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Research Article

# Non-native marine fishes in Florida: updated checklist, population status and early detection/rapid response

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## Abstract

It has been ten years since the last comprehensive assessment of non-native marine fishes in Florida. Herein, we report sightings of 41 species from Florida coastal waters since the earliest reported sighting in 1984. Information is provided on the population status of each species (e.g., established, eradicated, unknown), and our early detection/rapid response program to remove these fish is described. Of the 41 species, five have established reproducing populations. Nineteen species are either eradicated or failed, while the status of 17 additional species is unknown. Since 1999, 18 individuals comprising 13 species have been removed from coastal waters, most of which were collected through our early-detection/rapid-response program. Many of those fishes were transferred to public aquaria where they were displayed to provide educational information to the public. Most reports of non-native marine fishes originated from citizen scientists, emphasizing the importance of outreach and education.

**Key words:** ED/RR, nonindigenous marine fishes, response to introductions, citizen science

## Introduction

Controlling and mitigating effects of non-native species is estimated to cost 120 billion dollars in the USA each year (Pimentel et al. 2005). Once established, those species are rarely eradicated, and financial and human resource costs can grow beyond the ability of resource managers to effectively address the invasion. Invasions in marine environments pose special challenges due to limited ability to document and respond to invasions underwater, as well as the vastness and interconnectedness of the environment (Arndt et al. 2018).

The recent spread of non-native lionfishes (*Pterois volitans* (Linnaeus, 1758) and *P. miles* (Bennett, 1828); Schofield 2010) and their detrimental effects on native reef systems (e.g., Green et al. 2012) has brought awareness to the problems of marine fish introductions. Worldwide, the number of non-native marine fishes has increased steadily over the past few decades

(Arndt et al. 2018). In Florida, little attention was paid to non-native marine fishes until the arrival of the lionfishes. The first published report of non-native marine fishes in Florida is Courtenay (1995), a short (three paragraph) section of a newsletter in which he mentioned six species of non-native marine fishes but gave no details. Semmens et al. (2004) documented 16 non-native marine fish species off southeast Florida, and five years later Schofield et al. (2009) summarized reports of 33 non-native marine fishes observed in Florida waters. Herein, we provide an updated listing of non-native marine fishes in Florida, summarize sighting data for each species, and provide a population status for each species (e.g., established, eradicated, etc.). We also describe our early-detection/rapid-response (ED/RR) program for non-native fishes and its results to date.

## Materials and methods

Sighting records were compiled from the US Geological Survey's Nonindigenous Aquatic Species database (USGS-NAS 2018a). The USGS-NAS database is the federal repository of geo-referenced sighting reports for aquatic non-native species. Reports to the USGS-NAS database often come from citizen scientists who submit sighting records online via either the Reef Environmental Education Foundation (REEF) or USGS-NAS reporting websites (REEF 2018; USGS-NAS 2018b) as well as from published scientific literature and personal communications from natural-resource managers, biologists, and others. Records were verified by interviewing the reporters or obtaining photos of the specimens from them. Data in the USGS-NAS database change daily as new reports are added. The data we present in this report were queried on 11 December 2018.

Taxonomy of non-native fishes can be puzzling, as there are often more than one species in a genus that appear similar (e.g., *Pterois, Heniochus*). We are sometimes presented with only a photo or description of a species, especially for older reports. Without morphometric/meristic verification or genetic information, species identities are difficult to confirm. Additionally, it is possible that fishes are hybrids (e.g., Burford Reiskind et al. 2019). Because of these difficulties, we have combined some taxa in our reporting here (e.g., *Pterois*, *Heniochus*).

We assigned a population status to each species as follows:

- Established: Populations that are reproducing, evidenced by the presence of juveniles and numerous adults, including adults in breeding condition.
- Eradicated: All individuals reported were subsequently removed from the wild.
- Failed: Species not seen since it was detected (at least ten years prior); likely never reproduced.
- Unknown: Insufficient information to determine status.

The designation of "failed" is a presumption, as it can never be proven that the fish is no longer extant in the wild. We base our designation on a few lines of evidence: The locations from which these fishes were reported are not remote or difficult to access and are regularly visited by divers. We chose ten years since the last sighting as the cut-off for assigning species status, reasoning that most non-native fishes would have either died or been re-sighted by then.

### *Early-Detection/Rapid-Response (ED/RR)*

We developed an early-detection/rapid-response (ED/RR) program to remove non-native marine fishes from Florida waters. The purpose of the program is to remove newly-introduced species in hopes of eradicating them before they become established. Over time, we developed a process for reporting, validation, notification, removal and deposition of non-native marine fishes (see Supplemental material Appendix 1 for details).

## Results

Forty-one non-native marine fish species were documented from Florida coastal waters, including 3,078 lionfish records and 289 non-lionfish records (Supplementary material Table S1). Summary data in Table S1 include the Family to which the fish belongs, its scientific and common names, its native and introduced ranges, and comments on its population status. The first record was from 1984 (*Chromileptes altivelis* (Valenciennes, 1828)). Fishes were documented from both coasts of Florida (Atlantic and Gulf of Mexico), with a concentration of sightings in southeast Florida (Figure 1).

Sighting records of non-native marine fishes were received from a variety of sources, primarily from citizen scientists. Many sightings were provided by individuals trained to recognize native species and who were able to recognize unfamiliar species (i.e., not native). Commercial and recreational fishers also provided some sightings. Often, those records were reported to local law-enforcement or wildlife officials, who forwarded them to us.

### *Established species*

At this time, five species are established in Florida, of which the lionfishes (*Pterois volitans/miles*) are the most widespread. Genetic evidence has shown that most non-native lionfish are *P. volitans*, with *P. miles* only occurring rarely (Betancur-R et al. 2011). However, as they are indistinguishable without the use of genetics, they are grouped together in the USGS-NAS database and here. These species are established along the Atlantic seaboard from the Florida Keys north to North Carolina, with occasional strays carried north by currents as far as Massachusetts. The lionfishes are

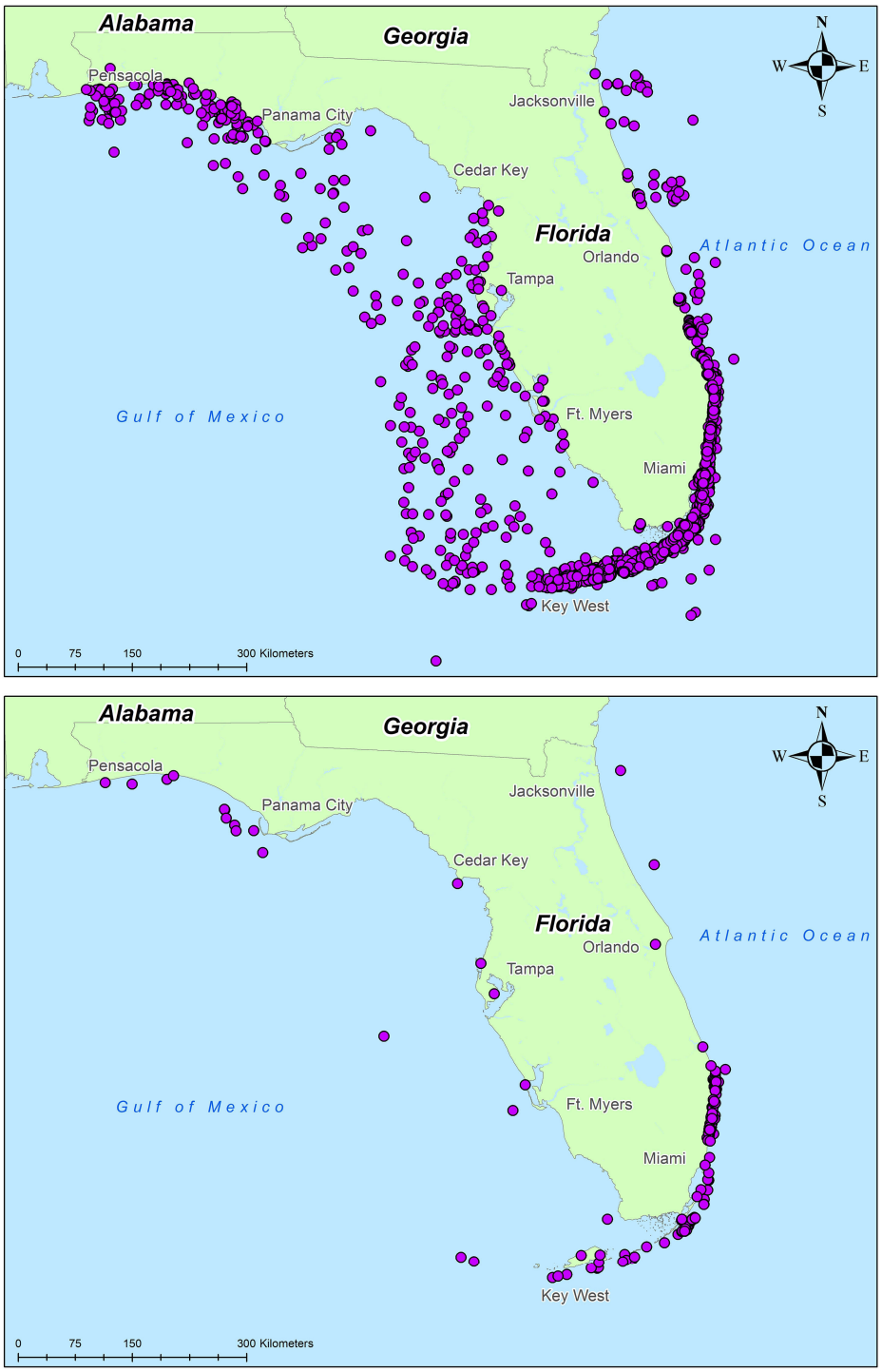


**Figure 1.** Maps showing sighting reports for lionfishes (*Pterois volitans/miles*; top panel) and all other non-native marine fishes (bottom panel) in Florida (USGS-NAS 2018a).

also established throughout the coastal Caribbean, Gulf of Mexico, and in South America south to Venezuela. One individual was captured in southern Brazil in 2014, although it is not clear whether that was a secondary introduction or dispersal from the Caribbean population (Ferriera et al. 2015). Lionfishes have been present in Florida waters since at least 1985 (Morris and Akins 2009). Sighting reports were minimal from 1985 (first report) until 2008, when there was a spike in reports (Figure 2).

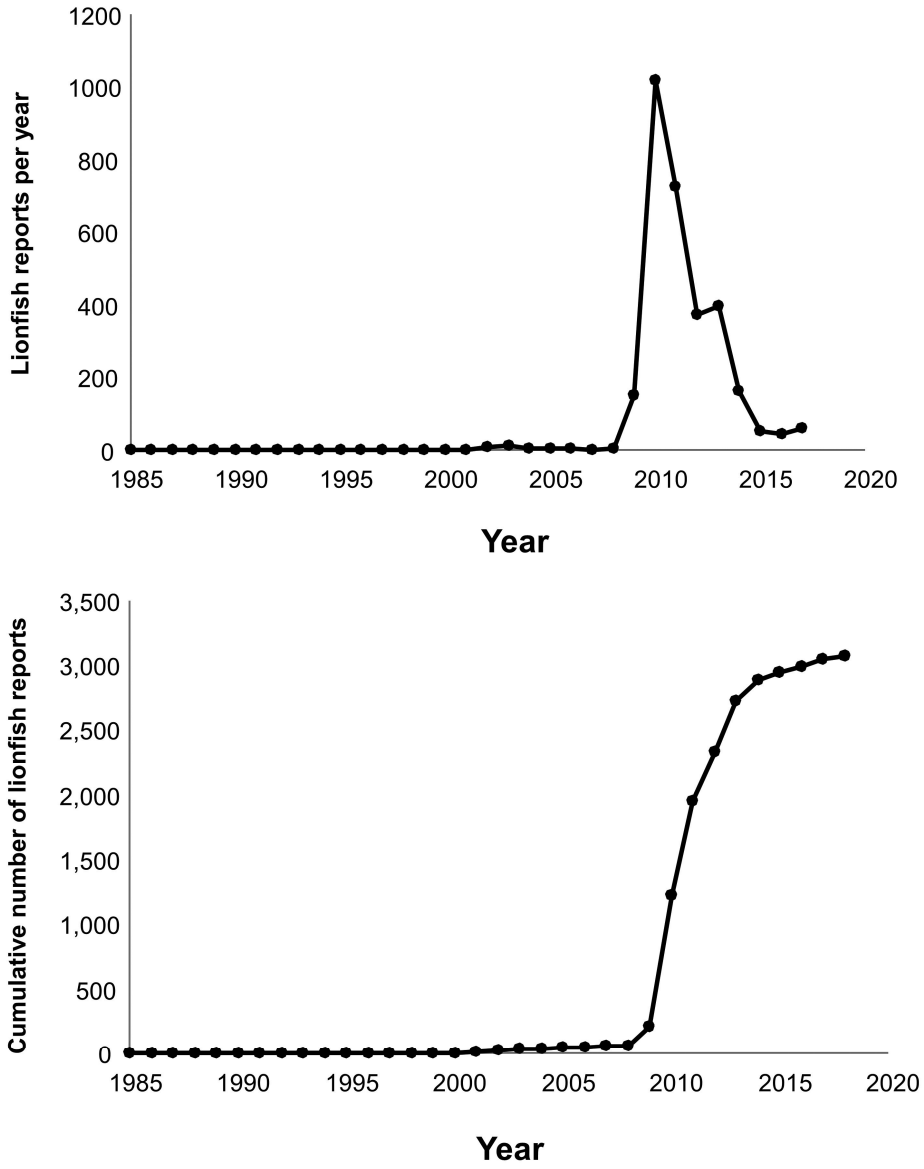


**Figure 2.** Number of lionfish (*Pterois volitans/miles*) sightings in Florida reported to the USGS-NAS database by year (top panel) and cumulative (bottom panel). Each report could represent more than one fish. See text for details of USGS-NAS data collection.

The year with the greatest number of reports was 2010 (1,021 lionfish reports), after which sighting reports decreased.

*Gramma loreto* Poey, 1868 has been present in Florida waters since at least the 1990s and possibly earlier. The species is considered non-native (Nelson et al. 2004) and is present in the aquarium trade, a major pathway of non-native fish introductions (Semmens et al. 2004). However, it is native to nearby locations, such as the Bahamas and Greater Antilles (Böhlke and Randall 1963; Mooi and Gill 2002). Thus, its presence in Florida may be a natural range extension as a vagrant.

*Hypsoblennius invemar* Smith-Vaniz and Acero P., 1980 is also of questionable origin. Native to the Lesser Antilles and South America, it may have reached the Gulf of Mexico via larval dispersal. Dennis and Bright (1988) report the species was first documented from oil platforms

off Cameron, Louisiana and Galveston, Texas in 1979, but that it was absent from earlier fish surveys. The species occupies barnacle tests, and one hypothesized mechanism of its transfer to the Gulf of Mexico includes transport of the species inside barnacles affixed to ships' hulls or oil and gas platforms towed from South America to the Gulf of Mexico.

*Neopomacentrus cyanomos* (Bleeker, 1856), an Indo-West Pacific damselfish, is a relatively recent addition to the Florida (and Gulf of Mexico) marine-fish community. It was first documented in the southwestern Gulf of Mexico on nearshore coral reefs near Coatzacoalcos, Mexico in 2013 (González-Gándara and de la Cruz-Francisco 2014). In 2014 and 2015, individuals were observed on reefs near Veracruz City, and at Madagascar Reef off the northwestern Yucatán Peninsula (Robertson et al. 2016). The species was detected in the northern GOM off Louisiana in 2016. In 2017 it was also found off Texas, Mississippi, Alabama and the Florida panhandle. At this time, it is not thought to be present along the Gulf coast of the Florida peninsula; however, future invasion there and into the Florida Keys is likely. The most probable explanation for its transfer is as a hitchhiker on towed oil and gas platforms from the native range (Robertson et al. 2016).

### *Eradicated species*

For the three eradicated species, only one individual was seen of each species, and it was subsequently removed. Those species include: *Amphiprion ocellaris* Cuvier, 1830, *Siganus unimaculatus* (Evermann and Seale, 1907) and *Acanthurus pyroferus* Kittlitz, 1834 (Tables S1, S2). Two of the eradicated individuals (*S. unimaculatus, A. pyroferus*) were collected by us as part of our ED/RR program.

### *Failed/Eradicated species*

For two species (*Naso lituratus* (Forster, 1801), *Rhinecanthus aculeatus* (Linnaeus, 1758)), there are large time gaps between sightings. Early sightings of those species were reported in 2006 or before; thus, since those sightings were more than ten years ago those introductions presumably failed (Table S1). Recent (2018) sightings of both species were verified, and the individuals removed by us as part of our ED/RR program (Table S2).

### *Failed species*

Fourteen species are designated as failed, as they have not been seen for more than ten years (Table S1). Of those, nine species were seen only once and never again (*Chiloscyllium punctatum* Müller and Henle, 1838, *Pomacanthus xanthometopon* (Bleeker, 1853), *Dascyllus trimaculatus* (Rüppell, 1829), *Acanthurus guttatus* Forster, 1801, *A. sohal* (Forsskål, 1775), *Zebrasoma desjardinii* (Bennett, 1836), *Z. scopas* (Cuvier, 1829),

*Rhinecanthus verrucosus* (Linnaeus, 1758), *Arothron diadematus* (Rüppell, 1829)). Each of the remaining five species were seen a few times, some in more than one location. Almost all sightings were of single individuals.

### *Unknown-status species*

Seventeen species are designated as having a status of unknown (Table S1). Some of these, such as *Platax orbicularis* (Forsskål, 1775), *Pomacanthus semicirculatus* (Cuvier, 1831), *P. maculosus* (Forsskål, 1775), *Zebrasoma flavescens* (Bennett, 1828) and *Z. veliferum* (Bloch, 1795) have been reported multiple times, often in numerous localities. It is possible that the popularity of these species as aquarium pets may have led to increased numbers of releases.

Of particular concern for possible establishment is *Chromileptes altivelis* (Valenciennes, 1828), which has been reported eight times in eight different locations between 1984 and 2012, including both Gulf and Atlantic coasts of Florida. Juveniles are strikingly beautiful and commonly sold in pet stores at a small size. However, they can quickly outgrow their tanks, which may instigate releases into the wild and thereby increase propagule pressure (Holmberg et al. 2015). Maximum size of this species is 70 cm total length (TL; Heemstra and Randall 1993). The specimen collected in 2012 off Key Largo was 68 cm TL and weighed nearly 7 kg. The species was also reported from Hawai'i several times in what were suspected as aquarium releases; however, those introductions are considered failed (Randall and Heemstra 1991; Mundy 2005).

*Acanthochromis polyacanthus* (Bleeker, 1855) is also of concern for potential establishment, but is of unknown status. We received two unverified reports of individuals from a Miami Beach marina in June and early July 2017 but were unable to obtain permissions to enter the water for several weeks. In late July 2017, a team from the Florida Fish and Wildlife Conservation Commission (FWC) visited the site on a boat and reported seeing 12–20 individuals. FWC personnel caught two specimens on hook-and-line, one of which was photographed (Figure 3). Unfortunately, because the carcasses were discarded, positive identification of the species could not be made. However, the photo allowed us to tentatively identify the species as *A. polyacanthus*. In late August 2017, we obtained permission to enter the water at the marina and surveyed the area, but no *A. polyacanthus* were observed. Subsequent to our survey, extreme conditions during hurricane Irma (September 2017) may have influenced the population, either causing mortality or relocation. There have been no subsequent reports of the species to date.

### *Early-detection/rapid-response*

Since 1999, 18 individuals from 13 species have been removed from Florida's coastal waters. Of those, 14 individuals in 9 species were removed

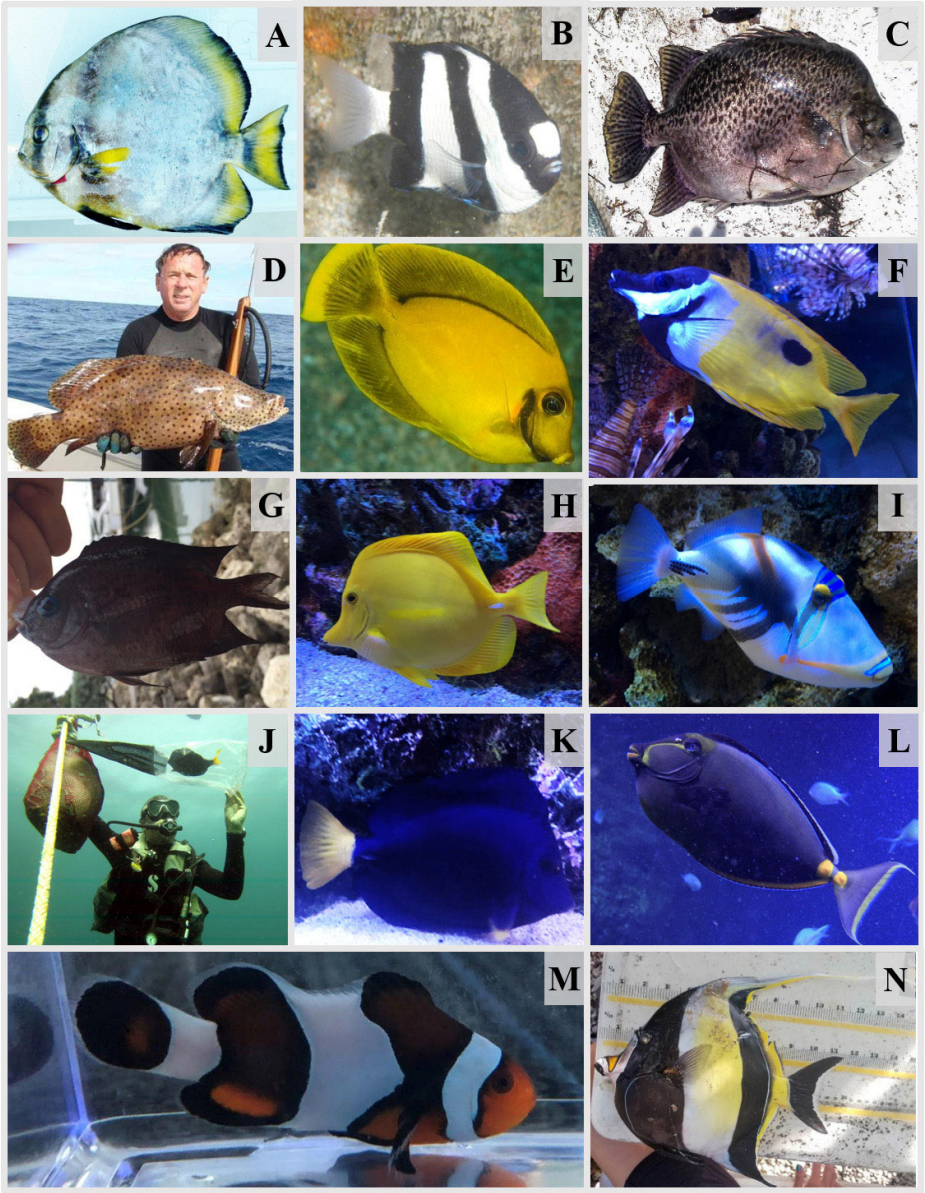


**Figure 3.** Photographs of non-native marine fishes removed from Florida waters. A: Orbicular batfish *Platax orbicularis* collected October 2018. Photo by Lad Akins. B: Humbug damselfish *Dascyllus aruanus* collected April 2009. Photo by Lureen Ferreti. C: Scat *Scatophagus argus* collected July 2011. Photo by Chad Gibson. D: Panther grouper *Chromileptes altivelis* collected December 2012. Photo by Wayne Grammes. E: Chocolate surgeonfish *Acanthurus pyroferus* collected December 2014. Photo by Deborah E. Devers. F: Foxface rabbitfish *Siganus unimaculatus* collected September 2016. Photo by Kat Nicholson, Phillip and Patricia Frost Museum of Science. G: Spiny chromis *Acanthochromis polyacanthus* collected July 2017. Photo by Alan Peirce, FWC. H: Yellow tang *Zebrasoma flavescens* captured August 2018. Photo by Kat Nicholson, Phillip and Patricia Frost Museum of Science. I: Lagoon triggerfish *Rhinecanthus aculeatus* captured April 2018. Photo by Kat Nicholson, Phillip and Patricia Frost Museum of Science. J: Photo by Emily Pepperman. K: Purple tang *Zebrasoma xanthurum* collected September 2018 (same individual as J). Photo by Andy Dehart, Phillip and Patricia Frost Museum of Science. L: Orangespine unicornfish *Naso lituratus* collected March 2018. Photo by Zach Ransom. M: Clown anemonefish *Amphiprion ocellaris* collected July 2018. Photo by Don Stansell. N: Moorish idol *Zanclus cornutus* collected November 2018. Photo by Vanessa McDonough, Biscayne National Park.

by us, often working closely with our partners (Table S2; Figure 3). Four fish were removed by individuals not directly associated with our ED/RR program, but who were in contact with us after the removals. Not all

attempts to remove fish were successful. We were unable to collect six individuals (five species; Table S2).

## Discussion

As of 2018, 41 non-native marine fish species have been documented from Florida's coastal waters. Most reports came from southeast Florida and the Florida Keys (Palm Beach, Broward, Miami-Dade and Monroe counties). While it is tempting to conclude that more non-native marine fishes occur in this area, it is important to remember that sighting data may not necessarily reflect fish abundance. It is possible that more people in those areas are reporting the presence of non-native fishes, possibly because more people are in the water there or because they are better-educated about reporting non-native species.

For lionfishes, only a few fish were reported each year between 1985 and 2008, presumably reflecting the lag phase of the invasion (Crooks 2005). A sharp increase in reports occurred in 2009–2010, which was probably a combination of increases in lionfish abundance combined with an increase in awareness and reporting. After 2010, the annual number of sighting reports decreased, probably because the public became accustomed to seeing lionfishes and stopped reporting them. Citizen scientists are a powerful ally in tracking non-native species (e.g., Darwall and Dulvy 1996; Delaney et al. 2008). Citizen science reports to the USGS-NAS database reported lionfishes earlier and more frequently than traditional fishery-independent monitoring programs, demonstrating their usefulness for tracking initial invasions (Scyphers et al. 2015). However, because of declines in reporting after establishment, traditional fishery-independent (agency-run) monitoring programs may be better suited to track population dynamics in the years after establishment (e.g., Ruttenberg et al. 2012).

Most of the non-native marine fishes found off the Florida coasts are present in the aquarium trade, and, like Semmens et al. (2004), we suspect that is their pathway of entry. A few of the same non-native marine fishes found in Florida have also been introduced in other countries. For example, *Pomacanthus maculosus* and *Heniochus acuminatus* (Linnaeus, 1758) were recently documented from southern Brazil (Adelir-Alves et al. 2018; Soeth et al. 2018). The study of the aquarium trade as a pathway for non-native species introductions in marine environments has lagged behind other pathways such as ballast water (Padilla and Williams 2004). However, in Florida it may be a fruitful area of future study. At the present time, too little information exists to determine at what point in the aquarium trade process fish are liberated into coastal environments: at ports of import, retail outlets, with the consumer or some other point. It is widely speculated that introductions may be the result of consumers deliberately releasing their pets as a means of humanely disposing of them (Courtenay and Taylor 1986; Courtenay and Stauffer 1990). If this is the case, it highlights

the important role of education and outreach, as well as the importance of providing options for responsible disposal of unwanted fishes. Educating the public (i.e., consumers) is vital, but could also be enhanced at the retail level. For example, Chang et al. (2009) suggested improving fish labelling at the point-of-sale and implementing programs to enhance invasive species awareness and education among store representatives.

Not all non-native marine fish in Florida are in the aquarium trade. Of the five established species in Florida, two (*Hypsoblennius invemar* and *Neopomacentrus cyanomos*) are thought to have arrived via hitchhiking on ships' hulls or towed oil and gas platforms (Dennis and Bright 1988; Robertson et al. 2016). The potential to transfer marine fishes with towed oil platforms has recently begun to receive attention, as Pajuelo et al. (2016) documented the transfer of 11 fish species to the Canary Islands in this manner. Similarly, Dulčić and Dragičević (2013a, b) reported the presence of an Atlantic serranid and an angelfish in the Mediterranean and suggested their transfer was associated with a recently towed oil platform. Additionally, an Indo-Pacific blenny that has established in several locations in the southwestern Atlantic Ocean is suspected of hitchhiking on ships' hulls or towed oil platforms (Gerhardinger et al. 2006). It is possible that the specimens of *Pomacanthus maculosus* and *Heniochus acuminatus* recently documented from southern Brazil (Adelir-Alves et al. 2018; Soeth et al. 2018) were also a result of this pathway.

Thus far, 18 individuals comprising 13 species have been removed from Florida's marine waters (Table S2). Of those, 14 individuals (in 9 species) were removed as part of our ED/RR program while the rest were removed by others. The goal of the ED/RR program is to remove new introductions before they can become established. Some managers consider a single individual of a species to be a low risk, as a single fish cannot usually start a population. However, imperfect detection of individuals may mean that the true number of individuals present is unknown. Furthermore, if one individual was introduced, the possibility of more introductions exists, providing the potential to build a population over time. And, even a single fish can transfer parasites or pathogens to native species. The best-documented marine-fish invasion is that of the lionfishes, which were rarely observed between 1985 and 2008 until the population increased rapidly. Our concern is that other non-native marine fishes may be in a similar lag-phase of invasion, either presently or in the near future. By discounting these minimal but persistent sightings of non-native fishes, assessments of their future risk could be inaccurate and a critical window for action could be missed (Crooks 2005). For these reasons, we attempt to remove non-native fishes even when only one individual is observed.

The effects of lionfishes have been documented extensively (e.g., Albins and Hixon 2008; Green et al. 2012; Albins 2013; Benkwitt 2015). In fact, it is one of only a few non-native marine fishes worldwide for which effects

have been determined (see review by Arndt et al. 2018). For most non-native marine fishes, there are no studies of their effects, thus there are no data to quantify their impacts (Arndt et al. 2018). Without adequate data to determine risk of effects, the only sensible approach is a precautionary one (Leprieur et al. 2009). Additionally, the most effective way to deal with new non-native species is to remove them as quickly as possible before they have the opportunity to spread (Simberloff 2003, 2009).

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**Supplementary material**

The following supplementary material is available for this article:

**Appendix 1.** Early-Detection/Rapid-Response (ED/RR) program for non-native marine fish in Florida.

**Table S1.** Summary of non-native marine fishes in Florida.

**Table S2.** History of non-native marine fish removals in Florida.

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