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Research Article

Distribution and status of five non-native fish species in the Tampa Bay drainage (USA), a hot spot for fish introductions

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Abstract

The Tampa Bay region of Florida (USA) is a hot spot for non-native freshwater fishes. However, published information on most non-native fishes in the basin is not current. Systematic sampling efforts targeting non-native fishes in the region were conducted from 2013–2015 by the University of Florida Tropical Aquaculture Laboratory. Data from these recent surveys were analyzed, along with historic and new data from published and unpublished sources, to assess current fish distributions and determine status. We focus on five of the non-native species sampled: pike killifish *Belonesox belizanus* Kner, 1860, green swordtail *Xiphophorus hellerii* Heckel, 1848, southern platyfish *Xiphophorus maculatus* (Günther, 1866), Mayan cichlid *Mayaheros urophthalmus* (Günther, 1862), and Jack Dempsey *Rocio octofasciata* (Regan, 1903). All five were found to have reproducing populations in the basin, each showing broader distributions than previously indicated. Non-native populations of four of the species have persisted in the Tampa Bay region since at least the 1990s. In contrast, the presence of Mayan cichlid in the basin was not confirmed until 2004. Based on numbers, distributions, and years of persistence, these five species all maintain established populations. Pike killifish and Mayan cichlid are established and spreading throughout multiple habitat types, while green swordtail, southern platyfish, and Jack Dempsey are localized and found primarily in more marginal habitats (e.g., small ditches and first order tributary streams). Factors affecting continued existence and distributions likely include aquaculture, biotic resistance, and thermal and salinity tolerances. We also clarify non-native species status determination using a multi-agency collaborative approach, and reconcile differences in terminology usage and interpretation.

Key words: exotic, invasive, Poeciliidae, Cichlidae, Florida

Introduction

Florida has records of more non-native freshwater fish species from outside the country than any other state in the United States (Shafland et al. 2008a; USGS 2017a). Florida is particularly susceptible to invasion because of its warm climate and diversity of aquatic habitats. Strong contributors to introductions include a large human population, numerous importation hubs, and a well-established aquaculture industry that rears hundreds of non-native fish species and varieties (Hill 2002; Hill and Yanong 2010). Research on non-native fishes has generally focused on southern Florida, a region where the sub-tropical climate has allowed approximately 40 fish species to establish populations (K Gestring, unpublished data;

Trexler et al. 2000; Schofield et al. 2010; Rehage et al. 2014; USGS 2017a). Less attention has been directed at non-native fishes in other regions.

One region in which the non-native fish fauna has received limited attention is the Tampa Bay area in west-central Florida. The Tampa Bay area is considered a hot spot for invasion, a conclusion supported by historic descriptions of regional fish introductions over the past several decades (Courtenay et al. 1974; Courtenay and Stauffer 1990). Unfortunately, the lack of directed sampling and a scarcity of publications with occurrence records in the peer-reviewed literature or publicly available databases mean much of the information on the distribution and status of non-native fishes in the Tampa Bay area is outdated.

The various agencies, groups, and scientists in Florida often disagree regarding the status of non-native fishes in the state; specifically, whether certain non-native species are reproducing, established, or spreading (Shafland et al. 2008a; FWC 2017a; USGS 2017a). These inconsistent conclusions are largely due to differences in terminology, data availability, and criteria used to determine non-native species status (Nico and Fuller 1999; Colautti and MacIsaac 2004). These determinations were also made at the state level rather than regions within the state; spatial scale can clearly affect terminology. Status determination in the Tampa Bay area is also confounded by inadequate up-to-date information on species' distribution and abundance. Moreover, distributions may change due to cold spells and other limiting factors, illustrating the importance of frequent updates.

A recent project completed by the University of Florida/IFAS Tropical Aquaculture Laboratory (UF TAL) included systematic sampling of freshwater non-native fishes in the Tampa Bay area (Tuckett et al. 2017). This effort resulted in new distributional records which highlighted a need to update information on the distribution and status of five non-native fishes: pike killifish *Belonesox belizanus* Kner, 1860, green swordtail *Xiphophorus hellerii* Heckel, 1848, southern platyfish *Xiphophorus maculatus* (Günther, 1866), Mayan cichlid *Mayaheros urophthalmus* (Günther, 1862; see Říčan et al. 2016), and Jack Dempsey *Rocio octofasciata* (Regan, 1903). These species were chosen because they have unique invasion histories, and previously uncertain geographic distributions and establishment statuses in the Tampa Bay area.

To provide a more comprehensive assessment of existing records, data were gathered from publicly available, online databases, internal agency databases, and personal collection records of coauthors. Prior to this collaborative effort, Tampa Bay distribution records pertaining to these five species were highly limited and only publicly available via USGS (2017a). In the present paper, we provide updated information on the Tampa Bay area distribution of these five non-native fishes, assess their current establishment status, and attempt to resolve issues regarding terminology and status criteria.

Methods

Study area

Tampa Bay is a large estuary in west-central Florida connected to the Gulf of Mexico (Figure 1). The Tampa Bay basin (6,853 km^2) includes all or parts of Pinellas, Pasco, Hillsborough, Polk, and Manatee counties (Rains et al. 2012). Numerous rivers, canals, tidal creeks, and ditches flow into the bay, although most natural waterways have been highly modified. Many of the watersheds are dotted with natural and human-made ponds, lakes, and wetlands. The lower reaches of the major river systems in this region, near their junctions with Tampa Bay, are estuarine environments. Thus, distribution records span a salinity gradient from Tampa Bay and adjacent river mouths to upstream freshwater environments. Temperature is an important factor limiting the abundance and distribution of non-natives originating from tropical regions (Shafland and Pestrak 1982). Tampa Bay winters are generally warmer than other parts of central Florida, with January mean minimum water temperatures ranging between 12–16 °C (Lawson et al. 2015).

Data collection

Data originated from the UF TAL, Florida Fish and Wildlife Conservation Commission (FWC), United States Geological Survey Nonindigenous Aquatic Species Database (USGS NAS), and author personal collections. Data from FWC originated primarily from the Florida Fish and Wildlife Research Institute (FWRI), but included records from the Wildlife Impact Management Section. The Florida Museum of Natural History (FLMNH 2017) also contributed records but these are all incorporated into the USGS NAS database. Some records are supported by voucher material (Tables S1–S5) deposited and catalogued in ichthyological collections of the FLMNH (Gainesville), and the Florida State Board of Conservation (FSBC) at FWRI (St. Petersburg, FL). A small proportion of USGS NAS data is designated as approximate or centroid (Fuller and Neilson 2015). These data were not included in our distribution maps.

Records from FWC (including FWRI) and author personal collections, except for pike killifish distribution data from Greenwood (2012, 2017), were

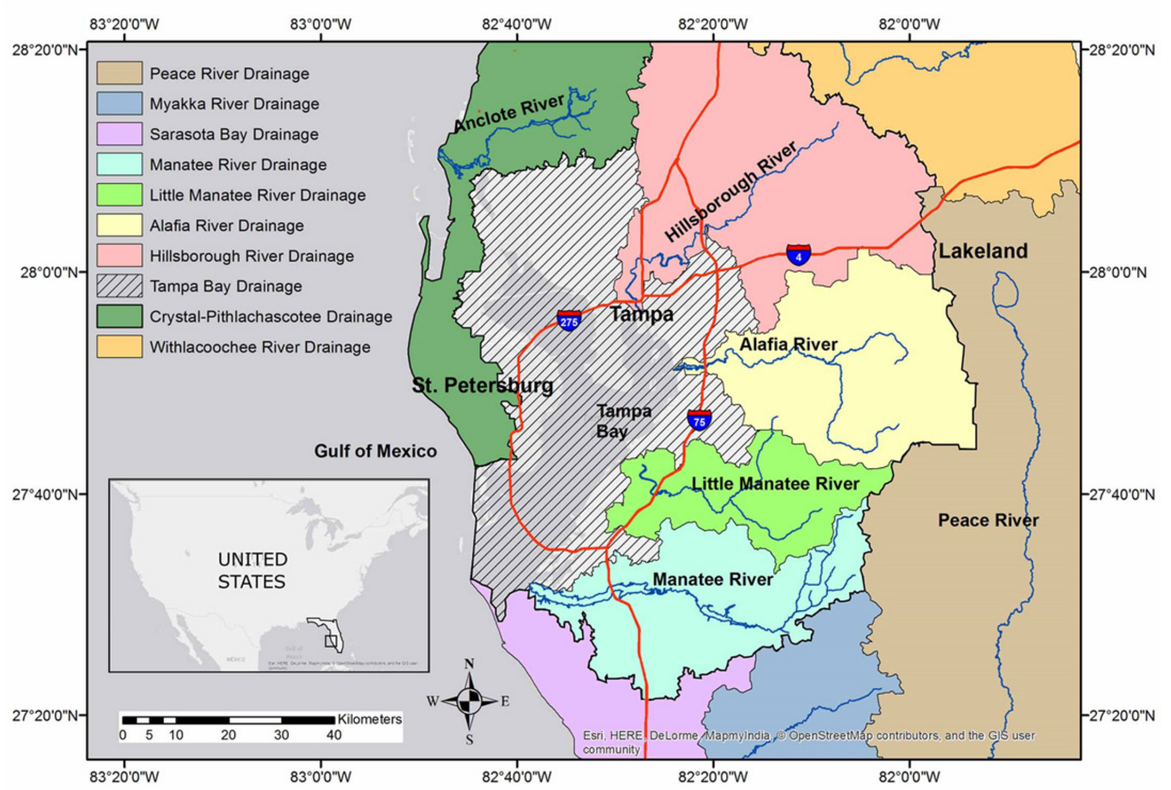

Figure 1. Maps showing the location of Tampa Bay and its major tributary drainages in the state of Florida, southeastern United States. Drainages are at the hydrologic unit code (HUC) 8 watershed level. The Tampa Bay Basin is composed of the Tampa Bay, Hillsborough River, Alafia River, Little Manatee River, and Manatee River Drainages, which are inside the black outline.

previously unpublished. The FWRI Fisheries Independent Monitoring program (FIM) data originated from its routine, stratified-random sampling of the Tampa Bay estuarine environment from 1995 to 2014. The FIM program uses a 21.3-meter seine for near-shore habitats with depths < 1.8 meters, and a 6.1-meter otter trawl for areas > 1.0 and < 7.6 meters deep. Larger fishes were captured using a 183-meter haul seine in areas shallower than 2.5 meters (FWC 2017b). Greenwood (2012) provides a summary of FIM methods, effort, locations, and time period for many of these samples. Additional data sources used variable sampling methods.

Much of our data resulted from recent fish sampling by the UF TAL (Tuckett et al. 2016b; Tuckett et al. 2017). Surveys covered a variety of habitat types, including human-made county ditches, natural streams, and local rivers including the Hillsborough River-Tampa Bypass Canal system, Alafia River, Bullfrog Creek, and Little Manatee River (Tuckett et al. 2017). Methods, gear type, and effort varied within and among sites. Sampling techniques were chosen to most effectively sample the particular habitat. In smaller systems such as county ditches and streams, 0.64 cm and 0.32 cm wire mesh baited minnow traps with 2-hour set times were used. In select areas, fishes were also captured using 40.64 × 30.48 cm dip nets with 0.64 cm mesh, a 3.05 m seine with 0.64 cm mesh, or a Smith-Root model LR-24 backpack electrofisher. River sites were primarily sampled using a boat electrofisher (Smith-Root model GPP9.0); however, backwater areas and sloughs were also sampled with minnow traps. GPS coordinates of capture sites were recorded.

The variability in effort and collection methods introduces biases which limit data interpretation. We therefore do not compare species abundances or presence/absence across sites. However, the large number of records allows us to update the known distribution of these species, and to assess their status in the Tampa Bay area. We divided the records into three time periods of interest: pre-2000, 2001–2010, and 2011–2016. These time periods were chosen because they best differentiate older records from newer records, and highlight the more recent and intense sampling efforts in 2013–2015.

Status determination

All locality records were compiled by species and added as point files to ESRI ArcMap 10.1 (Redlands, CA). For each species, the data were grouped by collection year and time period. Records collected prior to May 2016 were included. The terminology used to describe the status of non-native species is complicated (Colautti and MacIsaac 2004). Each of the five species was previously assigned a status by Shafland et al. (2008a), FWC (2017a), and USGS (2017a), regarding its establishment in Florida. Here, we summarize the statuses provided by these studies, and update it using the new records provided in our study (Table 1). The status for several of these species differed among sources (Table 2). Some sources were not up to date, and each status may have been based on a subset of existing records, highlighting the need for this update. We considered many characteristics when updating the status, including relevant historic ranges, distribution pattern, abundance, presence in systems from which they are unlikely to be eliminated, and evidence of reproduction (Shafland et al. 2008a, b). The terminology and criteria used in this paper are consistent with recommendations by Shafland et al. (2008b, Table 2), but also included additional descriptive terms for describing population persistence at smaller spatial scales.

Results and discussion

All five species are native to Central America and southern Mexico, with all except the green swordtail confined to the Atlantic slope (Greenfield and Thomerson 1997; Fuller et al. 1999; Miller et al. 2005; USGS 2017a). The pike killifish, green swordtail, and southern platyfish are members of the family Poeciliidae while Mayan cichlid and Jack Dempsey are in the family Cichlidae (Figure 2). These species vary in size from small-bodied (green swordtail and southern platyfish) to moderately sized (pike killifish and Jack Dempsey) to large-bodied (Mayan cichlid) (Table 3).

It is likely that all five species were introduced to the Tampa Bay area through aquarium release, escape from local fish farms, bait buckets, or a combination of those vectors. Pike killifish introduction is thought to have occurred by escape from a local ornamental aquaculture facility (Fuller et al. 1999; Greenwood 2012). Both the green swordtail and southern platyfish are popular aquarium fish that have been produced by ornamental fish farms in the Tampa Bay area for many decades (Chapman et al. 1997; Tuckett et al. 2016a). Their pathway of introduction is likely through escape from ornamental aquaculture facilities and aquarium release (Fuller et al. 1999). Mayan cichlid populations in the southern part of Tampa Bay are presumed to be the result of spread from South Florida via coastal habitats in southwest Florida (Adams and Wolfe 2007; Idelberger et al. 2011; USGS 2017a). Its disjunct distribution in the Old Tampa Bay area is likely a result of a separate introduction, possibly via bait bucket or aquarium release. Jack Dempsey were likely introduced via escape from fish farms and aquarium release because of their close proximity to fish farms and popularity in the aquarium trade.

Pike killifish Belonesox belizanus

The first confirmed record of the pike killifish in Florida dates to 1957 from a Dade County canal (Belshe 1961). It was later learned that the species had been introduced earlier in the year by the University of Miami, Department of Medicine following completion of a research project (Courtenay et al. 1974). The species subsequently spread throughout much of the southern part of the state (Green et al. 2006; USGS 2017a).

The earliest records of pike killifish in the Tampa Bay area are from 1994 in the lower Alafia River (Greenwood 2012). Additional specimens were collected from a roadside ditch within or near the Bullfrog Creek drainage, Hillsborough County, in 1997 (LG Nico, unpublished data). The USGS NAS database contained only three records for the Tampa Bay area, including reports from the Hillsborough (from 2000), Alafia (2000), and Little Manatee River (2015) drainages.

The pike killifish is now widespread in brackish and freshwater habitats from just north of the Alafia, south through the Little Manatee drainage to Port Manatee in southern Tampa Bay (Figure 3; Table S1). The status of the species in the Hillsborough River is unclear. In total there are 23 records from the 1990s, 208 records from 2000–2009, and 54 records from 2010–2015. The number of specimens collected per site ranged from 1–48 individuals. Habitats included open water, mangrove habitat, estuarine waters, river backwaters, and interior freshwater ditches. Courtenay (1997) alluded to the vulnerability of pike killifish to predators and suggested that this species avoided deeper, open waters for this reason.

The pike killifish has been listed as established in Florida for many years due to its stable populations and dispersal to other parts of South Florida (Shafland 1996; Shafland et al. 2008a; FWC 2017a; USGS 2017a). In the Tampa Bay area, pike killifish was established by at least 2012 (Greenwood 2012).

Pike killifish may continue to spread throughout the region into adjacent water bodies, using the

Table 1. Past and current status for each of the five target fish species in the Tampa Bay area. For descriptions of status terminology, please refer to Table 2.

Species/Status	Shafland et al. (2008a)	FWC (2016a)	USGS (2016)	Current Study
Pike killifish	Established in Tampa Bay area	Regionally established in Tampa Bay area	Collected in Tampa Bay area	Established, increasingly widespread
Green swordtail	Formerly reproducing in Tampa Bay area	Extirpated	Locally or possibly established in Tampa Bay area	Possibly established, localized/disjunct distribution
Southern platyfish	Formerly reproducing in Tampa Bay area	Extirpated	Locally or possibly established in Tampa Bay area	Possibly established, localized/disjunct distribution
Mayan cichlid	Reported in Tampa Bay area	Unknown in Tampa Bay area	Established in Mobbly Bayou, Tampa Bay	Established, increasingly widespread
Jack Dempsey	Formerly reproducing in Tampa Bay area	Extirpated	Collected in Tampa Bay area	Possibly established, fluctuating distribution

Table 2. Relevant terminology and definitions as outlined in Shafland et al. (2008b), FWC 2016a, and the data entry manual for USGS 2017a.

Source	Terminology	Definitions
Shafland et al. 2008b	Reproducing: Established	They can be consistently collected from water bodies too large for them to practically be eliminated, are abundant enough to indicate a stable population, and there is no species-specific environmental factor that would likely cause their demise.
	Reproducing: Possibly Established	There is evidence of reproduction, but they are so limited in range or abundance that they could potentially disappear.
	Reproducing: Localized	They are reproducing in confined and isolated areas from which they might be eliminated.
	Non-reproducing: Formerly Reproducing	They have reproduced, but have since disappeared or were eradicated.
	Non-reproducing: Species of Interest	They have been collected multiple times without evidence of reproduction.
FWC 2016a	Regionally Established Populations	Permanent populations that are found in several counties or locations.
	Locally Established Populations	Permanent populations that are found within a single county or 1-2 locations.
	Reproducing Species	Species that reproduce but have not formed stable populations.
	Observed Species	Species found in the environment but are not reproducing.
	Extirpated Species	Species that have been actively eliminated or that have naturally died out.
USGS 2017a	Established	Species is reproducing and over-wintering. Multiple year classes are present, and there are multiple collections in the area over a period of several years, comprising many individuals. Take into consideration species' biology and climate of introduced location to determine if survival/establishment is expected (e.g., pacu could be expected to become established in Florida, but not Minnesota). Eradication not possible or likely
	Locally Established	Species is reproducing and over-wintering, but in a localized area such as a small pond. Eradication may be possible
	Failed	Species has not been seen since it was introduced; likely never reproduced. Failed can only be used after some time has passed since last observation or if collected from an area where survival is impossible (e.g., tropical fish collected in northern cold water streams). Used for many aquarium introductions; single fish or species collected in an area where it cannot survive and reproduce due to physiological tolerances. Triploid fish.
	Stocked	Species persists through repeated stockings, such as trout or triploid grass carp
	Extirpated	Species died out by itself and is no longer present. Implies that species was previously established and reproducing
	Eradicated	Species no longer present due to human intervention
	Unknown	Population status is unknown or undetermined. State in "Comments" section why status is unknown. Example: "Only 5 individuals collected in 3 years". Could represent multiple introductions or very low population level

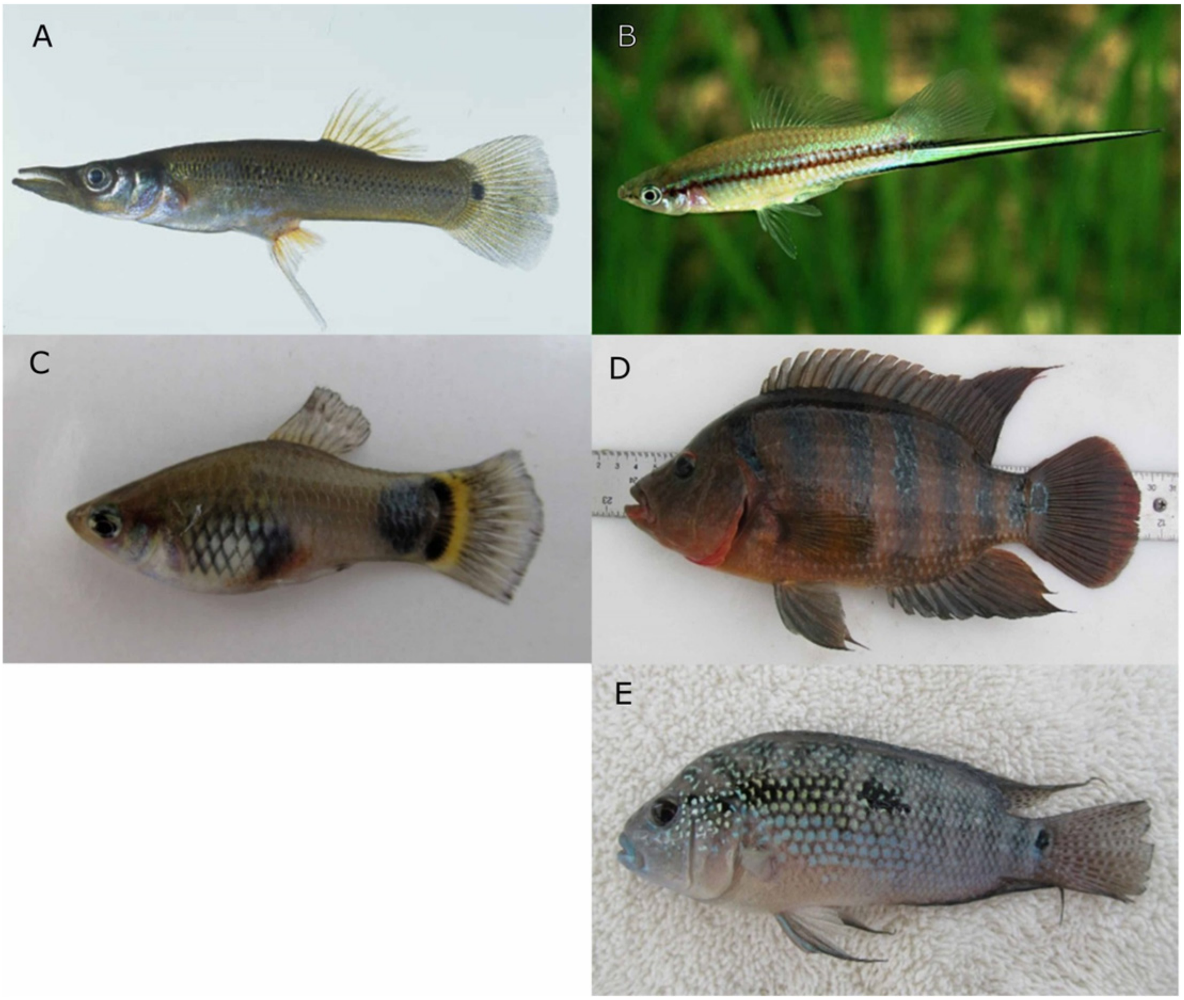

Figure 2. Photos of pike killifish (A) by Noel Burkhead, green swordtail (B) by Kjell Nilsson, southern platyfish (C) by Katelyn Lawson, Mayan cichlid (D) by Jeffrey Hill, and Jack Dempsey (E) by Katelyn Lawson.

Table 3. Factors assumed to influence the persistence, establishment, and spread of non-native fishes in the Tampa Bay area. Data are listed with references in parentheses from the following sources: (a) Shafland and Pestrak (1982), (b) Dial and Wainright (1983), (c) Turner and Snelson (1984) (d) Fuller et al. (1999); (e) Oldfield (2004), (f) Miller et al. (2005), (g) Schofield et al. (2009), (h) Schofield et al. (2010), (i) Tuckett et al. (2016a), (j) Froese and Pauly (2017) and (k) Q. Tuckett – unpublished data. For salinity, exact values for some species are unknown so ranges based on available information were used: low = 0–10 ppt, moderate = 11–20 ppt, high = 21+ppt.

Species	Maximum TL (cm)	Lower Lethal Temperature (°C)	Salinity Tolerance
Pike killifish	20 (j)	9.7 (a)	High (c)
Green swordtail	8 (f)	7.5 (i)	Low (b)
Southern platyfish	6 (d)	7.3 (k)	Low (b)
Mayan cichlid	39 (d)	10.0 (h)	High (g)
Jack Dempsey	25 (d)	8.0 (a)	low/moderate (b,e)

brackish habitats along the coastline of Tampa Bay and freshwater connections. Local populations persisted through the extreme cold event Florida experienced in January of 2010, where water temperature in parts of the Alafia River dipped below 10 °C (USGS 2017b). This is at or below the lower lethal temperature for pike killifish (Table 3). Its persistence despite this event suggests its salinity and temperature tolerances will likely allow it to persist in thermal refuges and continue spreading in the Tampa Bay area.

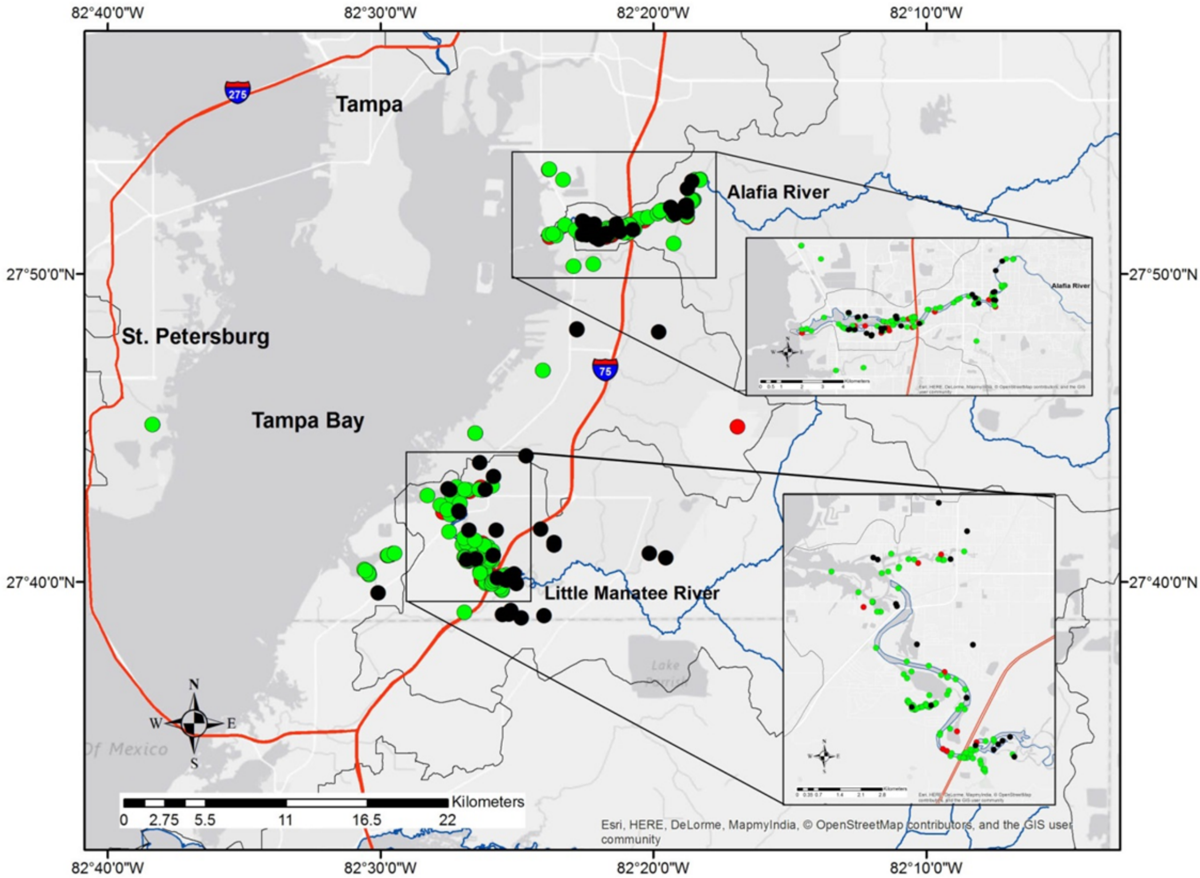

Figure 3. Map of Tampa Bay area (Florida, USA) showing geographic distribution of pike killifish *Belonesox belizanus*. Each circle represents a collection site, with color of symbol representing year range of collection: red 1995–1999, green 2000–2009, and black 2010–2015 (see also Supplementary material Table S1).

Green swordtail Xiphophorus hellerii

Green swordtail populations have historically been observed in Brevard (Dial and Wainright 1983), Palm Beach, Hillsborough, Polk, and Manatee counties (Fuller et al. 1999), and the species was thought to be established in some areas due to evidence of reproduction (Courtenay et al. 1974). However, the green swordtail is not consistently present in any part of Florida outside the Tampa Bay area and the fate of populations in Brevard and Palm Beach counties is unclear.

The first collection in the Tampa Bay area is from 1970 (USGS 2017a). The USGS NAS database contained eight green swordtail records with precise locality information for Hillsborough and Manatee Counties, but 75% of those are from the 1970s. The current distribution of the green swordtail in the Tampa Bay area is concentrated in southern Hillsborough County, with some isolated populations in Polk and Manatee counties (Figure 4; Table S2). Many of these populations occur in ditches near fish farms; however, they also occur in more natural streams. Although many of the escaped populations likely receive propagules from nearby aquaculture facilities, the fact that some populations are located several kilometers from the nearest fish farm suggests those populations may persist without continued propagule pressure. Those populations vary in size, stability, and connectivity to other populations, and are irregularly distributed across the landscape. The number of captured individuals for each green swordtail record varied from 1 to 147.

Shafland (1996) reported this species as formerly reproducing and that status has been maintained in more recent updates (Shafland et al. 2008a; FWC 2017a).

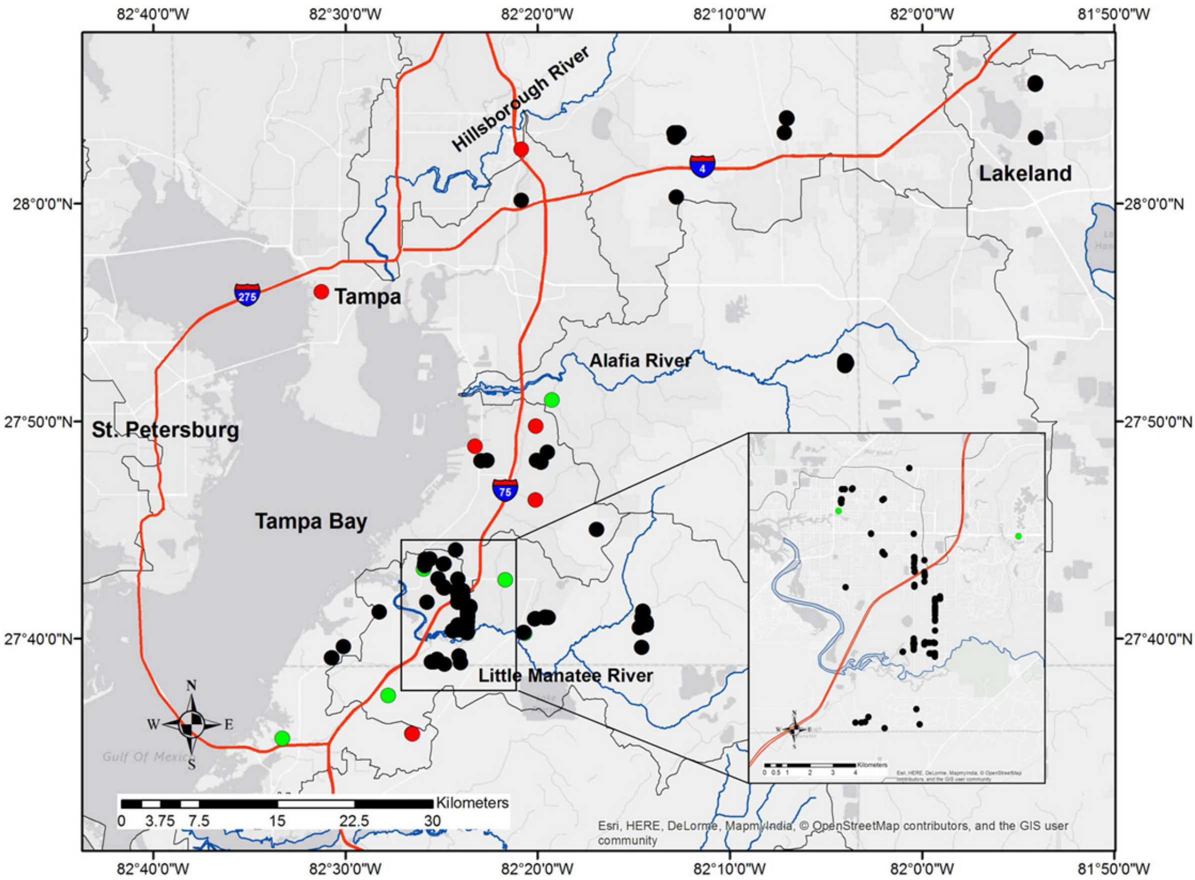

Figure 4. Distribution map of green swordtail *Xiphophorus hellerii* in the Tampa Bay area. Site symbols are organized by date range of samples: red dots indicate samples from 1970–1999, green dots indicate samples from 2001–2009 and black dots indicate samples from 2010–2015 (see also Supplementary material Table S2).

A recent study showed that escaped green swordtails had the ability to survive winters in the Tampa Bay region, especially with access to local thermal refuges such as aquaculture effluents (Tuckett et al. 2016a). Studies of the species' abundance, reproduction, cold tolerance, and current distribution in the Tampa Bay area allows us to conclude that the green swordtail is possibly established in the Tampa Bay area with localized, disjunct populations.

In the aquarium trade, hybrids of green swordtail and southern platyfish or variable platyfish *Xiphophorus variatus* Meek, 1904 exist and these hybrids may also escape from fish farms (USGS 2017a). Therefore, confusion exists regarding the exact identification of some specimens, particularly the females, which do not possess the eponymous sword. These colorful varieties are rarely detected in the environment; most records are of wild-type green swordtails (Tuckett et al. 2017).

Southern platyfish Xiphophorus maculatus

This species was first detected in Florida in the Tampa Bay region (Courtenay et al. 1974). The USGS NAS database contained five records of southern platyfish with precise localities in the Tampa Bay area, four records in Hillsborough County and one in Manatee County. Three of those records are from the 1970s, and two are from the 1990s. The recent surveys conducted by the UF TAL confirmed that the southern platyfish is distributed in the Little Manatee River and Bullfrog Creek drainages with a few isolated populations further north and east (Figure 5; Table S3). There are 148 records of southern platyfish collections from 1997 to 2015. Like the green swordtail, populations vary in size and follow a similarly disjunct distribution. The number of individuals collected at each site ranged from 1 to 115.

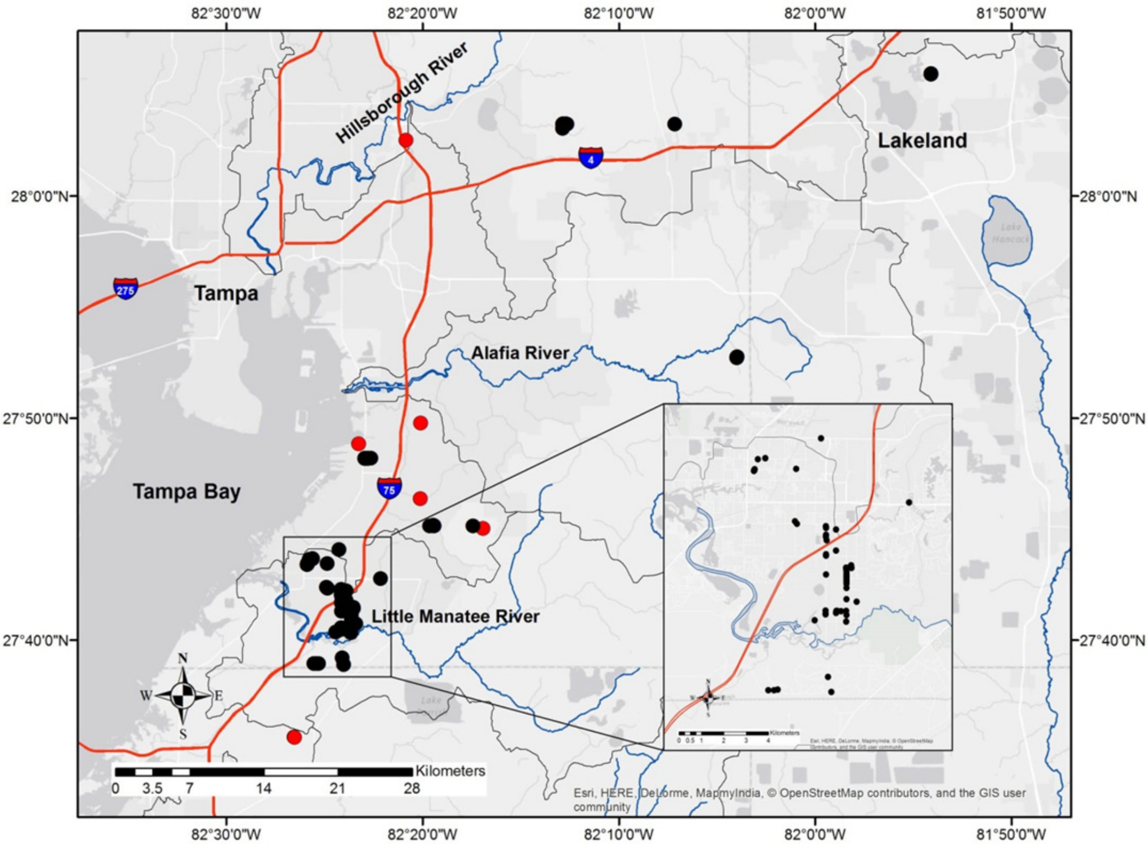

Figure 5. Distribution map of southern platyfish *Xiphophorus maculatus* in the Tampa Bay area. Site symbols are organized by date range of samples: red dots indicate samples from 1971–1999, and black dots indicate samples from 2013–2015 (see also Supplementary material Table S3).

It was thought that southern platyfish was established in the Tampa Bay region when first discovered due to evidence of reproduction (Courtenay et al. 1974); however, this view changed as populations appeared unstable and dependent upon continual escapees from fish farms (Courtenay and Stauffer 1990). Shafland (1996) listed the species as formerly reproducing and it has maintained this status in subsequent updates (Shafland et al. 2008a; FWC 2017a). Its current distribution shows that it is most often found near fish farms in ditches and other small aquatic systems and most populations may be sustained in part due to the frequent influx of propagules. Some populations have managed to maintain stability farther away from fish farms; however, dispersal has been very limited.

Based on the current distribution of southern platyfish and its typical close association with aquaculture facilities, we propose that this species is possibly established (Shafland et al. 2008b; Table 2) in Hillsborough County. We chose this status because if local aquaculture facilities cease production, it is possible that the loss of propagules from farms will lead to the extirpation of these isolated populations. Because of its tolerance to low temperatures, it is unlikely this fish will be extirpated by cold weather (Table 3).

A related species, the variable platyfish, has also been observed in Hillsborough County, but it is only rarely captured compared to the southern platyfish (Courtenay and Stauffer 1990; Tuckett et al. 2017). Some have speculated that the *Xiphophorus* in the Tampa Bay area are hybrids between these two species, which if true could have resulted in past misidentification of collected individuals.

Mayan cichlid Mayaheros urophthalmus

The most widely-accepted first record of Mayan cichlid in Florida was taken from the southern part of the state in Everglades National Park in 1983 (Loftus and Kushlan 1987; Fuller et al. 1999). This

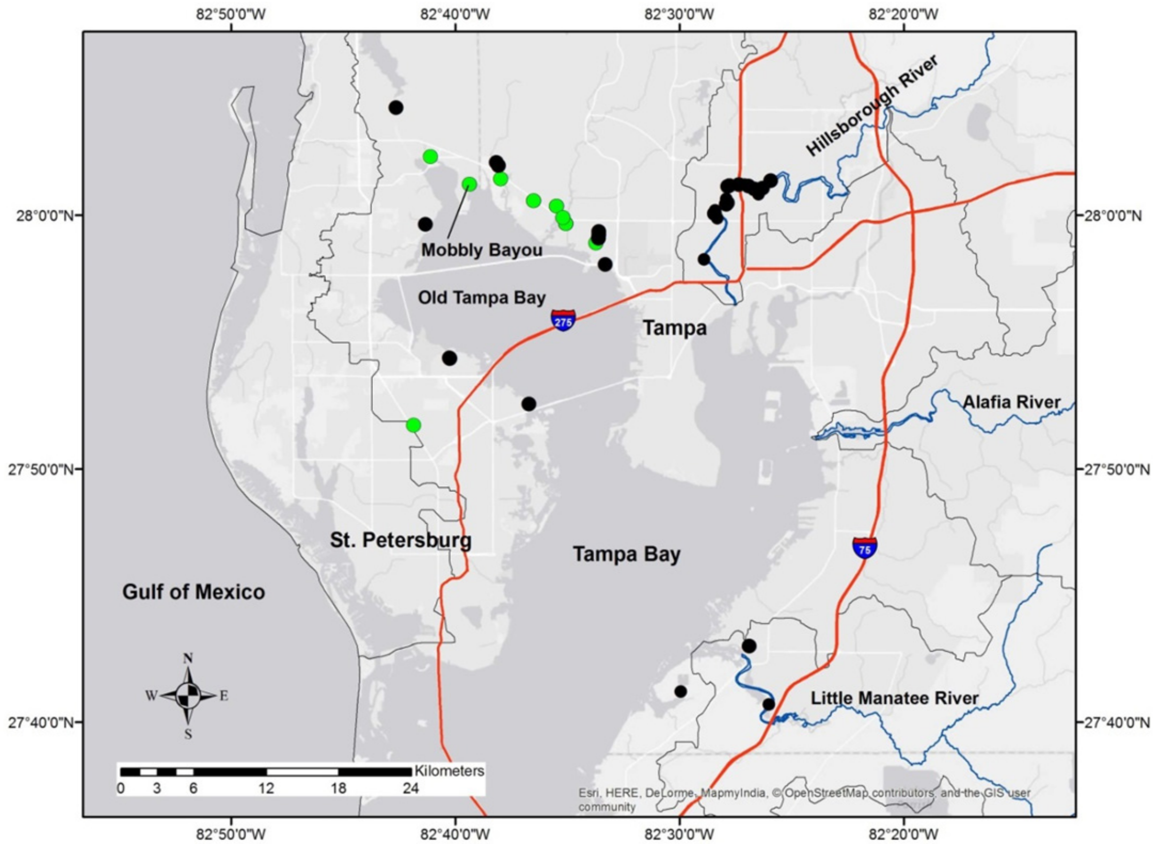

Figure 6. Distribution map of Mayan cichlid *Mayaheros urophthalmus* in the Tampa Bay area. Site symbols are organized by date range of samples: green dots indicate samples from 2001–2009 and black dots indicate samples from 2010–2016 (see also Supplementary material Table S4).

species has since spread and become established across south and southwest Florida and can be found in a wide variety of habitats with varying salinities (Shafland 1996; Trexler et al. 2000; Shafland et al. 2008a; Idelberger et al. 2011; Rehage et al. 2016).

Although not widely recognized, the earliest record of a Mayan cichlid in the Tampa Bay region of Florida is from 1975 and is based on a single specimen taken from a rock pit just east of the town of Ellenton, Manatee County (Fuller et al. 1999, W. Smith-Vaniz, personal communication). The site is within the Manatee River drainage at the far southern end of the Tampa Bay region. However, all subsequent records of Mayan cichlids in the Tampa Bay region are much more recent. Currently, Mayan cichlids occur in two primarily brackish areas of Tampa Bay, in Old Tampa Bay and the lower Hillsborough River in the north and in the lower Little Manatee River and Cockroach Bay in the south (Figure 6; Table S4). From 2004 to 2006, 89 Mayan cichlids were collected from Mobbly Bayou in Old Tampa Bay (Paperno et al. 2008). In total, we report 51 records of Mayan cichlid in the Tampa Bay area that were not previously available, with number of individuals collected per site ranging from 1–12 individuals. Paperno et al. (2008) observed multiple age classes over a four-year period, suggesting they are reproducing and recruiting successfully. On 5 August 2016, FWRI personnel observed Mayan cichlids being used as bait; the fish were removed from Bear Creek in Gulfport, Pinellas County (Charles Gardner, personal communication). On 28 August 2016, two adult Mayan cichlids were observed guarding a ball of fry in the Garrison Channel of Tampa Bay.

The lower lethal temperature for the Mayan cichlid will likely allow them to persist in the region and their high salinity tolerance could also allow them to disperse using the coastal waters of Tampa Bay (Table 3; Paperno et al. 2008; Schofield et al. 2010). Based on historical and current information, we conclude that the Mayan cichlid is established and spreading in the Tampa Bay area.

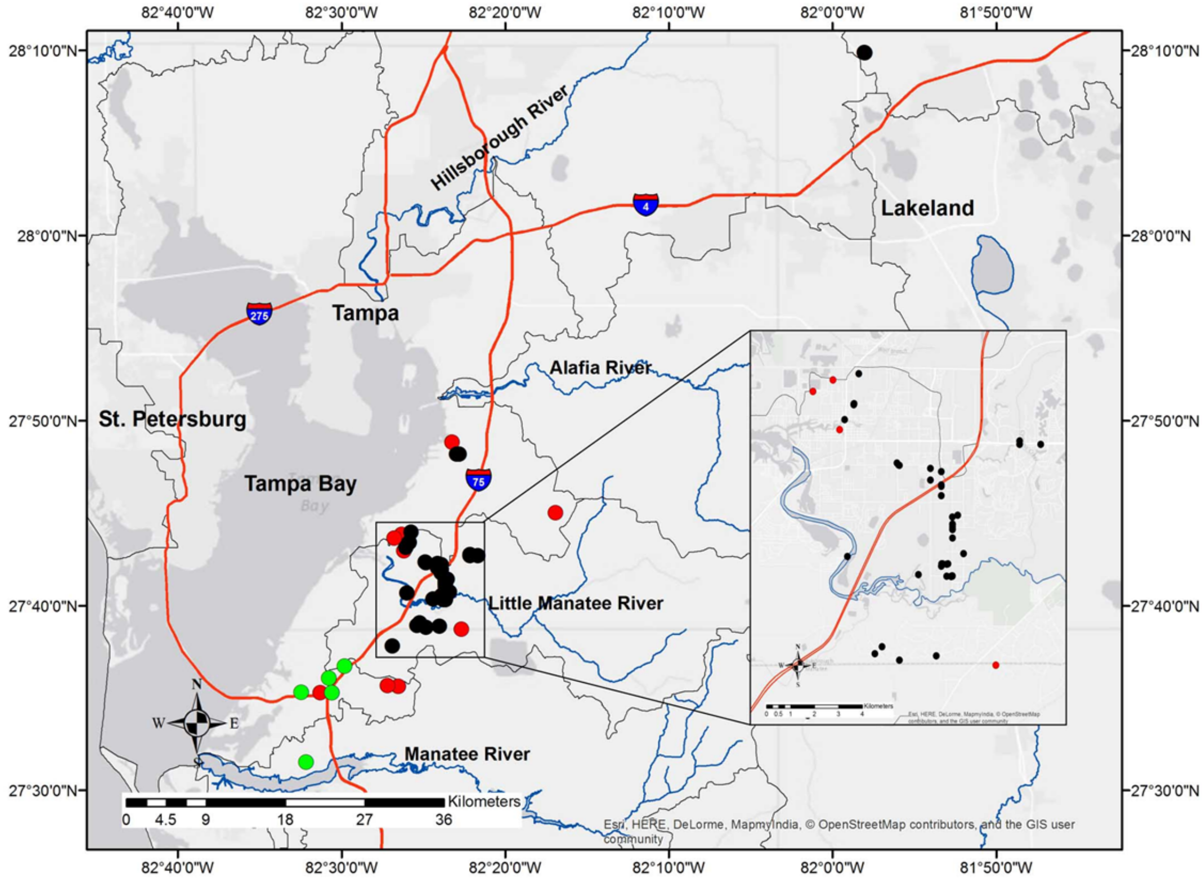

Figure 7. Distribution map of Jack Dempsey *Rocio octofasciata* in the Tampa Bay area. Site symbols are organized by date range of samples: red dots indicate samples from 1971–1999, green dots indicate samples from 2002–2010, and black dots indicate samples from 2013–2016 (see also Supplementary material Table S5).

Jack Dempsey Rocio octofasciata

Jack Dempsey has been observed in Florida public waters intermittently since the late 1960s (Shafland 1996; Fuller et al. 1999; FWC 2017a). Its documented history in Florida is unusual in that it has exhibited cycles of local establishment followed by declines and extirpation in several areas of peninsular Florida. Courtenay et al. (1974) reported that Jack Dempsey was found outside ornamental fish farms in Palm Beach and Hillsborough counties, Florida and that populations were potentially locally established. In the late 1970s Jack Dempsey were collected in Miami-Dade County (Hogg 1976) and eradicated from a rock pit in Levy County (Jennings 1986). In the 1980s, Jack Dempsey were collected at Satellite Beach in Brevard County (Dial and Wainright 1983), and a locally established population was found in a creek in Alachua County on the University of Florida, Gainesville campus (Jennings 1986).

Shafland (1996) moved the Jack Dempsey to a category of “possibly established” with the expectation that populations would not expand. This recategorization was a result of extensive sampling in Miami-Dade County that did not detect any Jack Dempsey (Loftus and Kushlan 1987; Shafland 1996; Hill 2003; Shafland et al. 2008a), and the lack of spread by the Alachua County and Satellite Beach populations. The status of Jack Dempsey was downgraded again by Shafland et al. (2008a) to the category of “formerly reproducing” following evidence of further declines. In July of 2005 and December of 2006 the creek in Gainesville was re-sampled but zero Jack Dempsey specimens were observed, indicating this population may no longer exist (Shafland et al. 2008a; JE Hill, unpublished data). A formerly reproducing population in Palm Beach County has also declined and had not been detected since 1996 (Shafland et al. 2008a). A nearby population was discovered in 2013, but its status is uncertain (USGS

2017a). FWC (2017a) currently lists Jack Dempsey as extirpated, and the USGS NAS currently lists it as extirpated in Alachua County and unknown in other counties. In contrast, new populations continue to be reported. Shafland et al. (2008a) hypothesized that Jack Dempsey is frequently released, survives well, and will likely be found reproducing in Florida in the future, but populations may decline like those from historic samples.

The USGS NAS database showed that Jack Dempsey has been observed recently in coastal Manatee County; however, all but one of the observations in Hillsborough County were records without coordinates from the 1970s. Jack Dempsey has been collected in ditches of varying proximity to fish farms, and in natural streams around the Tampa Bay area (Figure 7, Table S5). In total there are seven Jack Dempsey records from the 1990s, seven from 2002–2010, and 59 from 2013–2014. In the Tampa Bay area, Jack Dempsey has been recently observed in Manatee, Hillsborough, and Polk Counties. Its distribution in this area is likely the result of the high concentration of aquaculture facilities, yet these populations do appear to be persistent (Tuckett et al. 2017). There was evidence of reproduction (e.g., collection of juveniles) at several sites in 2013 and 2014 and total number collected ranged from 1–24 individuals at those sites. However, it is unclear how stable the populations of Jack Dempsey are in this area and some populations may be from recent introductions, since they were undetected in previous fish sampling of the Tampa Bay area from 2006–2010 (JE Hill, unpublished data).

Causes of their population declines are unknown and cold tolerance is unlikely to be a limiting factor (Dial and Wainright 1983) because less tolerant species like the Mayan Cichlid and Pike Killifish have persisted in the area (Table 3). We conclude that Jack Dempsey is possibly established in the Tampa Bay area, primarily in Hillsborough County. Several populations are reproducing and appear stable, but they may decline in the future as their history in Florida suggests.

Conclusion

Factors such as incomplete or unavailable data, inaccurate reporting of data, and conflicting interpretation of data resulting from sampling method and effort variability can all affect our understanding of non-native species distributions and status. These issues may be lessened if scientific collections and accurate sampling records were to be more consistently provided to permanent repositories, such as museums, and well-maintained and readily available databases. This data sharing is essential and can lead to better agreement among agencies and academic scientists. Reaching agreement is not easy; however, this collaborative approach to status determination minimized these difficulties. The categories and criteria put forth by Shafland et al. (2008b) were applied to new and historic records of our five focal species, allowing for a robust update of their regional status.

When interpreting the updated distributions, it is important to consider biotic and abiotic factors responsible for species patterns. Factors that promote or limit species distributions, such as thermal and salinity tolerance and biotic resistance play a role in structuring the distribution of each species. Pike killifish and Mayan cichlid have spread more than the other three species in a shorter period of time, possibly due to their ability to utilize brackish and marine habitats as corridors. Ultimately, the publication of updated distribution information is important for managers to determine where their efforts might be focused. Through the combined analysis of historical patterns of introduction and the current distribution of non-native fishes, we can gain a better understanding of the long-term fate of introduced populations.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Collection records of pike killifish in the Tampa Bay area.

Table S2. Collection records of green swordtail in the Tampa Bay area.

Table S3. Collection records of southern platyfish in the Tampa Bay area.

Table S4. Collection records of Mayan cichlid in the Tampa Bay area.

Table S5. Collection records of Jack Dempsey in the Tampa Bay area.

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