

## Research Article

**Risk assessment of chanchita *Cichlasoma dimerus* (Heckel, 1840), a newly identified non-native cichlid fish in Florida**Mary E. Brown<sup>1,\*</sup>, Robert H. Robins<sup>2</sup> and Pamela J. Schofield<sup>1</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 Museum, University of Florida, 1659 Museum Road, Dickinson Hall, Gainesville, FL 32611, USA

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**Abstract**

The risk of a newly discovered non-native fish species in Florida (USA): *Cichlasoma dimerus* ([Heckel, 1840]; Family: Cichlidae) is assessed. Its tolerance to cold temperatures was experimentally evaluated and information on its biology and ecology was synthesized. In the cold-temperature tolerance experiment, temperature was lowered from 24 °C by increments of 1 °C per hour, mimicking a typical cold weather front. Fish lost equilibrium at a mean temperature of 7.8 °C and died at 4.7 °C. Those values are lower than most other non-native fishes from the state that have been experimentally evaluated, and it appears *C. dimerus* is the most cold-tolerant cichlid established in Florida. The combination of cold-temperature tolerance and other biological/ecological factors (e.g., adult size, reproduction and parental care, diet, habitat, and other behaviors) along with the geographic range and habitat diversity of specimens vouchered in museums, indicate *C. dimerus* may be able to invade many freshwater ecosystems in the state, including environmentally sensitive freshwater springs.

**Key words:** Cichlidae, cold temperature tolerance, dispersal, ecophysiology, fecundity

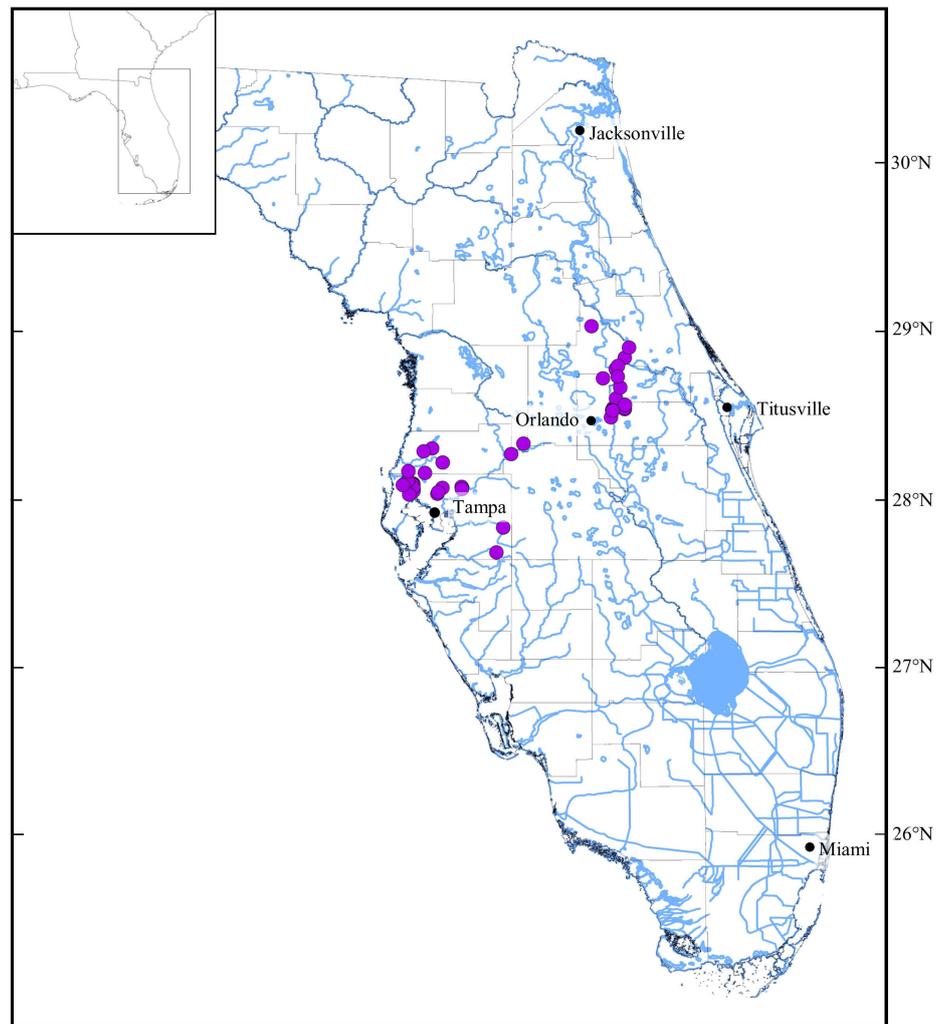
**Introduction**

Understanding the characteristics that facilitate non-native species invasions is central to risk assessment and management. Only a subset of introduced species persist and spread, and thus understanding the factors that either enable or prevent their success is important. For example, in Florida (USA), nearly 200 species of non-native fishes have been documented in freshwater habitats, yet only about 49 species are known to have established reproducing populations (Robins et al. 2018, 2020; USGS-NAS 2021). A subset of those established species has been able to disperse from their points of introduction and colonize new habitats, while others have either died out or maintained limited geographic ranges not far beyond their initial spread (e.g., Schofield and Pecora 2013; Lawson et al. 2017). At least 34 species of cichlids are reported as introduced to Florida, excluding hybrids and taxa identified to genus only (USGS-NAS 2021) and 21 are

considered established (Robins et al. 2018, 2020). Thus, cichlids represent 43% of the established non-native fish fauna in Florida (21 of 49 species) and seem well-suited to persisting and dispersing amongst Florida's subtropical habitats. Several cichlid species occupy much of the Florida peninsula.

In this report, several aspects of the ecology and physiology of the chanchita, *Cichlasoma dimerus* ([Heckel, 1840]; Family: Cichlidae) are summarized. *Cichlasoma dimerus* is a small- to medium-sized South American cichlid native to Bolivia, Paraguay, Uruguay, southern Brazil, and north-eastern Argentina (Kullander 1983). This species was only recently discovered in Florida (Robins et al. 2020) where it was previously confused with black acara *C. bimaculatum* (Linnaeus, 1758). It is now clear that Central Florida acara populations are *C. dimerus* while *C. bimaculatum* is restricted to the vicinity of Lake Okeechobee, the Caloosahatchee River drainage and the vast Everglades watershed including associated canal systems (Robins et al. 2020). *Cichlasoma dimerus* has been present in Florida for at least 21 years, yet little is known of its dispersal abilities and potential for negative impacts and it is unclear whether its geographic range will expand.

Many factors likely contribute to the variability in establishment and spread of non-native fishes in Florida, including biotic (e.g., predation, competition) and abiotic variables (e.g., cold tolerance, low-oxygen tolerance, salinity tolerance). Of the abiotic variables, cold tolerance is an important regulator of non-native fish geographic ranges in Florida (Shafland and Pestrak 1982). Many of Florida's non-native fishes are derived from tropical or subtropical regions that have climates similar to southern Florida. However, central and northern Florida habitats experience colder winter temperatures relative to the southern part of the state, potentially preventing tropical/subtropical fishes from establishing (Shafland and Pestrak 1982; Schofield et al. 2009). Thus, tolerance to cold winter temperatures is considered an important environmental variable relative to the ability of non-native fishes to colonize and disperse in the Florida peninsula. For some species, cold temperature tolerance has been correlated with broader geographic ranges to the north (Schofield and Huges 2011). However, that is not always the case, and some species that are tolerant to cold temperatures do not colonize large ranges (Schofield and Schulte 2016). Additionally, it is unclear how climate change will impact non-native fishes and their geographic ranges. Climate change may provide invasion opportunities for non-native species with broad environmental tolerances as habitats change over time (Rehage and Blanchard 2016). *Cichlasoma dimerus* is currently known only from Central Florida habitats (Robins et al. 2020; Florida Museum 2021; USGS-NAS 2021; Figure 1); however, it is possible the species may spread to other areas of the state. Furthermore, *C. dimerus* has been observed in environmentally sensitive springs habitats



**Figure 1.** Distribution of *Cichlasoma dimerus* in Florida as of September 2021 (Florida Museum 2021, iNaturalist 2021, USGS-NAS 2021; Table S1).

that are supplied by constant temperature water from the Floridan aquifer and may serve as thermal refuge during cold winters.

Other factors that may influence geographic spread of non-native fishes include reproduction, parental care, diet, habitat requirements, and behavior. The potential for further spread of *C. dimerus* is assessed through a combination of laboratory experiments (for cold tolerance) and literature review, providing a comprehensive overview of the ecology of *C. dimerus* and its potential risk for Florida's freshwater habitats.

### Materials and methods

Critical thermal methodology (CTM) was used to quantify temperature tolerance of *C. dimerus* (reviewed in Beiting et al. 2000). With CTM, fish are subjected to a continuous, constant (i.e., linear) decrease in temperature until a desired endpoint is reached. In this experiment, air temperature was decreased to produce a constant decrease in water temperature at the rate of 1 °C per hour, which is approximately the rate of temperature decrease in south Florida during a typical cold weather front (Schofield et al. 2009).

Two experimental endpoints were used: loss of equilibrium (LOE) and death. Loss of equilibrium was defined as the point at which the fish was alive but unable to right itself. Death was defined as lack of movement by the fish after it was gently prodded while submerged; if no response was observed, the fish was removed from the water with a hand net for further examination. The temperature at death is the lower lethal temperature, which defines the lower extreme of the tolerable thermal environment (Brett 1956). Studies that use the LOE endpoint sometimes assume that the experimental fish will survive if returned to pre-trial acclimation temperature after LOE has occurred (e.g., Cox 1974; Ford and Beitinger 2005). The present study examines this assumption further, as it has important ecological relevancy. It is important to know if fish survive after losing equilibrium, how long before they recover, and if experiencing LOE leaves them more susceptible to disease or other infection (e.g., Schofield et al. 2009).

*Cichlasoma dimerus* were collected with dip nets and a seine from Lawne Lake, Barnett Park, Orlando, Florida, USA in September 2020 and January 2021. Fish were housed at the U.S. Geological Survey (USGS) facility in Gainesville, Florida. They were held in 530-liter fiberglass tanks with flow-through well water and fed commercial flake food and bloodworms three times per week. Water temperature was held at 24 °C with submerged titanium heaters and thermostats.

The experiment was conducted in February 2021. A large (3.1 × 6.2 m) walk-in environmental chamber was used for the experiment, set at 24 °C with a 12:12 h light cycle. An additional self-contained laboratory (“warm room”) was likewise set at 24 °C with a 12:12 h light cycle to serve as the control space. Both the environmental chamber and warm room were equipped with plastic shelving and air supply lines.

Fish were measured ( $\pm 1$  mm total length [TL]), weighed ( $\pm 0.1$  g), and placed in individual plastic bins (33 × 20 × 11 cm) filled with 7.3 L of well water. Fish were divided into three treatments: control (n = 10), LOE (n = 20), and death (n = 20). Bins were placed on shelves in the walk-in environmental chamber set at 24 °C and left undisturbed to acclimate for 24 hrs. Treatments were spatially interspersed throughout the shelves. Bins were equipped with air stones, tight-fitting lids to prevent escape, and blinded on three sides, leaving the front unblinded.

The experiment began by manually decreasing the air temperature to produce a constant decrease in water temperature at the rate of 1 °C per hour. Simultaneously, bins housing fish in the control group were moved to the warm room for the duration of the experiment. Air temperature was decreased in increments as needed (1–2 °C) to achieve a constant decrease in water temperature. Every hour temperatures were checked in ten randomly selected bins with a handheld digital thermometer to confirm the water temperature was dropping consistently at 1 °C per hour. All fish

were visually checked every hour until the first fish achieved LOE, then fish were checked every 30 minutes until LOE or death occurred.

Once fish in the LOE treatments reached the LOE endpoint, water temperature was recorded and the fish was moved in its bin from the experimental chamber to the warm room, where it was monitored every 30 minutes for recovery from LOE, then daily for 14 days. When the fish recovered from LOE, water temperature and time elapsed since moving to the warm room was recorded. LOE fish in the warm room were fed three times per week and their water was changed three times per week. Fish in death treatments were not removed from experimental plastic bins until they died. For those fish, water temperature at LOE and death were recorded.

Fish that died during the experiment were preserved by fixing in ten percent formalin for 7 days, rinsed in water, then preserved in 70% ethanol. After the experiment, all fish remaining alive were anaesthetized in an ice slurry before being fixed and preserved in the same manner. Experimental fish were deposited at the Florida Museum (lot number UF 247219).

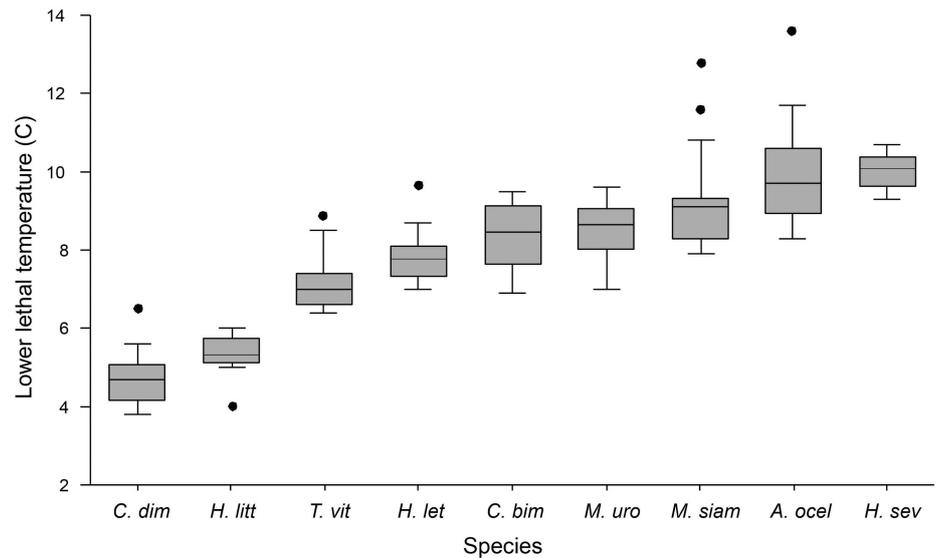
### Analyses

One-way Analysis of Variance (ANOVA) was used to test whether fish size (TL or mass) varied amongst treatments. Levene's test was used to check for heteroscedasticity. Lower lethal temperature was regressed against body mass to evaluate whether the two variables were related using linear regression.

Lower-lethal tolerances of most non-native fishes established in Florida have been experimentally evaluated, although methods have differed amongst laboratories and time periods. A subset of those experimental results was collected in the USGS laboratory with the same equipment and methods (fresh water, initial temperature 24 °C, rate of temperature decrease 1 °C per hour). Those data were combined with data for *C. dimerus* and evaluated with one-way ANOVA. The Tukey-Kramer post-hoc test was used to discriminate homogeneous subsets and Levene's test was used to check for heteroscedasticity. Species and data sources included:

- Schofield and Schulte 2016: croaking gourami *Trichopsis vittata* (Cuvier, 1831)
- Schofield and Kline 2018: spotfin spiny eel *Macrogathus siamensis* (Günther, 1861), Mayan cichlid *Mayaheros urophthalmus* (Günther, 1862), African jewelfish *Hemichromis letourneuxi* Sauvage, 1880 and banded cichlid *Heros severus* Heckel, 1840
- Gutierrez et al. 2016: oscar *Astronotus ocellatus* (Agassiz, 1831)
- Schofield and Huges 2011: *C. bimaculatum* and brown hoplo *Hoplosternum littorale* (Hancock, 1828)

NCSS Statistical Software package (NCSS 2021) was used for all calculations.



**Figure 2.** Box plot of lower lethal temperatures for nine species of non-native freshwater fishes in Florida. Dots indicate outliers. See Methods for data sources and analyses. Species abbreviations: *C. dim* = *Cichlasoma dimerus*, *H. litt* = *Hoplosternum littorale*, *T. vit* = *Trichopsis vittata*, *H. let* = *Hemichromis letourneuxi*, *C. bim* = *Cichlasoma bimaculatum*, *M. uro* = *Mayaheros urophthalmus*, *M. siam* = *Macrogathus siamensis*, *A. ocel* = *Astronotus ocellatus*, *H. sev* = *Heros severus*.

## Results

### *Cold-temperature tolerance experiment*

For the 50 fish used in the experiment, mean length was 57 mm TL with a range of 40 to 89 mm ( $\pm 1.2$  standard deviation [SD]) and mean mass was 4.8 g (range 1.4 to 16.6 g  $\pm 3.2$  SD). There was no difference in length or mass amongst treatments ( $P > 0.9$  for both comparisons). Variances were not heteroscedastic (Levene's test  $P > 0.5$  for both comparisons). There was no relationship between body mass and lower lethal temperature.

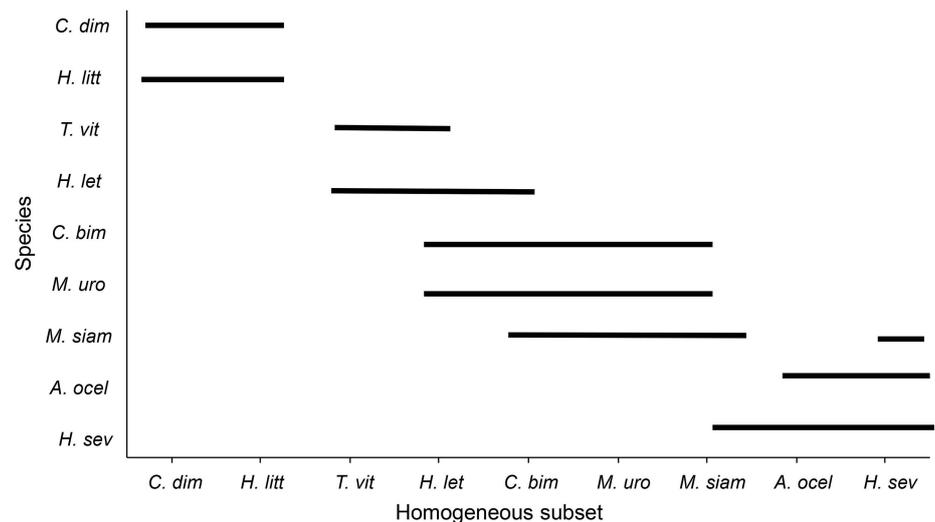
Fish lost equilibrium at a mean temperature of 7.8 °C ( $\pm 0.5$  SD; range 7.1 to 8.8 °C) and died at 4.7 °C ( $\pm 0.7$  SD; range 3.8 to 6.5 °C). Fish that were removed from the experimental chamber after losing equilibrium and re-warmed regained an upright posture at a mean temperature of 11.0 °C ( $\pm 0.8$  SD range 9.3 to 12.6 °C). The average time from loss of equilibrium to upright recovery was 1.3 hrs. All fish in the control and LOE treatments survived the 14-day post-experiment observation period.

There were significant differences in low-temperature tolerance among the nine non-native fishes tested in the same manner (one-way ANOVA;  $F = 86.5$ ,  $df = 8$ ,  $P < 0.001$ ). *Cichlasoma dimerus* and *H. littorale* were the most tolerant of cold temperatures and formed a homogeneous subset that did not overlap with any other species (Tukey-Kramer post-hoc,  $P < 0.05$ ; Figures 2, 3).

### *Literature review*

#### Adult size

*Cichlasoma dimerus* is a small- to medium-sized cichlid, reaching 117.1 mm standard length (SL) (Kullander 1983). The largest of ninety-six *C. dimerus*



**Figure 3.** Results of Tukey's multiple comparison test on lower lethal temperatures showing homogeneous subsets. Species abbreviations: *C. dim* = *Cichlasoma dimerus*, *H. litt* = *Hoplosternum littorale*, *T. vit* = *Trichopsis vittata*, *H. let* = *Hemichromis letourneuxi*, *C. bim* = *Cichlasoma bimaculatum*, *M. uro* = *Mayaheros urophthalmus*, *M. siam* = *Macrogathus siamensis*, *A. ocel* = *Astronotus ocellatus*, *H. sev* = *Heros severus*.

collected in a study of neotropical fish assemblages in flood plain lakes in Argentina measured 91 mm SL (Scarabotti et al. 2011). The largest individual collected and measured in Florida is 92.1 mm SL (Robins et al. 2020). *Cichlasoma dimerus* is the smallest cichlid species established in Florida.

### Reproduction and parental care

The reproductive biology of *C. dimerus* in laboratory settings is well-studied. Between 400–800 eggs are laid; the number being potentially linked to breeding pair body size and condition and by the size of the available spawning surface (Alonso et al. 2011). Pandolfi et al. (2009) reported egg clutches of “some 1,500 eggs” deposited as a uniform round layer on the substrate. Eggs are covered in an adhesive mucous secretion which affixes the eggs to the substrate (Meijide and Guerrero 2000). Both parents care for the eggs and larvae, defend the nest aggressively, and after hatching, transfer the larvae to a previously dug pit (Meijide and Guerrero 2000; Pandolfi et al. 2009). The optimal breeding temperature is 26 °C, at which larvae hatch on the third day and are free swimming after five days (Pandolfi et al. 2009) or eight days post-fertilization (Meijide and Guerrero 2000; Alonso et al. 2011). Larvae reach the pre-juvenile stage at 25 days post-fertilization and approximately 8 mm TL and the juvenile stage at 42 days post-fertilization and approximately 15 mm TL (Meijide and Guerrero 2000). Under ideal conditions young are 50 mm TL four months after hatching (Pandolfi et al. 2009). The breeding season lasts 6–8 months under natural conditions, from approximately September to April (in the Southern Hemisphere) and a breeding pair may spawn every 20 days (Pandolfi et al. 2009; Alonso et al. 2011). Under laboratory conditions, a breeding pair may spawn every 15 days if the young are removed (Alonso

2011). Studying the ovarian histology of spawning females, Varela et al. (2017) found captive females ten days post spawn in similar condition to pre-spawn females and concluded *C. dimerus* are functionally capable of a spawning interval equal to the shortest recorded for fishes under laboratory conditions.

### Diet

In the Cuiaba River basin, in the Cerrado and Pantanal regions of Mato Grosso state, Brazil, *C. dimerus* ate a generalist diet of insects, plants, and detritus mainly in the pelagic zone (Novakowski et al. 2016). Scarabotti et al. (2011) characterized *C. dimerus* as a sit and wait invertivore that likely ambushes its prey from macrophyte stands.

### Habitat

In Bolivia, Brazil, Paraguay, and Argentina, *C. dimerus* inhabited a wide variety of lentic and lotic habitats (Pandolfi et al. 2009). In the Esteros del Riachuelo, Corrientes, Argentina, *C. dimerus* inhabited densely vegetated areas with low flow (Alonso 2011). *Cichlasoma dimerus* collected from a series of floodplain lakes of the Salado River, Argentina, preferred vegetated and clear waters (Scarabotti et al. 2011). In Brazilian savanna streams, *C. dimerus* preferred a macrophyte and fine root microhabitat (Romero and Casatti 2012). In Nobres, Mato Grosso State, Brazil, Bessa et al. (2017) found *C. dimerus* most commonly over hard substrates but occasionally in association with large woody debris or the channel center.

### Dispersal and other behavior

Kullander (1983) theorized that *C. dimerus* uses the stomach for airbreathing and cited observations and photos in Sucksdorff (1981) as evidence that *C. dimerus* engages in overland migrations in shallow water requiring fish to move on their sides.

Multiple authors note complex behaviors for *C. dimerus* (Meijide and Guerrero 2000; Pandolfi et al. 2009; Alonso et al. 2011). In winter, when temperatures are cooler and *C. dimerus* does not breed, fish are gregarious and pale in coloration and a reduction in aggressive behaviors is attributable to the shortened photoperiod (Alonso 2011). During the longer photoperiod days of breeding season, a social dominance hierarchy predicated on male body size and color organizes intraspecific interactions in *C. dimerus*, though dominance in females is correlated with aggressive behaviors and not body size (Alonso 2011). Reproductive individuals of both sexes exhibit bright body color patterns, as do non-reproductive but territorial males, though color intensity and hue differs among all three groups; non-territorial or lower rank individuals are an opaque grey (Alonso 2011).

Two of three species of piranhas studied in the Pantanal region of Mato Grosso State, Brazil frequently attacked and fed on *C. dimerus* (Sazima and Machado 1990). In response to the approach of *Serrasalmus spilopleura* Kner, 1858, groups of *C. dimerus* formed a defensive ring, like that seen in the cichlid fish, *Mesonauta festivus* (Heckel, 1840) and simultaneously moved together as group to hide within vegetation (for an illustration of this behavior, see Fig. 11, Sazima and Machado 1990).

## Discussion

### *Cold tolerance*

In the laboratory experiment, *C. dimerus* lost equilibrium at 7.8 °C and died at 4.7 °C, which is the lowest of the nine non-native fishes that were tested in a similar manner. Low-temperature tolerance of *C. dimerus* was very similar to that of the callichthyid catfish *H. littorale*, one of the most widespread introduced fishes in Florida (Nico and Muench 2004; Figure 2). *Cichlasoma dimerus* is also more cold-tolerant than many other non-native fishes beyond the nine compared in our laboratory, including blue tilapia *Oreochromis aureus* (Steindachner, 1864), lower lethal limit = 6.2 °C ± 0.4 SD (Shafland and Pestrak 1982), and Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758), lower lethal limit = 6.8 °C (Attwood et al. 2003). *Cichlasoma dimerus* appears to be the most cold-tolerant cichlid established in the state.

Fish that were removed from the experimental chamber after losing equilibrium and re-warmed survived with no sign of infection and fed normally until the end of the 14-day holding period, at which point they were euthanized. By comparison, of the 13 *H. letourneuxi* that lost equilibrium in the freshwater treatment conducted by Schofield et al. (2009), two individuals died before warming, three died of protistan infections several days after the challenge, and eight survived the 14-day holding period (57%). In the same study, all *M. urophthalmus* that experienced LOE and were transferred to the warm room at the freshwater (n = 10) and estuarine (n = 9) salinities survived until the end of the 14-day holding period (Schofield et al. 2009). Less directly comparable but as concerns other non-native fish species established in Florida, Ndong et al. (2007) found reduced immune capability to bacterial infection in *Oreochromis mossambicus* (Peters, 1825), Mozambique tilapia, after exposure to low temperatures. Walking catfish, *Clarias batrachus* (Linnaeus, 1758), was more susceptible to disease and suffered high mortality during freezes in 1977 and 1981 in South Florida (Loftus and Kushlan 1987).

### *Geographic range in Florida*

*Cichlasoma dimerus* was first detected in Lake Tarpon, Pinellas County, Tampa Bay drainage, Florida, July 27, 2000, and is established in seven counties and five Central Florida river drainages (Robins et al. 2020; Figure 1).

The latitudinal distribution of *C. dimerus* in Florida is between 27.7–29.1 °N (Florida Museum 2021). The northern extent of this range is greater than the northernmost verifiable records for all but two of the 21 cichlid species established in Florida. The African tilapiines, *O. aureus* and *O. niloticus* are found throughout peninsular Florida including the Lower St. Johns/Ocklawaha River drainage. *Oreochromis aureus* inhabits the Lower St. Johns as far north as Jacksonville. A third species of tilapiine cichlid, blackchin tilapia, *Sarotherodon melanotheron* Rüppell, 1852, a salt tolerant and largely coastal species in Florida, is found as far north as Scottsmeer, (28.7 °N) on the east coast in warm, marine-influenced waters. *Hemichromis letourneuxi* is known from Starke Lake, Ocoee (28.6 °N). Among new world cichlids established in the state only *M. urophthalmus* approaches the northernmost extent of *C. dimerus*, with verifiable records on the east coast above 28.0 °N (Paperno et al. 2008) and recently as far north as Titusville, FL, 28.6 °N (iNaturalist 2021).

*Cichlasoma dimerus* has dispersed through a large portion of Central Florida in a span of approximately two decades. Colonization and dispersal of introduced species is determined by a host of factors besides temperature. Quantifying the extent to which abiotic and biotic factors, and their complex interplay facilitate or impede colonization and dispersal is challenging (Hill and Tuckett 2018). However, many established nonindigenous fishes in Florida share a suite of adaptations including large adult size, high fecundity, parental care of young by one or both parents, adaptability to a wide variety of habitats or environmental conditions, and dispersal ability (Loftus and Kushlan 1987; Kolar and Lodge 2002; Marchetti et al. 2004).

A literature review yielded much information on the biology of *C. dimerus* in its native range, including adult size, characteristics of reproduction and parental care, diet and habitat use, and behavior. These traits may have assisted *C. dimerus* to establish and disperse in Florida. However, to what extent native-range biology is faithfully reproduced by *C. dimerus* in Florida is not known. Exceptions include adult size, which could reasonably be expected to be fixed and appears as such based on limited collecting, largely in shallow water with dip nets and seines.

*Cichlasoma dimerus* is the smallest cichlid established in Florida, with the largest individual collected 92.1 mm SL. While most cichlids established in Florida are large (e.g., six species of African tilapiines, *M. urophthalmus*, *Parachromis managuensis* (Günther, 1867), *Cichla ocellaris* Bloch & Schneider, 1801, etc.), the similarly diminutive African jewelfish (to 120 mm SL though most are smaller) is also widely distributed throughout peninsular Florida. That at least two small cichlids introduced to Florida are widespread may indicate that other features are more important or compensate for small body size in determining whether a cichlid establishes in Florida and to what extent it disperses to new areas.

Schofield et al. (2021) showed that, in general, established introduced fishes that reach large adult sizes tend to have broader geographic ranges in Florida. It is possible that *C. dimerus* may escape the size limitations on geographic expansion if it is similar to *H. letourneuxi* or advantaged in some other capacity in which *H. letourneuxi* is not.

It must be noted that the spread of *C. dimerus* may be facilitated by human activity. A large rural area of Central Florida between the two known clusters of records of *C. dimerus* (Figure 1) appears devoid of *C. dimerus* but for two observational records (iNaturalist 2021). This area includes much of the Withlacoochee River drainage, including the headwaters, as well as the many lakes of southwestern Lake County and the Lake Apopka watershed in western Orange County (Upper St. Johns River drainage), and the headwaters of the Peace and Kissimmee River drainages.

*Cichlasoma dimerus* may be a habitat generalist in its native range and in Florida. In Florida, *C. dimerus* has colonized a variety of waterbodies including rivers, creeks, springs, floodplain, lakes, backwaters, ditches, and retention ponds (Florida Museum 2021). The species is found over vegetated or rocky substrate, including riprap or riprap-like erosion control structures along banks. It can be abundant within submerged terrestrial vegetation on the margins of waterbodies (*pers. obs.*; Florida Museum 2021). *Cichlasoma dimerus* in Florida is typically found at depths of less than 30 cm.

## Conclusion

*Cichlasoma dimerus* demonstrates a tolerance for cold temperatures which exceeds that of most established, non-native fishes in Florida. The species' colonization of a variety of water body types and habitats across a broad swath of Central Florida has likely been aided by this tolerance for lower temperatures. It seems likely that further adaptations as revealed in a review of the published literature have played a substantial role in the spread of *C. dimerus* in Florida. *Cichlasoma dimerus* is a small, fecund, lower trophic level generalist feeder. The species exhibits a complex social hierarchy that includes potential collective anti-predator defense strategies. *Cichlasoma dimerus* is likely capable of overland dispersal in modest flooding events, which are frequent in areas of peninsular Florida. However, human-mediated dispersal cannot be ruled out and may have facilitated its geographic spread. Targeted surveys in certain areas of the state may help to better complete our understanding of its geographic range. Collectively, these data may partially explain the rapid colonization of the species in Central Florida to date, including temperature-moderated, clear water springs. These data may prove useful to managers in forecasting or controlling the spread of this species.

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## Authors' contributions

MEB: research conceptualization; sample design and methodology, data collection, ethics approval, writing (original draft, review and editing); RHR: research conceptualization, investigation and data collection, writing (original draft, review and editing); PJS: sample design and methodology, data analysis and interpretation, funding provision, writing (original draft, review and editing).

## Declaration of interests

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

## Ethics and permits

The authors have complied with institutional policies governing the humane and ethical treatment of the experimental subjects. All procedures were in compliance with Institutional Animal Care and Use Committee regulations (approved protocol USGS/WARC/GNV 2019-03). Data for this study are publicly available (<https://doi.org/10.5066/P949CEKG>; Brown et al. 2021). Fish were collected under Scientific Fish Collection Permit FNE-2020-11 from the Florida Fish and Wildlife Conservation Commission.

## References

- Alonso F (2011) Behavior and physiology of social control of reproduction in cichlid fish *Cichlasoma dimerus* (Heckel, 1840). Bachelor's Thesis. Buenos Aires' University, Brazil, 56 pp
- Alonso F, Cánepa M, Guimarães Moreira R, Pandolfi M (2011) Social and reproductive physiology and behavior of the social cichlid fish *Cichlasoma dimerus* under laboratory conditions. *Neotropical Ichthyology* 9: 559–570, <https://doi.org/10.1590/S1679-62252011005000025>
- Attwood HL, Tomasso JR, Webb K, Gatlin DM (2003) Low-temperature tolerance of Nile tilapia, *Oreochromis niloticus*: effects of environmental and dietary factors. *Aquaculture Research* 34: 241–251, <https://doi.org/10.1046/j.1365-2109.2003.00811.x>
- Beitinger TL, Bennett WA, McCauley RW (2000) Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes* 58: 237–275, <https://doi.org/10.1023/A:1007676325825>
- Bessa E, Geffroy B, Gonçalves-De-Freitas E (2017) Tourism impact on stream fish measured with an ecological and behavioural indicator. *Aquatic Conservation: Marine and Freshwater Ecosystems* 27: 1281–1289, <https://doi.org/10.1002/aqc.2804>
- Brett JR (1956) Some principles in the thermal requirements of fishes. *The Quarterly Review of Biology* 31: 75–87, <https://doi.org/10.1086/401257>
- Brown ME, Robins RH, Schofield PJ (2021) Risk assessment of chanchita *Cichlasoma dimerus* (Heckel, 1840), a newly identified non-native cichlid fish in Florida. U.S. Geological Survey data release, <https://doi.org/10.5066/P949CEKG> (accessed 3 December 2021)
- Cox DK (1974) Effects of three heating rates on the critical thermal maximum in bluegill. In: Gibbons, JW, Sharita RR (eds), *Thermal Ecology*. U.S. Atomic Energy Commission, Savannah, pp 158–163
- Florida Museum (2021) Florida Museum fishes Specify web portal. <http://specifyportal.flmnh.ufl.edu/fishes/> (accessed 19 August 2021)
- Ford T, Beitinger TL (2005) Temperature tolerance in the goldfish, *Carassius auratus*. *Journal of Thermal Biology* 30: 147–152, <https://doi.org/10.1016/j.jtherbio.2004.09.004>
- Gutierrez SMM, Schofield PJ, Prodocimo V (2016) Salinity and temperature tolerance of an emergent alien species, the Amazon fish *Astronotus ocellatus*. *Hydrobiologia* 777: 21–31, <https://doi.org/10.1007/s10750-016-2740-8>
- Hill JE, Tuckett QM (2018) Abiotic and biotic contributions to invasion resistance for ornamental fish in west-central Florida, USA. *Hydrobiologia* 817: 363–377, <https://doi.org/10.1007/s10750-017-3496-5>
- iNaturalist (2021) iNaturalist database. <https://www.inaturalist.org/> (accessed 14 August 2021)
- Kullander SO (1983) A Revision of the South American Cichlid genus *Cichlasoma* (Teleostei: Cichlidae). Swedish Museum of Natural History, Stockholm, Sweden, 293 pp

- Kolar CS, Lodge DM (2002) Ecological predictions and risk assessment for alien fishes in North America. *Science* 298: 1233–1236, <https://doi.org/10.1126/science.1075753>
- Lawson KM, Tuckett QM, Ritch JL, Nico LG, Fuller PL, Matheson RE, Gestring K, Hill JE (2017) Distribution and status of five non-native fish species in the Tampa Bay drainage (USA), a hot spot for fish introductions. *BioInvasions Records* 6: 393–406, <https://doi.org/10.3391/bir.2017.6.4.15>
- Loftus WF, Kushlan JA (1987) Freshwater fishes of southern Florida. *Bulletin of the Florida State Museum Biological Sciences* 31(4): 147–344
- Marchetti MP, Moyle PB, Levine R (2004) Alien fishes in California watersheds: characteristics of successful and failed invaders. *Ecological Applications* 14: 587–596, <https://doi.org/10.1890/02-5301>
- Mejide FJ, Guerrero GA (2000) Embryonic and larval development of a substrate-brooding cichlid *Cichlasoma dimerus* (Heckel, 1840) under laboratory conditions. *Journal of Zoology* 252: 481–493, <https://doi.org/10.1111/j.1469-7998.2000.tb01231.x>
- NCSS (2021) Statistical Software package. NCSS, LLC. Kaysville, Utah, USA, <https://www.ncss.com/software/ncss/>
- Ndong D, Chen Y-Y, Lin Y-H, Vaseeharan B, Chen J-C (2007) The immune response of tilapia *Oreochromis mossambicus* and its susceptibility to *Streptococcus iniae* under stress in low and high temperatures. *Fish and Shellfish Immunology* 22: 686–694, <https://doi.org/10.1016/j.fsi.2006.08.015>
- Nico LG, Muench AM (2004) Nests and nest habitats of the invasive catfish *Hoplosternum littorale* in Lake Tohopekaliga, Florida: a novel association with non-native *Hydrilla verticillata*. *Southeastern Naturalist* 3: 451–466, [https://doi.org/10.1656/1528-7092\(2004\)003\[0451:NANHOT\]2.0.CO;2](https://doi.org/10.1656/1528-7092(2004)003[0451:NANHOT]2.0.CO;2)
- Novakowski GC, Casemiro FAS, Hahn NS (2016) Diet and ecomorphological relationships of four cichlid species from the Cuiaba River basin. *Neotropical Ichthyology* 14: e150151, <https://doi.org/10.1590/1982-0224-20150151>
- Pandolfi M, Cánepa MM, Mejide FJ, Alonso F, Vázquez GR, Maggese MC, Vissio PG (2009) Studies on the reproductive and developmental biology of *Cichlasoma dimerus* (Perciformes, Cichlidae). *Biocell* 33: 1–18, <https://doi.org/10.32604/biocell.2009.33.001>
- Paperno R, Ruiz-Carius R, Krebs JM, McIvor CC (2008) Range expansion of the Mayan cichlid *Cichlasoma urophthalmus* (Pisces, Cichlidae), above 28°N latitude in Florida. *Florida Scientist* 71(4): 293–304
- Rehage JS, Blanchard JR (2016) What can we expect from climate change for species invasions? *Fisheries* 41: 405–407, <https://doi.org/10.1080/03632415.2016.1180287>
- Robins RH, Page LM, Williams JD, Randall ZS, Sheehy GE (2018) Fishes in the Fresh Waters of Florida: An Identification Guide and Atlas. University of Florida Press, Gainesville, Florida, 467 pp, <https://doi.org/10.2307/j.ctvx1ht6s>
- Robins RH, Brown ME, Crutchfield RA (2020) Identification of acara (Cichlidae: *Cichlasoma*) established in Florida, USA. *BioInvasions Records* 9: 133–145, <https://doi.org/10.3391/bir.2020.9.1.18>
- Romero RM, Casatti L (2012) Identification of key microhabitats for fish assemblages in tropical Brazilian savanna streams. *International Review of Hydrobiology* 97: 526–541, <https://doi.org/10.1002/iroh.201111513>
- Sazima I, Machado FA (1990) Underwater observations of piranhas in western Brazil. *Environmental Biology of Fishes* 28: 17–31, <https://doi.org/10.1007/BF00751026>
- Scarabotti PA, López JA, Pouilly M (2011) Flood pulse and the dynamics of fish assemblage structure from neotropical floodplain lakes. *Ecology of Freshwater Fishes* 20: 605–618, <https://doi.org/10.1111/j.1600-0633.2011.00510.x>
- Schofield PJ, Huger DH (2011) Low-temperature tolerance of two non-native fishes (*Hoplosternum littorale* [Hancock 1828], *Cichlasoma bimaculatum* [Linnaeus 1875]) established in Florida. *Florida Scientist* 74(2): 73–83
- Schofield PJ, Kline J (2018) Lower lethal temperatures for nonnative freshwater fishes in Everglades national Park, Florida. *North American Journal of Fisheries Management* 38: 706–717, <https://doi.org/10.1002/nafm.10068>
- Schofield PJ, Pecora, DH (2013) Croaking gourami, *Trichopsis vittata* (Cuvier, 1831), in Florida, USA. *BioInvasions Records* 2: 247–251, <https://doi.org/10.3391/bir.2013.2.3.12>
- Schofield PJ, Schulte JM (2016) Small but tough: what can ecophysiology of croaking gourami *Trichopsis vittata* (Cuvier, 1831) tell us about invasiveness of non-native fishes in Florida? *NeoBiota* 28: 51–65, <https://doi.org/10.3897/neobiota.28.5259>
- Schofield PJ, Loftus WF, Kobza RM, Cook MI, Slone DH (2009) Tolerance of nonindigenous cichlid fishes (*Cichlasoma urophthalmus*, *Hemichromis letourneuxi*) to low temperature: laboratory and field experiments in south Florida. *Biological Invasions* 12: 2441–2457, <https://doi.org/10.1007/s10530-009-9654-6>
- Schofield PJ, Slone D, Reaver K, Tuckett Q, Hill J (2021) Invasion frustration: could biotic resistance explain lack of invasiveness for croaking gourami *Trichopsis vittata* in Florida, USA? *Aquatic Invasions* 16: 512–526, <https://doi.org/10.3391/ai.2021.16.3.08>

- Shafland PL, Pestrak JM (1982) Lower lethal temperatures for fourteen non-native fishes in Florida. *Environmental Biology of Fishes* 7: 149–156, <https://doi.org/10.1007/BF00001785>
- Sucksdorff A (1981) Ett hem på jorden. Möte med Pantanal i Mato Grosso, en brasiliansk vildmark. Stockholm, 160 pp
- USGS-NAS (2021) U.S. Geological Survey Nonindigenous Aquatic Species Database. Gainesville, FL, <http://nas.er.usgs.gov> (accessed 12 July 2021)
- Varela ML, Ferreira MF, Da Cuña RH, Lo Nostro FL, Genovese G, Mejjide FJ (2017) Dynamics of ovarian maturation throughout the reproductive cycle of the Neotropical cichlid fish *Cichlasoma dimerus* (Teleostei, Cichliformes). *Canadian Journal of Zoology* 95: 485–498, <https://doi.org/10.1139/cjz-2016-0198>