Honolulu, Hawaii
June 17-24, 1992

WESTERN PACIFIC YELLOWFIN TUNA RESEARCH GROUP WORKSHOP

AND

SPC STANDING COMMITTEE ON TUNA AND BILLFISH PROGRAM MEETING

Doc. No.14

LENGTH AND WEIGHT RELATIONSHIPS FOR YELLOWFIN TUNA IN THE WESTERN PACIFIC

by
P.J. Ward & C.M. Ramirez
Fisheries Resources Branch
Bureau of Rural Resources
Department of Primary Industries & Energy
John Curtin House
Brisbane Avenue
BARTON
CANBERRA ACT 2601
AUSTRALIA

Background paper for
Western Pacific Yellowfin Tuna Research Group Workshop
Honolulu, Hawaii
June 17-24, 1992

#14.

LENGTH AND WEIGHT RELATIONSHIPS FOR YELLOWFIN TUNA IN THE WESTERN PACIFIC

by
P.J. Ward & C.M. Ramirez

Background paper presented at the second meeting of the Western Pacific Yellowfin Research Group (Honolulu, 22-24 June, 1992)

Fisheries Resources Branch
Bureau of Rural Resources
Department of Primary Industries & Energy
John Curtin House
Brisbane Avenue
BARTON
CANBERRA ACT 2601
AUSTRALIA

June 1992

BRR Background Papers are informal publications which make available material for discussion and consultation. This paper has not been edited or reviewed by the BRR Publications and Information Section or cleared by the BRR Executive.

Summary

Thousands of yellowfin tuna, *Thunnus albacares*, have been weighed and measured in the Western Pacific. Most samples were gathered during the late-1950s and 1960s, predominantly from the Japanese longline fishery. Many length-weight relationships have been published for longline-caught yellowfin tuna, but few analyses or data are available for those caught by surface fisheries, such as purse seine.

Length-weight relationships have various uses in fisheries research and management, such as converting weight frequencies to lengths and raising length samples to length frequencies for catch-at-length tables in stock assessment. Accurate estimates of total catch are available for several Western Pacific fisheries and length samples can be collected relatively easily. But, in many situations it is not possible to weigh the sample. Given a length-weight relationship and an estimate of total catch, however, a length sample can be raised to a length frequency for the total catch.

The relationship between length and weight is far from constant in yellowfin tuna. Analyses of eastern Australian data revealed statistically significant differences in relationships derived from different areas, different seasons and gender. Length-weight relationships will also vary from year to year and between fishing methods.

These differences will cause significant errors in the catch-at-length tables derived from length-weight relationships, and then propagate into length- or age-based modelling that may use those tables. Ideally, unique length-weight relationships, derived from the population sampled, should be used for raising length samples. Better still, the sample should be weighed and the sex of each fish should be determined when lengths are measured.

Contents

Introduction

Growth of fishes is quite variable. The size of individual fish is strongly influenced by environmental conditions, such as temperature, and food supply. The relationship between a fish's length and its weight vary too - over time and between locations, depending on the abundance of food, competitors and reproductive activity.

Length-weight relationships have various uses in fisheries research and management. Accurate estimates of total catch are available for several fisheries in the Western Pacific and length samples can be collected relatively easily. But, in some situations it may not be possible to weigh the sample. Given a length sample and a good estimate of total catch, however, a length-weight relationship can be used to raise the length sample to a length frequency of the total catch. Catch-at-age tables for stock assessment may then be derived from these length frequencies using a length-age relationship.

This paper lists parameters for length-weight relationships (previously summarised by Yoshida 1979 and Suzuki 1991) for yellowfin tuna in the Western Pacific. Effects of season, area, fish gender and sample size on raising length samples to length frequencies are also assessed.

Published Length-weight Relationships

Yoshida (1979) reviewed length-weight relationships of yellowfin tuna in the Pacific and Indian Oceans and Suzuki (1991) reviewed those for yellowfin tuna in the Western Pacific. Table 1 summarises parameters and other relevant information for yellowfin tuna in the Western Pacific. Relationships are usually expressed in the power form:

$$W=aL^b$$

where L is the fork length (cm) and
W is the whole weight (kg).

The parameters a and b are estimated by a least-squares linear regression of the logarithmic form:

$$\log W=\log a+b\log L$$

Published accounts are mostly limited to yellowfin tuna caught by longline and there are few analyses of yellowfin tuna caught by surface methods, such as purse seine and ring net. This is cause for concern because purse seine and longline-caught yellowfin tuna may differ in condition. Of further concern is the fact that longline catches are dominated by large yellowfin tuna (90-150 cm). Relationships derived from these large yellowfin tuna may be poor predictors of weights of small yellowfin tuna, which are a significant component of the large purse seine and ring net catches.

High priority must be given to gathering length and weight data for yellowfin tuna less than 80 cm and yellowfin tuna caught by surface fisheries. In this regard, analysis of over 1,500 length-weight samples (25-140 cm) collected by the South Pacific Commission during the Regional Tuna Tagging Programme will be useful.

Table 1. Summary of length-weight relationships for yellowfin tuna of the Western Pacific Ocean. Relationships are of the form $W=aL^b$, where L is the fork length (cm) and W is the whole weight (kg). Relationships for gilled-and-gutted weights are indicated.

Source	*a*	*b*	Length Range (cm)	N	Area	Year(s)	Source
Tester & Nakamura (1957)	$2.852\text{x}10^{-5}$	2.9045	29-72	59	Hawaii	1951-55	troll whole weights
Kamimura & Honma (1959)	$6.006640\text{x}10^{-3}$	3.1878	100-150	11,344	Western & Central Pacific	1949-1955	longline gilled-and-gutted weights from fish markets
Ronquillo (1963)[1]	$2.352\text{x}10^{-5}$ $4.322\text{x}10^{-5}$	2.84682 2.87651	85-180 100-155	99(males) 43(females)	Philippines	1960	longline
Nakamura & Uchiyama (1966)	$3.2560\text{x}10^{-5}$	3.05834	70-180	4,822	Central Pacific	na	whole weights, probably longline
Morita (1973)	$2.51211\text{x}10^{-5}$	2.939597	26-157	2,043	Japan & South-western Pacific	na	whole weights mainly longline
Morita (1973)	$3.49515\text{x}10^{-5}$	2.868069	63-148	46	Eastern & Central Pacific	na	whole weights mainly longline
White (1982)	$3.10615\text{x}10^{-5}$	2.869	15-65	na	Philippines	1979-82	whole weights, mainly ring-net
Ward (unpub.)	$1.46517\text{x}10^{-5}$	3.031646	62-166	934	Eastern Australia	1980-91	longline whole weights
Ward (unpub.)	$8.3536\text{x}10^{-6}$	3.1132	62-196	2,815	Eastern Australia	1980-91	longline gilled-and-gutted weights

---

[1] Parameters are from text, p. 1079; *a*'s in figures 11 & 12 & table XI do not correspond.

Handling and Measuring

Length-weight relationships may be affected by how the fish were handled and measured. Presumably, relationships appearing in the literature are from data collected from fresh fish with measuring boards. But few published accounts actually specify the handling and measuring procedures.

Rigor mortis and chilling will also affect lengths. Lifting a large yellowfin tuna by the tail can dislocate vertebrae and significantly stretch the fish. Fresh fish should be measured with the mouth closed, from the tip of the lower jaw to the tail fork. Callipers permit a "point-to-point" measurement which avoids parallax error. If using a measuring tape, care must be taken not to curve it around the body. Measurements are known to be reported in a variety of ways: to the lower centimetre, upper centimetre or nearest centimetre.

Thawing a frozen 40 kg gilled-and-gutted yellowfin tuna will result in a weight loss of 2-3 kg. Some length-weight relationships, e.g., Kamimura & Honma (1959), may be based on gilled-and-gutted weights raised to whole weights using a ratio of 1:1.15 (see below).

Variation in Relationships

Statistical tests of eastern Australian data indicate significant differences between length-weight relationships according to gender, area and, possibly, season (Appendix 2). Preliminary analyses of data from the Eastern Pacific by Pedersen & Tomlinson (unpub.) also indicate that relationships vary over time and, possibly, between fishing methods.

It would be prudent to assemble and analyse recent and historic data, and develop relationships for variables that are likely to have a significant affect on stock assessment applications. Variables should include:

- area;
- season;
- year;
- fishing method; and,
- for purse seining, school type.

Fish gender should not important unless there is a bias in the sex ratio over these variables. However, yellowfin tuna larger than 160 cm tend to be males (Suzuki 1991) and those fisheries that take large yellowfin tuna may require gender-based relationships.

Effects on Estimated Length Frequency

While there might be statistically significant differences between relationships, this might not necessarily cause a noticeable effect on estimated length frequencies. Simulations were used to determine whether different length-weight relationships had a noticeable effect on estimated length frequencies.

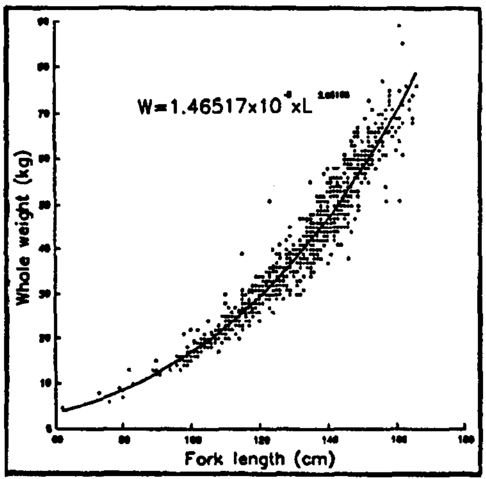

Figure 1. Length-weight relationship for yellowfin tuna derived from data collected by observers on Japanese longliners in eastern Australian waters, 1980-91.

The eastern Australian data (Figure 1) were used to represent the "true population". A "perfect sample" of this population was taken - it was simply 10% of the true population, distributed across the lengths in the same proportion as the true population (e.g., Appendix 3). The procedure described in Appendix 1 was used to estimate the number of fish at each length from this perfect sample. The effects of several length-weight relationships were assessed by comparing their estimated length frequencies with the true length frequency.

Ward (unpub.): The first length-weight relationship examined was the relationship derived from the true population itself. As expected, the estimated length frequency was almost identical to the actual length frequency (Appendix 3). The small deviation (1%) is from variance around the regression line and rounding error.

Note that estimated numbers are proportional to the actual numbers at each length. Thus, we need only compare the estimated total number (938) to the true number (934) to assess the accuracy of the length-weight relationship (Table 2).

Table 2. Summary of comparisons of estimates of populations size for different length-weight relationships.

Comparison	Source of Relationship	Est N	Actual N	% Error
(1) Using a "foreign" relationship on the eastern Australian data	Nakamura & Uchiyama	816	934	-14
	True population	938		0
(2) Using the eastern Australian relationship on northern fish	Eastern Australia	69	65	5
	True population	66		1
(3) Using the eastern Australian relationship on summer fish	Eastern Australia	120	114	5
	True population	114		0
(4) Using the eastern Australian relationship on male fish	Eastern Australia	448	444	1
	True population	446		0

Nakamura & Uchiyama (1966): The length-weight relationship of Nakamura & Uchiyama (1966) for longline-caught yellowfin tuna in the Central Pacific gave a much lower estimate of the total number. It under-estimated the true number (934) by 14% (Table 2).

Area: The specific northern length-weight relationship agreed closely to the true number. When yellowfin tuna from northern waters (north of 20°S) were used the length-weight relationship derived from the eastern Australian data (the relationship of Ward unpub.) over-estimated the true number by 5% (Table 2).

Season: The length-weight relationship derived from the eastern Australian data (Ward unpub.) also over-estimated the true number by 5% when yellowfin tuna caught during the southern summer were used (Table 2). The specific summer length-weight relationship agreed with the true number.

Gender: Using male yellowfin tuna made scant difference to the estimated length frequency. The length-weight relationship derived from the eastern Australian data over-estimated the number by only 1% (Table 2). The specific male length-weight relationship agreed with the true number.

These simulations show that using one, general length-weight relationship will result in significant errors in length frequency estimates. This has important implications for stock assessments relying on such estimates. Total removals from cohorts in age-structure models will be quite different, for example, according to the relationship used to generate the length frequencies.

The differences identified in the simulations are a matter of scale. Different relationships vary the estimated numbers at each length but the numbers at each length are directly proportional to those in the sample. An analysis of sampling strategies - number of samples the size of each sample, selection of fish - is necessary to assess how the estimated numbers of fish at each length vary relative to each other.

Sample Size

Random samples of the "true", eastern Australian population were taken to assess the effect of sample size on length frequency estimates. Repeated random samples of 25 fish were taken and number at each length was estimated by the standard procedure. The length-weight relationship derived from the true population itself and Nakamura & Uchiyama (1966) were used.

Results (Figure 2) show that a good estimate of the population's length frequency could be obtained from a sample of 175 fish. Comparison with results of Nakamura & Uchiyama (1966) suggest that, if the incorrect relationship is used, the estimates will almost always be incorrect. It does not matter how many fish are sampled, in fact there is a better chance of a correct estimate at very low sample sizes.

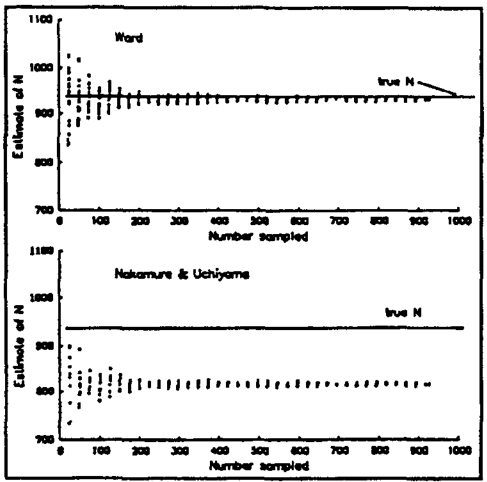

Figure 2. Effect of sample size on estimates of the true population size.

Whole Weight from Gilled-and-gutted Weight

Gilled-and-gutted weights, rather than whole weights, are reported in some fisheries, such as longline. A conversion factor of 1.15 is commonly used to convert gilled-and-gutted weights to whole weights. Length-gilled-and-gutted weight relationships are available, e.g., Kamimura & Honma (1959), Ward (unpub.; Table 1).

Alternatively, a whole weight to gilled-and-gutted weight relationship can be used to convert individual gilled-and-gutted weights before raising the length data. The eastern Australian data provide such a relationship:

$$W_w=1.27+1.12W_g \; (N=939,\; r^2=0.99)$$

where: W_w is the whole weight (kg) and
W_g is the gilled-and-gutted weight (kg).

Note again, however, that there were significant differences between slopes according to season, area and sex (Appendix 2).

The above relationship was applied to gilled-and-gutted weights from the eastern Australian data. The whole weight (37,832 kg) estimated by the relationship agreed closely with the true whole weight (37,852 kg). Multiplying gilled-and-gutted weights by 1.15 gave 37,627 kg) which was within 0.6% of the true whole weight.

References

Kamimura, T. & Honma, M. 1959. The relationship between length and weight of the landings of yellowfin from the Pacific Ocean. [in Japanese, English summary] *Report of the Nankai Regional Fisheries Research Laboratory* **11**:88-107.

Morita, Y. 1973. Conversion factors for estimating live weight from gilled-and-gutted weight of bigeye and yellowfin tunas. [in Japanese, English summary] *Bulletin of the Far Seas Fisheries Research Laboratories* 9:109-121.

Nakamura, E,L. & Uchiyama, J.H. 1959. Length-weight relations of Pacific tunas. In Manar, T.A. (ed) **Proceedings, Governor's Conference on Central Pacific Fisheries Resources, State of Hawaii.** pp 197-201.

Pedersen & Tomlinson (unpub.) The length-weight relationship for yellowfin tuna and skipjack tuna from the Eastern Tropical Pacific Ocean. Abstract of a paper presented at the Annual Tuna Conference, Lake Arrowhead, May 1992.

Tester, A.L. & Nakamura, E.L. 1957. Catch rate, size, sex, and food of tunas and other pelagic fishes taken by trolling off Oahu, Hawaii, 1951-55. US Fisheries and Wildlife Service. *Special Scientific Report on Fisheries, No. 250.* 25 pp.

Ronquillo, J.A. 1963. A contribution to the biology of Philippines tunas, Proceedings of the World Scientific Meeting on the Biology of Tunas and Related Species. *FAO Fisheries Report* 6(3):1683-1752.

Suzuki, Z. 1991. A review of biology and fisheries for yellowfin tuna *Thunnus albacares* in the Western and Central Pacific Oceans. Species Review TIC/91/BP#6 presented at the FAO Expert Consultation on Interactions of Pacific Tuna Fisheries. Noumea, New Caledonia, 3-11 December 1991. 37 pp.

White, T.F. 1982. The Philippine tuna fishery and aspects of the population dynamics of tunas in Philippine waters. Indo-Pacific Tuna Development and Management Programme Working Paper INT/81/034. 63 pp.

Yoshida, H.O. 1979. Compilation of published estimates of tuna life history and population dynamics parameters. Workshop on the Assessment of Selected Tuna and Billfish Stocks in the Indian and Pacific Oceans (Shimizu, Japan, 13-22 June 1979).

Appendix 1: Expansion of a Length Sample to a Length Frequency

The length frequency and length-weight relationship ($W=1.46517\times10^{-5}L^{3.031646}$) are from data collected by observers on Japanese longliners in the eastern Australian fishing zone (AFZ), 1980-91.

Fork Length (cm)	Number in sample	Est. Wt. for Length Step 1	Est. Total Wt. Step 2	Prop. of Total Step 5	Est. Freq. Step 6	Actual Freq.	Difference	%
62	0.1	3.98	0.40	0.00	1.0	1	0.00	0.4
73	0.1	6.53	0.65	0.00	1.0	1	0.00	0.4
76	0.1	7.38	0.74	0.00	1.0	1	0.00	0.4
79	0.1	8.30	0.83	0.00	1.0	1	0.00	0.4
80	0.2	8.62	1.72	0.00	2.0	2	0.01	0.4
82	0.1	9.29	[illegible]	[illegible]	[illegible]	1	0.00	0.4
83	0.1	9.64	[illegible]	[illegible]	[illegible]	1	0.00	0.4
89	0.2	11.91	[illegible]	[illegible]	[illegible]	2	0.01	0.4
90	0.5	12.32	[illegible]	[illegible]	[illegible]	5	0.02	0.4
91	0.1	12.74	1.27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
94	0.4	14.05	5.62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
96	0.5	14.98	7.49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
97	0.7	15.46	10.82	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
98	0.5	15.94	7.97	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
99	0.7	16.44	11.51	0.01	7.0	7	0.03	0.4
100	0.6	16.95	10.17	0.01	6.0	6	0.03	0.4
101	0.5	17.47	8.73	0.01	5.0	5	0.02	0.4
102	0.8	[illegible]	[illegible]	0.01	8.0	8	0.04	0.4
103	0.7	[illegible]	[illegible]	0.01	7.0	7	0.03	0.4
104	1.0	[illegible]	[illegible]	0.01	10.0	10	0.04	0.4
105	0.5	[illegible]	[illegible]	0.01	5.0	5	0.02	0.4
106	0.6	20.23	12.14	0.01	6.0	6	0.03	0.4
107	1.0	[illegible]	[illegible]	[illegible]	10.0	10	0.04	0.4
108	0.7	[illegible]	[illegible]	[illegible]	7.0	7	0.03	0.4
109	0.8	[illegible]	[illegible]	[illegible]	8.0	8	0.04	0.4
110	1.6	[illegible]	[illegible]	[illegible]	16.1	16	0.07	0.4
111	0.8	[illegible]	[illegible]	[illegible]	8.0	8	0.04	0.4
112	0.5	23.90	11.95	0.01	5.0	5	0.02	0.4
:	:	:	:	:	:	:	:	:
162	0.4	73.17	29.27	0.00	4.0	4	0.02	0.4
163	0.1	74.55	7.46	0.00	1.0	1	0.00	0.4
164	0.2	75.95	15.19	0.00	2.0	2	0.01	0.4
165	0.3	77.36	23.21	0.00	3.0	3	0.01	0.4
166	0.1	78.79	7.88	0.00	1.0	1	0.00	0.4
Total	93.4	3039.2	3768.6	1.00	938.1	934	4.11	

ave	40.3		% error	0.44
est number	938.1			

(1) using a length-weight relationship convert each length to a weight

(2) calculate the weight of each length by multiplying the number at each length by its estimated weight (1)

(3) estimate the average weight by dividing the estimated weight (2) by the number sampled (93.4)

(4) estimate the total number in the catch by dividing the total catch weight (37 852 kg) by the average weight (3)

(5) Estimate the raising factor by dividing the number of fish at each length by the total number (4)

(6) Estimate the length frequency by multiplying the estimated number (4) by the raising factor of each length

Table A.2.1 Comparison of slopes (*b*) for length-weight relationships derived from gilled-and-gutted weights collected by observers on Japanese longliners in the eastern Australian fishing zone, 1980-91. Relationships are in the form $W_g=aL^b$, L is the fork length (cm) and W_g is the gilled-and-gutted weight (kg). The parameters *a* and *b* are estimated by a least-squares linear regression of the logarithmic form, $\log W_g=\log a+b\log L$.

Variable		log*a*	*b*	N	df	t	$t_{\infty(2),0.05}$	Conclusion
Season	winter	-5.0912	3.1194	2,603	2,811	1.40	1.96	accept H_0, the populations are the same (0.10<P<0.20)
	summer	-4.9562	3.0544	212				
Area	north of 20°S	-4.8750	3.0117	143	2,811	-1.96	1.96	reject H_0, the populations are different (0.02<P<<0.05)
	south of 20°S	-5.0955	3.1217	2,672				
Sex	males	-5.0951	3.1219	1,172	2,541	2.72	1.96	reject H_0, the populations are different (0.005<P<0.01)
	females	-5.0232	3.0874	1,373				

Table A.2.2 Comparison of slopes (*b*) for whole weight to gilled-and-gutted weight relationships derived from data collected by observers on Japanese longliners in the eastern Australian fishing zone, 1980-91. Relationships are in the form $W_w=a+bW_g$ where W_w is the whole weight (kg) and W_g is the gilled-and-gutted weight (kg).

Variable		*a*	*b*	N	df	t	$t_{\infty(2),0.05}$	Conclusion
Season	winter	1.2880	1.1195	825	935	-2.03	1.96	reject H_0, the populations are different (0.02<P<0.05)
	summer	1.1263	1.1298	114				
Area	north of 20°S	1.1181	1.1394	65	935	3.37	1.96	reject H_0, the populations are different (P<0.001)
	south of 20°S	1.2877	1.1192	874				
Sex	males	1.1979	1.1204	447	891	-3.04	1.96	reject H_0, the populations are different (0.002<P<0.005
	females	1.2541	1.1239	448				

Comparing Two Slope

A Student's *t* test was used to test whether population regression coefficients were the same. Analysis of covariance is an alternative statistical method. The formula below show the calculations required for testing H_o: $\beta_1=\beta_2$ against H_a: $\beta_1<>\beta_2$ employing the *t* test:

$$t = \frac{b_1-b_2}{s_{b_1-b_2}}$$

(Note : Subscripts 1 and 2 refer to the two regression lines being analysed.)

where :

$$b = \frac{\Sigma xy}{\Sigma x^2}$$ (Regression coefficient)

$$s_{b_1-b_2} = \sqrt{\frac{(s_{yx}^2)_p}{(\Sigma x^2)_1}+\frac{(s_{yx}^2)_p}{(\Sigma x^2)_2}}$$ (Standard error of the difference between regression coefficients)

$$(s_{yx}^2)_p = \frac{(residual\ SS)_1+(residual\ SS)_2}{(residual\ DF)_1+(residual\ DF)_2}$$ (Pooled residual mean square)

$$residual\ SS = \Sigma y^2-\frac{(\Sigma xy)^2}{\Sigma x^2}$$

$$residual\ DF = n-2$$

The critical value of *t* for this test has $(n_1-2)+(n_2-2)$ degrees of freedom (i.e., the sum of two residual degrees of freedom, which is $df=n_1+n_2-4$). Reject H_o if $|t|$ is greater or equal the tabular *t* at the α (significance level) and df (degrees of freedom).