THE EFFECTS OF SIMULATED GLOBAL WARMING ON THE GROWTH AND ENERGETICS OF FRESHWATER FISH

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EXTENDED ABSTRACT ONLY - DO NOT CITE

Fish are likely to be amongst those animals most affected by global warming as their metabolic rate and physiology are fundamentally affected by environmental temperature. However, little of the vast literature on temperature physiology in fish relates to a small temperature increment in the natural environment (Wood and McDonald, 1997). Therefore, in 1992, we began a series of experiments to study the effects of simulated global warming on the growth and energetics of juvenile rainbow trout (*Oncorhynchus mykiss*). We added 2^{o}C to the *natural* thermal regime, in the presence and absence of two common freshwater pollutants in environmentally relevant media: ammonia in hard water (HW) and acidity (low pH) in soft water (SW). The experiments lasted 90 days in summer and in winter at a satiation ration (≈ 2.5% wet body weight d^{-1}) and in summer at a limited ration of 1% d^{-1}. The present paper summarizes the most important findings of the project.

The addition of 2^{o}C had little effect on the growth and physiology of juvenile trout fed to satiation over most of the summer, suggesting that there is physiological compensation for the additional temperature. However, at high ambient temperature in late summer, +2^{o}C caused a marked inhibition of appetite and growth in both SW- and HW-acclimated fish (Table. 1). A reduction in ration in summer to 1% d^{-1} did not increase the impact of simulated global warming. In winter, +2^{o}C stimulated appetite and growth by approximately 30% in HW-acclimated fish and 60% in SW-acclimated fish.

Table 1. Effects of simulated global warming (+2^{o}C) on appetite and growth of satiation-fed rainbow trout over the 30-day period of maximum (late) summer temperatures (20 – 24^{o}C). Values are means ± SEM. An asterisk indicates a value at +2^{o}C that is significantly different to that at ambient temperature (*P*<0.05).

	SW-acclimated fish		HW-acclimated fish	
	Ambient†	+2^{o}C	Ambient	+2^{o}C
Appetite (g d^{-1})	0.68 ± 0.08	0.49 ± 0.08*	0.66 ± 0.07	0.46 ± 0.07*
Growth rate (g d^{-1})	0.58 ± 0.04	0.07 ± 0.01*	0.72 ± 0.05	0.26 ± 0.03*
Conversion ratio	0.85 ± 0.07	0.14 ± 0.02*	1.10 ± 0.09	0.57 ± 0.07*

†Ambient temperature in SW was approx. 2-3^{o}C greater than that in HW.

The high sensitivity of growth to the experimental treatments was consistent throughout the project. The most sensitive physiological indicator of +2^{o}C was tissue protein metabolism i.e. rates of protein synthesis, accretion and degradation (Houlihan et al., 1995). For example, protein accretion in liver and white muscle was significantly (approx. 20%) reduced by +2^{o}C in the late summer due to an increase in protein degradation.

Sublethal ammonia inhibits growth in freshwater fish (Thurston et al., 1984) and therefore we were very surprised to find that fish exposed to 70µM total ammonia (T_{Amm} = NH_3 + NH_4^+) in summer were heavier, had greater N-absorption and retention efficiencies, and higher energy conversion efficiency. They also had higher plasma [ammonia], and greater liver and white muscle protein synthesis rates. We suggested that the increase in N-retention could be the indirect result of ammonia detoxification whereby ammonia was incorporated into glutamine and other amino acids, which could then be used as substrates for protein synthesis, but this idea remains highly speculative.

Low pH (5.2) exposure unexpectedly tended to stimulate appetite and growth but caused no disturbance of electrolyte balance, a typical symptom of acid toxicity (Morris et al., 1989). We hypothesized that the fish were able to replace branchial ion losses with dietary salt: when we further reduced ration to maintenance levels (1% $4d^{-1}$), exposure to pH 5.2 indeed resulted in lower whole-body $[Na^+]$ and $[Cl^-]$ and mortalities of 34% compared to 10% at the control pH 6.2.

Sublethal toxicant exposure exacerbated the effects of +2°C. For example, at the high ambient temperatures of late summer, ammonia in HW or low pH in SW increased the negative growth effects of +2°C. Similarly, at a (winter) maintenance ration, exposure to both +2°C and low pH caused a greater ionoregulatory disturbance than +2°C or low pH alone. In satiation-fed fish in winter, those exposed to +2°C and sublethal toxicants had the highest appetite, growth and food conversion efficiency.

The ability of the fish to acclimate to the experimental conditions was tested by challenging fish with acute lethal temperature and/or toxicant concentrations. Fish exposed to +2°C had a slightly (0.2-1.0°C) but significantly higher lethal temperature than those exposed to ambient temperature when fed to satiation. However there was no evidence of acclimation to ammonia or low pH; pre-exposure to sublethal toxicants offered no protection to subsequent acute lethal challenges.

In conclusion, the impact of global warming on freshwater fish will vary seasonally. The additional temperature may provide growth benefits in winter, but may threaten fish populations living towards the upper end of their thermal tolerance zone in (late) summer. The project also demonstrated that the effects of pollutants under environmentally realistic conditions might be rather different from those in the classical, physiological literature.

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