

**METABOLIC PHYSIOLOGY OF THE SOUTHERN BLUEFIN
TUNA (*THUNNUS MACCOYII*) AND MULLOWAY
(*ARGYRO SOMUS JAPONICUS*).**

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ABSTRACT

The bluefin tuna have a variety of distinctive anatomical and physiological adaptations that enhance performance. However, our understanding of bluefin tuna physiology is limited by the logistical difficulties of studying these large pelagic fish. This thesis examines some aspects of the metabolic physiology of the southern bluefin tuna. It provides insight into the high-performance, high-energy demand physiology of bluefin. It also examines the metabolic physiology of the mullet, another important aquaculture species for which physiological information is currently limited.

1. Routine metabolic rate (RMR) of southern bluefin tuna (SBT) (*Thunnus maccoyii*), the largest tuna specimens studied so far (body mass = 19.6 kg (\pm 1.9 SE)) was measured in a large (250,000 l) flexible polypropylene respirometer “mesocosm respirometer”. Mean mass-specific RMR was 460 mg kg⁻¹ h⁻¹ (\pm 34.9) at a mean water temperature of 19°C. When total RMR is added to published values of other tuna species at equivalent swimming speeds, there is a strong allometric relationship with body mass ($654 \cdot M_b^{0.95}$, $R^2 = 0.97$). This demonstrates that interspecific RMR of tuna scale with respect to body mass similar to that of other teleosts, but is approximately 5-fold higher than the standard metabolic rate (SMR) of other active teleost species.
2. This study reports on the first measurements of the metabolic cost of food digestion and assimilation (specific dynamic action, SDA) of a tuna species. Oxygen consumption ($\dot{M}O_2$) and swimming velocity of southern bluefin tuna (SBT) (*Thunnus maccoyii*) were elevated for periods between 20-45 h (longest for the largest rations) post-ingestion of sardines (*Sardinops sagax*). It is suggested that the purpose of increased swimming velocity was to increase ventilation volume as a response to the enhanced metabolic demand associated with SDA. The magnitude of SDA as a proportion of gross energy ingested (SDA coefficient) averaged 35 ± 2.2 %. This demonstrates that the absolute energetic cost of SDA in SBT is approximately double that recorded in other teleost species.
3. This study examines the effects of sardines (*Sardinops sagax*) with high- (12.9%) or low- (1.8-4.0%) lipid level on specific dynamic action (SDA) and swimming velocity of southern bluefin tuna (SBT) (*Thunnus maccoyii*). Fish swam faster during the SDA period with the increase in velocity being greatest for the fish that ingested the high-lipid sardine. Magnitude of SDA was also greater for fish that ingested the high-lipid sardines. However, the energetic cost of SDA as a proportion of ingested energy was not significantly different between fish that ingested the high- (34.3 ± 2.4 %) and low-lipid sardines (31.5 ± 2.9 %). These results confirm that the high energetic cost of SDA is ecologically relevant.

4. In this study the metabolic and behavioural responses of both fasted and postprandial southern bluefin tuna (*Thunnus maccoyii*, SBT) to low dissolved oxygen (DO) was examined. In moderate hypoxia (4.44 and 3.23 mg l⁻¹), swimming velocity (*U*) and routine metabolic rate (RMR) of fasted fish was mildly enhanced. At 2.49 mg l⁻¹, *U* increase to over double in the normoxic speed, possibly as an escape response. At 1.57 mg l⁻¹, both *U* and RMR were suppressed and SBT failed to survive the entire 20 h exposure period. This reveals that SBT are remarkably well adapted to low DO. Feeding did not greatly influence their hypoxia tolerance. In a subsequent experiment there were no significant differences in *U*, RMR and gastric evacuation rates of postprandial SBT in hypoxia (2.84 mg l⁻¹) compared to those in normoxia (7.55 mg l⁻¹).
5. In this study, 768 h of simultaneous recordings of metabolic rate (MR, = heat production) and visceral temperature were made in both fasted and postprandial southern bluefin tuna (SBT, *Thunnus maccoyii*) of two sizes (~10 and 20 kg) and at two water temperatures (~19 and 16°C). Duration and magnitude of specific dynamic action (SDA) were strongly related to duration and magnitude of postprandial visceral warming providing the first empirical evidence of a link between SDA and postprandial visceral warming. Visceral temperature of fasted SBT was also directly related to MR. In this case, source of heat is thought to be metabolic work performed within the red muscles which warmed the viscera through thermal conductance. Visceral excess temperatures were over 1°C warmer in larger than smaller SBT. Better heat retention ability of the larger SBT is likely attributed to improved *retia mirabilia* development and greater thermal inertia. SBT at 16°C maintained visceral excess temperatures significantly warmer than similarly sized fish at 19°C. This demonstrates some ability of SBT to physiologically regulate visceral warming.
6. In this study, the effect of progressively severe hypoxia levels on the swimming performance and metabolic scope of juvenile mullet (*Argyrosomus japonicus*) were investigated. In normoxic conditions (6.85 mg l⁻¹), standard metabolic rate (SMR) and cost of transport were typical for sub-carangiform fish species. Mullet had a moderate scope for aerobic metabolism (5 times the SMR). The critical dissolved oxygen level was 1.80 mg l⁻¹ revealing that mullet are well adapted to hypoxia. In all levels of hypoxia (5.23, 3.64, and 1.86 mg l⁻¹) the active metabolic rate was reduced however, the critical swimming velocity was reduced only at 3.64, and 1.86 mg l⁻¹. Mullet metabolic scope was significantly reduced at all hypoxia levels, suggesting that even mild hypoxia may reduce growth productivity.

This work contains no material which has been accepted for the award of any other degree or diploma in any university or tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Publications arising

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Fitzgibbon, Q. P., Seymour, R. S., Ellis, D. & Buchanan, J. (2007). The energetic consequence of specific dynamic action in southern bluefin tuna (*Thunnus maccoyii*). *Journal of Experimental Biology* **210**, 290-298.

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