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Salinity Tolerance of Two Gobies (*Microgobius gulosus*, *Gobiosoma robustum*) from Florida Bay (USA)

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SHORT PAPERS AND NOTES

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SALINITY TOLERANCE OF TWO GOBIES (*MICROGOBIUS GULOSUS*, *GOBIOSOMA ROBUSTUM*) FROM FLORIDA BAY (USA).—Alteration to the rate and timing of freshwater flow across marshes and into bays can cause shifts in water-quality parameters that may ultimately affect distributions of fauna (e.g., Irlandi et al., 1997; Serafy et al., 1997). Water management practices may result in alterations to seasonal patterns of freshwater discharge, accompanied by rapid shifts in water-quality parameters (e.g., contaminants, salinity) that can stress resident organisms. For example, the opening of canal locks adjacent to Biscayne Bay (Florida) often reduced the salinity of downstream marine waters 15 ppt (Cofer-Shabica and Wang, 1989). Motile animals may move from areas of salinity variability to stable-salinity regions (e.g., as shown by Perez, 1969 for *Leiostomus xanthurus* and *Micropogonias undulatus*). However, fish incapable of fleeing regions that experience rapid changes in salinity levels may exhibit symptoms of stress, such as increased metabolic rates and oxygen consumption (Davenport and Vahl, 1979; Von Oertzen, 1984; Moser and Hettler, 1989; Haney et al., 1999) and altered hematocrit (Plaut, 1998, 1999). Trade-offs in energy expenditures must be made to rectify osmotic concentrations, often at the cost of growth, reproduction, or resistance to other stressors (Moore, 1972; Wedemeyer et al., 1990). Thus, inability to withstand salinity variability may ultimately lead to changes in patterns of habitat use or an attenuated fauna in habitats adjacent to water-management structures.

The hydrology of the expansive Everglades marsh and its downstream estuary (Florida Bay) has been considerably altered by an extensive system of canals and water-management structures. Florida Bay consists of a network of seagrass-covered carbonate mudbanks and mangrove islands (Thayer and Chester, 1989; Zieman et al., 1989). The mudbank morphology of the bay, combined with locally variable water-mass restriction, water management practices, and seasonal patterns of freshwater inflow, produces a series of distinct subregions within the bay (Boyer et al., 1997). Fluctuations in freshwater inflow have the greatest effect in the northeastern portion of the bay (Powell et al., 1986). Seasonal fluctu-

ations in salinity, in combination with the restriction of water masses in the northeastern bay, result in a wide range of salinity conditions: 8.0–64.8 ppt (Schmidt, 1979); 0.2–57.5 ppt (Ley et al., 1994). Southern and western parts of Florida Bay are the least affected by freshwater inflow and have water masses that are more mixed with the Gulf of Mexico and Atlantic Ocean waters, producing a minor salinity range, 27–44 ppt (Sogard et al., 1989a).

Fish species diversity is low in the northeastern portion of the Bay relative to the southern and western regions (Sogard et al., 1987, 1989a, 1989b; Thayer and Chester, 1989). Differences in patterns of fish distribution across Florida Bay have been correlated weakly with seagrass canopy characteristics, sediment types, and salinity patterns (Sogard et al., 1987, 1989b). Montague and Ley (1993) showed that the standard deviation of salinity was the best predictor of benthic animal density, and that lower benthic animal biomass occurred at sites with greater fluctuation in salinity. However, no experimental evidence exists that correlates salinity tolerance with faunal distributions. In this study, I determined the tolerance limits of two gobies (*Microgobius gulosus*, *Gobiosoma robustum*) to acute changes in salinity. These species were chosen because they were locally abundant and showed different patterns of habitat use relative to salinity variability.

Microgobius gulosus and *G. robustum* are relatively common fishes found over a wide range of salinities throughout their extensive natural distributions along the coasts of the Gulf of Mexico (Gulf) and in the Atlantic Ocean (Atlantic) from Florida to Chesapeake Bay (Table 1). *Microgobius gulosus* and *G. robustum* are ecologically similar in most respects, share similar food habits, and sometimes occur syntopically (e.g., Springer and Woodburn, 1960; Tagatz, 1967; Rey et al., 1990; Sheridan, 1992; Serafy et al., 1997). However, in Florida Bay their densities are markedly asymmetrical in regions with different salinity regimes. *Gobiosoma robustum* is generally more abundant in the southern and western portions of Florida Bay, which are heavily influenced by Gulf and Atlantic waters (Sogard et al., 1987). Alternatively, *M. gulosus* is most abundant in the northeastern portion of Florida Bay, where environmental effects of water management are strongest (Sogard et al., 1987). Admittedly, many factors may contribute to this partitioning of habitat

TABLE 1. Salinities associated with collections of *Microgobius gulosus* and *Gobiosoma robustum*. Data are presented in order of publication.

Site	Salinity (ppt)	Citation
<i>Microgobius gulosus</i>		
Cedar Key, Florida	>15.4	Kilby (1955)
Bayport, Florida	<10.5	Kilby (1955)
Tampa, Florida	20–30	Springer and Woodburn (1960)
Cape Sable region, Florida	0–32	Tabb and Manning (1961)
Coot Bay, Florida	12–28	Tabb and Manning (1962)
Nine Mile Pond, Texas	Mean = 35	Baird (1965)
St. Johns River, Florida	0–19.9	Tagatz (1967)
Big Pine Key, Florida	36	Birdsong (1981)
Barataria Bay, Louisiana	Mean = 17.3 ± 3.6 SD	Baltz et al. (1993)
Lake Pontchartrain, Louisiana	Mean = 4.5 ± 0.23 SE	Duffy and Baltz (1998)
Various Florida sites	0–37	FLMNH database ^a
<i>Gobiosoma robustum</i>		
Cedar Key, Florida	17.5–31.5	Reid (1954)
Cedar Key, Florida	7.0–37.6	Kilby (1955)
Tampa Bay, Florida	22–32	Springer and Woodburn (1960)
Cape Sable region, Florida	4–31	Tabb and Manning (1961, 1962)
Mississippi Sound, Mississippi	6.2–33.8	Dawson (1966)
St. Johns River, Florida	0–11.0	Tagatz (1967)
Various Florida sites	1–37.6	FLMNH database ^a

^a Florida Museum of Natural History, University of Florida, Gainesville, FL 32611.

(e.g., differences in vegetational parameters, physicochemical conditions, or predator–prey–competitor densities). In this study, I was particularly interested in the ability of these fish to survive rapid shifts in salinity because freshwater is presently being diverted via canals, and this will directly affect salinities in the north-eastern Florida Bay. It is unlikely that the overall (chronic) level of salinity affects distribution of these fish because they occur over a wide range of salinities (Table 1). However, it is possible that variation in tolerance to rapid shifts in salinity may explain their distributional differences in Florida Bay. Specifically, I expected that *M. gulosus* would be more tolerant than *G. robustum* to rapid changes in salinity because *M. gulosus* inhabits regions of Florida Bay that undergo greater salinity fluctuations relative to those experienced by *G. robustum*.

Methods.—Study species: *Microgobius gulosus* were collected from Davis Cove, northeastern Florida Bay, on 4–5 Sep. 2001 (25°12.467'N 80°32.425'W; salinity = 19 ppt). *Gobiosoma robustum* were collected from Crab Key, southeastern Florida Bay, on 5 Sep. 2001 (24°59.861'N 80°39.687'W; salinity = 38 ppt). Fish were collected with a 1-m² throw trap (Kushlan, 1981), which is the most effective gear available for sampling demersal organisms on the shallow, soft mudbanks of Florida

Bay (Powell et al., 1986; Jordan et al., 1997). All fish were transported back to the U.S. Geological Survey in Gainesville for laboratory experiments. Fish were held in monospecific groups of approximately 30 individuals in aerated 36-liter aquaria and fed live brine shrimp ad libitum. Within the first few days of holding in the laboratory, the salinity of all holding aquaria was adjusted to 30 ppt in increments of ≤ 5 ppt/d. Salinity was held at 30 ppt until acute transfer.

Experimental protocol: On 24 Sep. 2001, fish were transferred in batches of four to experimental aquaria with the following salinities: 0, 5, 10, 15, 30 (control), 45, 50, 55, and 60 ppt. Three replicates were completed for each treatment; therefore, a total of 108 individuals were tested for each species (nine treatments $\times$ four fish per aquaria $\times$ three replicates). Filtered seawater (30 ppt) was diluted with deionized water for salinities of 5–30 ppt. Synthetic sea salts (Forty Fathoms®, Aquatic Ecosystems, Inc.) were added to filtered seawater for salinities >30 ppt. Water was collected from the C-111 canal (at U.S. 1) for use in the 0-ppt treatment to mimic a freshwater pulse. Water-quality parameters (Ca, Mg, Na, HCO₃, alkalinity, hardness, and pH) were analyzed for samples from Crab Key, Davis Cove, and the C-111 canal and for filtered seawater from the U.S.

TABLE 2. Water-quality parameters for samples from Florida Bay (Crab Key, Davis Cove), the C-111 canal, and filtered seawater used in acute salinity-tolerance experiment. Water-quality parameters were determined by the U.S. Geological Survey Water Quality and Research Laboratory, Ocala, FL. Values represent single estimates.

Site	Ca (mg/liter)	Mg (mg/liter)	Na (mg/liter)	HCO ₃	Alkalinity	pH
Crab Key	370.2	1,264.7	10,920	181.86	149.16	8.09
Davis Cove	271.5	820.8	6,825	202.77	166.31	8.13
Seawater	325.0	1,108.0	9,230	165.16	135.46	7.98
C-111 canal	68.1	14.6	133	207.05	174.26	8.41

Geological Survey Water Quality and Research Laboratory, Ocala, FL.

Experimental aquaria consisted of 36-liter glass aquaria divided into four sections with black Plexiglas partitions sealed with aquarium-grade silicone. These partitions prevented water from moving between the compartments of the aquaria and also served as a blind that prevented the fish from seeing each other. Additionally, black plastic sheeting was wrapped around all sides of each aquarium to minimize external disturbances. Each aquarium compartment was fitted with a sponge filter and treated as a separate experimental unit. Treatments were interspersed among compartments within experimental aquaria so that an equivalent number of treatments were allocated to aquaria on the bottom, middle, and top shelves of the racks where aquaria were placed. Water temperature was measured in five aquaria each day. Fish were checked at 2, 4, 6, and 8 hr elapsed time after acute transfer on the first day and then each morning for the next 10 d. Fish were not fed during the experiment.

Data analysis: Thirty individuals of each species were measured [standard length (SL)] and weighed to the nearest 0.01 g. Regression analysis was used to determine the relationship between SL and mass. Data for each species were fit with both linear and quadratic functions to determine the relationship that best described the data.

Survival was estimated with a Kaplan-Meier product limit estimator (Kaplan and Meier, 1958). This estimator is preferred to other estimators because it is free of assumptions surrounding the hazard function (e.g., constant survival during intervals; White and Garrott, 1990). Detailed descriptions of the estimator and its properties can be found in Kaplan and Meier (1958), Cox and Oakes (1984), Pollock et al. (1989), and White and Garrott (1990). The log-rank test was used for comparison among survivorship curves generated by the Kaplan-Meier estimator (Savage, 1956; Cox

and Oakes, 1984). For a log-rank test, each time step is treated as a 2×2 contingency table. The log-rank test is then derived by combining the results from each contingency table as an approximate chi-square test statistic with one degree of freedom. The log-rank test was used to compare survivorship curves among treatments (within species) and between species (within treatments). All calculations were conducted in SPSS® version 10.0, and alpha was set at $P = 0.05$. Because chi-square probabilities cannot be computed when cells contain very low expected values (generally for $>50\%$ of the cells with values less than 5), it was not possible to statistically compare treatments with zero mortality.

Results.—*Microgobius gulosus* ranged from 16 to 32 mm in SL (mean = 22.6 ± 4.0 SD) and from 0.04 to 0.34 g in weight (mean = 0.13 ± 0.07 SD). *Gobiosoma robustum* ranged from 14 to 23 mm in SL (mean = 17.8 ± 2.0 SD) and from 0.03 to 0.22 g in weight (mean = 0.10 ± 0.05 SD). For both species, a linear trend most appropriately described the length-weight relationship (*G. robustum* $P < 0.001$, $R^2 = 0.786$; *M. gulosus* $P < 0.001$, $R^2 = 0.940$). On average, *G. robustum* were heavier than *M. gulosus* at a given length. Analysis of covariance showed that the slopes were not different ($P = 0.448$), but the Y-intercept for *M. gulosus* was lower than for *G. robustum* ($P < 0.001$).

Water-quality parameters for Crab Key, Davis Cove, and the filtered seawater used in the experiment are given in Table 2. Water temperature averaged 22.4 C (± 1.08 SD, range = 20.7–23.5) during the course of the experiment. Daily differences in water temperature among aquaria ranged from 0.1 C to 0.5 C.

Two control (30 ppt) *M. gulosus* that had been transferred in the same batch of four died during the first 3 d of the experiment (one at 24 hr and the other at 72 hr). These fish were the largest males used in the experiment and had sustained physical injuries that

Fig. 1. Survivorship of (A) *G. robustum* and (B) *M. gulosus* over a range of salinities for 240 hr.

were likely due to their fighting with each other. These individuals were removed from the data analysis. No other individuals in the control treatment died during the experiment. I observed neither fighting nor physical injuries in any other experimental fish.

Survival curves differed among treatments for both species ($P < 0.001$; $df = 8$; Fig. 1). Survival at 0 and 60 ppt was significantly lower than in the control group for *G. robustum* (0 ppt, $P < 0.001$; 60 ppt, $P = 0.006$). Survival at 0, 50, and 60 ppt was significantly lower than in the control group for *M. gulosus* (0 ppt, $P = 0.024$; 50 ppt, $P = 0.011$; 60 ppt, $P < 0.001$). Survival was lower for *M. gulosus* than for *G. robustum* at 50 and 60 ppt ($P = 0.005$ and $P < 0.001$, respectively).

Microgobius gulosus exhibited a more rapid response to salinity stress than *G. robustum*. Most mortalities for *M. gulosus* occurred in the first 24 hr of the experiment (Fig. 1B). Only one *M. gulosus* died between 24 and 72 hr, and none died after 72 hr. *Gobiosoma robustum* generally exhibited an increased latency to death from salinity stress when compared to *M. gulosus*: Individuals of *G. robustum* died as late as 192 hr (8 d) after acute transfer (Fig. 1A).

Discussion.—The premise of this study was to determine whether *M. gulosus* and *G. robustum*

exhibited differential tolerance to acute salinity shifts, which may be related to their distributions within Florida Bay. Given that *M. gulosus* inhabits the northeastern region of Florida Bay, which is more likely to be exposed to rapid shifts in salinity than the less variable habitat over which *G. robustum* is distributed (southern and western Florida Bay), it was hypothesized that *M. gulosus* would be more tolerant to salinity shifts. This should be true of downward shifts in salinity, especially because freshwater pulses may occur from seasonal events (e.g., storms) and outputs from freshwater canals. However, there is no compelling evidence for differences in acute salinity tolerance during the 10-d experimental period because both species showed significantly reduced survival (relative to the control) at similar salinity levels (0 and 60 ppt).

Although this study lasted 10 d, natural challenges to fish from rapid shifts in salinity may be of various durations. For example, organisms may be subjected to relatively short-lived salinity fluctuations from tidal cycles, storm events, or canal outflows that last only a few hours before previous salinity levels are restored. In this study, although both species showed the same overall tolerance to acute shifts, *M. gulosus* exhibited a more rapid response than did *G. robustum*. This is also contrary to the hypothesis that *M. gulosus* should be more tolerant to salinity shifts. In summary, it appears that both species are quite tolerant to a large range of salinities, whether induced rapidly (as in this study) or in a chronic fashion, as evidenced from their distribution throughout a wide salinity range. Furthermore, it seems that *M. gulosus* is somewhat less tolerant to acute salinity shifts at the high end of the range studied. In any case, there is no strong evidence that salinity alone restricts the distribution of either of these species within Florida Bay.

Tolerance to rapid salinity shifts has been documented as an interactive function related to energy requirements from feeding (Vahl and Davenport, 1979) as well as to activity levels, oxygen concentration, and temperature (e.g., Von Oertzen, 1984). These factors were not specifically addressed in this study; however, increased activity, metabolic demands from feeding, or reduced oxygen levels may further decrease the salinity tolerances documented herein. The temperature range in this study was in the midrange of temperatures normally seen in Florida Bay (annual range approximately 18–32 °C; Powell et al., 1986). It is therefore likely that salinity tolerance may decrease

from the levels shown in this study in the warmer summer months or cooler winter months.

Although the range of tolerated salinities appears to be roughly equivalent for these two species, salinity may be only one of the many factors determining the ultimate ranges of their distribution. Serafy et al. (1997) found that although the distribution of some fish across sites with and without canal influence (and corresponding salinity variability) correlated with their ability to survive freshwater pulses in laboratory experiments, that of others did not. For example, two species that were tolerant to freshwater pulses in the laboratory (*Haemulon sciurus* and *H. parra*) were less abundant in canal-influenced sites (where freshwater pulses are likely to occur) than in stable-salinity sites. Other factors such as tolerance to additional physicochemical characteristics as well as the presence of food, competitors, and predators surely play an important role in the distribution of these species. Additionally, as Moser and Gerry (1989) point out, salinity fluctuations resulting from increased freshwater runoff are likely correlated with a number of other factors, such as altered current regimes, higher turbidity, and increased herbicide or pesticide levels. Contaminant inputs through canal runoff may be especially concentrated after lengthy periods of drought (Brook, 1982) and further increase metabolic demands (Calow, 1991). Finally, the focus of this study was on lethal effects of salinity shifts on adult *M. gulosus* and *G. robustum*. Sublethal effects of salinity shifts (e.g., changes in behavior, growth, and reproduction) as well as egg and larval requirements are also of critical importance in the delineation of correlates of habitat quality.

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