Establishment and Post-Hurricane Survival of the Non-native Rio Grande Cichlid (*Herichthys cyanoguttatus*) in the Greater New Orleans Metropolitan Area

Otto Thomas Lorenz[1,*] and Martin T. O'Connell[2]

Abstract - We conducted multiple surveys to determine the distribution of the non-native *Herichthys cyanoguttatus* (Rio Grande Cichlid) in the Greater New Orleans Metropolitan Area (GNOMA). First, in 2003–2004, we trapped for *H. cyanoguttatus* in Lake Pontchartrain (an oligohaline estuary) to determine if this freshwater species occurred in estuarine habitats. Our goal was to test the prediction that *H. cyanoguttatus* used estuarine corridors to disperse. Second, we sampled and compared 16 GNOMA sites before and after the 2005 hurricanes to determine how *H. cyanoguttatus* populations responded. Finally, we monitored *H. cyanoguttatus* populations monthly over two years (2006–2007) at six sites within the GNOMA to determine if numbers continued to increase after the hurricanes. We confirmed that *H. cyanoguttatus*: 1) does occur in estuarine habitats (0 to 8 psu), 2) effectively survived the 2005 hurricanes, 3) has increased significantly from 2006 to 2007 at three of six GNOMA sites, 4) is currently found more often in urban sites, and 5) persisted through the atypically cold winter of 2009/2010.

Introduction

Herichthys cyanoguttatus Baird and Girard (Rio Grande Cichlid) is a non-native fish species that has become established in the canals and bayous of the Greater New Orleans Metropolitan Area (GNOMA), LA. The species is native to northeast Mexico and southern Texas from the Rio Conchos to southern drainages of the Rio Grande River (Baird and Girard 1854). It has been introduced beyond its native range into multiple drainages of Texas (Brown 1953, Fuller et al. 1999, Hubbs et al. 1978), and has also become established in portions of Florida (Fuller et al. 1999). Observations suggest that the Florida populations are confined to artificial habitats such as urban canals (Fuller et al. 1999). More recently, *H. cyanoguttatus* has become established in both natural and artificial waterbodies of the GNOMA (Fig. 1). The presence of *H. cyanoguttatus* in the GNOMA has been confirmed for at least ten years, though anecdotal evidence suggests it may have been in the region for twenty to thirty years (Fuentes and Cashner 2002, O'Connell et al. 2002). As with the Florida populations, the GNOMA populations occur mostly in artificial freshwater canals and bayous. Because these populations are adjacent to the Mississippi River to the south, Lake Pontchartrain (an oligohaline estuary) to the north, and natural swamps

[1]355 CERM Building, 2045 Lakeshore Drive, Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA 70148. [2]Department of Earth and Environmental Sciences and Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA 70148. [*]Corresponding author - otlorenz3@yahoo.com.

and marshes to the east (Bayou Sauvage National Wildlife Refuge) and west (La Branche Wetlands), there is a need to determine if this non-native fish is capable of expanding its range beyond the artificial habitats it currently occupies.

A dispersion model, developed to better understand the dynamics of the early stages of expansion, suggested that populations of *H. cyanoguttatus*, nominally a freshwater species, were dispersing into new areas by traveling through low-salinity conditions (5 to 12 psu) in Lake Pontchartrain (O'Connell et al. 2002). Should this be the case, an important implication is that estuarine habitats may not serve as a barrier to continued *H. cyanoguttatus* expansion beyond the GNOMA and into valuable nearby fishery habitat. Lorenz and O'Connell (2008) have shown this species to tolerate salinities of at least 16 psu, while the closely related and invasive *Hemichromis letourneuxi* Sauvage (African Jewelfish) from Florida has survived in salinity ranges up to 50 psu (Langston et al. 2010).

Biotic resistance is another possible barrier to invasive species, as shown with *Callinectes sapidus* Rathburn (Blue Crab) affecting the invasion of *Carcinus maenas* L. (Green Crab) (Jensen et al. 2007), and with predacious fish affecting the range of introduced Speckled Dace Girard (*Rhinichthys osculus*) in California (Harvey et al. 2004). It is possible that the natural swamps and marshes outside of the GNOMA will offer some form of biotic resistance to further *H. cyanoguttatus* expansion. Since the 1990s, specimens of *H. cyanoguttatus* have been periodically collected in natural water bodies beyond the urban habitats such as the La Branche Wetlands west of the GNOMA (C. Schieble, University of New Orleans, New Orleans, LA, and A. Cheek, B. Henry, and S. Temple, Southeastern Louisiana University, Hammond, LA, pers. observ.; Fig. 1). Although *H. cyanoguttatus* has occurred in considerable numbers in these wetlands, their occurrence is never as consistent as it is in the more urban GNOMA habitats. One of our goals is to examine the possible roles of salinity and biotic resistance in determining the expansion of *H. cyanoguttatus* in the region.

The levee failures that followed hurricanes Katrina and Rita in 2005 inundated large portions of the GNOMA with estuarine waters. These disasters interrupted our survey efforts for *H. cyanoguttatus*. We used this opportunity to also conduct a pre/post hurricane comparison to determine if range expansion was affected by the hurricane and subsequent effects. We sampled repeatedly in 2005 and 2006 pre- and post-hurricanes at the same sampling locations and approximately during the same time of year. To further explore possible post-hurricane effects, we conducted additional monthly samples at another six sites in Bayou St. John and other City Park water bodies from January 2006 to December 2007. These sites are located in the north-central portion of Orleans Parish, and were inundated with floodwaters for approximately three weeks in 2005 (Fig. 1). While *H. cyanoguttatus* occurred in Bayou St. John prior to the levee failures, the non-native species had only just begun to disperse into City Park water bodies in 2005. Based on these surveys, we aimed to answer the following questions: 1) Does *H. cyanoguttatus* occur in Lake Pontchartrain estuarine habitats as predicted by the dispersion model? 2) Did populations of *H. cyanoguttatus* survive the effects of the 2005 levee failures and hurricanes? 3) Has *H. cyanoguttatus* increased in numbers in Bayou St. John and other City Park water bodies since the hurricanes?

Methods

In order to document the success and spread of *H. cyanoguttatus* in GNOMA, three surveys were conducted: (1) to study the possibility that the lake serves as a corridor, (2) to determine the range of the cichlids and possible hurricane effects, and (3) to monitor the spread of cichlids post-hurricane at focal locations.

Field sites

Aquatic habitats in the GNOMA include canals and other modified waterways within the City of New Orleans and its suburbs. We expanded sampling into field sites just outside of the GNOMA to examine the possible expansion of *H. cyanoguttatus* into more natural areas. These areas include wetlands with no concrete canals or direct urban runoff. The sites in Lake Pontchartrain were located on a concrete seawall that extends into deep estuarine (5 to 12 psu) water. Abiotic conditions at most of these sites are similar, relatively alkaline and hard

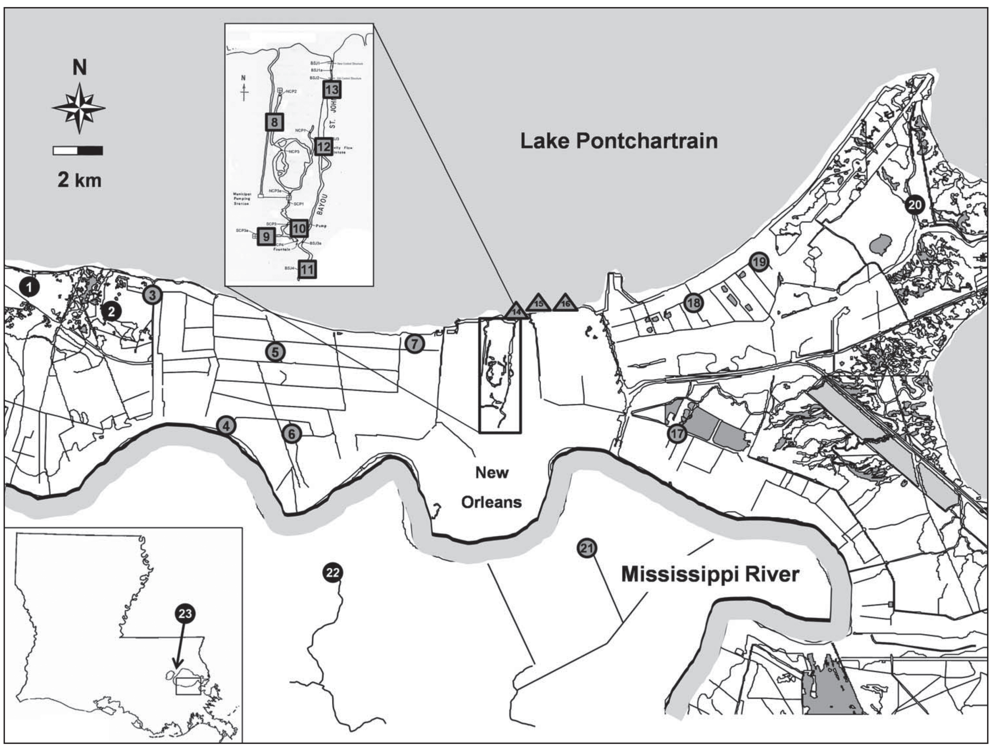

Figure 1. Sampling locations for three different surveys of *H. cyanoguttatus* in the GNOMA**.** Triangles represent the seawall study. Squares represent the Bayou St. John and City Park study. Circles represent sites sampled for the pre- and post-hurricane survey. Dark circles represent where *H. cyanoguttatus* was not collected. Sites numbered are: 1. Bayou Trepagnier, 2. LaBranche wetlands, 3. West Kenner, 4. Mississippi River, 5. Veterans Canal, 6. Harahan, 7. Bonnabel Canal, 8. Marconi Lagoon, 9. Metairie Bayou City Park, 10. Pontchartrain Lagoon City Park, 11. Bayou St. John South, 12. Bayou St. John Central, 13. Bayou St. John North, 14–16. Seawall sampling sites, 17. St. Bernard Parish, 18. St. Charles Canal, 19. Gannon Canal, 20. Bayou Sauvage, 21. Algiers, and 22. Bayou Segnette.

water with pH consistently above 7 and general hardness above 100. The most variable abiotic variable is salinity, which varies tidally and seasonally.

Potential estuarine corridors survey (2003–2004)

To test the prediction that *H. cyanoguttatus* uses estuarine habitats as dispersal corridors, we placed traps along the armored seawall that covers most of the southern shore of Lake Pontchartrain (Fig. 1). This artificial habitat represents a challenge to most conventional fish-collecting methods because it consists of 12–15 concrete steps (30-cmd height) that extend from land to below the water surface. The area of high-energy turbulence associated with the edge of the seawall precludes safe collection of fishes with gillnets, seines, or hoopnets. Electrofishing along the seawall is also impractical because of periodically elevated salinities (over 8 psu). Trapping was conducted from February 2003 to January 2004 at three sampling sites near the mouth of London Avenue Canal, which flows into Lake Pontchartrain, near the University of New Orleans in the north-central region of Orleans Parish (Fig. 1). We constructed nine double-funnel traps (90 x 40 x 20 cm) with openings of 15 x 8 cm. These were custom-designed to fit on the seawall and capture fishes moving along the inundated steps (mean depth of 1.5 m). Traps were constructed of plastic-treated mesh (3 x 1 cm) of the type used for crab traps. Similar traps have been used to capture *H. cyanoguttatus* in Texas (Buchanan 1971). Both adult and juvenile *H. cyanoguttatus* have been collected from London Avenue Canal, making it a potential source for individuals moving into or through the lake, as these canals end at pumping stations, which pump water into the lake. The double-funnel traps allowed us to determine the direction of fish movement along the seawall, with funnels facing either towards or away from the mouth of London Avenue Canal.

The three sampling sites were located approximately 200 m apart along the seawall, and three traps were fished along the three uppermost inundated steps at each site. Sampling consisted of setting funnel traps once monthly for a year, with all traps being simultaneously fished from sunrise to sunset. Funnel traps were baited with raw chicken necks, and during high wave conditions, the traps were weighted down with cinder blocks. Salinity (psu) and temperature (ºC) were measured five times throughout the day (sunrise, 0900, noon, 1500, and sunset) at each site during each sampling period using a YSI meter (model 63). All fishes collected were anesthetized with sodium bicarbonate, fixed in 10% formalin, and preserved in 70% ethanol. Fishes were later identified, counted, weighed to the nearest gram, and measured to the nearest mm standard length (SL), and all specimens were added to the University of New Orleans Vertebrate Collection.

Pre- and post-hurricane surveys (2005–2006)

Since an early survey of sites in Orleans and Jefferson parishes in 1998 (Fuentes and Cashner 2002), there has been no assessment of the geographical extent of *H. cyanoguttatus*' range within and outside of the GNOMA. We surveyed 16 sites in and around the GNOMA to determine which regions contained *H. cyanoguttatus* populations (Fig. 1). Sampling consisted of trapping with the funnel traps used in the 2003 seawall survey. Site selection was based on our attempt to sample known and potential expansion sites for *H. cyanoguttatus* (O.T. Lorenz and M.T. O'Connell pers. observ.). Among the sites we identified, two were in Lake Pontchartrain, one in the Mississippi River, and two (Bayou Segnette and Algiers) were across the River on the West Bank (one of which, Bayou Segnette, is a natural waterway). Other sites included two natural waterways to the west of the GNOMA (a small bayou near the Town of Ruddock and Bayou Trepagnier) and one natural site to the east (Bayou Sauvage). The remaining seven sites were located within the more urbanized sections of the GNOMA, but included Bayou St. John, a semi-natural water body that is part of the City Park lagoon system (Fig. 1).

Trapping was conducted over a six-week period from June to mid-July 2005 and consisted of 20-h overnight sets of each trap, with three traps per site (total of three trap-nights per site). Traps were baited with canned catfood. Water temperature, general hardness, carbonate hardness, salinity, pH, and dissolved oxygen were measured using a YSI meter (model 63) at each sampling location. All trapped *H. cyanoguttatus* and native sunfishes (Centrarchidae) were counted. We focused solely on sunfishes because these are the most common fishes found in association with *H. cyanoguttatus* and are the most likely to be interacting with the non-native fish over spawning sites (O.T. Lorenz and M.T. O'Connell, pers. observ.).

To determine if the 2005 hurricanes impacted the abundance or distribution of *H. cyanoguttatus* at these sites, we repeated these survey methods in identical fashion the following summer from June to mid-July 2006. The number of fishes collected between these two periods was compared using a paired, non-parametric sign test (SPSS v. 15.0). We chose a conservative test (sign test) because of the low sample size. Whether more fishes were caught in urban or natural environments was tested with a multivariate general linear model (Wilks' Lambda), using the sites listed in Table 1 as urban or natural. These methods were used because the data were not normally distributed. Although environmental data were unreplicated, we combined these data for both years and ran multiple regression models to determine if environmental data could predict abundances of each species collected.

Bayou St. John and City Park survey (2006–2007)

As part of a survey to assess post-hurricane population recovery in Bayou St. John and other water bodies located in City Park, we sampled six sites monthly for two years from January 2006 to December 2007. These sites are of particular interest because they are stocked with gamefish and are fished more than the sites sampled in the GNOMA study. The three Bayou St. John sites (Bayou St. John North, Central, and South) are considered estuarine, receiving intermittent water from Lake Pontchartrain to the north (Fig. 1). The Bayou St. John North site is closest to Lake Pontchartrain and tends to have higher salinities (2006 salinity range = 7.0–8.1 psu) than the other five sites. Salinities are slightly lower at the central (2006 salinity range = 6.4–7.7 psu) and south Bayou St. John sites (2006 salinity range = 6.9–7.8 psu). The three City Park sites are less saline (2.3 to 5.4 psu), though indirectly connected to Bayou St. John though various pump systems. One of the City Park sites, Marconi Lagoon, is the most isolated of the six sites. Habitat conditions in Marconi Lagoon are more natural than the other sites, and prior to the current surveys, no *H. cyanoguttatus* had been observed in the area.

To better understand the survival and possible expansion of *H. cyanoguttatus* populations at these sites, we counted all *H. cyanoguttatus* collected during this time period. Sampling consisted of three replicate seine (5 **x** 1.5 m, 6.35-mm mesh) hauls at each site monthly in 2006 and 2007 with a standard area of approximately 25 m^2 sampled by each seine haul. Seine hauls were approximately 10 m apart to prevent overlapping areas from being sampled. We compared the number of *H. cyanoguttatus* collected at each site between 2006 and 2007 (36 seine pulls per site per year) to test for significant increases using a paired, non-parametric sign test (SPSS v. 15.0). Salinity (psu) and water temperature (ºC) were measured for each seine haul using a YSI meter (model 63).To compare physical parameters between years for each site, sign tests were run for the 36 measurements collected (three per month).These variables were also compared between 2006 and 2007 to assess any relationship between them and *H. cyanoguttatus* numbers.

Results

Potential estuarine corridors survey (2003–2004)

From February 2003 to January 2004 (with no sampling in September 2003 due to high waves and turbulence), traps were fished along the seawall for a total of 1073.1 hours (9 traps x 119.2 trap hours). Specimens of *H. cyanoguttatus* were collected in May (*n* = 5), June (*n* = 1), and October (*n* = 2), confirming the

Table 1. Fishes collected in the surveys before and after hurricanes Katrina and Rita.

	Herichthys cyanoguttatus		*Lepomis macrochirus*		*Micropterus salmoides*		*Lepomis miniatus*		Other *Lepomis*	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Urban sites										
Veterans Canal	3	1	1	0	0	0	0	0	0	0
Bonnabel Canal	5	2	2	0	2	0	0	0	0	0
Harahan	3	4	1	0	0	0	0	0	1	1
Western Kenner	1	6	1	0	0	0	0	0	0	0
St Charles Canal	6	3	0	0	0	0	0	0	0	0
Gannon Canal	5	0	0	0	0	0	0	0	1	0
Bayou St John	1	1	1	0	1	1	0	0	0	0
St Bernard Parish	2	0	1	0	1	1	0	0	0	0
Algiers	0	0	0	0	0	0	0	0	1	0
Natural waterways										
Bayou Segnette	0	0	0	1	0	0	1	0	0	4
Ruddock	0	0	1	0	1	0	0	0	1	1
Sauvage	0	0	1	0	0	0	1	0	1	0
Bayou Trepagnier	0	0	1	0	0	0	0	0	0	0
Lake/river sites										
Mississippi River	0	0	0	0	0	0	0	0	0	0
Pontchartrain 1	0	0	0	0	0	0	0	0	0	0

occurrence of this species in estuarine habitats of Lake Pontchartrain. Salinities for these collections ranged from 0.4 psu in June to 5.1 psu in October, while collection temperatures ranged from 21.8 ºC in October to 30.5 ºC in June. The salinity of Lake Pontchartain can get as high as 16 psu or more during droughts and hurricane storm surges.

Only 14 fishes were collected in these traps, and *H. cyanoguttatus* (*n* = 8) was the most common species. The remaining fishes included three *Fundulus grandis* Baird and Girard (Gulf Killifish), one of which was collected in February and the other two were collected in October. Also collected were one *Poecilia latipinna* Lesueur (Sailfin Molly) in December, one *Gobiosoma bosc* Lacepède (Naked Goby) in March, and one *Paralichthys lethostigma* Jordan and Gilbert (Southern Flounder) in July.

Pre- and post-hurricane surveys (2005–2006)

A total of 81 fishes representing nine species were collected during the two surveys (51 fishes in 2005 and 30 fishes in 2006). Only native *Lepomis macrochirus* Rafinesque (Bluegill) exhibited a significant (sign test: $P = 0.039$) change in abundance (decrease) from 2005 to 2006. There was no significant change in abundance between years for any other species, including *H. cyanoguttatus,* and there was no significant decrease in the Bluegill that were found sympatrically with *H. cyanoguttatus*. There were significantly more *H. cyanoguttatus* in urban than in non-urban habitats (GLM, Wilk's lambda test: $F_{22,146} = 2.523$, $P < 0.001$), whereas there was no difference for centrarchids (Table 1). In 2005, *H. cyanoguttatus* was collected at 9 of the 16 sites sampled, most of which were urban sites within the GNOMA, except for the Lake Pontchartrain 2 site (Table 1).

In 2006, *H. cyanoguttatus* was collected at 7 of the 16 sites sampled. The two sites that had *H. cyanoguttatus* in 2005 and not in 2006 were the St. Bernard (new Parish record) and Gannon Canal sites (Table 1). The remaining 7 sampling stations (the Algiers site, Bayou Segnette, Ruddock, Bayou Sauvage, Bayou Trepagnier, the Mississippi River site, and the Lake Pontchartrain 1 site) produced no *H. cyanoguttatus* in either year (Table 1). These sites include the four natural localities (Bayou Segnette, Ruddock, Bayou Sauvage, and Bayou Trepagnier) located outside of the GNOMA.

Because readings of abiotic parameters were unreplicated, we could not test to determine if *H. cyanoguttatus* was influenced by these factors. Many sites, however, were higher in salinity the second year (Table 2). This included the Lake Pontchartrain 2 site, which had *H. cyanoguttatus* present at a salinity of 8.0 psu. *Micropterus salmoides* Lacepède (Largemouth Bass) and *L. macrochirus* were most commonly caught with *H. cyanoguttatus. Lepomis miniatus* Jordan (Red-spotted Sunfish) were only caught in two sites where *H. cyanoguttatus* was not found. Only two species (*H. cyanoguttatus* and *P. latipinna*) produced significant predictive models based on abiotic factors. A combination of salinity and temperature predicted *H. cyanoguttatus* abundance ($R^2 = 0.241$, $P = 0.034$), with higher abundances occurring in lower salinities and higher temperatures. An opposite relationship was observed for *P. latipinna*, with a combination of salinity and temperature predicting abundance (R^2 = 0.124, P = 0.032), but abundances were highest at higher salinities and lower temperatures.

Bayou St. John and City Park survey (2006–2007)

From 2006 to 2007, the number of *H. cyanoguttatus* increased significantly (sign test: $P < 0.05$) at all three City Park sampling sites, with two sites having over 200 *H. cyanoguttatus* captured. There was no increase in abundance at the three Bayou St. John sites, with less than 50 *H. cyanoguttatus* caught at all three sites (Fig. 2). Pontchartrain Lagoon had significantly more *H. cyanoguttatus* in 2007 than in 2006 (sign test: $P < 0.01$), and Metairie Bayou actually had a greater than 25-fold increase in *H. cyanoguttatus* (sign test, $P < 0.01$). While these sites had similar densities to the Bayou St. John sites in 2006, in 2007 these sites consistently had the most *H. cyanoguttatus* (Fig. 2). Marconi Lagoon also exhibited a significant (sign test: $P < 0.01$) increase in *H. cyanoguttatus* from 2006 to 2007, but the numbers were more similar to those seen at the Bayou St. John sites (Fig. 2). This significant increase is likely due to the fact that *H. cyanoguttatus* were only first collected in Marconi Lagoon in October 2006.

Salinity decreased significantly from 2006 to 2007 at four sampling sites: Bayou St. John North (7.5 to 6.3; sign test: $P < 0.01$), Central (7.3 to 6.1; sign test: $P < 0.01$), South (7.2 to 5.9; sign test: $P < 0.01$), and Marconi Lagoon (2.9 to 1.6; sign test: $P < 0.01$). Salinity did not change between the years at Pontchartrain Lagoon (sign test: P = 1.00) and Metairie Bayou (sign test: P =

Table 2. Abiotic data collected from the surveys before and after hurricanes Katrina and Rita. Note the higher salinities nine months after the hurricanes, in particular Bayou Saint John and the second Lake Pontchartrain site, both of which contained *H. cyanoguttatus* that year.

	2005					2006				
	Salinity	Temp	pH	GH	KH	Salinity	Temp	pH	GH	KH
Urban sites										
Veterans Canal	0.4	32.6	8.44	140	150	0.4	28.0	8.08	180	130
Bonnabel Canal	0.5	29.7	8.88	220	150	0.5	30.5	8.13	220	160
Harahan	0.2	29.0	7.70	140	100	0.7	27.4	7.66	300	330
Western Kenner	0.5	31.8	8.15	200	140	0.4	31.6	8.67	180	110
St Charles Canal	0.4	28.2	7.46	180	90	1.9	31.6	7.34	500	120
Gannon Canal	0.5	30.0	8.61	160	90	1.0	33.0	6.94	300	140
Bayou St John	3.3	30.7	8.36	560	40	7.6	30.2	6.99	560	30
St Bernard Parish	0.3	28.2	7.69	260	180	0.5	28.7	7.08	280	120
Algiers	0.5	31.7	7.71	260	130	0.3	30.1	7.11	140	80
Natural waterways										
Bayou Segnette	0.7	30.7	8.46	220	160	1.0	33.0	8.60	240	240
Ruddock	0.7	29.0	7.71	200	120	2.4	29.9	7.64	580	160
Sauvage	1.1	28.7	7.34	220	70	11.3	34.0	8.84	560	50
Bayou Trepagnier	2.7	31.1	7.08	560	150	7.8	29.8	8.08	1600	80
Lake/River sites										
Mississippi River										
Pontchartrain 1						9.0	30.0	7.60	560	30
Pontchartrain 2						8.0	32.2	7.57	560	40

0.24). Bayou St. John South was the only sampling site to exhibit a significant change in temperature (23.38 to 22.57 ºC; sign test: $P = 0.03$), with 2007 being significantly colder than 2006.

Discussion

Our sampling confirmed that *H. cyanoguttatus* occurs in Lake Pontchartrain in oligohaline conditions (5 to 12 PSU), supporting the results of an earlier dispersal model that proposed that this nominally freshwater fish species was capable of expanding via estuarine corridors (O'Connell et al. 2002). This model required fish to move through the lake because of land barriers between eastern and western canal complexes in the GNOMA. While collecting eight fish over the course of a year near the mouth of a single canal may not be strong evidence that Lake

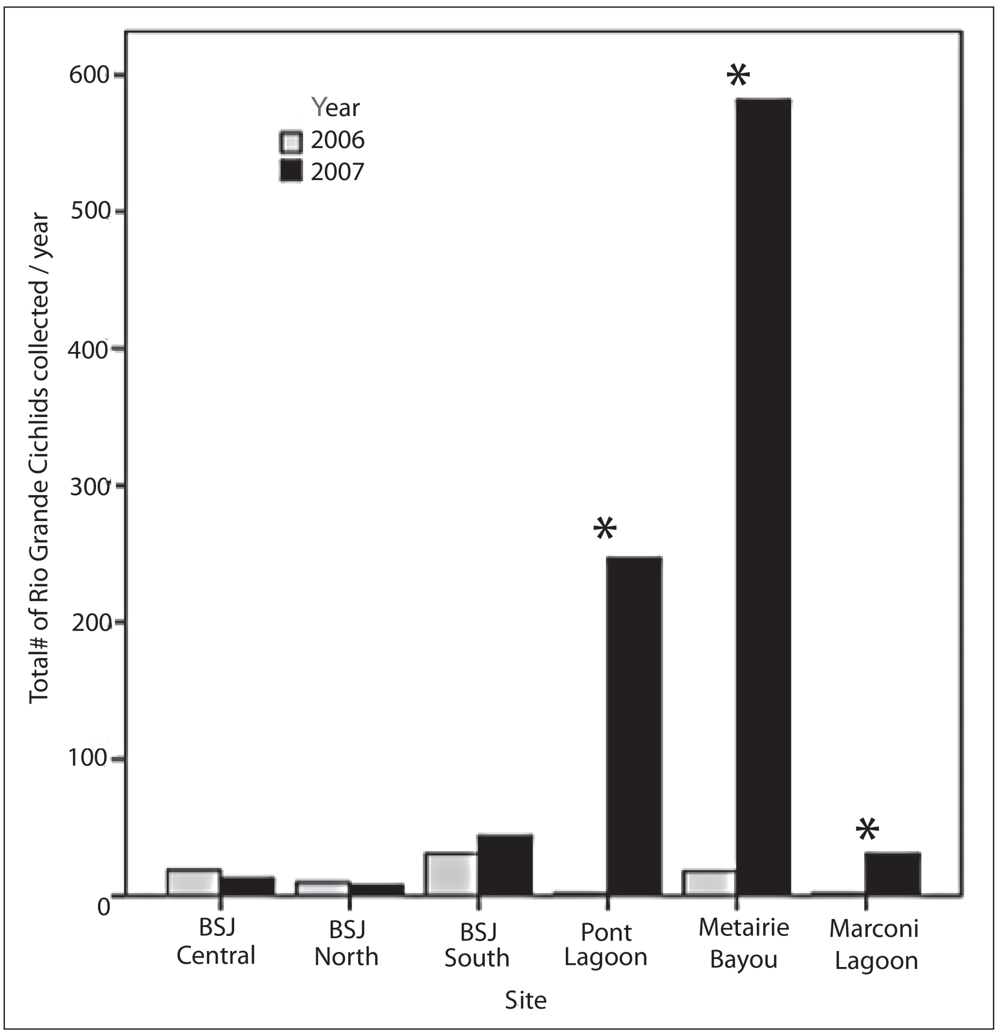

Figure 2. Survey data for Bayou Saint John (BSJ) and City Park sites. Increase in numbers of *H. cyanoguttatus* was significant from 2006 to 2007 for all City Park sites (sign test: $P < 0.01$). Significant differences are marked with asterisks.

Pontchartrain is a dispersal corridor, we also have numerous collections since this study of *H. cyanoguttatus* from this area from other projects (O.T. Lorenz, unpubl. data). We also verified that populations of *H. cyanoguttatus* survived the 2005 hurricane-related levee failures and now continue to increase their numbers in water bodies in urban New Orleans. Although our 2005–2006 pre- and post-hurricane surveys did not collect *H. cyanoguttatus* from canals on the other side of the Mississippi River (from the GNOMA), they have since been collected from this region on a regular basis and persist as far away from the city as Port Sulphur (90 miles southeast from New Orleans; O.T. Lorenz, unpubl. data). Incidentally, all GNOMA urban populations, West Bank populations, and even the extreme southern population in Port Sulphur persisted through the atypically cold winter of 2009–2010; O.T. Lorenz, unpubl. data).

The most common fish collected in seawall traps placed along the south shore of Lake Pontchartrain was *H. cyanoguttatus*. Monthly trapping over a year caught very few fishes overall; and we believe this is due to a combination of the targeted nature of the traps and the low quality of the estuarine habitats on the artificial concrete seawall. Our main goal was to determine if *H. cyanoguttatus* was in Lake Pontchartrain, so we designed the traps based on previous research that targeted this species in Texas (Buchanan 1971). Our goal was achieved, but at the possible cost of incomplete collection of other fish species that occur in these habitats. The funnel traps are not appropriate for collecting native estuarine species such as *Lepisosteus oculatus* Winchell (Spotted Gar), *Anchoa mitchilli* Valenciennes (Bay Anchovy), and *Mugil cephalus* L. (Striped Mullet). Species that are common (O'Connell et al. 2004), but were not captured by these traps, include *Anchoa mitchilli* and *Brevoortia patronus* Goode (Gulf Menhaiden). These species and others were consistently observed along the seawall during trapping, yet were never collected by the traps.

Brackish waters are not complete barriers for many cichlids, as was demonstrated by the presence of eight native and two non-native species of cichlids living sympatrically with marine species in an estuarine lagoon in Mexico (Chavez-Lopez et al. 2005). *Cichlasoma urophthalmus* Günther (Mayan Cichlid), an invasive in South Florida, can tolerate salinity up to and exceeding that of seawater (Stauffer and Boltz 1994). Another Florida invasive, the African Jewelfish can tolerate salinities up to 50 psu (Langston et al. 2010). Other invasive cichlids have similar levels of salinity tolerance (Lemarie et al. 2004). Some tilapia species can even survive at lower temperatures when in saline conditions than they could survive in freshwater conditions. This fact could partially explain the success of *Oreochromis niloticus* L. (Nile Tilapia) in Mississippi (Peterson et al. 2005). Brackish barriers can act as barriers to invasive fishes (Dial and Wainright 1983, Scott et al. 2007), but certain species (notably cichlids) have a high tolerance of brackish and full-salinity conditions. *Herichthys cyanoguttatus* had no significant decrease (or increase) in growth while exposed to salinities (0 to 16 psu) that exceed that of Lake Pontchartrain and surrounding wetlands (Lorenz and O'Connell 2008). Interestingly, multiple regressions indicated a prevalence of *H. cyanoguttatus* in warmer fresh waters relative to *P. latipinna,* which was more common in cooler and more saline conditions. The maximum salinity tolerance of *H. cyanoguttatus* is presently unknown, and deserves further investigation. Both *H. cyanoguttatus* and its sister species *H. carpintis* inhabit rivers leading into estuaries, with anecdotal reports of *H. carpintis* being seen in mangroves in its native range (Don Conkel, Don Conkel's Tropicals, Odessa, FL, pers. comm.). This indicates a potential salinity tolerance approaching or exceeding seawater. It is possible that the salinity data here were biased because the more natural systems also had higher salinities when compared to the canal systems where *H. cyanoguttatus* is common.

The 2005–2006 pre- and post-hurricane survey results also suggest that other abiotic factors may have little effect on *H. cyanoguttatus* in both urban and natural habitats. Measures of hardness and pH did not vary consistently between urban and more natural sites. Temperature limits the spread of cichlid species because of the tropical nature of this family of fishes (Hubbs 1951, Schofield et al. 2009, Shafland and Pestrak 1982, Siemien and Stauffer 1989). Preliminary results with temperature-measuring data loggers have indicated that temperatures are slightly lower both in the summer and winter at the more natural Bayou Trepagnier site (Fig. 1) versus the less natural Bayou St. John site (O.T. Lorenz, unpubl. data). Consistent sampling in LaBranche wetlands has yielded few *H. cyanoguttatus,* and the species is only found there periodically.

The patterns of presence and absence of *H. cyanoguttatus* in the GNOMA before and after the hurricanes can be interpreted in a few ways. Similar to other invasive species, *H. cyanoguttatus* appears to be very tolerant of disturbances and disturbed habitats. Several studies have shown that aquatic invasive species can be spread by flooding (Rahel and Olden 2008). In this study, native *L. macrochirus* was the only species observed to significantly decline after the hurricanes, while the invasive *H. cyanoguttatus* continued to increase in numbers in City Park. Because *L. macrochirus* and *H. cyanoguttatus* compete over territories in the field and under laboratory conditions (Courtenay et al. 1974, Lorenz et al. 2011), there may be some negative interactions between these species. Poeciliids may also be impacted by the spread of *H. cyanoguttatus* (M.T. O'Connell, unpubl. data), which would not be surprising considering the potential niche overlap of *H. cyanoguttatus* and poeciliids (Olden et al. 2006). Niche overlap would indicate competition, but fish are also an occasional food item for *H. cyanoguttatus* (O.T Lorenz, unpubl. data). The only conspicuous disappearance of *H. cyanoguttatus* was in the heavily flooded St. Bernard Parish. Under similar conditions in Spain, invasive *Lepomis gibbosus* L. (Pumpkinseed Sunfish) increased in number during non-flooding years and decreased significantly when exposed to heavy flood regimes (Bernardo et al. 2003). We expect such flood-related mortality may have influenced *H. cyanoguttatus* populations in St. Bernard Parish after the hurricanes of 2005.

The survival and subsequent significant increase of *H. cyanoguttatus* populations at our City Park sampling sites and elsewhere in the GNOMA further show the persistent and resilient nature of this non-native fish species. The inundation of these urban habitats, along with the subsequent flood waters, likely provided *H. cyanoguttatus* direct routes for dispersal (Caillouet et al., in press). Their success in habitats where they had been in low numbers before 2005 suggests an ability to rapidly colonize flooded areas. Although we measured no significant increase in *H. cyanoguttatus* numbers from our three Bayou St. John sites in 2007, populations persist at all of these sites. A possible explanation for why *H. cyanoguttatus* did not increase over that time is that Bayou St. John experienced a marked increase in populations of *M. salmoides* in 2006 that significantly impacted other resident species (A.M.U. O'Connell and M.T. O'Connell, unpubl. data). Anecdotally, it it has been reported that *H. cyanoguttatus* remains in high densities in canal systems other than Bayou St. John. Regardless of whether the population increase of this native predator species was caused by over-stocking or a natural post-storm increase in numbers, it suggests the possible role of native piscivores in reducing non-native fish populations. In addition, there is an annual City Park Bass Rodeo where there is a competition for capturing the most *H. cyanoguttatus*. Hundreds of pounds of *H. cyanoguttatus* are caught during this event. Because this is not practiced elsewhere, anglers may have some impact on Bayou Saint John populations. The City Park Bass Rodeo of 2011 yielded far less *H. cyanoguttatus* (40), possibly indicating City Park populations are decreasing from their initial spike in numbers in 2007.

Our results also suggest the role that salinity and temperature play in determining the success or failure of *H. cyanoguttatus* within these urban habitats. While all three of the Bayou St. John sites became significantly fresher from 2006 to 2007, the numbers of *H. cyanoguttatus* did not change significantly. These sites experienced maximum salinities of 7.7 to 8.1 psu during 2006, yet *H. cyanoguttatus* are still present and nesting at all of these sites, just as they do at lower salinities. Temperatures in the three City Park sites remained similar from 2006 to 2007, yet *H. cyanoguttatus* numbers increased significantly. Based on these results, the results from our other surveys where *H. cyanoguttatus* was collected at similar salinities and temperature, and the results from other laboratory experiments on abiotic influences (Lorenz and O'Connell 2008), we feel that these two factors may not restrict the future expansion of this non-native species.

In this study, we find little impact of salinity and hurricanes on the persistence of this species in the lake and the canals. In fact, the species now has spread to more canal systems since this survey, including multiple sites on the opposite side of the Mississippi River. We also have found a lack of current success for *H. cyanoguttatus* in natural areas, possibly affected by cold or biotic resistance. The level of disturbance, low native biodiversity, and urban effects may favor *H. cyanoguttatus*. They were not found in Bayou Segnette, Bayou Sauvage, and Bayou Trepagnier (even though they had previously been found in Bayou Trepagnier). Bayou Saint John is a relatively urban site with concrete sides in several locations, possibly aiding the success of this species. It is possible that it will continue to be difficult for *H. cyanoguttatus* to have population increases from one year to the next in natural habitats. It should be noted that invasive cichlid species can suddenly become successful after decades of restriction to urban habitats, as demonstrated by the sudden expansion of *Hemichromis letourneuxi* in Florida (P.J. Schofield,US Geological Survey, Gainesville, FL, pers. comm.) after over 50 years of being restricted to canals in southern Florida.

Acknowledgments

This research was supported by a Louisiana Board of Regents Graduate Student Fellowship and by grants from the American Cichlid Association and Sports Fish Restoration Grant. Fishes were collected under Louisiana Department of Wildlife and Fisheries Scientific Freshwater Collecting Permit # 64-2007 and handled in accordance with IACUC permit # UNO-171. We thank C.S. Schieble, J. Van Vrancken, M.T. Lorenz, and A.M.U. O'Connell for help with fieldwork. J. Howard provided valuable advice on experimental design. We would also like to thank R.C. Cashner, J.M. King, and the late S.L. Penland for their encouragement and support of these endeavors. This manuscript represents publication No. 9 for the Nekton Research Laboratory, Pontchartrain Institute for Environmental Sciences.

Literature Cited

Baird, S., and C. Girard. 1854. Description of new species of fishes collected by John H. Clark on the V.S. and Mexican boundary survey, and in Texas, by Captain Stewart Vliet. United States Proceedings of the Academy of Natural Sciences of Philadelphia 7:24–29.

Bernardo, J.M., M. Ilheu, P. Matono, and A.M. Costa. 2003. Interannual variation of fish assemblage structure in a mediterranean river: Implications of stream flow on the dominance of native or exotic species. River Research and Applications 19:1–12.

Brown, W. 1953.Introduced fish species of the Guadalupe River basin. Texas Journal of Science 5:245–251.

Buchanan, T.M. 1971. The reproductive ecology of the Rio Grande Cichlid, *Cichlasoma cyanoguttatum*. Ph.D. Dissertation.University of Texas, Austin, TX. 226 pp.

Caillouet, K., J. Carlson, D. Wesson, and F. Jordan. 2008. Colonization of aboandoned swimming pools by larval mosquitoes and their predators following Hurricane Katrina. Journal of Vector Ecology 33:166–172.

Chavez-Lopez, R., J. Franco-Lopez, A. Moran-Silva, and M.T. O'Connell. 2005. Long-term fish assemblage dynamics of the Alvarado Lagoon estuary, Veracruz, Mexico. Gulf and Caribbean Research 17:145–156.

Courtenay, W.R., H.F. Sahlman, W.W. Miley, and D.J. Herrema.1974. Exotic fishes in fresh and brackish waters of Florida. Biological Conservation 6(4):292–302.

Dial, R.S., and S.C. Wainright. 1983. New distributional records for non-native fishes in Florida. Florida Scientist 46(1):8–15.

Fuentes, G.N., and R.C. Cashner. 2002. Rio Grande Cichlid established in the Lake Pontchartrain drainage, Louisiana. Southwest Naturalist 47(3):456–459.

Fuller, P.L., L.G. Nico, and J.D. Williams.1999. Nonindigenous fishes introduced into inland waters of the United States. Special Publication 27. American Fisheries Society, Bethesda, MD. 613 pp.

Harvey, B.C., J.L. White, and R.J. Nakamoto. 2004. An emergent multiple predator effect may enhance biotic resistance in a stream fish assemblage. Ecology 85: 127–133.

Hubbs, C. 1951. Minimum temperature tolerances for fishes of the genera *Signalosa* and *Herichthys* in Texas. Copeia 1951(4):297.

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

Jensen, G.C., P.S. McDonald, and D.A. Armstrong. 2007. Biotic resistance to Green Crab, *Carcinus maenas*, in California bays. Marine Biology 151:2231–2243.

Langston, J.N., P.J. Schofield, J.E. Hill, and W.F. Loftus. 2010. Salinity tolerance of the African Jewelfish *Hemichromis letourneuxi*, a non-native cichlid in south Florida, USA. Copeia 2010:475–480.

Lemarie, G., J.F. Baroiller, F. Clota, J. Lazard, and A. Dosdat. 2004. A simple test to estimate the *salinity* resistance of fish with specific application to *O. niloticus* and *S. melanotheron*. Aquaculture 240(1–4):575–587.

Lorenz, O.T., and M.T. O'Connell. 2008. Growth of non-native Rio Grande Cichlids (*Herichthys cyanoguttatus*) at different salinities and in the presence of native Bluegill (*Lepomis macrochirus*). Journal of Freshwater Ecology 23:537–544.

Lorenz, O.T., P.J. Schofield, and M.T. O'Connell. 2011. Aggressive interactions between the invasive Rio Grande Cichlid (*Herichthys cyanoguttatus*) and native Bluegill (*Lepomis macrochirus*), with notes on Redspotted Sunfish (*Lepomis miniatus*). Journal of Ethology 29:39–46.

O'Connell, M.T., R.C. Cashner, and G.N. Fuentes. 2002. Application of a diffusion model to describe a recent invasion: Observations and insights concerning early stages of expansion for the introduced Rio Grande Cichlids in southeastern Louisiana. Aquatic Invaders 13(4):13–21.

O'Connell, M.T., R.C. Cashner, and C.S. Schieble. 2004. Fish assemblage stability over fifty years in the Lake Pontchartrain Estuary: Comparisons among habitats using canonical correspondence analysis. Estuaries 27(5):807–817.

Olden, J.D., N.L. Poff, and K.R. Bestgen. 2006. Life-history strategies predict fish invasions and extirpations in the Colorado River basin. Ecological Monographs 76:25–40.

Peterson, M.S., W.T. Slack, and C.M. Woodley. 2005. The occurrence of non-indigenous Nile Tilapia (*Oreochromis niloticus*) in coastal Mississippi, USA: Ties to aquaculture and thermal effluent. Wetlands 25:112–121.

Rahel, F.J., and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22:521–533.

Schofield, P.J., W.F. Loftus, R.M. Kobza, and M.I. Cook. 2009. Tolerance of nonindigenous cichlid fishes (*Cichlasoma urophthalmus, Hemichromis letourneuxi*) to low temperature: Laboratory and field experiments in south Florida. Biological Invasions 12:2441–2457.

Scott, D.M., R.W. Wilson, and J.A. Brown.2007.The osmoregulatory ability of the *invasive* species Sunbleak, *Leucaspius delineatus,* and Topmouth Gudgeon, *Pseudorasbora parva,* at elevated *salinities*, and their likely dispersal via brackish waters. Journal of Fish Biology 70 (5):1606–1614.

Shafland, P.L., and J.M. Pestrak.1982. Lower lethal temperatures for fourteen non-native fishes in Florida. Environmental Biology of Fishes7(2):149–156.

Siemien M.J., and J.R. Stauffer, Jr. 1989. Temperature preference and tolerance of the Spotted Tilapia and Rio Grande cichlid. Archivfür Hydrobiologie115(2):287–303.

Stauffer, J.R., and S.E. Boltz.1994. Effect of *salinity* on the temperature preference and tolerance of age-0 Mayan *Cichlids.* Transactions of the American Fisheries Society 123(1):101–107.