Bioenergetics of Captive Pacific Bluefin Tuna, *Thunnus orientalis*.

Growth and Energy Conversion for a Captive Population; Maintained by Monterey Bay Aquarium & the Tuna Research & Conservation Center; A Twelve-Year Study.

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Calculated growth rates and whole body caloric contents

Figure 1. Fork length (Lt, cm) at age (t, years) and the fitted von Bertalanffy growth curve for Pacific bluefin tuna, *Thunnus orientalis*.

Figure 2. Relationship between fork length (FL, cm) and the whole body weight (BW, kg) of Pacific bluefin tuna, Thunnus orientalis.

Fig. 1

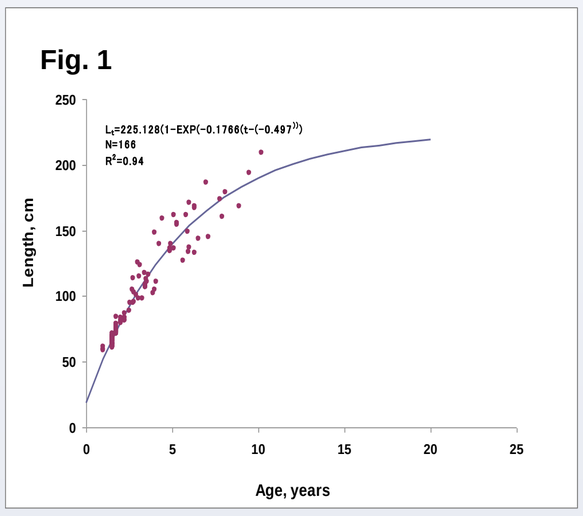

Fig. 2

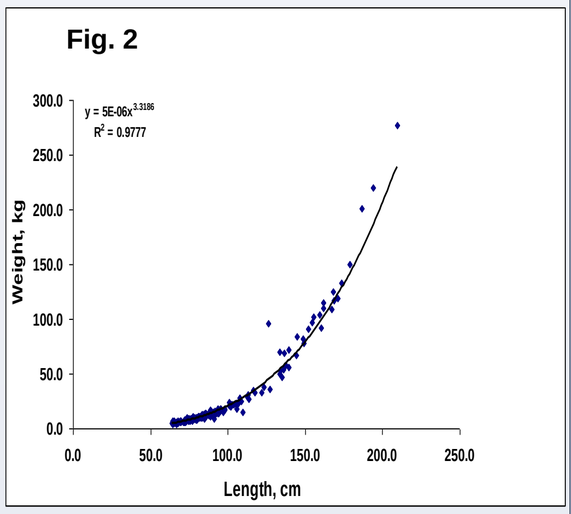

Table 1. Calculated lengths at age taken from Figure 1, and weights from Figure 2.

Age	Length	Growth,	Weight At Age	Change
Years	cm	mm^{-1}day	kg	g^{-1}day
0	18.92	-	0.1	-
1	52.30	0.91	2.4	6.4
2	80.29	0.77	9.9	20.6
3	103.73	0.64	23.2	36.3
4	123.39	0.56	41.1	49.2
5	139.86	0.45	62.3	57.9
6	153.66	0.38	85.0	62.3
7	165.24	0.32	108.1	63.2
8	174.93	0.27	130.5	61.5
9	183.1	0.22	151.7	57.9
10	189.9	0.19	171.1	53.4

Figure 3. Average daily growth, Table 1

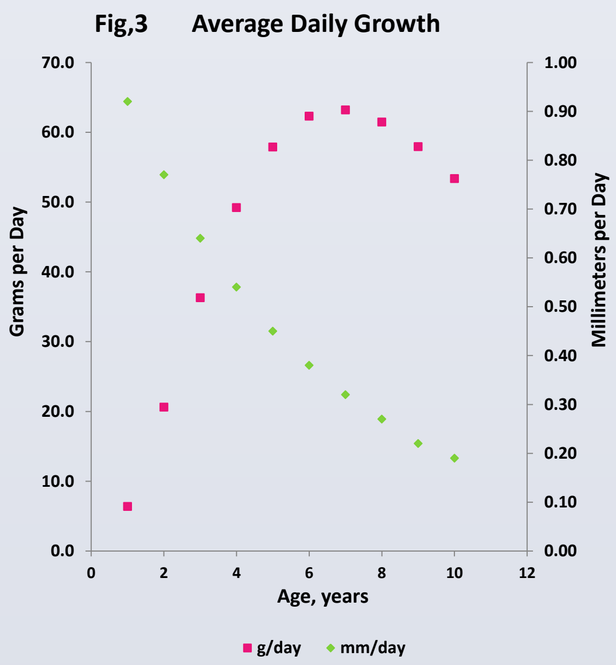

Table 2. Pacific bluefin tuna organ, muscle and skeleton masses are shown. Proximate analysis for percent protein and fat, total Kcals for each are derived and the Kcals per gram determined for the entire tuna. Values shown represent the means for four Pacific bluefin tuna with masses of 11.6, 11.6, 12.6, and 20.0 kg with an average mass of 13.95 kg. Sections 1,2 & 3 are comprised of the collar and pectoral fins; the skeletal system running posterior the head to the end of the first dorsal fin including the pelvic fin;, and an area from the second dorsal fin down to the anal fin.

Sample	Weight (g)	Weight (% of Total Mass)	Protein (%)	Protein (kcal)	Fat (%)	Fat (kcal)	Total (kcal)
Liver	139.09	1.01	18.55	100.34	4.53	49.98	150.33
Atrium*	5.04	0.04	19.50	3.83	2.65	1.07	4.90
Ventricle	18.95	0.15	16.83	12.70	2.68	3.99	16.69
Bulbous Arteriosis	7.63	0.06	17.20	5.14	3.73	2.24	7.37
Caecum	168.71	1.24	15.73	104.02	2.39	31.63	135.66
Spleen	46.80	0.34	22.88	42.09	1.62	6.09	48.18
Stomach	138.56	1.01	18.78	102.40	1.68	18.74	121.14
Intestine	30.39	0.22	16.65	19.79	1.77	4.24	24.03
Gonad	6.69	0.05	16.63	4.55	18.86	6.17	10.72
Gallbladder	10.89	0.09	9.49	3.62	2.75	2.04	5.66
Gills	745.50	5.38	16.58	496.54	4.02	233.72	730.26
Skin	626.00	4.40	20.60	495.05	18.68	908.57	1403.62
Red Muscle	2196.00	15.45	22.30	1917.90	2.37	401.37	2319.27
White Dorsal Muscle	2570.50	18.26	24.45	2447.20	1.14	212.84	2660.04
White Ventral Muscle	2641.50	19.53	22.93	2365.90	3.63	746.13	3112.03
Head	1944.00	13.44	13.18	1012.13	21.45	3115.08	4127.20
Skeletal Section 1	756.00	5.54	17.50	519.44	10.78	629.46	1148.90
Skeletal Section 2	500.00	3.72	18.28	359.85	8.21	311.25	671.11
Skeletal Section 3	303.00	2.23	21.33	251.30	2.49	62.28	313.57
Tail	386.00	2.79	19.90	299.44	3.47	111.91	411.36
Total	13237.45	94.93		10560.36		6858.00	17418.36

Solving thegrowth equation where Growth equals ingested energy minus the sum of the cost of digestion, routine metabolic rate, activity rate and excretion.

Table 3. Processes involved in converting the values and units used in ingested energy and the energetic costs into Joules, including references for each process.

	Process	Action Result	Reference
Energy Ingested		**KJ**	
32 Kcals kg^{-1} day^{-1} At 20^{O}C	1 Kcal = 4.184 KJ	1393.1	Brett & Groves, 1997
Energetic Costs			
RMR	174 mgO^{2} kg^{-1} h^{-1} 1 mgO^{2} = 14.32J	621.9	Blank et al, 2006 Clark et al, 2010
SDA	9.2% of ingested energy	128.2	Clark et al, 2010
AMR	16.6% of resting metabolic rate	103.2	Temporal changes, archived O_2; holding tank concentration records
EE	20% of ingested energy	278.6	Kitchell et al, 1978

Table 4. Growth = Ingested energy (EI) – (Specific Dynamic Action (SDA) + Routine Metabolic Rate (RMR) +Activity Metabolic Rate (AMR) + Excretion and Egestion (EE)). All units for these components are given in Kilojoules. Food Conversion Ratio (FCR) is the ratio of the food weight in grams ingested divided by the daily growth in grams. Energy Conversion Ratio (ECR) is derived from Available Energy for Growth divided by the total energy value (KJ) of the tissue. Gross energy conversion (GEC) is the tissue energy divided by Ingested energy value. The values obtained for FCR is 27.4:1, 56.3 percent for ECR, and 11 percent for gross energy conversion (GEC)

Diet	EI	RMR	SDA	AMR	EE	Energy Available for Growth	Growth g/day	Kcals /g fish mass	KJ Tissue Energy
Process Results									
32 Kcals $^{-1}$kg^{-1} day	1393.1	621.9	128.2	103.2	278	261.8	26.6	1.32	147
Food types and amounts, grams	Squid	Sardine	Gelatin	Total fed	Growth g^{-1}day	Energy conversion			
	350 g	350 g	30 g	730 g	26.6	27.4:1 FCR			
						56.3% ECR			
						11.0% GEC			

Results and Discussion

- Energy conversion ratios are obtained from the Growth equation listed in Table 4. The conversion ratios are determined using the above equation and solving for the resulting tissue energy. The FCR is at the high end of reported values when squid is included in the diet; by calculating a 100% sardine diet the ratio is lowered to 21.8, a value within reported FCR.
- The value of 11% obtained for Gross Energy Conversion, GEC) is comparable with published data. However the result for Net Energy Conversion at 56.3% seems low, a possible explanation may include a low digestibility for the gelatin mix, removing this particular food item would lower the energy available for growth and raise the net energy conversion to 58.0%.
- The total fat content found in the examined musculature which includes all tissues combined is 7.1%, this is considerably lower than reported values form other species of Thunnus such as albacore, where values from the northeastern Pacific known to be as high as 17%,
- The low values for fat content are most likely the result of the low fat diet and possibly a temperature effect considering the collection was maintained at 20^{O}C which is slightly higher than the preferred temperature range of 16-18^{O}C, which may have a small negative effect on fat deposition.
- The increase in fork length expressed in millimeters per day ranged from 0.19 to 0.92 with a 10-year average of 0.47
- Weight decrease in the older fish,8-10 year class may be due to the small number of fish in these size classes for measurement data and possibly to being outcompeted for food by the smaller tuna in the exhibit.