Effects of temperature on survival and growth of juvenile spinefoot rabbitfish (*Siganus rivulatus*)

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Abstract

Interest in culturing marbled spinefoot rabbitfish *Siganus rivulatus* is increasing in countries on the Eastern Mediterranean, Red Sea and Arabian Gulf. However, information on environmental tolerances and requirements for optimal growth are scarce. In the present work, the temperature requirements for spinefoot rabbitfish were investigated in two experiments. In the first experiment, juvenile rabbitfish were distributed into eight 180 L square tanks at 12 fish per tank. The temperature in four tanks was reduced at a rate of 1°C day⁻¹ and in four tanks was increased by 1°C day⁻¹ until the fish stopped feeding. Minimum and maximum temperatures for feeding were recorded. In the second experiment, the fish were placed in four temperature treatments (17, 22, 27, 32°C) at four replicates per treatment for 8 weeks. Survival and growth were evaluated. Fish stopped feeding at 14 and 36°C. Their maximum growth rate was at 27°C, and survival was 100% in all treatments. The relationship between specific growth rate and temperature was parabolic, described by the equation: 

\[
\text{SGR} = -0.0014 \times T^3 + 0.0798 \times T^2 - 1.3089 \times T + 6.7342
\]

The results show that *S. rivulatus* is a eurythermal fish whose optimal temperature for growth is circa 27°C.

Keywords: *Siganus rivulatus*, rabbitfish, temperature

Introduction

The marbled spinefoot rabbitfish *Siganus rivulatus* is a euryhaline herbivorous fish distributed in the Indo-West Pacific region (Woodland 1983). It is one of the most successful Lessepsian migrants, having established itself along the eastern Mediterranean coast since the opening of the Suez Canal in 1869 (Por 1978). Presently, there is a good market for fish in Eastern Mediterranean countries, and rabbitfish is even becoming important in Greek fisheries (Papconstantinou 1990). Moreover, interest in the aquaculture of fish is increasing as evident from recent publications (El-Sayed, Mostafa, Mohammadi, Dohaiymi & Kayid 1993; Osman, Yousif, Anwah & Cherian 1996; Yousif, Osman, Anwah & Cherian 1996; El-Dakar 1999; Stephanou & Georgiou 1999; Saoud, Kreydiyyeh, Shalfoun & Fakh 2007). Siganids are easily reared and have commercial importance for fishery production (Juario, Duray, Duray, Nacario & Almendras 1985; Hara, Kohno & Taki 1986). However, little is known of the environmental tolerances of the marbled spinefoot.

The growth rate of fish is affected by several biotic and abiotic factors (Brett & Groves 1979), of which temperature is very important (Fry 1971; Somero, Dahlhoff & Lin 1996). Ambient water temperature regulates growth rate by affecting many physiological processes in fish (Brett 1979; Jobling 1996) such as food consumption, metabolic rate, reproduction, activity and survival (Jobling 1994; Hillman, Miller & Nishitani 1999). Furthermore, fish are more susceptible to disease at extreme temperatures (Holt, Sanders, Fryer & Pilcher 1975). Provided that food availability is unrestricted, metabolic rate increases as temperature increases. Growth is found to decrease at temperatures above the optimum because of a possible decrease in appetite and high energy cost of maintenance metabolism (Xiao-Jun & Ruyung 1992; Jobling 1994). At low temperatures, growth is

restricted because of low metabolic rates and low food intake. Hence, when culturing a species, best performance is obtained when temperatures are optimal.

In the present manuscript, we conducted two experiments to determine the upper and lower temperatures of feed intake in marbled spinefoot rabbitfish and the optimum temperature for growth of the same fish. Survival, growth and condition index (CI) are reported, and a temperature–growth model for *S. rivulatus* is developed.

**Materials and methods**

**Fish holding conditions**

Juvenile rabbitfish were caught in traps off the beach north of Beirut and transported to the marine research laboratory at the American University of Beirut (AUB). The fish were held in four 180 L square fibreglass tanks and allowed to acclimatize to the new conditions (photoperiod 14L/10D, oxygen > 6 mg L\(^{-1}\), salinity 35 g L\(^{-1}\) and temperature 23 °C) for 12 days. During acclimation, they were offered a 50% protein, 20% lipid trout commercial diet (Golden Extruded, Chile) *ad libitum*. The same feed was used during the experiments. Throughout the experiments, water characteristics were monitored and maintained at O\(_2\) > 5.5 mg L\(^{-1}\), NH\(_3\)-N < 0.1 mg L\(^{-1}\), NO\(_2\)-N < 0.05 mg L\(^{-1}\) and 7.8 ≤ pH ≥ 8.2. Ammonia and nitrite concentrations were measured using the Solorzano (1969) method and the Parsons, Maita and Lalli (1985) method, respectively, and pH was maintained using NaHCO\(_3\). The experimental system consisted of four identical recirculating systems, each composed of four 180 L square fibreglass tanks (60 × 60 × 50 cm: L × W × H), connected to a biological filter and settling tank. The temperature was gradually increased or decreased by using a thermostat-controlled heater or chiller submerged into the sump tank. Water was recirculated between the filter and the tanks using a submersible pump, and aeration was provided via a regenerative blower and submerged air diffusers.

**Maximum and minimum temperature for feeding**

Ninety-six fish (8 ± 0.8 g; mean ± SE) were randomly caught out of the four holding tanks and distributed into eight tanks (12 fish per tank, four tanks per system) in two of the recirculating systems. After 2 days, the temperature in one system was raised at a rate of 1 °C day\(^{-1}\), and in the other system it was decreased at a rate of 1 °C day\(^{-1}\). The fish were offered feed to satiation every morning and their feeding behaviour recorded. When the fish stopped feeding, the temperature was maintained stable for 3 days without feeding and then the fish were offered feed again. If they still did not feed, the heater or chiller was turned off and the temperature allowed to return to 25 °C, and the fish were then offered feed and observed for 3 more days. Throughout the experiment, dead fish were removed and mortalities recorded twice daily, in the morning and in evening. At the end of this experiment, the fish used were discarded and the fish in the holding tanks were used for the next experiment.

**Optimal temperature for growth**

The temperature in the four holding tanks was adjusted over a period of 5 days to 17, 22, 27 and 32 °C and then held at these temperatures for a week. The temperatures were chosen because 17 and 32 °C are the minimum and maximum seawater temperatures recorded on the Lebanese coast in the year 2004 (I.P. Saoud, unpubl. data). Following acclimation, the fish in each tank were size sorted and the large and small individuals discarded. Thirteen fish were individually weighed (7.4–7.6 g) and stocked per tank in each recirculating system. The fish were maintained for 8 weeks and all the fish in each tank were group weighed every other week. Feed was offered at 3% body weight (of largest group weight) daily, divided into two equal morning and evening feedings for 1 week after weighing. The ration was increased by 5% for the second week and then readjusted to 3% body weight after the fish were weighed again. The 5% increase in feed ration in the second week is to reduce the risk of underfeeding and thus stunting growth during the second week after weighing. All treatments were offered the same amount of feed as the tanks that had the largest biomass, thus ensuring that ration size did not further increase the growth rate of faster growing fish. The temperature was recorded twice daily using a YSI 85 DO (Yellow Spring, OH, USA) measuring device and also a mercury thermometer. Eight weeks after the start of the experiment, all tanks were harvested and the fish from each tank were group weighed and then their individual weight and length were measured.
Studied characteristics

Survival and weight gain for each treatment were determined. The average weight of fish for each tank was also calculated. Fulton’s CI was calculated using the formula CI = (W L⁻¹) × X, where W is the weight in grams, L is the total length in millimetres and X is a constant equal to 100 000 (Anderson & Gutreuter 1983). A growth curve (weight vs. time) for each replicate was drawn, and the mean slopes were compared among treatments. The specific growth rate (SGR) for each tank in per cent per day was calculated as:

\[
SGR = 100 \times \left( \frac{\ln W_f - \ln W_i}{t} \right) \text{ per day,}
\]

where \( W_i \) is the initial weight, \( W_f \) is the final weight, and \( t \) is the time in days (Hopkins 1992). A model for SGR vs. temperature was then developed. The optimal temperature for feed conversion was not estimated because that would have entailed collecting leftover feed which might have caused stressed their fish and affect growth in the and survival (see Thyrel, Berglund, Larsson & Naslund 1999).

Statistical analysis

All results were compared using one-way ANOVA. Significant ANOVA was followed by Student–Newman–Keuls multiple comparison test (Steel & Torrie 1980). Differences were considered significant at \( P < 0.05 \). Regression lines of weight vs. time curves were tested for goodness of fit before comparison of regression slopes. All statistical analyses were performed using SPSS (V8 for Windows, SPSS, Chicago, IL, USA).

Results

Maximum and minimum temperature for feeding

In the treatment where the temperature was raised by 1 °C daily, the marbled spinefoot rabbitfish actively sought out and consumed feed offered until the temperature reached 35 °C. At 35 °C, they reacted slowly when feed was offered, taking approximately 40 s before starting to feed. At 36 °C, the fish stopped eating. After 2 days at 36 °C, three fish were found dead in one tank and one was found dead in each of the other tanks. On the third day, the fish were offered feed again and only two fish in one of the tanks swam towards the feed offered and attempted to consume a pellet each. We were unable to see if they consumed the pellet or not. The heating unit was turned off and the water temperature returned to 26 °C in 24 h. The fish resumed feeding and no mortalities were observed for 3 days, after which the fish were removed from the tanks and the system prepared for the second experiment.

In the treatment where the temperature was reduced by 1 °C daily, the marbled spinefoot rabbitfish actively consumed feed offered until the temperature reached 16 °C. At this temperature, both fish activity and feeding frenzy slowed down, but the fish still consumed the feed offered. At 14 °C, feeding stopped completely. The next day, one fish was found dead and on the day after that, another was found dead in another tank. During the night between the second and third day after feeding was stopped, a power failure shut down the chiller, and at 8:00 hours on the next day the temperature had risen to 18 °C. The experiment was terminated and the fish were offered feed, which they readily consumed. The temperature was allowed to rise to 25 °C, and after 3 days most of the fish had died or were lethargic and moribund. All the fish were then removed and the system prepared for the second experiment.

Optimal temperature for growth

Fish survival in all treatments was 100%. Growth at 27 °C was significantly greater than at all other temperatures tested (\( P < 0.05 \)) (Table 1, Fig. 1). There was no difference in weight between fish at 32 and 22 °C, but weight in both treatments was significantly greater than fish weight at 17 °C. Similarly, SGR was significantly greater at 27 °C than at 22 and 32 °C, which were significantly greater than SGR at 17 °C. The CI of the fish at 27 °C was significantly greater than at all other temperatures, but there was no significant difference in CI among fish in other treatments (\( P < 0.05 \)) (Table 1).

The differences in growth rate were apparent by the end of the first 2 weeks; fish at 27 and 32 °C had grown significantly faster than fish at other temperatures, and fish at 22 °C had grown significantly faster than fish at 17 °C (Fig. 1). By day 42, it was obvious that fish at 27 °C were growing faster than fish at 22 and 32 °C and that fish at 17 °C were practically not growing. The relationship between SGR and temperature was described by the equation

\[
SGR = -0.0014 (T^3) + 0.0798 (T^2) - 1.3089 (T) + 6.7342 \quad (r^2 = 0.9828, \, n = 16 \, \text{tanks, where } T \, \text{is temperature in } °C. \text{The shape of the relationship is parabolic with a maximum SGR at 27 } °C.
\]
Table 1 Mean initial weight (W), initial condition index (CI), survival (S), final weight (Wf), specific growth rate (SGR) and final condition index (CI) for juvenile rabbitfish at four different temperatures ± SE

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>W (g)</th>
<th>CI</th>
<th>S (%)</th>
<th>Wf (g)</th>
<th>SGR (% day⁻¹)</th>
<th>CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>7.5 ± 0.08</td>
<td>1.06</td>
<td>100</td>
<td>23.5 ± 0.69</td>
<td>2.04 ± 0.05</td>
<td>1.29 ± 0.02</td>
</tr>
<tr>
<td>27</td>
<td>7.5 ± 0.05</td>
<td>1.06</td>
<td>100</td>
<td>32.3 ± 0.84</td>
<td>2.61 ± 0.05</td>
<td>1.38 ± 0.01</td>
</tr>
<tr>
<td>22</td>
<td>7.4 ± 0.03</td>
<td>1.06</td>
<td>100</td>
<td>22.5 ± 0.69</td>
<td>1.98 ± 0.05</td>
<td>1.31 ± 0.02</td>
</tr>
<tr>
<td>17</td>
<td>7.6 ± 0.04</td>
<td>1.06</td>
<td>100</td>
<td>11.9 ± 0.3</td>
<td>0.82 ± 0.04</td>
<td>1.29 ± 0.00</td>
</tr>
<tr>
<td>PSE</td>
<td>0.66</td>
<td>0.05</td>
<td></td>
<td>0.00</td>
<td></td>
<td>0.02</td>
</tr>
</tbody>
</table>

Means not sharing same letter are significantly different from each other (P<0.05).
PSE, pooled standard error.

Table 2 Average slope (a) of growth vs. time in days in the quadratic equation W = at + b where W is mean weight and t is time in days

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Slope (a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>3.68b</td>
</tr>
<tr>
<td>27</td>
<td>5.63a</td>
</tr>
<tr>
<td>22</td>
<td>3.53c</td>
</tr>
<tr>
<td>17</td>
<td>0.47c</td>
</tr>
<tr>
<td>PSE</td>
<td>0.09</td>
</tr>
</tbody>
</table>

All regression coefficients (r²) were >0.98. Values not sharing same letter are significantly different (P<0.05).
PSE, pooled standard error.

The average slopes of growth curves further demonstrate that 27°C was the optimal temperature for growth of marbled spinefoot rabbitfish in the present experiment. The slopes of growth curves were significantly greater at 27°C than at 22 and 32°C, which were equal but significantly greater than the slope at 17°C (Table 2).

Discussion

The results of the present experiment show that marbled spinefoot rabbitfish are highly eurythermic, capable of surviving between 15 and 36°C. Stephanou and Georgiou (2000) report having maintained S. rivulatus in tanks in Cyprus at temperatures ranging from 15°C in winter to 28°C in summer, and we know that the fish live and feed off the Lebanese coast during the summer when temperatures reach 32°C. However, there are no reports of rabbitfish surviving 72 h at 36°C. In the present experiment, the fish survived at 15 and 35°C and were even feeding at these temperatures. Although the fish were probably in their zone of resistance and would have died if maintained for long periods at these temperatures, it is important for aquaculturists to know the short-term range of tolerance of a fish.

When the temperature dropped from 36 to 26°C in 24 h, the fish did not die but when it rose from 14 to 25°C, they died in 3 days. The results would suggest that S. rivulatus is more capable of tolerating rapid decreases in temperature than rapid increases in temperature. It is common knowledge that fish should be acclimated slowly to temperature changes and that rapid temperature shifts may kill the fish. However, rapid increases in temperature affect fish differently from rapid decreases (Schmidt-Nielsen 2002). Brett (1956) stated that fish acclimate faster to increasing temperatures than to decreasing temperatures although that is probably because the acclimation rate in fish is governed by metabolism, which increases with increasing temperature and
decreases with decreasing temperature. Although the results of the present experiment suggest that marbled spinefoot rabbitfish are more resistant to a decrease in temperature than to an increase, we should keep in mind that the temperature increase was at low temperatures (14–25 °C) while the temperature decrease was at relatively high temperatures (36–26 °C). Under these circumstances, fish mortality with temperature increase and acclimation with temperature decrease would be predictable according to Brett (1956). Furthermore, one should remember that thermal tolerance also depends on the thermal history of the fish (Schmidt-Nielsen 2002), oxygen concentration in the water (Brett 1944), changes in metabolic enzyme systems (Hochacha & Somero 1973), age and size of the fish (Jonassen, Imsland & Stefansson 1999) and diet (Larsson & Berglund 2005). Fish in the present work were offered the same feed, were of the same size and age, and had the same thermal history. Further research into whether increasing and decreasing temperatures had similar effects at high and low temperatures is warranted.

Survival in the 56-day growth experiment was 100%, indicating that marbled spinefoot rabbitfish were within their temperature range of tolerance between 17 and 32 °C. However, it is obvious from our results that 27 °C is much closer to their optimum temperature for growth than the other temperature regimes tested. A parabolic relationship between temperature and growth, in which growth rate increases with increasing temperature, reaching an intermediate temperature where growth rate is maximized and beyond which growth rate is decreased (Brett 1979; Jobling 1996), was observed in the present work. Similar results were reported for juvenile fish of various species such as pollack Pollachius pollachius (Person-Le Ruyet, Buchet, Vincent, Le Delliou & Quemener 2006), barramundi Lates calcarifer (Katersky & Carter 2005; Robin & Carter 2005), European sea bass Dicentrarchus labrax (Person-Le Ruyet, Mahe, Le Bayon & Le Delliou 2004), halibut Hippoglossus hippoglossus (Jonassen et al. 1999), spotted wolffish Anarhichas minor (Imsland, Foss, Sparboe & Sigurds- son 2006), burbot Lota lota (Hofmann & Fischer 2003) and turbot Psetta maxima (Burel, Person-Le Ruyet, Gaumet, Le Roux, Severe & Boeuf 1996). The reasons for the parabolic shape of the temperature vs. growth curve are discussed by Fry (1971) and will not be re-iterated here. Suffice it to say that growth is dependent on the relationship between energy intake and expenditure, and both are factors affected by temperature. Growth is observed to decrease at temperatures above the optimum because of a possible decrease of appetite and increased metabolism (Xiao-Jun & Ruyung 1992; Jobling 1994). At low temperatures, growth is restricted because of low metabolic rates and low food intake. Feed efficiency was not calculated because feeding was not observed, and we do not know if the fish consumed all the feed offered. The only observation made was that, in the 17 °C treatment, most of the feed offered remained in the bottom of the tank and was periodically removed with a net.

Although the optimal temperature for growth observed in the present work was 27 °C, various researchers suggest that optimal temperatures are affected by diet. Elliott and Hurley (2000) state that the optimal temperature for brown trout Salmo trutta growth increases with the energy concentration of the diet. Similar results were discussed by Brett (1979) and Jobling (1993). Allen and Wooten (1982) found that the stickleback Gasterosteus aculeatus growth rate decreased with an increasing temperature when the ration was restricted but increased with temperature when the ration was increased. However, Larsson and Berglund (1998) found that artic char Salvelinus alpinus offered an invertebrate diet exhibited similar growth rates to those offered a commercial fish feed. In the present study, all fish were offered the same diet and the effects of diet in response to temperature were not evaluated. By the end of the experiment, fish at 27 °C were being offered less feed as a per cent of their body weight than fish in all other treatments. Nevertheless, fish at 27 °C continued to grow faster than those at all other treatments. Although such a protocol might have slowed down the growth rate of fish at 27 °C, it strengthens the argument that 27 °C is the optimal temperature for marbled spinefoot rabbitfish growth. Feeding to satiation was not possible in the present experiment because after 2 weeks the water colour made it impossible to observe the feeding behaviour of the fish.

The weight–length relationships of fish, such as Fulton’s CI, are a relative measure of well-being (see Anderson & Neumann 1996). In the present experiment, the condition of the fish was better at harvest than at stocking for all treatments. However, the CI had improved faster at 27 °C than at all other temperatures evaluated. The fact that CI had improved in all treatments is probably because the feed used was higher in protein and lipid as compared with this species’ natural foods (Lundberg & Golani 1995). The fact that CI was best at 27 °C strengthens the
argument that 27 °C is the optimal temperature for S. rivulatus. Koskela, Pirhonen and Jobling (1997) found that highest CI for Salmo salar was not at the temperature that exhibited the fastest growth. They do not discuss the reasons for this, but their discussion suggests that differences in weight are related to lipid deposition, where an increase in per cent lipid deposition resulted in a decrease in per cent body water and thus a decrease in weight.

The eurythermicity of marbled spinefoot rabbitfish makes them a good candidate for aquaculture. If reared in outdoor tanks or ponds, they will survive short-term winter temperatures down to 15 °C and in the summer up to 35 °C. In the eastern Mediterranean and Red Sea region, these extreme temperatures are seldom experienced. In Lebanon, the highest temperature observed in 2004 was 32 °C in August, and the temperature remained above 22 °C until 14 December (I. P. Saoud, unpubl. data). This means that aquaculturists can stock their tanks in May and do not have to harvest until the Christmas season when the prices are highest, demand is highest and supply of wild catch is low. Further research on temperature acclimatization rates at various temperatures is warranted, but the information presented herein is encouraging for farmers considering the aquaculture of S. rivulatus.

References


