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The Relationship of Food Conversion Efficiency and  
Growth Potential in Juvenile Mosquitofish, Gambusia affinis

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## Abstract

New information concerning respiratory metabolic rates of juvenile mosquitofish ( $\bar{x} = 915 \text{ mg O}_2 \text{ kg}^{-1} \text{ h}^{-1}$  at  $20^\circ \text{ C}$ ) was applied to existing data on mosquitofish respiration and combined with findings on growth and food consumption rates to determine percentages of net ingested energy used for growth and respiration over a  $10\text{-}35^\circ \text{ C}$  temperature range. The energy percentage used by mosquitofish for respiration was minimized at  $25\text{-}30^\circ \text{ C}$  while that used for growth (= food conversion efficiency) was maximized at the same temperature. A calculated growth potential index, derived from an overall energy balance equation, was also maximized at the  $25$  to  $30^\circ \text{ C}$  range and proved to be closely correlated with food conversion efficiency ( $r = 0.98$ ). Possible future applications of the growth potential index for estimating food conversion efficiencies in field populations of fishes are suggested.

## Introduction

As biological systems conform to the laws of thermodynamics, ingested food energy (I) must emerge either as energy expended for respiratory metabolism (M), or growth (G), or as energy excreted (E) (Brett and Groves 1979). This can be simply expressed in the equation:

$$I = M + G + E \quad (1)$$

Because some of the ingested energy may be in an indigestible form, a coefficient of digestibility (p) restricts energetic calculations to digestible energy (pI) alone. Similarly, consideration of solely the digestible energy which is not ultimately excreted (net energy) can be expressed in:

$$pI_{(net)} = M + G \quad (2)$$

The close relationship among these three variables (equation 2) has been discussed by Winberg (1956), who used the term "utilization of food for growth" to describe the weight increase divided by food consumption. This type of conversion ratio is routinely used by animal (including fish) culturists to describe the efficiency of converting feed to animal biomass (Stickney 1979). Rearrangement of equation 2 yields:

$$\frac{G}{pI_{(net)}} = \frac{G}{M + G} \quad (3)$$

showing the relationship between conversion efficiency (  $\frac{G}{pI_{(net)}}$  ) and a growth/respiration ratio  $\frac{G}{M + G}$ .

The objective of the present study was to test the usefulness of the

$\frac{G}{M + G}$  factor in estimating the energy conversion efficiency for growth in the mosquitofish (Gambusia affinis).

#### Materials and Methods

Growth rates of young mosquitofish fry (12-17 mg) held in 38 l aquaria were determined by 5-20 day feeding experiments. Food consumption rates were determined on the same fish by weighing the sectioned, tubificid worms presented as food and reweighing worm biomass remaining at the next feeding (ad lib. rations) and calculating the mass difference by subtraction. These experiments were performed at several temperatures and are discussed in detail elsewhere (Wurtsbaugh and Cech, in prep.). Respiratory metabolic (oxygen consumption) rates were measured at several temperatures in larger mosquitofish  $\bar{x}$  body mass ( $\sim 0.5$  g) using flow-through respirometers (Fig. 1). These respirometers which permitted little movement by the mosquitofish are described in detail by Cech et al. (in prep.). Dissolved oxygen levels in all systems were maintained near air saturation, and every effort was made to avoid disturbing the test fish.

In addition, respiratory metabolic rates of twenty fry (25 mg  $\bar{x}$  body mass) were determined at 20° C using 10 ml glass syringes as static respirometers. At  $\sim 25$  min. intervals, 1 ml water samples from these syringes were inserted into an electrometric oxygen analyzer (Radiometer PHM 71, E5046). Thus, measurements of dissolved oxygen difference between successive samples and the water volumes remaining in the syringe allowed calculation of oxygen consumption rates. Subsequent wet and dry (to constant mass in 70° C oven) weighing of fish (Mettler H-10) adjusted metabolic rates

for body mass.

Comparisons of the juvenile rates of metabolism with that of the larger fish in the flow-through respirometers at 20° C showed a 2.113-fold increase in mass-specific respiration in the juveniles compared with the larger fish. Past studies with other fishes have shown that temperature does not significantly affect the relationship between body mass and mass-specific respiratory metabolism (Beamish 1964). Therefore the 2.113 factor was applied to the metabolic rates measured from the larger fish in the flow-through respirometers at the other temperatures. Oxygen consumption data was converted to calories fish<sup>-1</sup> day<sup>-1</sup> by using an oxycalorific coefficient (3.38 cal mg<sup>-1</sup> O<sub>2</sub>) based on the digestible proximate analysis of the tubificid diet (53% protein, 6% lipids, 41% carbohydrates of ash-free dry mass). Digestible caloric content of the worms was similarly calculated by multiplication of the caloric value g<sup>-1</sup> by the ash-free dry mass percentage. Gain in mass day<sup>-1</sup> (growth) was also converted to calories fish<sup>-1</sup> day<sup>-1</sup> by using whole body mass caloric equivalents for another poeciliid fish (Lebistes reticulata) from Cummins and Wuycheck (1971).

### Results and Discussion

The mosquitofish fry consumed 915 mg O<sub>2</sub> kg<sup>-1</sup> h<sup>-1</sup> ( $\bar{x}$ ) at 20° C. Transformation of digestible food ingested and growth as well as respiratory metabolism to calories fish<sup>-1</sup> day<sup>-1</sup> allows calculation of percentages of the ingested energy being used for growth and respiratory metabolism. The percentage of ingested energy being used for growth in mosquitofish increases with temperature from 10 to 30° C before declining somewhat at 35° C (Table 1). Wurtsbaugh and Cech (in prep.) showed that the exponential rate of food consumption increase with temperature also declines

dramatically at the highest temperature, such that food consumption at 35° C is only slightly higher than at 30° C.

Although absolute respiratory metabolic energy demands increase exponentially with temperature (Cech et al., in prep.), the percentage used for respiration declines as temperature increases from 10°C to 25° C (Table 1). At the temperatures where growth percentage (= conversion efficiency) is maximal (25° and 30° C), the percentage of ingested energy used for respiration is minimized (Table 1). Thus, the potential for growth in mosquitofish is maximized at 25 to 30° C, if adequate rations are available.

The  $\frac{G}{M + G}$  factor, which we are calling the "growth potential index" should relate closely to conversion ratio according to equation 3. Calculations of this index at the six experimental temperatures show a trend similar to that of growth percentage or conversion efficiency (Table 1). Maximal index values and conversion efficiencies both occur at the same temperature range (25 to 30° C). The calculated correlation coefficient relating growth potential index to conversion efficiency is 0.98, supporting the close relationship expected from equation 3. Growth and metabolism data from Edwards et al. (1972) on Atlantic cod (Gadus morhua) were used to calculate growth potential indices. These indices also showed a high positive correlation with the cod food conversion efficiencies ( $r = 0.99$ ).

It is also noteworthy that the total percentage of ingested energy used for both growth and respiration by mosquitofish is quite constant from 15 to 35° C (Table 1). Thus, the percentage of other energy demands of the young mosquitofish (e.g. for movement, digestion of food, etc.) must also remain approximately constant at these temperatures. The exceedingly high total percentage calculated at 10°C (91%) is made up entirely by respiratory

metabolic energy costs, since no growth was measured at 10° C (Table 1). Food consumption at 10°C was the lowest measured by Wurtsbaugh and Cech (in prep.), equaling a maintenance ration (i.e. no positive or negative growth) at this temperature. It was also observed that mosquitofish held at 10° C were much less active than those held at warmer regimes. Thus, activity probably represented a significant energy cost to the fish held in the warmer (>10° C) aquaria.

The possible utility of the growth potential index for estimating food conversion ratios of fish in nature remains to be tested. Food consumption and conversion efficiencies are often difficult to measure directly under field conditions. Thus, an estimate of these variables from proportional bioenergetic factors would be useful in several environmental circumstances. For example, mosquitofish have been globally introduced into a variety of aquatic environments as biological controllers of disease-carrying insects such as mosquitoes. A food-rich environment for mosquitofish, such as a slough or a flooded rice field presumably would provide an appropriate habitat to estimate food conversion ratios under a broad spectrum of environmental conditions (e.g. temperature, dissolved oxygen concentrations, etc.). Mann (1978) has summarized the important influences of season, fish size, etc. on conversion ratios in fishes. The growth potential index could be calculated by measuring changes in weight over times (growth, as from mark and recapture experiments) and field respiratory metabolic rates from fish in syringes or other static respirometers (e.g., jars) incubated in the environment.

Continued research is needed to further define critical bioenergetic relationships from carefully designed laboratory experiments and to

subsequently test these relationships in the field. Current research in our laboratory seeks a more complete understanding of the bioenergetic relationships of the mosquitofish with various environmental factors, towards construction of predictive models at the population level.



Acknowledgements

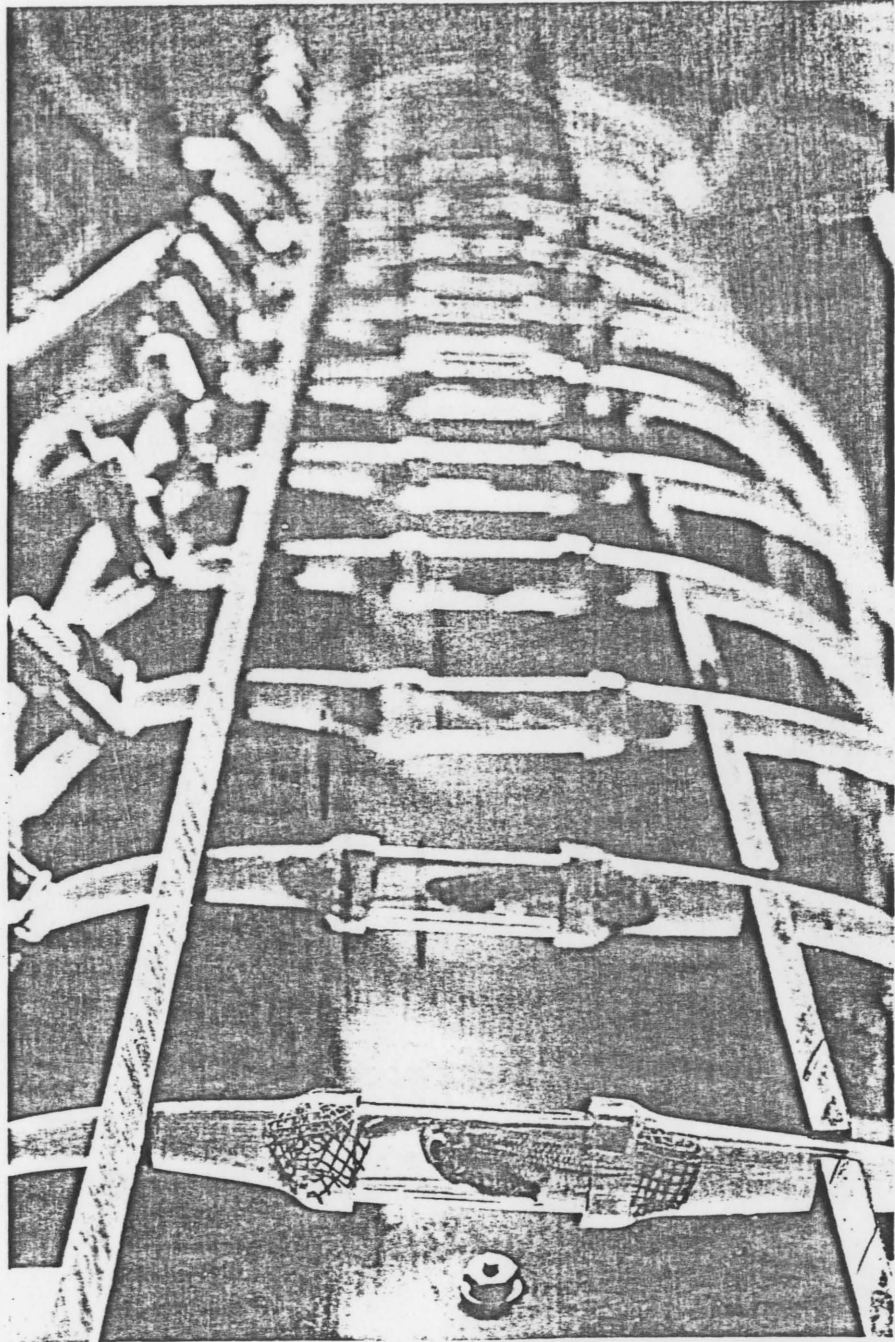
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Figure Legend

Figure 1.

Multi-chambered, flow-through respirometer apparatus containing mosquitofish, Gambusia affinis (uncovered and removed from temperature-controlled water bath for photographic purposes).

FIG. 1



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TABLE 1.  
 Partitioning of Ingested Energy into Growth  
 and Respiration by Mosquitofish (*Gambusia affinis*)

Temperature (°C)	Growth <sup>a</sup> % of ingested energy)	Respiration (% of ingested energy)	Growth + Respiration (% of ingested energy)	Growth Potential Index ( = $\frac{G}{M + G}$ )
10	0	91	91	0
15	6	29	35	0.16
20	19	25	44	1.78
25	26	13	39	2.95
30	27	19	46	2.45
35	24	21	45	2.17

<sup>a</sup>Data from Wurtsbaugh et al. (in prep.)