake-edges-fish-fight (Accessed 26 April 2012)

Wu L-W, Liu C-C, Lin S-M (2011) Identification of exotic sailfin catfish species (*Pterygoplichthys*, Loricariidae) in Taiwan based on morphology and mtDNA sequences*. Zoological Studies* 50: 235-246, http://dx.doi.org/10.2108/zsj.28.235

Appendix 1, Part A. Capture records and visual sightings of *Pterygoplichthys* in the Santa Fe River drainage, Suwannee River basin, Florida (USA) over the period from 2009 to 2012. Numbers under column "Map" for "captured catfish" correspond to numbered symbols appearing in Figure 3 map (note: number "5" in column is location where four specimens were captured together on same date). Figures elsewhere in paper with images of selected captured specimens listed are referenced in brackets in the Taxa column. Other abbreviations are: TL = total length of specimen; SL = standard length of specimen; GSI = gonado-somatic index; nd = not determined; museum cat. no. = catalog number for captured specimens deposited at the Florida Museum of Natural History (UF).

Map	Taxa	Date	Location [field #]	Record type (no. of catfish) [museum cat. no.]	TL [SL] (mm)	Body mass (g)	Gender (reproductive stage)	Gonads mass (g) [GSI]	Collectors or observers
1	*Pterygoplichthys gibbiceps* (or hybrid) [Fig. 5]	26 Aug 2009	Poe Spring at Poe Springs County Park near town of High Springs (29°49'32.58"N, 82°38'56.30"W) [LGN09-47]	Captured 1 [UF 184196] observed 2 or 3	270 [198]	189	female (maturing)	nd	Pete Butt, Leo G. Nico, Stephen Walsh, and Georgia Shemitz
2	*P. disjunctivus* (or hybrid) [Fig. 6]	11 Nov 2010	Santa Fe River, in river channel between Rum Island and Ginnie Springs (29°49'58.00"N, 82°40'58.91"W) [LGN10-73]	Captured 1 [UF 184197] observed 2 or 3	431 [321]	802	male (immature)	nd	Jerry Johnston and turtle research group
3	*P. disjunctivus* (or hybrid)	13 Mar 2011	Hornsby Spring at Camp Kulaqua near town of High Springs (29°51'01.3"N, 82°35'35.5"W) [LGN11-05]	Captured 1 [UF 184198] observed 3	505 [390]	1480	male? (mature or maturing)	nd	Matthew Kail, Jerry Johnston, Joe Mitchell, and turtle research group
4	*P. disjunctivus* (or hybrid) [Figs. 7A & B]	2 Mar 2012	Santa Fe River at Big Awesome Suck (29°51'12.65"N, 82°43'09.7"W) [LGN12-06]	Captured 1 [UF 184199] observed 2	585 [455]	2066	female (maturing)	nd	Matthew Kail
5	*P. disjunctivus* (or hybrid) [Fig. 7C]	11 May 2012	Santa Fe River at Big Awesome Suck [LGN12-15] (see above)	Captured 4 [UF 184200] observed 2	547 [429]	1354	male (mature or maturing)	3.5 [0.3]	Matthew Kail and Pete Butt
5	*P. disjunctivus* (possibly *P. disjunctivus* × *P. pardalis*) [Figs. 7D & 9]	(see above)	(see above)	(see above)	532 [402]	1538	female (mature, gravid)	164 [10.7]	Matthew Kail and Pete Butt
5	*P. disjunctivus* (or hybrid) [Fig. 7E]	(see above)	(see above)	(see above)	570 [444]	1467	male (mature or maturing)	1.5 [0.1]	Matthew Kail and Pete Butt
5	*P. disjunctivus* (or hybrid) [Fig. 7F]	(see above)	(see above)	(see above)	569 [432]	1723	female (mature, gravid)	84 [4.9]	Matthew Kail and Pete Butt
6	*P. disjunctivus* (or hybrid)	13-May-2012	Santa Fe River at Big Awesome Suck (29°51'12.65"N, 82°43'09.7"W) [LGN12-16]	Captured 1 [UF 184202] observed 1	565 [425]	1842	female (mature, gravid)	149 [8.1]	Pete Butt and Leo G. Nico

Appendix 1, Part B. Visual sightings of loricariid catfishes in the Santa Fe River drainage, Suwannee River basin, Florida (USA) over the period from 2009 to 2012. All are tentatively assumed to be *Pterygoplichthys* and the same taxa as those captured.

Map	Taxa	Date	Location	Record type (no. of catfish)	TL [SL] (mm)	Body mass (g)	Reproductive stage	Collectors or observers
7	armored catfish (probably *Pterygoplichthys*)	19 Aug 2009	Poe Spring (see Appendix 1, Part A)	Observed 2 or 3	nd	nd	adult	Pete Butt
8	(see above)	23 Nov 2009	Hornsby Spring (see Appendix 1, Part A)	Observed 2	nd	nd	adult	Jerry Johnston and turtle research group
9	(see above)	17 Nov 2010	Upper Santa Fe River, just upstream from River Sink within O'Leno State Park (29°55'23.34"N, 82°33'43.16"W)	Observed 1	nd	nd	adult or subadult	Matthew Kail turtle research group
10	(see above)	21 Nov 2010	Hornsby Spring (see Appendix 1, Part A)	Observed 1	nd	nd	adult or subadult	Leo G. Nico, Howard Jelks, Jerry Johnston, and turtle research group
11 to 19	(see above)	2010-2011	Multiple sites along Santa Fe river from 29°55'18.92"N, 82°33'50.53"W downstream to 29°54'14.77"N, 82°46'00.76"W. Sites included: about 0.5 km below I-75 bridge; points at or near River Rise and River Sink; deep hole on river at outlet of Hornsby Spring run; at Rum Island; river just above Blue Spring; oxbow about 2 km downstream from Ginnie Spring; at Big Awesome Suck, and about 2 km downstream of Wilson Spring	Observed 1 or more at multiple (at least 9) points along river	nd	nd	adult or subadult	Matthew Kail