

## Estimation of caloric content for fish biomass

James F. Kitchell<sup>1</sup>, John J. Magnuson<sup>1</sup>  
& William H. Neill<sup>2</sup>\*

<sup>1</sup>Laboratory of Limnology, University of Wisconsin, Madison, Wisconsin 53706, USA

<sup>2</sup>Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, Hawaii 96812, USA

### Keywords:

Calories, Fish biomass, Energy content, Skipjack tuna, *Katsuwonus pelamis*, Starvation

### Synopsis

Analyses of tissues from just-caught and captive, starved skipjack tuna, *Katsuwonus pelamis*, indicated a significant effect of starvation on water, ash, and caloric content. Caloric content of just-caught whole fish was 1.45 to 1.48 kcal g<sup>-1</sup> wet weight and was directly comparable to values determined for white muscle (edible) tissue samples. Examination of recent literature yielded caloric data for 81 fish species. These data plus those from our study indicated that the assumption 1 g wet weight = 1 kcal can result in substantial error. Less than 40% of the data were within the range 0.90–1.10 kcal g<sup>-1</sup> wet weight. A linear relationship between caloric content (Y) and percent water (X) derived as  $Y = 5.537 - 0.059X$  resulted in an overall improvement in estimation of caloric content.

### Introduction

Studies of fish energetics frequently require an estimate of caloric value to convert biomass to its energy equivalent. The current convention is that 1 g of wet biomass is roughly equivalent to 1 kcal (Winberg 1960, Winberg & Edmondson 1970, Warren 1971) and is widely used in reports ranging from single species modeling studies (Norstrom, McKinnon & de-Freitas 1976) to large-scale applications on a global basis (Crisp 1975, Rounsefell 1975). A report by Brett (1973) and a compilation of data by Sidwell et al. (1974) indicate that a single conversion does not

suffice for universal application to fishes when accuracy greater than  $\pm 30\%$  is desired. Summarizing data for many consumer species, Pandian (1975) concluded that intraspecific variation of up to 1.5 kcal g<sup>-1</sup> dry weight may be due to nutritional history.

We propose a linear relationship between energy content and percent water of wet weight to estimate more accurately the caloric equivalent of fish biomass. Caloric content of whole fish, red muscle, and white muscle of skipjack tuna, *Katsuwonus pelamis*, was determined from starved captive fish and from fish just caught at sea to test this hypothesis and to estimate the energy content of scombrid fishes.

### Method and materials

Skipjack tuna were from pole-and-line catches near Hawaii. Four fish captured on 29 March 1974 were immediately killed, weighed, and measured. Two of the four were frozen intact. The remaining two were dissected and samples of red and white muscles were removed, weighed, and frozen for later analyses.

Fish captured on 2 April 1974 were maintained alive for 10 days without food in a tank at the Kewalo Research Facility (Nakamura 1972) of the National Marine Fisheries Service. Four fish were then removed, killed, weighed, and measured; two were frozen intact and two were dissected for muscle samples as above. Initial weights prior to starvation were not obtained because skipjack tuna do not survive handling.

Whole fish and muscle samples were oven dried at 70° C up to 17 days, then at 85° C to a constant dry weight. Entire samples were ground and homogenized, redried, then stored in a desiccator. Approximately 1 g subsamples were removed for measurement of ash and caloric content. The ash fractions, three replicates per sample, were determined by burning subsamples overnight in a muffle furnace (640°–650° C). Calorimetry, five replicates per sample, was performed with a Parr\* oxygen bomb calorimeter as generally prescribed in American Society for Testing Materials (1966), except that acid titrations were not performed because our previous experience had indicated that the corrections are insignificant for within-taxon comparisons.

\* Present address: Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas 77843, USA

\* Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

## Results

Caloric yields of the two just-caught skipjack tuna (Table 1) were very similar: 1.45 and 1.48 kcal g<sup>-1</sup> wet weight. White muscle samples (Table 1) generally approximated whole fish energy yield in wet weight units among both just-caught and starved fish. Thus edible portions, for which most calorimetry data are available, can provide a reasonable estimate for the total animal. Red muscle is a small proportion of total muscle and, while it appears to have a higher energy content, inclusion with white muscle would not greatly influence an estimate of whole fish energy content from the edible portion.

Starvation had a significant effect on caloric, water, and ash content (Table 1). Extensive comparisons among tissues and treatments are precluded owing to our small sample sizes. Even so, a two-way analysis of variance performed with data on calories per gram dry weight did indicate a significant ( $P < 0.05$ ) effect of starvation on caloric content.

Several trends are clear and consistent with those reported elsewhere (Brett 1973). Both water and ash fractions were greater for starved fish while energy content per unit weight decreased with starvation.

Caloric differences were most apparent on a wet weight basis and in red muscle (Table 1). These observations suggest that there is greater utilization of high energy sources (e.g. fat or oil) from red muscle than white muscle during starvation. More important to the problem of estimating energy content of whole fish, energy content on a wet weight basis is inversely related to body water content. Changes in energy and water content may be due to different conditions of reproductive activity, depletion of energy reserves during migration, and/or seasonal variation in lipid content due to changes in food quality and consumption rates (Pandian 1975).

## Discussion

The caloric content of skipjack tuna is considerably higher than the 1.0 kcal g<sup>-1</sup> rule of thumb used in fish bioenergetic studies. Caloric density is altered by starvation. Fasted, exercised sockeye salmon, *Oncorhynchus nerka*, also demonstrated significant increases in body water content and decreases in energy content per unit wet and dry weight (Brett 1973). In addition, of the 79 species represented in data tabulated by Sidwell et al. (1974) only 32 had caloric values

Table 1. Caloric values of whole fish, red muscle, and white muscle of just-caught and starved (10 days) skipjack tuna, *Katsuwonus pelamis*. Means for percent ash of wet weight and kilocalories per gram dry weight are given for each fish plus or minus one standard error.

Tissue (treatment)	Fish wet weight (kg)	Fork length (cm)	Percent of wet tissue weight		Kilocalories per gram weight		
			Water	Ash	Wet	Dry	Ash-free dry
Whole fish (just caught)							
Fish #1	1.48	43	71	3.38 ± 0.05	1.45	4.97 ± 0.02	5.62
Fish #4	1.56	44	71	3.19 ± 0.02	1.48	5.04 ± 0.01	5.65
Whole fish (starved)							
Fish #5	1.56	45	74	3.22 ± 0.02	1.22	4.75 ± 0.01	5.43
Fish #7	2.28	50	75	3.56 ± 0.03	1.13	4.54 ± 0.02	5.29
Red muscle (just caught)							
Fish #2	1.50	43	71	1.20 ± 0.04	1.63	5.58 ± 0.02	5.82
Fish #3	1.42	43	72	1.05 ± 0.02	1.52	5.42 ± 0.02	5.63
Red muscle (starved)							
Fish #6	1.48	44	76	1.00 ± 0.01	1.30	5.40 ± 0.01	5.64
Fish #8	2.57	52	74	1.08 ± 0.01	1.38	5.41 ± 0.01	5.65
White muscle (just caught)							
Fish #2	1.50	43	72	1.25 ± 0.04	1.46	5.20 ± 0.01	5.44
Fish #3	1.42	43	72	1.19 ± 0.01	1.43	5.17 ± 0.02	5.40
White muscle (starved)							
Fish #6	1.48	44	76	1.16 ± 0.03	1.28	5.21 ± 0.01	5.47
Fish #8	2.57	52	76	1.22 ± 0.07	1.21	5.08 ± 0.01	5.35

between 0.90 and 1.10 kcal g<sup>-1</sup> wet weight.

The results of starvation treatments (Table 1 and Brett 1973) and inspection of data summarized by Sidwell et al (1974) confirm a strong interaction between tissue water content and energy yield per unit weight. That relationship would be expected, of course, in that the energy values are associated with the dry weight (i.e., organic plus ash) fraction. Analysis of skipjack tuna tissues emphasizes the potential error associated with accepting the energy value of 1 kcal g<sup>-1</sup> wet weight as well as that associated with the assumption that weight loss is directly equivalent to energy expenditure. Weight loss underestimates energy loss during starvation because hydration occurs as the hydrophobic lipid reserves are utilized. Caloric density decreases but weight changes are not strictly proportional due to simultaneous increase in tissue water content. The reverse is very probably true as fish are increasing lipid reserves; energy stored would be underestimated by weight increments alone.

Caloric values of other tuna species also tend to be high, ranging from 0.98 kcal g<sup>-1</sup> wet weight for big-eye tuna, *Thunnus obesus*, to 1.69 kcal g<sup>-1</sup> for Atlantic mackerel, *Scomber scombrus* (Sidwell et al. 1974). In general, caloric values are highest for those fishes that are highly active (e.g. Scombridae) or those that migrate substantial distances (e.g. Salmonidae and Scombridae).

Recognizing that results from calorimetry and/or proximate analysis are desirable but not often available to investigators of fish energetics, we propose that an easily measured parameter – per cent water of live weight – will provide the basis for a more accurate estimate of energy content. The relationship between caloric value and water content of fish biomass is estimated by the regression equation given in Figure 1.

When all data in Figure 1 are considered, less than 40% of caloric measurements are within ± 10% of the estimate from the convention of 1 g wet weight = 1 kcal. An overall improvement comes from use of the regression where approximately 60% of caloric measurements are within 10% of the estimate. The coefficient of determination (r<sup>2</sup>) is 0.66 for the regression. For skipjack tuna, application of the 1 g wet weight = 1 kcal assumption results in estimates that are low by about 30%. Application of the regression equation (Fig. 1) results in estimates that are low by about 10%. Use of the regression constitutes a significant improvement for fish with a high energy yield and low water content like a tuna but little or no improvement for fish with water contents between 75% and 80%.

Thus an improved estimate of energy content for fish may frequently be made with this regression equation (Fig. 1) or one similarly derived when direct

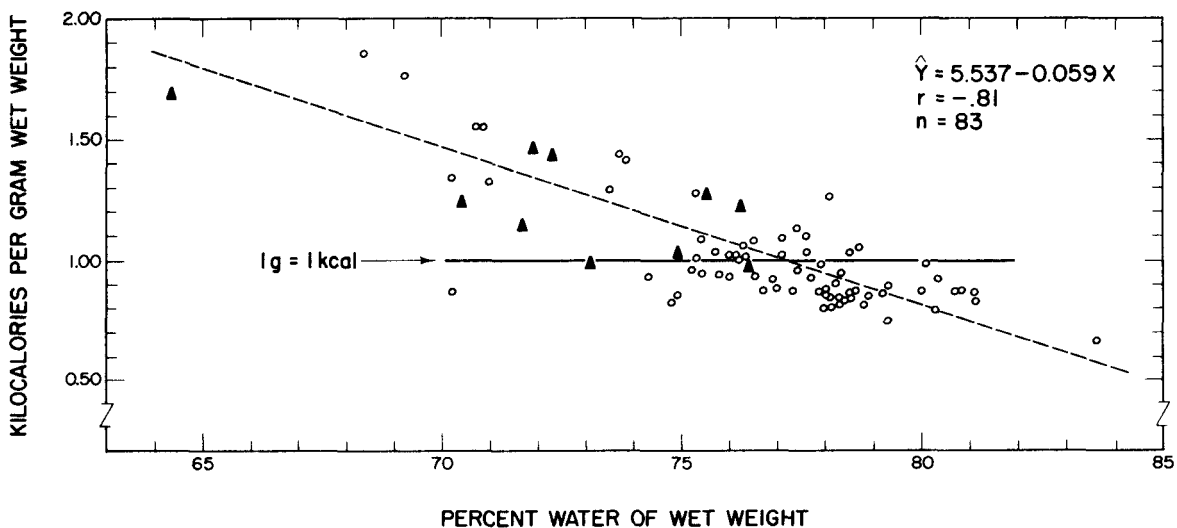


Fig. 1. Relation between water content and energy yield of fish biomass. Data for the 81 species represented are from Brett (1973), Sidwell et al. (1974), and our study (Table 1). Included are two data for starved sockeye salmon and skipjack tuna. Triangle data are those for species of the family Scombridae.

measurements of caloric content are not available. Data summarized here suggest that the relationship can be applied both within and between taxa of fishes. Within a taxon, more accurate data on temporal variation in energy content, particularly that associated with lipid reserves, may be determined from regression analysis of some caloric data in combination with regular monitoring of the more readily measured body water content. Ontogenetic changes may be similarly determined (Pandian 1975) but should include a correction for increased inorganic (ash) fractions of the dry weight due to increased proportions of total weight associated with structural tissues.

### Acknowledgments

This study was supported in part by Contract Nos. 03-3-208-37, 03-4-208-274, and 03-5-208-184 from the U.S. Department of Commerce, NOAA, National Marine Fisheries Service and by a grant from the University of Wisconsin Brittingham Oceanography Fund. We thank John Gryskiewicz for technical assistance in calorimetric analyses.

### References cited

- American Society for Testing Materials. 1966. Method D. 271, for Parr bomb calorimeter. Am. Soc. Test. Mater. 19: 42-46.
- Brett, J. R. 1973. Energy expenditure of sockeye salmon, *Oncorhynchus nerka*, during sustained performance. J. Fish. Res. Board Can. 30: 1799-1809.
- Crips, D. J. 1975. Secondary productivity in the sea. pp. 71-89. In: D. E. Reichle, J. F. Franklin & D. W. Goodall (ed.), Productivity of World Ecosystems. Natl. Acad. Sci., Washington D.C.
- Nakamura, E. K. 1972. Development and uses of facilities for studying tuna behavior. pp. 245-277. In: H. E. Winn & B. L. Olla (ed.), Behavior of Marine Animals. Current Perspectives in Research 2: Vertebrates. Plenum Publ. Corp.
- Norstrom, R. J., A. E. McKinnon & S. W. deFreitas. 1976. A bioenergetics-based model for pollutant accumulation by fish. Simulation of PCB and methyl-mercury residue levels in Ottawa River yellow perch (*Perca flavescens*). J. Fish. Res. Board Can. 33: 248-267.
- Pandian, T. J. 1975. Mechanisms of heterotrophy. pp. 51-249. In: O. Kinne (ed.), Marine Ecology, Vol. II, Part 1. J. Wiley and Sons, New York. Rounsefell, G.A. 1975. Ecology, Utilization and Management of Marine Fisheries, C.V. Mosby Co., St Louis, 516 pp.
- Sidwell, V. D., P. R. Foncannon, N. S. Moore & J. C. Bonnet. 1974. Composition of the edible portion of raw (fresh or frozen) crustaceans, finfish, and molluscs. I. Protein, fat, moisture, ash, carbohydrate, energy value, and cholesterol. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 36(3): 21-35. (Also MFR Paper 1043)
- Warren, C. S. 1971. Biology and Water Pollution Control. W. B. Saunders, Philadelphia. 434 pp.
- Winberg, G. C. 1960. Rate of metabolism and food requirements of fishes. Fish. Res. Board Can., Transl. Ser. No. 194, 202 pp. + 32 tables.
- Winberg, C. G. & T. Edmondson. 1970. Symbols, Units and Conversion Tables for the IBP. Blackwell Sci. Publ., London. 51 pp.