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IMPORTANCE OF FOOD RATION AND WATER TEMPERATURE ON GROWTH OF JUVENILE GREEN SUNFISH (*LEPOMIS CYANELLUS*)

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Abstract.—A randomized design was used to test the difference in growth rates of juvenile green sunfish (*Lepomis cyanellus*) subjected to three treatments (food ration, temperature and salinity). Food ration and water temperature were similarly important in affecting growth of juvenile green sunfish. Juvenile green sunfish were found to accomplish similar growth with scarce food and optimum temperature as with abundant food and sub-optimum temperature. This equal and independent relation to biotic and abiotic factors should be expected in a ubiquitous generalist species, such as green sunfish.

Sunfishes (*Lepomis* sp.) are widespread in North America (Lee et al. 1980) and are found in aquatic habitats with varying physical/chemical conditions and food availability. Bluegill (*L. macrochirus*) and green sunfish (*L. cyanellus*) are the most ubiquitous sunfish species. The green sunfish is highly adaptable and found in most types of aquatic habitats (Robinson & Buchanan 1992) because of a broad tolerance to a range of ecological conditions, particularly surviving in environmental extremes of turbidity, dissolved oxygen, temperature and flow (Pflieger 1975). Hence, green sunfish is often the first species to inhabit new water bodies and one of the first to repopulate flooded areas after a drought (Pflieger 1975; Smith 1979). As well as being sought by anglers (USFWS 2002), sunfishes are an important food source for piscivores such as largemouth bass (*Micropterus salmoides*) (Lewis et al. 1961) and flathead catfish (*Pylodictis olivari*) (Turner & Summerfelt 1971).

Predicting year-class strength of fish is often an elusive goal in fisheries management. Fish are most vulnerable to mortality during early life stages (Houde 1989; Rutherford & Houde 1995) and identification of the biotic and abiotic factors controlling survival and growth of young fish is essential for understanding recruitment (Miller et al. 1988). Faster growth in early life stages of fish often results in increased survival to age 1 yr (Forney 1976; Post & Prankevicius 1987; Rice et al. 1987; Luecke et al. 1990). Slow growth during the first summer of life often is implicated as a primary factor influencing winter mortality (Gutreuter & Anderson 1985), as small fish remain vulnerable to predation (Cowan et al. 1996) and may be more susceptible than large fish to starvation (Cargnelli & Gross 1996, 1997) due to lower energy reserves (Fullerton et al. 2000). Slight increases in growth can generate an order of magnitude or greater improvement in annual recruitment (Houde 1987, 1989; Davis et al. 1991; Rice et al. 1987, 1993). Thus, the underlying processes that regulate growth of young fish are critical for understanding fish recruitment (Miller et al. 1988).

Complex interactions of biotic and abiotic factors often regulate growth of larval and juvenile fish (Claramunt & Wahl 2000). Three commonly identified biotic and abiotic variables affecting growth of larval and juvenile fishes are food availability (Letcher & Bengston 1993; Welker et al. 1994; Chipps et al. 2000; Romare 2000), water temperature (Letcher & Bengston 1993; Keckeis et al. 2001; Hurst & Conover 2002) and salinity (Abookire et al. 2000; Jarvis et al. 2001; Hurst & Conover 2002). Somatic growth of sunfish is rapid during their first year of life; thus, this life stage provides an excellent opportunity to assess growth differences in short periods (< 1 month). This study was designed to determine which environmental variable is most influential on growth of juvenile green sunfish.

MATERIALS AND METHODS

Age 0-1 yr green sunfish (total length: 27.8–54.6 mm) were collected from McCullough Park in Lubbock, Texas during October 2001 using a seine (1.8 by 9.1-m, 5-mm mesh). Each green sunfish was randomly assigned to a 1-L aquarium (one fish per aquarium) within one of three 76-L water baths for a period of 30 days. Aeration was supplied to each aquarium through an airstone. Each water bath was partially filled with water (approximately 19 L) and contained a rack that held aquaria off the bottom of the water bath for improved water circulation to obtain consistent temperature throughout the water bath and aquaria. Each aquarium was an entirely separate system within each water bath, which allowed for a fully replicated design. A photoperiod (14 h light: 10 h dark) was maintained for the duration of the experiment. Water quality parameters (pH, salinity, dissolved oxygen, NH_4, and temperature) were measured in each aquarium every other day. After measuring water quality parameters, 25-40% of the water was siphoned from each aquarium to remove debris and waste. Each aquarium was then refilled with fresh water.

Fish were individually weighed (nearest 0.01g wet weight after blotting with absorbent paper) and measured (nearest 0.1 mm total length)

Table 1. Mass ratio (final mass/initial mass) was modeled as a general linear model of temperature (t), food ration (r) and temperature-food ration interaction ($t * r$).

Effect	*df*	Type III sum of squares	Mean square	Variance	*f* value	Pr > *f*
Full Model	11	2.1384	0.1944		5.33	< 0.0001
r	3	1.0260	0.3421	0.01655	6.39	0.0267
t	2	0.7310	0.3655	0.01342	6.83	0.0284
$t * r$	6	0.3212	0.0535	0.00292	1.47	0.2056

at the beginning and the end of the experiment. Before each weighing, fish were starved one day to evacuate their digestive systems. Otherwise, fish were fed bloodworms (San Francisco Bay Co.) once daily.

The experimental design was a fully replicated ($r = 2$) randomized design with three random effects (food ration, temperature and salinity) (Scheiner & Gurevitch 2001). Temperatures (20, 25 and 30°C) that could potentially be encountered by age 0-1 yr green sunfish during summer were subjectively selected. Each green sunfish within each water temperature was randomly assigned a food ration (6, 19, 26 and 36% of initial mass) in the range of 4 to 40% of initial mass and a salinity level (1, 2 and 4 ppt) in the freshwater range (0–4 ppt). Treatments were tested as random effects, which allowed investigation of the effects across the tested ranges and allowed generalizations to be made about the treatments. The two replicates of each treatment-level combination were assessed for 72 fish simultaneously.

Because fish growth is size dependent, mass ratio (final mass/initial mass, MR) was modeled using the general linear model procedure (Scheiner & Gurevitch 2001) as a function of food ration, temperature, salinity and all possible interactions with a significance of alpha = 0.05. This procedure was used because it allows for an analysis of variance on unbalanced random effect models (Scheiner & Gurevitch 2001), which was appropriate because two fish died during this experiment and were excluded from analyses. After initial analysis, salinity (including all associated interactions) was found to have no effect on the growth of the sunfish and was removed from subsequent analysis. As a result, the final MR model was a function of food ration (r), temperature (t) and a food ration-temperature interaction (r^*t). The effects were ranked in order of significance to MR by proportional contribution to the total sum of squares.

RESULTS

The final model ($\mathrm{MR} = f(r, t, r^*t)$) explained 50% of the variation in growth of juvenile green sunfish (Table 1). Food ration was the most

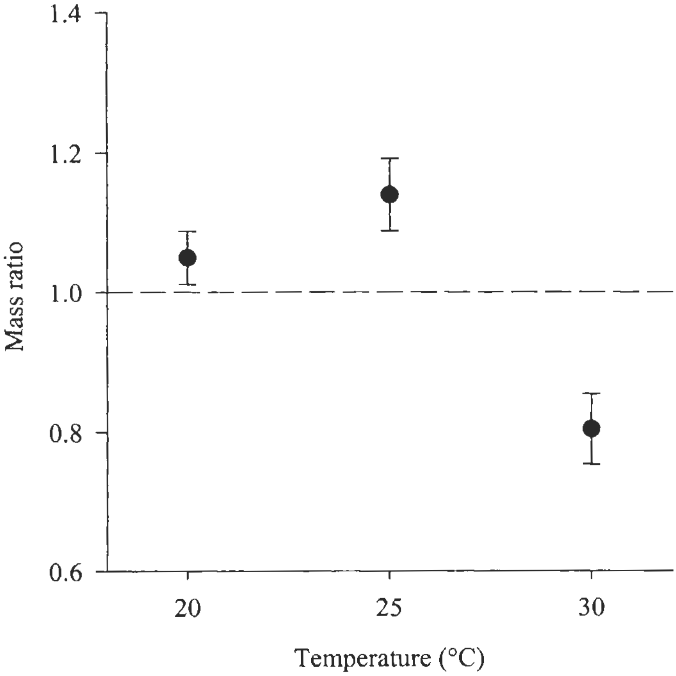

Figure 1. Mean ± SE mass ratio (final mass / initial mass) of juvenile green sunfish held at 20, 25 and 30°C for 30 days. The reference line refers to a mass ratio of one, which indicates no growth; values > 1 indicate weight gain and values < 1 indicate weight loss.

significant factor influencing growth of juvenile green sunfish ($P = 0.0267$), but was only slightly more significant than temperature ($P = 0.0284$). Fish held at 20 and 25°C gained weight (Figure 1), whereas fish at 30°C lost weight. Juvenile green sunfish growth was also positively related to food ration (Figure 2). Fish that were provided the two smallest food rations lost weight. There was no significant interaction ($P = 0.21$) between food ration and temperature.

DISCUSSION

The aim of this study was to assess the importance of food ration, temperature and salinity on juvenile green sunfish growth. Salinity did not have an effect probably because a narrow range (1–4 ppt) was tested that may not have been sufficient to detect growth differences. Food ration and temperature each had a strong effect on the growth of the juvenile green sunfish. Food abundance and water temperature acted independently and were almost of equal significance in determining the

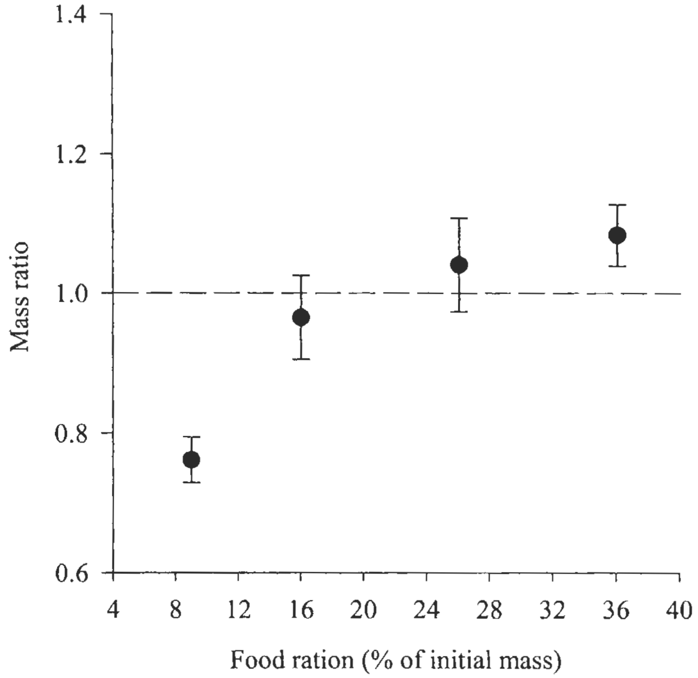

Figure 2. Mean ± SE mass ratio (final mass/initial mass) of juvenile green sunfish provided four food rations (6, 19, 26 and 36% of initial mass) for 30 days. The reference line refers to a mass ratio of one, which indicates no growth; values > 1 indicate weight gain and values < 1 indicate weight loss.

growth of juvenile green sunfish. Mischke et al. (2001) conducted a similarly designed experiment on larval hybrid sunfish (green sunfish x bluegill) and found that feeding regime (brine shrimp three times per day for three days after hatch and commercial feed for 25 additional days versus brine shrimp three times per day for seven days and commercial feed for 21 additional days after hatch) affected larval growth more than temperature (19, 21 and 24°C). This differs from the results of this study, which found almost equal effects of food ration and temperature on the growth of juvenile green sunfish.

Temperature affects the maximum and maintenance energy intakes of fish (Elliot 1994). The energy demand increases when a fish is subjected to temperatures different from its optimum, which creates a greater need for food consumption (Letcher & Bengtsom 1993). The difference between the energy required for maintenance and the energy that is consumed is the opportunity for growth. Maximum growth of fishes tends to occur at the upper end of the preferred temperature range and declines quickly beyond the optimum temperature (Elliot 1994).

Limitations of food abundance at all temperatures resulted in reduced growth of juvenile green sunfish. The costs of increased temperatures include greater metabolic rates (Brett & Groves 1979; Elliot 1994) and decreased assimilation efficiency with greater ingestion rates (Boehlert & Yoklavich 1984). Thus, optimal temperatures accelerate growth, whereas unfavorable temperatures tend to halt or even reverse growth because away from their optimum, the energy demands increase (Conover 1990).

For survival it is important that larval and juvenile fish grow as rapidly as possible to avoid predation (Werner & Gilliam 1984; Bailey & Houde 1989) and store enough energy reserves for winter (Gutreuter & Anderson 1985). The reproductive season of green sunfish is May through August (Moyle 1976), therefore age 0-1 yr green sunfish can be exposed to a wide range of biotic and abiotic factors and hence varying energy demands. Green sunfish spawned at a time that provides optimal conditions, abundant food and intermediate temperatures during their first several months of life, will be most likely to survive predation and winter conditions and recruit to the adult population. Following the results of this study, it is expected that green sunfish spawned in less than optimal temperatures will overcome the increased energy demand by consuming more prey. In addition, green sunfish that are spawned during periods of low food availability would likely have greater survival if spawned at or close to their optimal temperature. Thus, juvenile green sunfish can accomplish similar growth under dissimilar environmental conditions. This equal and independent relationship to biotic and abiotic factors should be expected in a ubiquitous generalist species, such as green sunfish.

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