

## Research Article

# Introduction and dispersal of non-native bullseye snakehead *Channa marulius* (Hamilton, 1822) in the canal system of southeastern Florida, USA

Amy J. Benson<sup>1,\*</sup>, Pamela J. Schofield<sup>1</sup> and Kelly B. Gestring<sup>2</sup>

<sup>1</sup>U.S. Geological Survey, Wetland and Aquatic Research Center, 7920 NW 71<sup>st</sup> Street, Gainesville, FL 32653, USA

<sup>2</sup>Florida Fish and Wildlife Conservation Commission, 12016 Lee Road, Boynton Beach, FL 33473, USA

Author e-mails: [abenson@usgs.gov](mailto:abenson@usgs.gov) (AJB), [pschofield@usgs.gov](mailto:pschofield@usgs.gov) (PJS), [kelly.gestring@myfwc.com](mailto:kelly.gestring@myfwc.com) (KBG)

\*Corresponding author

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## Editors' Note:

This study was contributed in relation to the 20th International Conference on Aquatic Invasive Species held in Fort Lauderdale, Florida, USA, October 22–26, 2017 (<http://www.icaiss.org/html/previous20.html>). This conference has provided a venue for the exchange of information on various aspects of aquatic invasive species since its inception in 1990. The conference continues to provide an opportunity for dialog between academia, industry and environmental regulators.

## Abstract

An established population of bullseye snakehead (*Channa marulius*), a large predatory fish from southeastern Asia, was identified for the first time in North America from waters in southeastern Florida, USA, in the year 2000. Since then, it has dispersed throughout the extensive canal system in the area from West Palm Beach south to Miramar. Collection data were compiled to determine the extent of the distribution. The range encompasses three separate areas totaling approximately 830 km<sup>2</sup>. Over an 18-year period, the range increased an average of approximately 46 km<sup>2</sup> per year. There is concern that this non-native species may threaten the fauna in unique protected natural areas of southern Florida, such as Everglades National Park.

**Key words:** invasive fish, non-native species, range expansion, canals, Florida

## Introduction

The state of Florida in the United States has a long history of non-native fish introductions (Courtenay and Robins 1973; Courtenay et al. 1974; Schofield and Loftus 2015). Introductions may occur in many ways including intentionally through deliberate releases or unintentionally through incidental releases and escapes (Benson 2000). To date, over 160 non-native fish species have documented occurrences in fresh waters of Florida (USGS 2018). Of those 160, 34 species have reproducing populations in the State (Shafland et al. 2008). Florida's native fishes evolved from North American temperate stocks, but the non-native fish fauna is comprised primarily of tropical and subtropical species from Asia, Africa, and the Americas that are well-suited to southern Florida's mild climate (Loftus and Kushlan 1987).

Nearly two decades ago, a member of the Channidae family of snakehead fishes, *Channa marulius* (Hamilton, 1822), was collected for the first time in the United States (USA) from waters in Florida. Snakeheads are a group of air-breathing freshwater fishes comprising two genera. The genus *Channa* Scopoli, 1777 is recognized with 42 valid species that are native to Asia in a wide range of habitats spanning from tropical to boreal, and the genus *Parachanna* Teugels and Daget, 1984 has three valid species from tropical Africa (Fricke et al. 2018). The common name “snakehead” refers to the snake-like appearance, having a long cylindrical body shape and eyes that are forward on the head.

Four species of snakehead have been documented in open waters of the USA, three of which have established reproducing populations. *Channa argus* (Cantor, 1822) (northern snakehead) is established in



**Figure 1.** Bullseye snakehead (*Channa marulius*) collected on May 1, 2015 in the E-1WN Canal in Delray Beach, Palm Beach County, Florida, USA. Total Length = 753 mm. Photo by Howard Jelks, USGS.

the Mid-Atlantic states and was initially discovered in 2004 in the Potomac River drainage of Virginia (Odenkirk and Owens 2005) as well as in the lower White River system of Arkansas several years later (Holt and Farwick 2009). *Channa maculata* (Lacepède, 1801) (blotched snakehead) has been established in Hawaii for more than a century and was believed to have been imported for human consumption (Devick 1991). *Channa micropeltes* (Cuvier, 1831) (giant snakehead) has been collected in six states in the conterminous USA as single specimens only and no reproducing populations have been reported. Lastly, *Channa marulius* (bullseye snakehead; Figure 1) at first thought to be a species complex (Britz et al. 2017), has been established in southeastern Florida since sometime prior to 2000 (Courtenay and Williams 2004).

*Channa marulius*, the largest of the Channidae family, is native from Pakistan and India to Southeast Asia and China (Talwar and Jhingran 1991) where it is known to reach 120 cm in length (Bardach et al. 1972). Coloration is grey to green on the dorsal side and white on the ventral side (Figure 1). Lateral sides are rusty orange to brown with scattered small white spots and a row of five to six large dark spots (Talwar and Jhingran 1991). All fins are without spines and dorsal and anal fins are long, running much of the length of the fish (Wee 1982). It is distinguishable from all but one other snakehead species *C. maruloides* (Bleeker, 1851) by a distinctive ocellus near the base of the caudal fin that fades with age (Talwar and Jhingran 1991). The identity of the Florida population was eventually confirmed through DNA testing as *C. marulius* (Serrao et al. 2014). It represents the only known established population of *C. marulius* in North America.

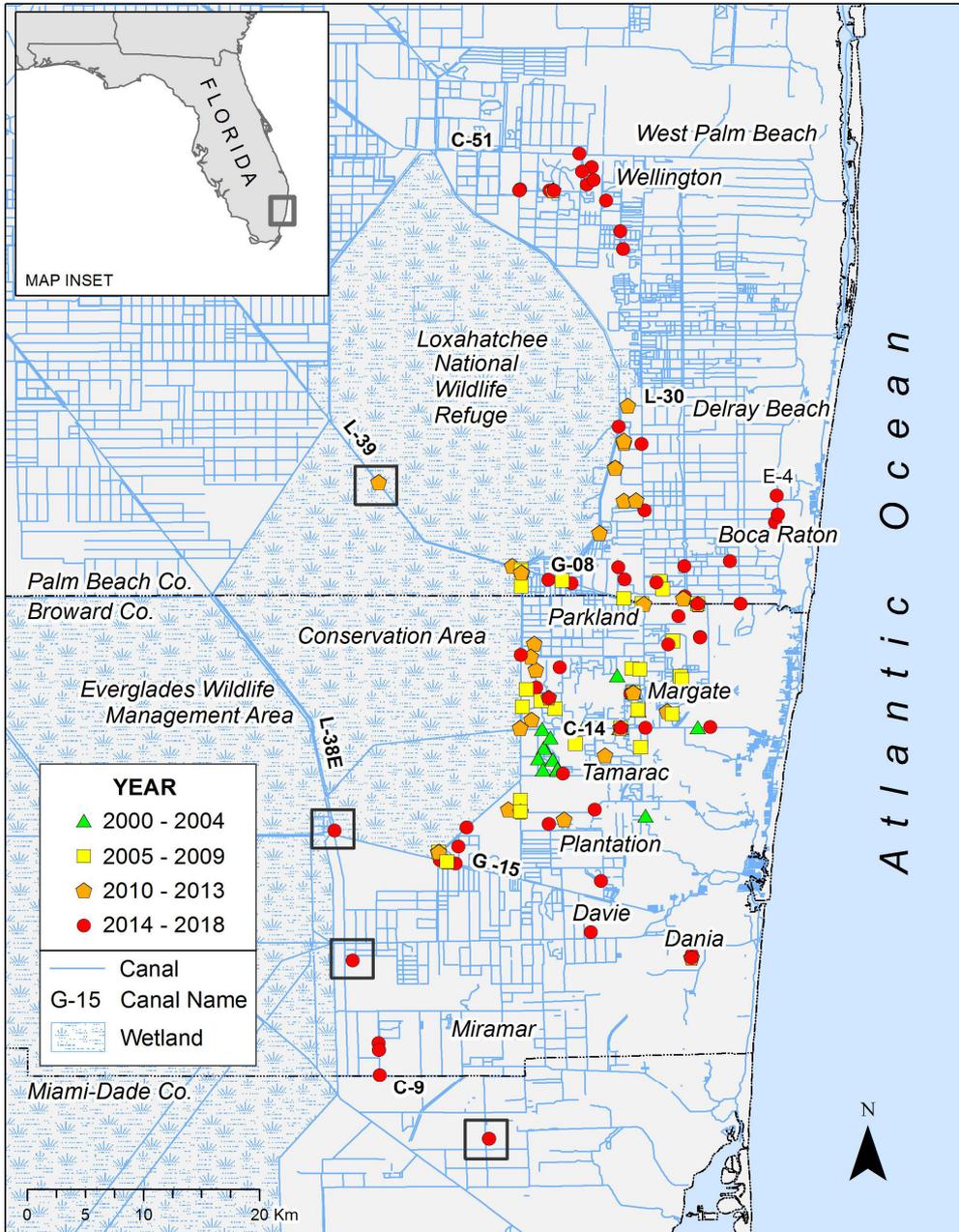
Although *C. marulius* has been present in Florida's southeastern canal system for at least 18 years, there

has been no single account providing information on its distribution. In this paper, we compile observations and collections of *C. marulius* to produce a timeline of introduction and dispersal in southeastern Florida while also providing life history information that may help explain its success.

## Methods

*Channa marulius* observation reports and collection information were accessed from the U.S. Geological Survey's Nonindigenous Aquatic Species Database (USGS 2018), a national repository for spatially-referenced data. Records in this database are compiled from scientific literature, published reports, and museum specimens. In addition, unpublished data are voluntarily contributed from a variety of sources including different levels of government (federal, state, county, municipalities), universities, non-government agencies, citizen scientists, and anglers. Collection data from active monitoring of *C. marulius* each year after their discovery by the Florida Fish and Wildlife Conservation Commission (FWC) were also included.

From these data, a geospatially-referenced data layer of *C. marulius* occurrence location points was constructed. ArcGIS (ESRI, Redlands, CA) convex hull tool, which creates a polygon using the outermost points, was used to calculate cumulative areas of snakehead range annually from 2000 to 2018. Because the current distribution of *C. marulius* in south Florida is not contiguous, ranges of three separate populations in the towns of Wellington, Miramar, and Tamarac were calculated. The Wellington, Miramar, and Tamarac distribution ranges were then added together to produce a total cumulative area range. Four collection locations were not included in the convex hull calculations as they were single fish, distant from

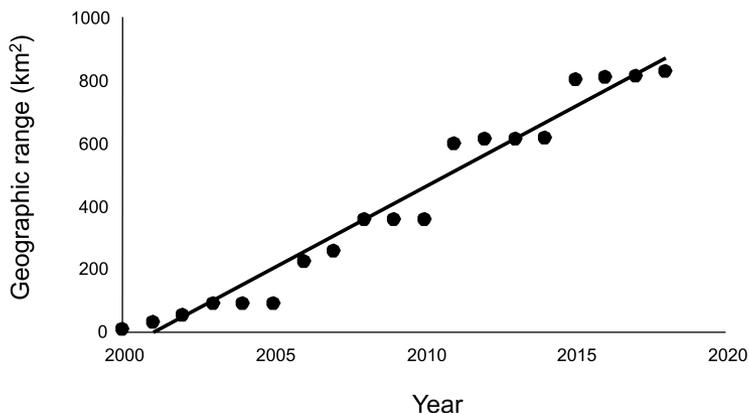


**Figure 2.** Cumulative collection and observation data for bullseye snakehead (*Channa marulius*) in southeastern Florida, USA. Data are from the USGS Nonindigenous Aquatic Species database available at <http://nas.er.usgs.gov>. Collection locations with black squares represent historical collections of single fish. These were not used in the range calculations.

the general population (Figure 2). These four fish were removed, and we do not believe there were additional fish in these locations. We used linear regression to examine the relationship between year and cumulative geographic range (km<sup>2</sup>). The analysis was performed using NCSS 11 Statistical Software (NCSS, LLC, Kaysville, UT).

### Results

A total of 224 *C. marulius* locations in Florida were compiled from 2000 through June 2018. The first documented occurrence of *C. marulius* in the USA was October 5, 2000 in a residential pond in Tamarac, Broward County, Florida (Figure 2; Table S1). The



**Figure 3.** Linear regression of geographic range by year for bullseye snakehead (*Channa marulius*) in southern Florida. Each dot represents the cumulative range encompassed by the species by year.

specimen was caught by an angler who reported it to FWC for identification. The following day FWC sampled the pond where they identified two large adults and eventually discovered a population of multiple size classes numbering over one hundred (Florida Museum specimen UF 129392); thus, the species was considered reproducing and established in the pond. We cannot know if this location was the initial point of introduction or the only point of introduction.

Since then *C. marulius* has dispersed over an area approximately 80 km from north (26.68°N) to south (25.95°N) and 35 km from east (80.10°W) to west (80.44°W) (Figure 2). The species has spread to new locations by dispersing naturally (swimming), but also by human transport. Through 2004, *C. marulius* was found primarily in the portion of the C-14 Canal located in Tamarac and the neighboring community of Margate. The convex hull area created by the distribution of snakehead locations covered 88 km<sup>2</sup> at the end of 2004. From 2005 to 2009, *C. marulius* was collected as far south and west as the North New River Canal (G-15) west of Plantation, and as far north as the Hillsboro Canal (G-08) in Parkland, expanding the convex hull area of distribution to 358 km<sup>2</sup>. Over the next four years, 2010 to 2013, *C. marulius* continued to disperse southward to Tigertail Lakes in Dania, northward in the L-30 Canal west of Delray Beach while a single fish was collected from the L-39 Canal bordering Arthur R. Marshall Loxahatchee National Wildlife Refuge, a distribution area now covering 614 km<sup>2</sup> in the four-year period. After 2013, additional collections were made extending the distribution in all directions. A single *C. marulius* was collected in 2015 from the G-15 Canal where it intersects with the L-38E Canal making it the westernmost location, while the E-4 Canal near Boca Raton marked the easternmost location. In 2016,

*C. marulius* was found in the West Palm Beach Canal (C-51) in Wellington, its northernmost location. To the south, the species extended its distribution when collections were made in Miramar just north of the Miami-Dade County line. The known distribution range encompassed an area of 830 km<sup>2</sup> by June 2018. Over an 18-year period, there was an average increase in the distribution range of approximately 46 km<sup>2</sup> per year. The range expansion across years closely fit a linear function ( $r^2 = 0.96$ ; Figure 3).

In general, *C. marulius* inhabits canals that comprise the interconnected human-made water management system constructed to provide freshwater and flood protection for southeastern Florida (Miami-Dade, Broward, and Palm Beach counties). The large main canals in this area generally flow in an easterly or southerly direction and empty into the Atlantic Ocean. Those canals are generally box-cut with vertical shorelines cut into the lime rock substrate and average approximately 30 m wide and greater than 3 m deep. They can also have aquatic vegetation on a 1–2 m wide littoral shelf. Main canals connect with an extensive system of increasingly smaller, shallower and more vegetated canals that drain urban surface waters during heavy rain events. Many canals are connected to human-made “lakes” that range from less than one to several hundred acres, a few of which are deep (e.g., 18 m). All main canals and some lateral canals have water control structures that can act as barriers to fish movement. From survey observations, *C. marulius* was often associated closely with shoreline structure including floating aquatic vegetation, overhanging woody vegetation, and boat docks. They also tended to be more abundant in shallow, heavily-vegetated secondary canals than in the main canals. The species is present in a number of isolated ponds and small lakes in southeastern Florida, suggesting it is being moved by people.

## Discussion

The Channidae family was recognized early on as a potential problem by the State of Florida. In March of 1970, the State recommended that the genera *Channa* and *Ophicephalus* (currently a junior synonym of *Channa*) “be included on our list of restricted fishes” (*pers. comm.* from V.E. Ogilvie to J.W. Woods 1970). In 1979, the Channidae family was placed on the State of Florida’s Prohibited Non-native Aquatic Species list (F.A.C. Rule 68A-23.008) that prohibited the possession of live fish with permitted exceptions for research and exhibition (FWC 2010). Despite being on the State’s prohibited list, *C. marulius* was later collected in Florida and established a reproducing population.

Like so many other introductions of fishes, it is not known exactly how, when, and where *C. marulius* first entered the United States. However, why it was introduced is likely explained. Several snakehead species are valued as food fishes and to a lesser degree aquarium pets and have been introduced widely across Asia through trade and aquaculture (Courtenay and Williams 2004). *Channa marulius*, however, is not often found in the aquarium trade because of its aggressiveness towards other fish (Schmidt 2001). In Thailand, it is a popular gamefish among tourists which may have led to illegal stocking in Florida although there is no direct evidence (Courtenay and Williams 2004). In India and Pakistan where it is native, *C. marulius* is cultured as a food fish for human consumption (Bardach et al. 1972) and commercially harvested from the wild (Dua and Kumar 2006). Live fish fetch the highest price, but they are also sold freshly dead or dried (Wee 1982). Snakehead is viewed as an economically important species within its native range (Parameswaran and Murugesan 1976) so much so that its importance in local human diets has led to the decline of some wild populations in India (Habib et al. 2011; Ali et al. 2013). As part of their cultural heritage, tribes in West Bengal, India have chosen to protect *C. marulius* where industrial development has had a negative impact on biodiversity (Deb and Malhotra 2001).

Little has been documented about the reproduction of *C. marulius* in Florida. In its native range, sexual maturity for some individuals begins at about 360 mm total length (TL) in males and females alike; but it is not until males reach 560 mm TL and females 660 mm TL are they all sexually mature (Devaraj 1973). Naturally, *C. marulius* lay their floating eggs in areas with vegetation; however, they will spawn in fish farm ponds without aquatic vegetation (Parameswaran and Murugesan 1976), which could help explain their success in artificial habitats of southeastern Florida.

In general, the fecundity of snakeheads is considered relatively low compared to other fishes (Wee 1982) and depending on the maturity stage (i.e. size), the number of eggs for *C. marulius* ranged from approximately 2,200–18,400 (Devaraj 1973). Snakeheads exhibit biparental nest guarding behavior, thereby increasing reproductive success in all habitats (Parameswaran and Murugesan 1976; Wee 1982; Schmidt 2001). Like all other species in the Channidae family, adult *C. marulius* are carnivorous (Talwar and Jhingran 1991), feeding primarily on fishes and crustaceans. Very young snakeheads feed on protozoa and algae as larvae; then as they grow into fry, the diet shifts to zooplankton, and eventually to include insects, benthic crustaceans, mollusks, and larvae and fry of other fish (Wee 1982; Bhuiyan et al. 2006). Its ability to adapt to a wide variety of available food is also likely to allow the snakehead to easily adapt to novel environments.

The native habitat of *C. marulius* is described as lakes and rivers, with deep pools and clear water (Talwar and Jhingran 1991). In addition, the species can be found in canals, lakes, and swamps with little or no flow in its native range (Rainboth 1996), which is similar to the habitats *C. marulius* occupies in Florida. Courtenay and Williams (2004) stated the native range spanned from latitudes 7°N to 34°N, which partially includes a temperate climate. Using an ecological niche model to predict suitable habitat that included variables such as frost frequency and air temperatures, Herborg et al. (2007) showed a North American distribution for *C. marulius* limited to most of Mexico and the southern United States up to approximately 35°N latitude. However, preliminary testing of the lower temperature limit is approximately 10 °C (KBG, *unpublished data*), which may restrict the species to southern Florida.

The habitat of extreme southern Florida, including Everglades National Park (ENP) and Big Cypress National Preserve, consisting of wetlands, swamps, and coastal river headwaters is home to 92 native freshwater fishes (Loftus and Kushlan 1987). It is possible that *C. marulius* could spread beyond the canal system into unique natural ecosystems such as those in ENP, a designated UNESCO World Heritage Site, which may potentially provide suitable habitat and a diverse array of prey. Within novel environments of the canal system of southern Florida, Gandy and Rehage (2017) showed that fish assemblages favor non-native species over natives. This canal system likely provides a conduit for non-native fishes to disperse into protected areas (Loftus 1988); 17 non-native fish species have already been documented in ENP (Kline et al. 2014). Kline et al. (2014) stated that legislation is in place to minimize

the spread of non-native species into ENP, but at the same time, plans to restore the Everglades region will use the canal system to deliver water to those natural areas. Unfortunately, canal habitat may protect non-native fish from drought (Loftus and Kushlan 1987) and unseasonably cold winter temperatures in some waters (Schofield et al. 2010), thereby serving as a potential continuous source of non-native fish to natural areas. We believe *Channa marulius* has not yet reached its potential distribution and will likely continue to disperse in southeastern Florida where suitable habitats exist.

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### Supplementary material

The following supplementary material is available for this article:

**Table S1.** A list of locations in the State of Florida, USA where bullseye snakehead (*Channa marulius*) collections were made from 2000 to 2018.

This material is available as part of online article from:

[http://www.reabic.net/journals/bir/2018/Supplements/BIR\\_2018\\_Benson\\_etal\\_Table\\_S1.xlsx](http://www.reabic.net/journals/bir/2018/Supplements/BIR_2018_Benson_etal_Table_S1.xlsx)