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Relative Abundance and Biomass of Exotic Fish in Roadway Corridors

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Abstract: The introduction of exotic fish has been detrimental to wetland ecosystems, thus making it important to understand their distributions in respect to roadway corridors in the South Florida region. We sampled fish with modified minnow traps at 18 study sites within three different landscape (urban, herbaceous marsh, forested marsh) and habitat type features (storm water ponds and canals) in order to determine the relative abundance of exotic fish. Our results suggest that exotic fish do have a higher relative abundance and proportion of biomass in the urban landscape, the canal habitat feature type, and the urban canal feature. Understanding patterns of exotic fish biomass and relative abundance in roadway corridor features could be useful for future management of these species in the South Florida region.

Introduction

Invasive species are the second greatest threat to native biodiversity next to habitat destruction (Rahel, Bierwagen, & Taniguchi, 2008). Invasive species are exotic species that are likely to cause environmental or economic harm (Beck et al., 2008). In wetlands of South Florida, exotic fish species have the potential to become invasive depending on their behavior, diet, and other interactions within the ecosystem (Florida Fish and Wildlife Conservation Commission, 2015).

Understanding the impacts that exotic fish have on the overall biodiversity in South Florida is limited by the lack of science-based information. There have been a minimum of 34 established exotic fish populations recorded in Florida (Schofield, Slone, Gregoire, & Loftus, 2014), though measures of biomass and relative abundance in various landscape and vegetation types are poorly known. Such information would be useful for developing management plans that could prevent the spread of exotic fish into other areas of Florida, and aid in understanding the impacts that these species may have on the surrounding ecosystem (Havens & Aumen, 2000).

The spread of exotic fish into marshes of South Florida is facilitated through the canal system that was created to drain the vast Everglades wetland. Dispersal of fishes through this canal system has been demonstrated effectively for members of the family Cichlidae (Kline et al., 2014; O'Connor & Rothermel, 2013). Though Florida is not home to indigenous species of Cichlidae, they make up the majority of exotic fish in South Florida with as many as 13 cichlid species recorded in the region (O'Connor & Rothermel, 2013). The African jewelfish Hemichromis letourneuxi is one of the most common cichlid species found within the region, thought to have been released in the 1960s from the aquarium trade. Today it has successfully established itself from Miami-Dade County throughout the freshwater wetlands and tidal habitats of the Florida Everglades system and into selected areas of Central Florida. Originally from Africa, H.letourneuxi is considered an opportunistic carnivore that preys on a wide range of fish and crustaceans and will tolerate water salinities up to 50 ppt (Schofield et al., 2014). This cichlid species, similar to others of its kind, has a reputation of being aggressive. Therefore, scientists believe that the H. letourneuxi may out compete native fish species for spawning sites.

The Mayan cichlid Cichlasoma urophthalmus of Central America has also become a prominent member of the fish community in South Florida. The species was first recorded in Everglades National Park in 1983 (Loftus & Kushlan, 1987), approximately two decades after the introduction of the H. letourneuxi. Since then, it has spread north over 300 kilometers on both coasts and can now be found throughout South Florida in canals, marshes, and mangrove swamps (Faunce, Patterson, & Lorenz, 2002). C. urophthalmus can tolerate water salinities up to 38 ppt and breeds in both fresh and saltwater (Adams & Wolfe, 2007). Though C. urophthalmus mostly feeds on fish, it is considered a generalist because it consumes a wide range of vegetation, crustaceans, and gastropods. Its ability to breed and eat indiscriminately makes it a species of concern for fresh and brackish water ecosystems (Porter-Whitaker, Rehage, Liston, & Loftus, 2012).

Our goal was to determine whether the proportion of exotic and native fish species and their biomass differed among landscape types (urban, forested marsh, and herbaceous marsh) and between smaller-scale habitats (canals and ponds) in South Florida. We hypothesized that exotic fish species would have a higher relative abundance and proportion of biomass in the urban landscape compared to the forested and herbaceous marsh landscapes due to the closer proximity of urban study sites to the highly populated east coast of South Florida. Further, we expected a higher relative abundance and proportion of biomass of exotic fish species in canals versus stormwater ponds because the canal network has few barriers to dispersal (Schofield et al., 2014).

Method

Fish were sampled in two habitat types (canals and stormwater ponds) at three replicate sites within three landscape cover types (urban, forested marsh, herbaceous marsh) for a total of 18 sample sites (Figure 1). Each of the 18 sampling sites within canals and stormwater ponds were divided into three subsites. The first subsite location within each canal and stormwater pond was randomly selected by estimating the minimum and maximum bearing and distance that encompassed the site with a compass and rangefinder. A random bearing and distance within the predetermined ranges were chosen using a random number table. The second and third subsite locations were determined by selecting a random direction and a random distance (≥10 m) from the first and second subsites, respectively.

Fish Sampling Within each subsite, an array of minnow traps was set at various distances and

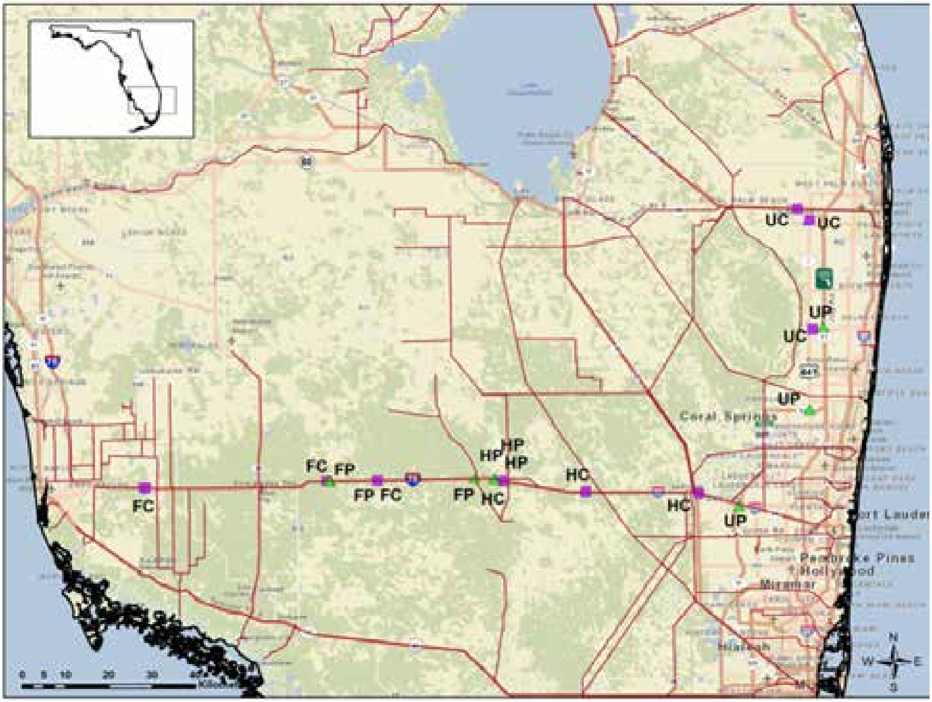


Figure 1. Locations of fish sampling sites at canals (□) and stormwater ponds (Δ) within herbaceous marsh, forested marsh, and urban landscapes along roadway corridors in South Florida. UC = Urban Canal, UP = Urban Pond, HC = Herbaceous Canal, HP = Herbaceous Pond, FC= Forested Canal, FP = Forest Pond.

depths (Figure 2) to sample the full range of the water column. From one edge of the shoreline to the other, minnow traps were placed horizontally and equally spaced across the subsite with some additional traps suspended below on a line. The number of minnow traps suspended on a line varied based on the depth of the site. Suspension lines in deep (>1.5 m) canals or stormwater ponds consisted of three traps: one just below the water surface, one mid-water column, and one resting on the substrate. For sites at intermediate depths (1.0-1.5 m), suspension lines held two traps: one just below the water surface and one resting on the substrate. For shallow site depths (<1.0 m), each suspension line contained only one trap resting on the substrate. Minnow traps consisted of two inverted funnel openings on both ends of a mesh-covered cylinder.

The funnel openings were modified from a 2.54 cm diameter opening to a 10 cm oval with a maximum width of 3 cm to allow the capture of larger-bodied prey (Evans, Klassen, & Gawlik, 2015). Minnow traps were set periodically throughout the day and retrieved the following day after being deployed for a minimum of 18 hours. Fish retrieved from traps were immediately euthanized with a Tricainemethane Sulfonate (MS-222®) solution (350 mg/L). In the lab, fish specimens were fixed with Prefer® and identified to species using keys, field guides, and online databases. Also, each fish was weighed to the nearest 0.01 g and measured (standard length). Within seven days, specimens were transferred to a 70% ethanol solution for storage. Fish were handled in accord with Florida Atlantic University's Institutional Animal Care and Use Committee Protocol A14-11.

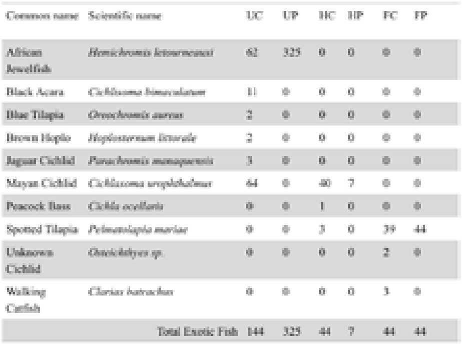
Statistical Analyses

Chi-square tests were used to test for differences in the proportion and biomass of exotic fish among landscape types (urban, forested marsh, herbaceous marsh), habitat features (canal and pond), and landscape types (canals only). All chi-square tests were performed using Microsoft Excel.

Results

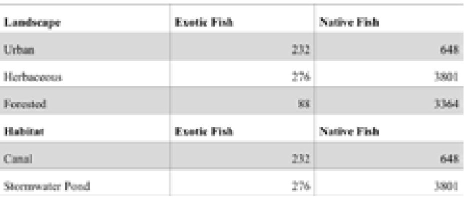
A total of 5,057 individual fish were collected from 9 July to 14 December, 2014, of which, 608 were exotic species and 4,449 were native species (Table 1). C. urophthalmus (111 individuals) and H. letourneuxi (387 individuals) were the most abundant exotic fish species captured. Another member of the Cichlidae family, the spotted tilapia Pelmatolapia mariea (86 individuals), was also observed in relatively high numbers but only in forested landscapes. Other exotic fish such as the blue tilapia Oreochromis aureus, brown hoplo Hoplosternum littorale, peacock bass Cichla ocellaris, and other exotics were captured as well, but not in high numbers (Tables 1-3).

Table 1. Number of exotic species identified from minnow traps in landscape cover types and habitat types. UC = Urban Canal, UP = Urban Pond, HC = Herbaceous Canal, HP = Herbaceous Pond, FC= Forested Canal, FP = Forest Pond.



Common name	Scientific name	UC	UP	HC	HP	FC	FP
African Jewelfish	*Hemichromis letourneuxi*	62	325	0	0	0	0
Black Acara	*Cichlasoma bimaculatum*	11	0	0	0	0	0
Blue Tilapia	*Oreochromis aureus*	2	0	0	0	0	0
Brown Hoplo	*Hoplosternum littorale*	2	0	0	0	0	0
Jaguar Cichlid	*Parachromis managuensis*	3	0	0	0	0	0
Mayan Cichlid	*Cichlasoma urophthalmus*	64	0	40	7	0	0
Peacock Bass	*Cichla ocellaris*	0	0	1	0	0	0
Spotted Tilapia	*Pelmatolapia mariae*	0	0	3	0	39	44
Unknown Cichlid	*Osteichthyes sp.*	0	0	0	0	2	0
Walking Catfish	*Clarias batrachus*	0	0	0	0	3	0
	Total Exotic Fish	144	325	44	7	44	44

Table 2. Number of exotic fish identified from minnow traps by landscape cover types and corridor features.



Landscape	Exotic Fish	Native Fish
Urban	232	648
Herbaceous	276	3801
Forested	88	3364
Habitat	**Exotic Fish**	**Native Fish**
Canal	232	648
Stormwater Pond	276	3801

Table 3. Biomass of exotic fish identified from minnow traps by landscape cover types and corridor features.

Landscape	Exotic Fish (g)	Native Fish (g)
Urban	918.80	134.83
Herbaceous	91.36	286.81
Forested	107.15	667.00
Habitat	**Exotic Fish (g)**	**Native Fish (g)**
Canal	347.43	240.15
Stormwater Pond	769.26	782.16

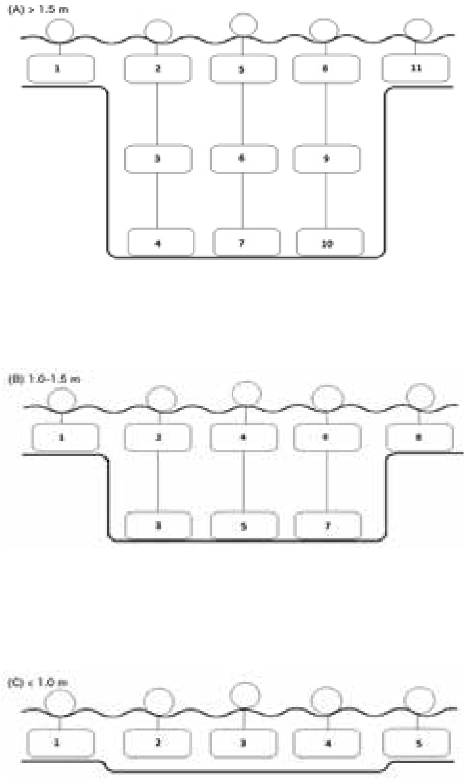


Figure 2. Figure from Evans et al. (2014). Model of minnow trap distribution at fish sampling sites with depths (A) >1.5 m, (B) 1.0-1.5 m, and (C) <1.0 m. Circles depict floats that are connected via line to the minnow traps, which are depicted with rectangles.

Exotic fish among landscape types

There was a significant difference ($\chi^2 = 2648.48$, df = 2, $p < 0.001$) in the relative abundance of exotic fish among the landscape types. The proportion of exotic fish sampled in the urban landscape (74%) was more than ten-fold that of the herbaceous (5%) and forested (3%) landscapes (Figure 3). There was also a significant difference ($\chi^2 = 1088.44$, df = 2, $p < 0.001$) in the proportion of exotic fish biomass among urban (87%), forested (14%), and herbaceous marsh (24%) landscapes (Figure 4).

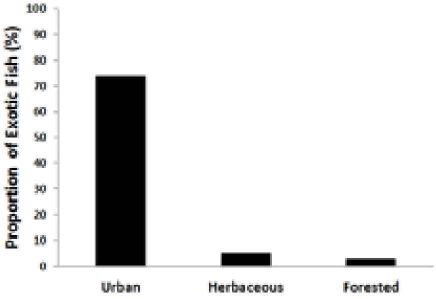


Figure 3. The proportion of exotic fish in urban, herbaceous and forested landscape types.

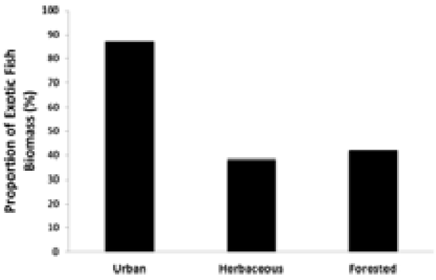


Figure 4. The proportion of biomass of exotic fish in urban, herbaceous and forested landscape types.

Exotic fish between habitat types

The relative abundance of exotic fish in the canal habitat (26%) was significantly higher ($\chi^2 = 207.14$, df = 1, $p < 0.001$) than in the stormwater pond habitat (10%; Figure 5). Similarly, there was a significantly higher ($\chi^2 = 15.56$, df = 1, $p < 0.001$) proportion of biomass of exotic fish in the canal habitat (59%) than in the stormwater pond habitat (50%; Figure 6).

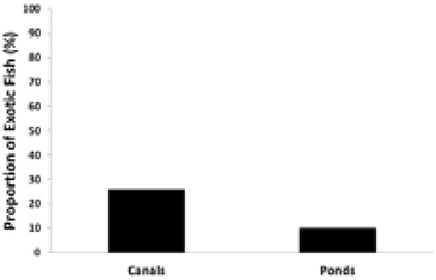


Figure 5. The relative abundance exotic fish in stormwater pond and canal habitat types.

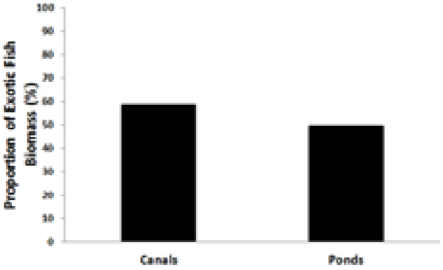


Figure 6. The proportion of biomass for exotic fish species in stormwater pond and canal habitat types.

Exotic fish in canals among landscape types

There was a significant difference ($\chi^2 = 275.92$, df = 2, $p < 0.001$) in the relative abundance of exotic fish among urban (69%), forested (24%), and herbaceous marsh canals (9%) (Figure 7). There was also a significant difference ($\chi^2 = 132.27$, df = 2, $p < 0.001$) in the proportion of exotic fish biomass among urban (87%), forested (38%), and herbaceous marsh canals (42%) (Figure 8).

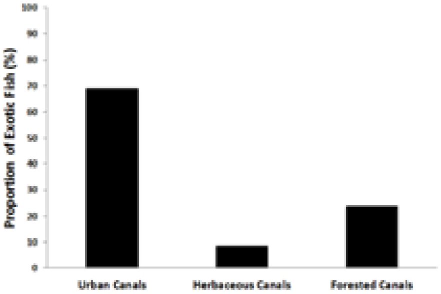


Figure 7. The relative abundance of exotic fish in urban, herbaceous, and forested canals.

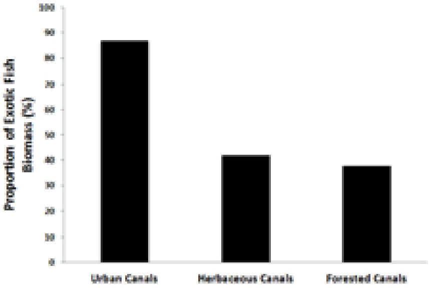


Figure 8. The proportion of biomass of exotic fish in urban, herbaceous, and forested canals.

Discussion

Results from this study suggest that exotic fish are predominantly found in the urban landscape and in canals. These patterns are consistent with the notion that aquarium fish releases are the origin of most introduced exotic fish (Florida Fish and Wildlife Conservation Commission, 2015). The connectivity of other landscapes to the urban landscape, via canal systems, allows for their dispersal, as has been documented with the sailfin catfish Pterygoplichthys multiradiatus and Asian swamp eel Monopterus albus (Loftus & Kushlan, 1987; Shafland, 1996; Shaflan, 2008). The connectivity of the urban landscape to more natural landscapes in South Florida deserves special attention because Everglades restoration projects (e.g., The Comprehensive Everglades Restoration Plan (CERP), 1999) will increase water delivery from canals to natural areas. Such management activities could potentially enhance the invasion and range expansion of exotic fish (Kline et al., 2014). Furthermore, as hypothesized, the same features (i.e. the urban landscape and canals) that supported a higher proportion of exotic fish also supported a higher biomass of exotic fish species relative to native species. It is not clear whether landscapes and canals are higher quality habitat for exotic fish or whether they have not had enough time to disperse to other habitats.

Apart from the connectivity that canals create, it is also possible that sampling bias played a role in the observed patterns of exotic fish. For instance, large cichlids >155mm and >70g were consistently captured in one large urban pond, while individuals from other sampling sites ranged from 16-87mm and 0.08-13.73g. Although sites were selected randomly within habitat and landscape types, it is possible that the inclusion of particular sites with unusual characteristics could have biased the subsequent samples. Nevertheless, the chances of selecting an unusual site were equal among the landscape and habitat types.

Out of all the exotic fish captured in the 18 study sites, H. letourneuxi and C. urophthalmus were the most abundant and comprised the largest proportion of exotic fish biomass. These results were generally expected based on prior knowledge of H. letourneuxi and C. urophthalmus being two of the most abundant exotic species found throughout South Florida (Kline et al., 2014). Other exotic fish such as spotted tilapia Pelmatolapia mariea, blue tilapia Oreochromis aureus, brown hoplo Hoplosternum littorale, peacock bass Cichla ocellaris, and others were not observed in relatively high numbers, suggesting that perhaps landscape, habitat and/or other existing factors are limiting these species from achieving the high relative abundances demonstrated by H. letourneuxi and C. urophthalmus.

One limitation of our study was that it was temporally restricted to a six-month sampling period during the summer and winter in South Florida. During the winter months, low water temperatures can be lethal to exotic fish and have the potential to lower their abundance drastically (Adams & Wolfe, 2007). The average minimum temperature recorded from Miami on July 4, 2014 to December 14, 2014 was 23°C. However, in 2010 temperatures dropped to 0°C and caused widespread mortality of both native and exotic fish. This highlights the importance of rare, but severe temperature events on fish populations; however, it was beyond the scope of this study to determine how exotic fish populations change as a function of extreme weather events. Access to longer term data may allow scientists to better understand how density and biomass fluctuate seasonally and possibly identify specific locations where exotic fish seek thermal refuge from cold water. Year-round sampling would also provide a clearer picture of seasonal variation in fish density and biomass patterns.

Another limitation of this study is spatial restriction to roadway habitats in three South Florida counties. Data from other Florida counties, particularly more northern counties, would provide a fuller picture of exotic fish patterns in the state. For example, a comparison of urban exotic fish between South and Central Florida would be particularly informative because it would quantify the role of temperature, a likely limiting factor for many exotic fish species.

The information gathered from this project identified new patterns of exotic fish abundance and biomass in South Florida roadway corridors. To that end, we propose that our research could be useful for management actions aimed at eliminating thermal refuges (e.g. filling unnaturally deep habitats to allow water cooling; Schofield et al., 2009), as well as for hydrological, electrical, and biological methods designed to control the spread of exotic species. Our study suggests that early detection for exotic fish should focus on urban areas, particularly on canals. These areas allow for harsher eradication methods because of low impacts to native fish, which are proportionately more abundant in marshes. Focusing management of exotic fishes in canals is likely to be more effective and less harmful to native species than attempting to manage exotic fishes after they are established in natural marshes.

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