GILL AND INTESTINAL NA$^+$-K$^+$ ATPase ACTIVITY, AND ESTIMATED OSMOREGULATORY COSTS, IN HIGH-ENERGY-DEMAND TELEOSTS: YELLOWFIN TUNA (*Thunnus Albacares*), SKIPJACK TUNA (*Katsuwonus Pelamis*), AND DOLPHIN FISH (*Coryphaena Hippurus*)

Richard Brill
Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii, 96822, U.S.A.
Mailing address: NMFS, 2570 Dole St., Honolulu, Hawaii 96822-2396, U.S.A., phone: 808-592-8304, FAX: 808-592-8300, e-mail: rbrill@honlab.nmfs.hawaii.edu

Yonat Swimmer
Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, Hawaii, 96822, U.S.A.

EXTENDED ABSTRACT ONLY - DO NO CITE

Skipjack and yellowfin tuna (*Katsuwonus pelamis* and *Thunnus albacares*, respectively) and dolphin fish (*Coryphaena hippurus*) have gill blood-water barriers up to approximately an order of magnitude thinner; and gill surface areas, ventilation volumes, and cardiac outputs from several times to up to almost an order of magnitude greater than those of other teleosts (Perry, 1992; Bushnell and Jones, 1994). As a consequence, tunas (and presumably also dolphin fish) exhibit routine oxygen transfer factors (TO_2, the rate of O_2 transfer from water to blood per unit partial pressure difference between inhalant water and venous blood) at least an order of magnitude above those of other fishes (Bushnell and Brill, 1992). We propose that the morphophysiological adaptations which permit tunas to achieve such exceptional TO_2s, and maximum metabolic rates (MMR) that are several times greater than those of other fishes, should also result in high water and ion flux rates across the gills and concomitant high osmoregulatory costs. In other words, we contend that teleosts which are capable of achieving exceptionally high TO_2s and MMR, necessarily have high standard metabolic rates (SMR) due to elevated rates of energy expenditure required for osmoregulation. Although osmoregulatory costs in tunas and dolphin fish have never been measured, studies have confirmed that these fish all have SMR several times those of other active teleosts (e.g., Brill, 1987). Previous investigators have shown a link between Na^+-K^+ ATPase activity in the gills and activity patterns by studying epipelagic and slugglish deep-sea fishes (Gibbs and Somero, 1990). Based on these observations, we hypothesize that high-energy-demand fishes (i.e., tunas and dolphin fish) have elevated gill and intestinal Na^+-K^+ ATPase activities to compensate for the high rates of passive ion and water movements occurring across their exceptionally large, thin gills.

To test this idea and indirectly estimate osmoregulatory costs, we measured Na^+-K^+ ATPase activity (V_{max}) in homogenates of frozen samples taken from the gills and intestine of skipjack and yellowfin tunas, and the gills dolphin fish. As a check of our procedures, we made similar measurements using gill and intestinal tissue from hybrid red tilapia (*Oreochromis mossambicus* x *O. niloticus*). We also determined gill filament and gut masses so as to be able to calculate the fraction of the SMR attributable to maximal Na^+-K^+ ATPase activity.

Contrary to our supposition, we found only small difference in Na^+-K^+ ATPase activity per unit mass of gill tissue in these four species, although Na^+-K^+ ATPase activity per unit mass of intestinal tissue was higher in tilapia (Table 1). Our results, were, moreover, comparable to values previously reported for tilapia and active marine teleosts .

Table 1.

	gill Na^+-K^+ ATPase (mmoles ATP h^{-1} g^{-1} wet weight)	gill Na^+-K^+ ATPase (mmoles ATP h^{-1} mg^{-1} protein)
yellowfin tuna	245 ± 20, n=13	4.6 ± 0.5, n=14
skipjack tuna	217 ± 36, n=10	4.2 ± 0.8, n=12
dolphin fish	342 ± 39, n=7	9.7 ± 1.1, n=12
tilapia	341 ± 41, n=7	7.3 ± 0.4, n=13
yellowfin tuna	165 ± 16, n=14	3.4 ± 0.4, n=15
skipjack tuna	227 ± 41, n=10	4.9 ± 0.6, n=10
tilapia	439 ± 42, n=7	5.2 ± 0.5, n=7

Based on gill and intestinal Na^+-K^+ ATPase activity, we estimate the cost of osmoregulation to be at most 13 %, and 9 %, of the SMR in yellowfin and skipjack tuna (respectively), and 63% hybrid red tilapia. Our results, therefore, do not support our original suppositions. Rather, we conclude: (1) rates of energy expenditure required for counteracting the passive influx of ions and the water loss occurring across the gills of tunas and dolphin fish are not exceptional when expressed as a fraction of the SMR; and (2) osmoregulatory costs are not responsible for the elevated SMR of tunas and dolphin fish.

References

Brill, R. W. 1987. On the standard metabolic rates of tropical tunas, including the effect of body size and acute temperature change. Fish. Bull. U.S. 85: 25-35.

Bushnell, P. G. and R. W. Brill. 1992. Oxygen transport and cardiovascular responses in skipjack tuna (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) exposed to acute hypoxia. J. Comp. Physiol. B 162:

131-143.

Bushnell, P. G. and D. R. Jones. 1994. Cardiovascular and respiratory physiology of tuna: adaptations for support of exceptionally high metabolic rates. Environ Biol Fishes 40:303-318.

Gibbs A, Somero GN (1990) Na^+-K^+-adenosine triphosphate activities in gills of marine teleost fishes: changes with depth, size and locomotory activity. Mar. Biol. 106:315-321.

Perry, S. F. 1992. Morphometry of vertebrate gills and lungs: a critical review. In S. Egginton and H. F. Ross (eds) Oxygen Transport in Biological Systems: Modeling of pathways from environment to cell. Society for Experimental Biology Seminar Series 51. Cambridge University Press, Cambridge, pp 57-77.

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