Metabolic Rate of the Albacore Tuna *Thunnus alalunga*

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Abstract

The oxygen consumption rates (\(\dot{V}O_2\)) of 6 specimens (6 to 13 kg) of the albacore tuna *Thunnus alalunga* were measured at sea, using specimens collected 300 km west of San Diego, California (USA) during July and August, 1981. Fish were tested in a closed continuous-flow respirometer, where they swam at about 1.3 body lengths s\(^{-1}\) velocity in 15° to 19°C water. The albacore tuna is a temperate pelagic species experiencing water temperatures from about 10° to 20°C and attaining a maximum weight of 45 kg. The \(\dot{V}O_2\) ranged from 1249 to 3336 ml h\(^{-1}\) (the mean \(\dot{V}O_2\) for the 6 fish was 2228 ml h\(^{-1}\)); such values approach those of mammals of a similar size and are 3 to 4 times those of most active fishes (e.g. sockeye salmon). Among fishes, the only higher \(\dot{V}O_2\) values yet recorded were for the skipjack tuna *Katsuwonus pelamis*, a tropical species. The remarkably high metabolic rates of tunas are presumably correlated with their continuous swimming activity and the maintenance of endothermy. The exponent relating \(\dot{V}O_2\) to body weight (1.18), although large, is not statistically different from the exponents for most other active vertebrates.

Introduction

Tunas, the most advanced and highly specialized group of fishes in the teleost family Scombridae, must swim continuously to maintain hydrostatic equilibrium (Magnuson, 1973, 1978) and to ventilate their gills (Roberts, 1978). Continuous swimming by tunas doubtlessly entails a large energetic investment (Gooding et al., 1981; Stevens and Dizon, 1982; Graham et al., unpublished observations). Verification of this hypothesis by direct measurement of the swimming metabolic rates of tunas is, however, technically difficult due to their generally large body size, fast swimming speeds, and poor survivorship in captivity.

Gooding et al. (1981) were the first to measure the swimming \(\dot{V}O_2\) of tuna. They studied 0.4 to 6.0 kg specimens of skipjack tuna (*Katsuwonus pelamis*) swimming at speeds ranging from 50 to 75 cm s\(^{-1}\) in temperatures from 23° to 25°C. The work by Gooding et al. revealed the following remarkable characteristics of skipjack tuna metabolism and swimming energetics: (1) skipjack tuna \(\dot{V}O_2\) (0.522 mg O\(_2\) g\(^{-1}\) h\(^{-1}\)) was nearly the same as that of a mammal of similar size and thus much higher than that of most active fishes; (2) compared to a sockeye salmon (*Oncorhynchus nerka*, family Salmonidae) swimming at similar speeds but in 15°C water, a skipjack tuna has a \(\dot{V}O_2\) that is 2 to 5 times higher; (3) the rate of increase in \(\dot{V}O_2\) with swimming velocity was proportionally less in skipjack tuna than in a sockeye salmon, implying that tunas, relative to salmonids, may be more efficient swimmers; (4) the \(\dot{V}O_2\) of skipjack tuna was proportional to wet-body weight raised to a power of 1.19 (i.e. \(\dot{V}O_2 \approx M^{1.19}\)), an exponent much higher than values (0.6 to 1.0) typical for active metabolism-body weight relationships in other vertebrates (Brett and Groves, 1979; Schmidt-Nielsen, 1979).

The notable results obtained for skipjack tunas by Gooding et al. (1981) invite additional experimentation with tuna swimming metabolism in order to verify these findings and understand how swimming energetics may vary among tuna species. Although their work was of extremely high quality, many of the \(\dot{V}O_2\) determinations made by Gooding et al. were with groups rather than individual swimming skipjack tuna, and fish swimming speed could not be precisely controlled. Also, conclusions about the relative magnitude of the \(\dot{V}O_2\) of skipjack tuna (and therefore all tuna species) relative to the \(\dot{V}O_2\) of other active fishes (e.g. salmonids) may be biased somewhat by the
water temperature differences (skipjack 23° to 25°C, sockeye 15°C) present in the existing comparative data.

The present paper reports investigations of the swimming \( \dot{V}O_2 \) of the North Pacific albacore tuna \( Thunnus alalunga \), conducted on board the “David Starr Jordan”, research vessel of the National Oceanic and Atmospheric Administration-National Marine Fisheries Service. Our objectives were to measure \( \dot{V}O_2 \) as soon as possible after capture. We have studied the albacore because it, unlike the skipjack tuna, is a temperate-zone species and thus would provide \( \dot{V}O_2 \) data directly comparable, in terms of habitat temperature, to that for sockeye salmon. Another objective of our work was to investigate the scaling of \( \dot{V}O_2 \) with body weight in \( T. alalunga \). We also report some observations on the effects of temperature and hypoxia on the albacore. In addition to increasing our knowledge of the specializations of tunas for locomotion, investigations of tuna swimming physiology are important to an understanding of the migration and movements of these fishes and to ensure proper management of the fishery.

Materials and Methods

Specimens of \( Thunnus alalunga \) were caught by trolling feathered jigs in surface waters approximately 300 km west of San Diego, California (USA) in July and August, 1981. Sea surface temperatures in the area ranged from 17.5° to 19.0°C. Hooked fish were brought on board within 60 s of striking a jig, and a hose with running seawater was immediately placed in the mouths to irrigate the gills during hook removal. Only fish without serious hook injury were selected for respirometer tests.

Swimming \( \dot{V}O_2 \) measurements were made on 6 albacore, ranging in weight from 6 to 13 kg. Each fish was initially submerged in a 200 liter tank containing chilled (15° to 17°C), oxygenated seawater, and its gills were ventilated with flow from a subsimible pump. After initial observations revealed the fish to be in good condition, it was transferred to the working section of a tunnel respirometer (Fig. 1), where continuously flowing water required it to swim in order to maintain a stationary position. A single-speed centrifugal pump (capacity 4 000 liters min\(^{-1} \)) circulated water from the reservoir (2 800 liters) through the working section of the respirometer and back to the reservoir. The parallel bypass channel and gate valve in the system (Fig. 1) permitted some modulation of flow through the working section. This was necessary initially to “train” fish to swim in the chamber (10 to 30 min) and to stimulate swimming throughout each experiment. A removable clear Lucite lid, fitted with a rubber gasket and held in place by wingnuts, was used to introduce or remove a fish from the respirometer. A black plastic cover over the front half of the lid darkened the chamber during experiments. This had a calming effect on the fish and, together with vertical black and white stripes painted inside the front part of the working section, may have provided orientation cues for maintaining station.

Refrigeration units in the reservoir maintained temperature between 14° and 18°C. All pipes used in respirometer construction were PVC (15.2 cm i.d.). The 110 cm long aluminium working section (Fig. 1) was square in cross-section (26x26 cm), and tapered at each end (for 42 cm) to permit direct attachment to PVC flanges. A 23 cm long stack of 2 cm (i.d.) diana PVC collimator tubes in the anterior part of the working section helped to reduce turbulence. A small 45° grating was also installed anterior to the collimator (Fig. 1) to deflect water to the inner side of the working section and straighten flow from the upstream union with the bypass channel (Fig. 1). Dye injections were used to verify rectilinear flow through the working section.

A calibrated flow meter was used to determine water velocity in the working section. The average velocity was 0.73 m s\(^{-1} \). Actual experimental velocities were higher, however, because of the solid blocking effects of fish body cross-sectional area (Webb, 1975). To take this into account, size-dependent velocity relationships had to be calculated as follows for each fish tested, using the methods described by Bell and Terhune (1970). Chamber velocity, \( U \), is proportional to the product of the rated tunnel velocity, \( U_t \), and the velocity factor speed increment, \( K \), imposed by fish cross-sectional area,

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U = U_t (1 + K)
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