

IMPLICATIONS OF WATER QUALITY FOR LARVAL FISH METABOLISM, ACTIVITY AND GROWTH IN EXTENSIVE REARING CONDITIONS

P.C. Gehrke

*NSW Fisheries Inland Fisheries Research Station
PO Box 182
Narrandera NSW 2700*

Introduction

The principal objectives in rearing larval fish are survival and growth of the larvae. Under extensive rearing conditions, these objectives are pursued with relatively low capital, technical and labour inputs when compared with increasingly intensive operations.

It is possible in rearing conditions to achieve excellent survival but poor growth, or alternatively, poor survival and excellent growth, but from a physiological perspective at the level of individual organisms, unfavourable environmental conditions initially cause reduced growth, and further environmental deterioration leads to death. In this context, good growth implies survival at one extreme, and death of the individual represents the other extreme on a continuum of responses to the environment. Survival, therefore, is implicit in the following discussion of factors affecting larval metabolism and growth, and only sublethal responses to water quality are considered.

Energetics of growth

Growth is only one of several processes competing for an allocation of energy ingested by fish larvae. Not all ingested energy is assimilated, a portion of ingested energy being excreted. The

assimilated portion is allocated to metabolism and growth. Excretion in adult teleost carnivores typically accounts for 27% of ingested energy (Brett and Groves 1979), but when food is readily available, excretory losses may approach 60% (Gehrke 1988). The larvae of marine fish are less efficient at assimilating energy from their diet, and may excrete between 30 and 39% of ingested energy. Larval metabolism, however, accounts for only 31% of dietary energy compared to 44% in adult teleost carnivores, but variability in larval excretion rates dictates whether any metabolic savings can be partitioned into accelerated growth (MacKenzie *et al.* 1990). Growth, then, relies on surplus energy left over from excretory and metabolic losses.

Metabolic rates are profoundly influenced by both water quality and exercise levels, implying that it is possible, in theory, to increase the amount of energy available for growth by reducing the proportion of ingested energy consumed by metabolism.

Enhancing growth by manipulating energy usage

Fish larvae derive their initial energy from their yolk supply, and require no locomotor activity to obtain that energy. Once the yolk is con-

sumed, however, all energy requirements must be met by ingested energy, which involves activity to forage and capture prey.

The most important factor affecting metabolic rates of fish is body size, which accounts for over 80% of the variation in both standard and active oxygen consumption (Thurstan and Gehrke 1991). After body size, the next major factor determining metabolic energy requirements is activity level (Blaxter 1969; Brett 1970; Rombough 1988) which accounts for 12.95% of fish oxygen requirements after size effects have been removed (Thurstan and Gehrke 1991). By adding effects due to temperature, oxygen and salinity, up to 30% of the variation in metabolic intensity can be explained. The remaining variation is due to effects between species, different experimenters, and chemical or biological factors which are not usually published.

Potential exists for improving growth of larvae by maintaining conditions which minimise larval activity and metabolism. How might this be achieved? Larvae of many species are not capable of sustained activity, but rather, alternate between periods of burst activity and inactivity (Rombough 1988). Burst activity relies on anaerobic metabolism which accumulates an oxygen debt and is energetically less efficient than aerobic pathways. Thus, where adverse water quality dictates that larvae avoid unfavourable habitats (Gehrke 1990; Gehrke in press) affected larvae may be forced to swim relatively large distances at considerable energetic expense. By maintaining water temperature and oxygen tension within ranges which do not elicit avoidance behaviour, larval activity may be reduced.

The most direct way to increase the amount of energy available for growth is to increase energy intake. Not all of the additional energy ingested will be allocated for growth: losses through excretion and metabolic energy consumption will both rise, but the absolute amount of energy available for growth will increase. At normal rearing densities of larvae, it may not be possible to maintain the increased ration with-

out eventually depleting the food supply in the pond before fish are large enough to transfer. In ponds at Narrandera, fish effectively consume the plankton in a pond within 4 to 8 weeks, feeding *ad libitum*. Fertilising ponds after stocking may prolong plankton production, but can also cause oxygen tensions to deteriorate, so the relative benefit needs to be assessed.

If food density is in excess of requirements, as normally occurs when larvae are stocked into rearing ponds, it might be assumed that larvae are consuming a maximum ration, in which case attempts to increase that ration further may prove fruitless. Importantly, MacKenzie *et al.* (1990) indicate that ingestion rates of fish larvae, when standardised for effects of size and temperature, do not increase any further when food density exceeds $185 \mu\text{g l}^{-1}$, and that maximal ingestion rate is $75 \mu\text{g d}^{-1}$ for a standard larva of $125 \mu\text{g}$ (all weights measured as dry weight) at 18.7°C . In rearing ponds at IFRS, total plankton densities frequently reach or exceed $3000 \mu\text{g l}^{-1}$ around the time of stocking, which is well above the critical prey density, so that food availability does not limit ingestion of energy. Presumably, however, the benefit of maintaining high plankton density is that larvae forage less and metabolise less energy for activity.

Water quality in extensive rearing facilities

One of the major differences between extensive and intensive approaches to fish rearing is the effort invested in controlling water quality. At one extreme, extensive operations may not attempt to control water quality at all, and perhaps not even monitor environmental conditions. At the other extreme, intensive water engineering and process controls now enable water quality to be controlled independent of climatic influences. Water quality in extensive rearing ponds tends to follow climatic conditions closely, and management techniques are based upon anticipating weather patterns and avoiding extremes by sensible location of ponds and pond design.

Within the realm of normal pond water quality variables, temperature and oxygen most frequently reach undesirable levels and it is by working with this minimal combination of factors that pond water quality is managed during the rearing period. This selection of factors is not merely coincidental, but is of fundamental importance because temperature and oxygen exert a greater influence on larval metabolism and activity than most other physical and chemical factors.

Direct effects of water quality

Growth and metabolism both operate more efficiently as temperature tends toward an optimum, making it desirable to minimise the effects of rapid temperature changes in a pond. Sudden changes in temperature of only a few degrees Celsius can have dramatic effects on growth. At 16°C, spangled perch (*Leiopotherapon unicolor*) metabolise 41.5% of their energy intake. This figure increases to 72.2% at 14°C, and to a phenomenal 201.5% at 13°C (Gehrke 1988). Thus, a drop in temperature of only 3°C can influence a change from normal growth rates to fish which lose weight rapidly. Sudden bouts of cold weather could therefore result in reduced or negative growth in rearing ponds until the return of warmer weather.

Deficiencies in oxygen availability have different effects depending upon the size of the larvae and fingerlings. Newly-hatched larvae expend little or no energy in ventilation because they obtain a significant proportion of their oxygen requirements by diffusion across the external body surface. Before metamorphosis, the gills become the dominant site of respiratory gas exchange, and ventilation contributes from 5 to 30% of the standard metabolic oxygen requirement.

As environmental oxygen tension declines, the scope for activity or growth declines until oxygen uptake is barely adequate to maintain

standard metabolism. At this point, 100% of assimilated energy is devoted to maintaining essential metabolic processes, and any further decline in oxygen availability below this critical oxygen tension forces a reduction in metabolic rate. Larvae and fingerlings may survive in ponds where dissolved oxygen is maintained above the critical oxygen tension somewhere between 20-40% of air saturation, but growth is likely to be restricted under such conditions. To reduce growth restrictions due to oxygen availability, oxygen tension in rearing ponds should be maintained as high as possible. Certainly, minimum oxygen concentrations recommended by convention may be adequate for short term survival, but caution is advised in accepting any such minimum concentration where growth of larvae is desired (Doudoroff and Shumway 1967).

Conclusions

Growth of fish larvae can, in theory, be enhanced by increasing surplus energy, or by increasing the efficiency of converting energy into growth. In extensive rearing facilities, options for increasing energy ration are limited and possibly of little benefit. Alternatively, additional energy for growth can be obtained by minimising metabolic energy consumption by managing water quality to reduce larval activity.

References

- Blaxter, J.H.S. (1969). Development: Eggs and larvae. In 'Fish Physiology' (Eds W.S. Hoar and D.J. Randall) Vol. III pp. 178-241. Academic Press, New York and London.
- Brett, J.R. (1970). Fish - The energy cost of living. In 'Marine Aquaculture' (Ed. W.J. McNeil) pp. 37-52. Oregon State University Press, Corvallis.
- Brett, J.R. and T.D.D. Groves (1979). Physiological energetics. In 'Fish Physiology'. (Eds W.S. Hoar, D.J. Randall and J.R. Brett.) Vol. VIII, pp. 279-352. Academic Press, New York and London.

- Doudoroff, P. and D.L. Shumway (1967). Dissolved oxygen criteria for the protection of fish. In 'A Symposium on Water Quality Criteria to Protect Aquatic Life'. (Ed. E.L. Cooper.) American Fisheries Society Special Publication No. 4, pp. 13-19. American Fisheries Society, Bethesda.
- Gehrke, P.C. (1988). Feeding energetics and angling catches of spangled perch, *Leiopotherapon unicolor* (Günther 1859), (Percoidei: Teraponidae). *Australian Journal of Marine and Freshwater Research* **39**, 569-577.
- Gehrke, P. C. (1990). Spatial and temporal dispersion patterns of golden perch *Macquaria ambigua* larvae in an artificial floodplain environment. *Journal of Fish Biology* **37**, 225-236.
- Gehrke, P.C. (in press). Avoidance of floodplain habitat by fish larvae: water quality or food limitation? *Australian Journal of Marine and Freshwater Research*.
- MacKenzie, B.R., W.C. Leggett and R. H. Peters (1990). Estimating larval fish ingestion rates: can laboratory derived values be reliably extrapolated to the wild? *Marine Ecology Progress Series* **67**, 209-225.
- Rombough, P.J. (1988). Respiratory gas exchange, aerobic metabolism, and effects of hypoxia during early life. In 'Fish Physiology' (Eds W.S. Hoar and D.J. Randall) Vol. XIA. pp. 59-161. Academic Press, New York and London.
- Thurstan, R.V. and P.C. Gehrke (1991). Respiratory oxygen requirements of fishes: a description of OXYREF, a data file based on test results in the published literature. Second International Symposium on Fish Physiology, Fish Toxicology, and Water Pollution. Sacramento, California, September 1990. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, USA.