A PRELIMINARY STUDY OF STREAM FISH RESPIRATION IN CYCLING TEMPERATURES AND ITS POTENTIAL INFLUENCE ON GROWTH RATES

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ABSTRACT.

Resting routine metabolism was monitored for the tahoe sucker, (*Catostomus tahoensis*), in acrylic static respirometers while exposed to naturally-occurring diel temperature fluctuations (8-18°C) and to constant temperatures (3, 8, 13 and 18° C). Oxygen consumption rates increased exponentially with increasing temperature according to: (for constant temperature) log Y = 1.130 + .060T; (for fluctuating temperature) log Y = 1.392 + .051 T, where Y = oxygen consumption rate (mg O_2 kg^{-1} body mass h^{-1} and T = temperature (°C). Comparison of these regressions indicates metabolic increases for fish exposed to fluctuating temperatures, compared with those in constant temperature regimes. Metabolic rate was also monitored in Brett-type respirometers where suckers were subjected to water velocities equivalent to one body length sec^{-1} in a fluctuating temperature environment. Oxygen consumption rates of these fish increased with increasing temperatures according to: log Y = 1.378 + .046T. Physiological effects of fluctuating temperatures on metabolism and growth of stream fishes should be considered in forestry and fisheries management decisions.

INTRODUCTION

Many freshwater and marine fishes exist in environments which fluctuate in temperature on a daily basis. Some marine and lake dwelling fishes can behaviorally regulate their body temperature by migrating vertically or horizontally (Brett 1971, Neill and Magnuson 1974). Fishes living in small streams, however, usually live in vertically isothermal environments which may show wide diel temperature fluctuations during particular seasons (Needham and Jones 1959).

Although the effects of constant temperatures on metabolic rates of fishes has been studied (Winberg 1956), the effects of fluctuating thermal regimes in relation to metabolism in fishes is poorly known. Brett (1971) suggested that fishes subjected to daily temperature fluctuations by migrating vertically in lakes would gain an energetic advantage by feeding in warmer waters near the surface and digesting their food in deeper, cooler waters. This energetic advantage would presumably be demonstrated by faster growth rates. Brett (1971) assumed that the respiratory metabolic rates of fishes in a fluctuating temperature environment approximate those at constant temperatures equivalent to the mean of the temperature cycle. If metabolic costs are higher in fluctuating temperature environments (either in stream systems or due to behavioral regulation in stratified systems) the proposed energetic benefit could be reduced or negated.

The purpose of this study was to provide preliminary information on metabolic rates of the tahoe sucker, (*Catostomus tahoensis*), held at natural summer temperature cycles of small streams and at constant temperatures. Metabolic comparisons in fluctuating and constant temperature environments provide essential data for the eventual quantification of animal and population energy budgets necessary in the understanding of stream fish community dynamics.

METHODS

Tahoe suckers (4-120 g, $\bar{x}$ = 38 g body mass) were collected in Sagehen Creek, Nevada County, California with an electroshocker (Smith-Root Type V). Oxygen consumption rates as a measure of respiratory metabolism were determined for 24 suckers with static respirometry and 8 suckers with active respirometry in cyclic temperatures and 70 suckers at constant temperatures. Natural (July-September) photoperiod was maintained.

Small (1.4 l) and large (4.7 l) cylindrical, plexiglass respirometers accomodated the size range of fish for static respirometry. A small (4.9 l) Brett-type respirometer (Brett 1964) was used for oxygen consumption determinations for fish subjected to water velocities equivalent to one body length sec^{-1}. Static and active respirometers were situated in darkened, insulated water baths and received a continuous flow of water until determinations began. Oxygen consumption rates were determined by measurements of dissolved oxygen in the sealed respirometers over a time period appropriate to the fish mass and temperature using the formula:

$$O_2 \text{ consumption } (mg O_2\ kg^{-1}\ hr^{-1}) = \frac{(60 \text{ min})(\text{respirometer volume})(\text{initial } O_2 \text{ conc.} - \text{final } O_2 \text{ conc.})}{(\text{time interval})(\text{fish mass in kg})}$$

After each determination, fish mass was determined (± 1 g) using a spring balance (Pesola). Experimental protocols for fluctuating and constant temperatures for static respirometers and active respirometry were as follows.

Fluctuating Temperature

All suckers used in oxygen consumption trials at fluctuating temperature were held in stream enclosures at natural diel temperature fluctuations at least 60 h after capture. After being transferred to individual respirometers each fish was given a minimum of 12 h to accustom themselves to the apparatus. Stream water was continuously circulated through the water bath and through the respirometers after each experimental run. Therefore, respirometer temperatures equalled stream temperatures with no time lags.

Dissolved oxygen concentrations were directly measured using a YSI model 54 electrode and meter system. The YSI system was calibrated before each series of oxygen determinations. Oxygen consumption was measured several times during each day, both at the lowest and highest peak diel temperatures and at several temperatures between these extremes. Time intervals for each determination averaged 45 min, over which temperature changes in the respirometers were generally $<1^{\circ}C$.

Constant Temperatures

Oxygen consumption rates were determined at four constant temperatures (3°, 8°, 13° and $18^{\circ}C \pm 0.5^{\circ}$ C). All suckers were held in a 600 l insulated fiberglass tank for at least 14 days after capture to acclimate fish to the desired constant temperature. Suckers were given 12 h to adjust to the respirometers. Water at the desired constant temperature was continuously circulated through the water baths and the respirometers after each determination.

A Beckman Model 160 Physiological Gas Analyzer and O_2 macroelectrode with an A.F. Bradley water bath were used for determining dissolved oxygen tensions. The Beckman system was calibrated before each measurement. Oxygen consumption rates were measured three times for each fish throughout the day, except at $3^{\circ}C$ where only two determinations were made. Care was taken in all systems to avoid disturbances to the fish and to avoid hypoxia-induced changes in metabolic rate (Winberg 1956).

Active Respirometry

Oxygen consumption rates in the active respirometers were determined only in fluctuating temperature and only at flow rates equivalent to one body length sec^{-1}. Protocol for active respirometry was similar to static respirometry with the exception that the Beckman system was used for oxygen determinations.

RESULTS AND DISCUSSION

Our preliminary reslults show that oxygen consumption rates of the tahoe sucker exposed to fluctuating or to constant temperatures increase exponentially with increasing temperature. The oxygen consumption rates for tahoe suckers are higher for any given temperatures in a fluctuating temperature regime (Fig. 1). Oxygen consumption rates of suckers subjected to fluctuating temperatures and current velocities equivalent to one body length sec^{-1} also increase exponentially with increasing temperature (Fig. 1). Respiratory metabolic rates of suckers exposed to water current (1 body lenght sec^{-1}) were higher than for those situated in static respirometers at the constant mean temperature, but somewhat lower than those in static respirometers at fluctuating temperatures (Fig. 1). It is possible that the flowing water had a calming effect on these stream fish.

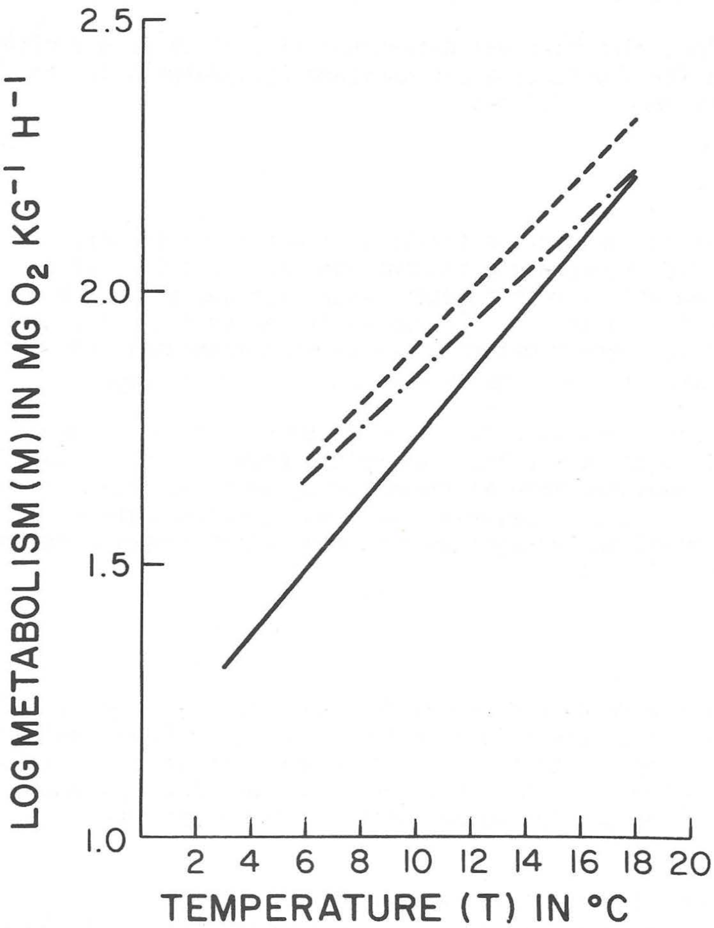

FIGURE 1: The Relationship of Log Respiratory Metabolism (M) to Environmental Temperature (T)

-------- = Fluctuating temperature regime: static water conditions, $\log M = 1.392 + .051\ T$

— · — · = Fluctuating temperature regime: flowing water conditions, $\log M = 1.378 + .046\ T$

——— = Constant temperature regime: static water conditions, $\log M = 1.130 + .060\ T$.

Longanecker (unpublished data) compared oxygen consumption rates of rainbow trout, (*Salmo gairdneri*), in natural cycling temperatures in Sagehen Creek with oxygen consumption rates at constant temperature obtained from a literature review and found increased metabolic rates occur in cyclic temperatures. If all fishes respond metabolically in a similar fashion to the tahoe sucker and rainbow trout in cycling thermal regimes found in stream systems the growth advantage proposed by Brett (1971) may not be realized.

Hokanson et al. (1977) examined growth rates of juvenile rainbow trout in the laboratory at temperature regimes similar to small streams (temperature cycles $\pm$ 4^{0}C about mean temperatures) and at constant temperatures equivalent to the mean of the temperature cycles. They found that peak growth rates of the juvenile trout occur at temperature cycles having mean temperatures of 15.5^{0}C or lower. At these lower temperatures growth rates were significantly higher than at the equivalent constant temperatures. Growth rates in temperature cycles with a mean temperature above 15.5^{0}C were reduced and not significantly different than at constant temperatures equivalent to the mean of the cycles. Also, Clarke (1978) and Britte and Geen (1980) have found that sockeye salmon, (*Oncorhynchus nerka*), grow faster in a fluctuating temperature regime. However, the temperature cycles resembled square waves and were not the sinusoidal-type regimes found in small streams.

In addition to the laboratory studies described here, growth rates of the tahoe sucker from Sagehen Creek and the adjacent Little Truckee River and Stampede Reservoir have been estimated using back-calculation of annular marks from pectoral fin rays (Vondracek et al. 1981). Mean water temperatures were similar at the collection sites in Sagehen Creek, the Little Truckee River and Stampede Reservoir during the summer, which is the peak growth period. Growth rates were significantly higher in Stampede Reservoir which experiences little daily temperature fluctuation in comparison to the streams (Vondracek et al. 1981).

Activity in fishes can increase metabolic rate (Webb 1978). Our preliminary results show that the tahoe sucker does not exhibit an increase in metabolic rate when subjected to a water velocity equivalent to one body length/sec. (Fig. 1). The small sample size of fish used in the active respirometer (8) preclude meaningful distinctions to be made between "active" and "resting" fish. Also, behavioral observations in the active respirometer and in Sagehen Creek reveal that tahoe suckers rest on the bottom and exhibit no swimming activity (Vondracek unpublished). Regardless, activity does not appear to be the cause of increased metabolic rates in fluctuating temperature regimes.

In summary, no consistent growth advantage is apparent for fishes in cycling temperature regimes. We suggest that the increased metabolic rate in cycling temperatures may be a factor. The most likely cause of increased oxygen consumption in ectothermic animals exposed to cycling temperatures is probably enzyme inefficiency (Wieser 1973). The observed metabolic differences have important implications for land management, forestry and fish stocking practices. Land or silviculture techniques which increase temperature fluctuations in stream systems may adversely affect the growth rates of resident fishes. Fish stocking programs should also include assessments of temperature fluctuations to better predict growth rates of stocked individuals. In addition, more studies are needed to better define and understand the interactions of the physiological functioning of fishes in fluctuating thermal environments.

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