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# Combining Weight-Length Relationships and condition factors to estimate the population structure for Skipjack tuna in the Western and Central Pacific Ocean

The arguments between Weight-Length Relationship (WLR) and Condition Factor ( $K$ ) have been lasted since the day they occurred. This paper described WLRs and  $K$ s of Skipjack tuna (*Katsuwonus pelamis*) samples in Purse Seine fisheries from three cruises (August-September cruise (A-S) in 2009, November-December cruise (N-D) in 2012, and June-July cruise (J-J) in 2013) in the Central and Western Pacific Ocean (CWPO). The results showed that fork length of more than 70% of specimen was below 60 cm (76% in A-S, 87% in N-D, and 73% in J-J).  $b$  values of WLRs in class of fork length  $> 60$ cm were below 3 significantly ( $P = 0.062$ ), while  $b$  values when fork length  $< 60$  cm were  $> 3$  significantly ( $P = 0.028$ ). Moreover,  $K$  values in different fork length classes for each cruises had one turning point: 60-65cm for J-J, 60-65cm for N-D, and 55-60cm for A-S, and  $K$  values were still significantly larger than those of fork length  $< 40$ cm ( $P = 0.06$ ). However,  $b$  values at larger fishes were significantly smaller than those of fork length  $< 40$ cm. We suggest to combine WLRs and  $K$  values at different growth phases for evaluating population structure for skipjack tuna.

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19 **Introduction**

20 Skipjack tuna (*Katsuwonus pelamis*) occupied the largest catches (more than 70%) of tunas in the  
21 Western and Central Pacific Ocean (WCPO), where occupied half of the total tuna catch in the  
22 world. Eighty-six percent of the catch of skipjack tuna were caught by Purse Seine (PS) fishery,  
23 and PS accounted for 75% of the total catch in the WCPO (Harley, Williams, & Hampton, 2011).  
24 The catch of fishes can reflect the stock assessment (Pauly, 2013). With a very high  
25 productiveness and a maximum age below 4.5 years, the changes in basic biological parameters  
26 (size) for skipjack tuna had significant implications for the stock assessment changes (Fromentin  
27 & Fonteneau, 2001; Hampton 2001).

28  
29 Some studies had focused on the biological parameter such as Weight-Length Relationship (WLR)  
30 for Skipjack tuna in the CPWO (Wild & Hampton, 1993; Sun & Yeh, 2001; Froese & Pauly, 2013),  
31 however, all of them concentrated the relationship from all of specimen of Skipjack tuna. Thus,  
32 the information covered by different age/body classes could not be identified obviously. Moreover,  
33 from the report of status of stocks of skipjack tuna in the WCPO (Harley, Williams, & Hampton,  
34 2011), the size range between 40cm and 60 cm (between 1 and 2+ year-old fish) dominated the  
35 catch, while the medium-large (60cm-80cm, older than 2+) fishes occupied a large proportion in  
36 the PS fisheries. However, few about the biological parameters were known at different growth  
37 phases currently. Besides, confuses could be came out when  $a$  and  $b$  (regressed parameters of  
38 WLR) were used to compare the differences among different stages of one observation, different  
39 *in situ* observations, because  $a$  values can deeply affect  $b$  values and a higher  $b$  value associated  
40 with a small  $a$  value (Froese, 2006). Additionally, few studies worked on the Fulton's condition

41 factor ( $K$ ) for skipjack tuna recently. Previous studies had shown that  $K$  values changed seasonally  
42 (see Froese, 2006 and references therein) - Skipjack tuna was strongly affected by macro-marine  
43 conditions, e.g. El Niño and La Niña (Lehodey et al., 1997, 2013; Loukos et al., 2003)- and  
44 changed with the growth phases. However, none of these had been reported for skipjack tuna.

45

46 Thus, in this study, two aims were to focused: 1) report biological data (length frequency,  
47 weight-length relationship and condition factor) of Skipjack tuna to investigate the full  
48 relationships in CPWO from different sampling seasons and different growth phases; 2)  
49 investigate a better way to compare the fish population structure and growth progresses by  
50 morphology parameters.

51

## 52 Materials & Methods

53

### 54 Study area

55

56 We have sampled Skipjack tuna on board from three cruises in the CPWO: August-September  
 57 Cruise (A-S) in 2009, November-December Cruise (N-D) in 2012, and June-July Cruise (J-J) in  
 58 2013 (Fig. 1). All the sampling stations were followed by the fishing locations, and the vessels for  
 59 sampling have the same stretched mesh size and the same Purse Seine nets governed by WCPFC  
 60 (Western and Central Pacific Fisheries Commission). Details of the vessels are: 70m in length,  
 61 1198 tons in Gross Tonnage for *JIN HUI NO.6* vessel of A-S (28 stations with 551 specimen were  
 62 measured), 80m in length, 2109 tons in Gross Tonnage for *LOJET* vessel of N-D (50 stations with  
 63 737 specimen were measured), 71m in length, 1041 tons in Gross Tonnage for *LOMETO* vessel of  
 64 J-J (24 stations with 392 specimen were measured).

65

### 66 Length frequencies

67

68 In this study, the fork length frequency was calculated by a 5 cm fork length interval between 30  
 69 cm and 75 cm. For each interval, the left boundary was closed, take the interval of 30-35 cm as an  
 70 example, the fork length of this interval is from 30 cm ( $>30\text{cm}$ ) to 35cm ( $\leq 35\text{cm}$ ). The formula  
 71 for calculating the frequency is:

72

$$F_i = \frac{n_i}{N} \times 100\% \quad (i = 30 - 35\text{cm}, 35 - 40\text{cm} \dots 70 - 75\text{cm}) \quad (1)$$

73 where  $F_i$  is the frequency for a certain interval;  $n_i$  is the number of specimen in one fork length  
 74 interval;  $N$  is the total specimen in one cruise.

75

76 WLRs

77

78 The calculation of WLRs were followed by equation 2, where  $a$ ,  $b$  were the regressed parameter,  $L$   
 79 is the fork length (cm), and  $W$  is the wet weight (g).

$$W = aL^b \quad (2)$$

80 For the parameters in the equation (2), the linear relationship between  $\log a$  (logarithmic value for  
 81  $a$ ) and  $b$  was used to examine whether the parameters regressed can be used for other researches,  
 82 and the parameter data will be removed if one of them was far away the regressed line by a high  
 83 correlation (Froese, 2006). For  $b$ , if  $b > 3$ , most of this situations occurred when the larger  
 84 specimen were thicker than small specimen (Froese, 2006).

85

86 Condition factor ( $K$ )

87

88 Condition factor ( $K$ ) was calculated as the refereed in Froese (2006) with the formula (3):

$$K = 100 * \frac{W}{L^3} \quad (3)$$

89 For a given form, the volume can be calculated as the multiplication by one constant parameter  
 90 with the one measurable parameter cubic function, e.g. for the sphere,  $V = 4/3\pi r^3$ ; for a cube,  $V =$   
 91  $l^3$ . For a general style, the volume style can be written as  $V = P * M^3$ , where  $P$  is the constant  
 92 parameter determined by the form, and the  $M$  is a measurable length/diameters which have a

93 relative correlations with other measurable biometric parameters. For Skipjack tuna, the volume  
 94 can be written as the form of equation (4):

$$V = f(L)L^3 \quad (4)$$

95 To connect the wet weight with the volume, one parameter representing density needed. Some  
 96 assumptions were settled below: 1) a mean density ( $\rho$ ) for a certain fork length; 2) high linear  
 97 relative correlations between fork length and the maximum height ( $H$ ), and between fork length  
 98 and the maximum width ( $D$ ) (Pornchaloempong et al., 2012; Tičina et al., 2011); 3) the bone shape  
 99 could not change for a given fork length. Then the equation (4) can be rewritten as equation (5):

$$W = \rho * k * H * D * L = \rho * k * k_2 L * k_3 L * L \quad (5)$$

100 Where  $\rho$ ,  $k$ ,  $k_2$ ,  $k_3$  is the measurable parameter for a given shape Skipjack tuna. Moreover,  $H$  is a  
 101 relative stable parameter,  $\rho$  is a mean density, and  $k$  is an ideal body shape parameter for a given  
 102 bone shape, then equation (5) can be simply rewritten:

$$W = S * k_3 * L^3 = \frac{100}{K} L^3 \quad (6)$$

103 where  $S$  is consistent parameter for a given shape in a certain fork length interval. Based on the  
 104 analysis processes above, the higher  $K$  value was equal to a lower  $k_3$ , which means a thicker/fatter  
 105 body for a given fork length.

106



## Result

### 1 Frequency distribution of fork length

Table 1 showed the frequencies of fork length of Skipjack tuna over the three cruises. The fork length distributions from 40 to 70cm was the domain fork length (about 84% of total specimen) and the frequency of fork length below 60cm was 73% during the cruise of J-J. Moreover, the min fork length was 28cm, and the max fork length was 74cm in this cruise (Tab. 1). 94% of the fork length was accumulated between 40 and 65 cm with 29cm as the min fork length and 67 as the max fork length over the cruise from A-S (Tab. 1). And the frequency of fork length below 60cm was 76%. For the cruise of N-D, 67% of specimen was distributed between 40 and 55cm with a peak distribution (36%) in the interval between 45 and 50cm, and the min and max fork length was 30 and 73, respectively. Moreover, the frequency of fork length below 60cm was 87% (Tab. 1).

### 2 WLRs

The LWRs of combined sex (CM) and different length intervals were calculated where the results had excluded the obvious thin or fat specimen (Tab. 2). The result of LWRs comparing among the three cruises by CM was:  $b$  (J-J) >  $b$  (A-S) >  $b$  (N-D). Additionally, all of the  $b$  values in the class of fork length > 60 cm was below 3 significantly ( $P = 0.062$ ,  $t$ -test, and as the same as below test method) with a relative weak correlation. Despite  $b$  values of fork length > 60 cm, the other  $b$

values of other classes was above 3 significantly ( $P = 0.028$ ,  $H_0: b=3$ ;  $H_1: b>3$ ) ( $b$  values from all the cruises). Furthermore, all of the correlations of the CM group were stronger than those of different fork length classes.

Parameters from the regressions were needed to be tested for wiping off the outline data (Froese 2006). Figure 2 illustrated the linear regression of the plot over  $\log a$  and  $b$  in our study have a very high correlation ( $R^2=0.996$ ). For more compares with other similar studies, a high correlation was also been founded where the data were from this study and FishBase data (Fig. 2. solid line, here, we had excluded the sexed and doubted data) (Froese & Pauly, 2013)

In this study, we also compared  $b$  values from specimen in a whole cruise and specimen in different fork length classes. For the cruise J-J,  $b$  value in CM had a significant difference with  $b$  values of groups (all groups) ( $P=0.030$ ,  $t$ -test,  $H_0: b_{\text{classes}}=b_{\text{CM}}$ ,  $H_1: b_{\text{classes}}\neq b_{\text{CM}}$ , as the same as below), and had the difference by  $P = 0.075$  ( $b$  from the groups without the class of fork length  $> 60\text{cm}$ ). For the cruise A-S,  $b$  value in CM had the difference by  $P = 0.489$  of  $b$  values in all groups, and had the difference by  $P = 0.732$  ( $b$  from the groups without the class of fork length  $> 60\text{cm}$ ). For the cruise N-D,  $b$  value in CM had the difference by  $P = 0.414$  of  $b$  values in all groups, and had the difference by  $P = 0.997$  ( $b$  from the groups without the class of fork length  $> 60\text{cm}$ ).

3 distributions of  $K$  value over the cruises

Figure 3 illustrated the distributions of  $K$  value over the three cruises. The ranges of  $K$  value of J-J,

151 A-S, and N-D were: from 1.3 to 1.84 ( $1.62 \pm 0.18$ ); from 1.57 to 2.02 ( $1.86 \pm 0.15$ ); from 1.44 to  
 152 1.78 ( $0.65 \pm 0.13$ ), respectively. All of the  $K$  values in an individual cruise have an increasing trend  
 153 over one fork length range firstly and then declining after the fork length. The turning point for J-J  
 154 was 60-65 cm, for N-D was 60-65 cm, for A-S was 55-60cm. Among the cruises, all of the  $K$   
 155 values of specimen form A-S cruise were larger than those in the other two cruises. For the other  
 156 two cruises, the  $K$  values of N-D were higher when fork length  $< 60$ cm than  $K$  values in J-J, while,  
 157 the trend changed when fork length  $> 60$ cm.

158

159 Comparisons over the three cruises with combined WLRs and  $K$  values

160

161 The minimum  $K$  values of the class of fork length  $> 60$  cm were significant higher than those of  
 162 the groups of fork length  $< 40$  cm from the three cruises ( $P=0.06$ ), however the  $b$  values when  
 163 fork length  $> 60$  cm were significant smaller than  $b$  values of fork length  $< 40$ cm ( $P = 0.037$ ).

164

## Discussion

The parameters of WLRs in the confidence interval indicated the allometric growth (Froese, 2006), and are effected by many factors from ecological to individual (Percin and Akyol, 2009). Only  $b$  values were chosen commonly when compared with each other, although the WLRs had been uses for nearly 90 years (see Froese (2006) for WLRs' historical detail). In this study, the WLRs of CM class indicated positive allometric growth ( $3.302 \pm 0.064$ ) for Skipjack tuna for all specimen in WCPO, and these similar results had been showed by Wild & Hampton (1993), Sun & Yeh (2001), and Froese and Pauly (2013). However,  $b$  values changed significantly (especially over the classes that fork length > 60cm) when fork length classes were carried out that was also Froese (2006) recommend. Thus, that  $b$  values from overall specimen for one individual cruise send one direct understanding that the larger specimen were thicker than smaller specimen, and  $b$  values from classes (e.g. fork length > 60cm, or fork length >40 cm in J-J) showed an opposite understanding the allometric growth for a same population. Although our sample size was relative narrow compared with some reports which occupied more than thousand samples (data from Fishbase, 2014), the sample size in our study still can obtain the acceptable  $a$ ,  $b$  values (Froese, 2006).

Additionally,  $K$  values were also a parameter to estimate fish body structure in some extent like  $b$  values for a certain fork length, but argues between  $K$  and  $b$  had lasted since 1920 (Froese, 2006 and within the references). In this study,  $K$  values in A-S were larger than  $K$  values of the other two cruises showed that the specimen caught by free swimming schools in A-S had thicker bodies than others on the same fork length interval (Fig. 3). The trends for  $K$  values in this study were

similar with the results from Harley, Williams, & Hampton (2011) and we agreed that empty stomachs can induce a lower  $K$  value for bluefin tuna (*Thunnus thynnus*) studies from Percin and Akyol (2009). However, what Percin and Akol (2009) suggested that the declined  $K$  values for large fishes were caused by health problem was not accepted by our studies. Although the  $K$  values decreased at the large fish, the values were still larger than those on the other classes (Fig.3). Similar argues occurred in Froese (2006). It is easy to imagine that the  $K$  value in A-S should be similar with the  $K$  values in the other cruise if the large/old specimen were on a bad health conditions. Hence, we suggested that  $K$  values decreasing on larger/older fishes were caused possible by the sensitivities increasing to the ambient surroundings like the larval or young fishes before the first mature (Stenseth et al., 2002).

To avoid the arguments about  $K$  values compared on different fork length, we combined the WLRs and  $K$  values to estimate the population structures for Skipjack tuna in this study. For all of the three cruises, more than 70% of specimens were smaller than 60 cm (fork length), and  $b$  values had no significant differences when fork length < 60 cm. However, the significant difference occurred when added the class that fork length > 60 cm (e.g. J-J cruise, see the results). Similarly,  $K$  values had a turning point when fork length around 60 cm over the cruises. Furthermore, dividing the population structure for Skipjack tuna into two stages (growing stage and old stage) were benefit to focus on the specific growth and environmental condition sensitivity. For the growing stage,  $b$  values were able to demonstrate the growth rate; for the old stage,  $K$  values were able to show the sensitivities to ambient factors or health conditions.

209 **Conclusion**

210

211 Biological parameters are considered as fundamental analysis in the fishery, while we send our  
212 focuses the  $b$  and  $K$  values on the differences in the different growth phases and seasons.  
213 Significant differences in allometric growth were found when comparing on different length  
214 groups, and with a relative lower  $b$  and correlations at fork length  $> 60$  cm, While  $K$  values may  
215 be still higher than other groups. Both of them can shown the fatness of skipjack tuna, but the  
216 results seems contrary. Thus, we suggests that combining the  $b$  and  $K$  to evaluate the population  
217 structure of skipjack tuna, which comparing  $b$  at fork length  $< 60$  cm, and  $K$  at fork length  $> 60$   
218 cm. It must be point out that the methods combined  $b$  values and  $K$  values is one preliminary  
219 experiment to fully develop the benefits of two parameters, rather than be confused or argued  
220 which one is better for estimate population structure. In order to strengthen the implication of  
221 population structure, WLRs and  $K$  values from Skipjack tuna observer program and from many  
222 relative studies should be combined and compared to look for a sustainable Skipjack tuna fishery.

223

224

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 227 vessel, and *LOMETO* vessel, and we could not accomplish the fielding sampling work without  
 228 their help on board.  
 229

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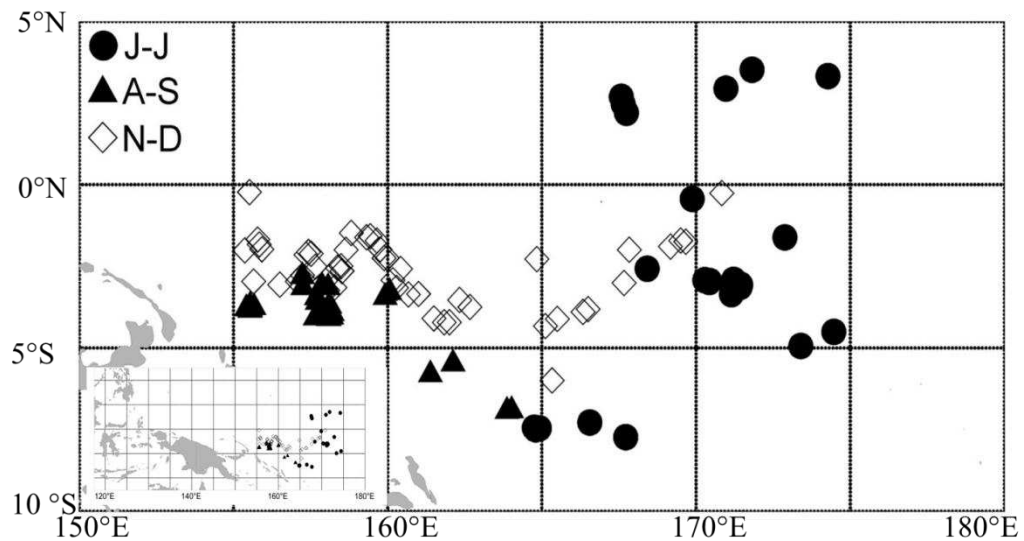


Figure 1: sampling map during the three cruises. Black circle (J-J) symbol is the station in the June-July cruise in 2013; black triangle (A-S) symbol is the station in August-September cruise in 2009; hollow diamond (N-D) symbol is the station in November-December cruise in 2012.

Table 1 Frequency of different fork length group of skipjack tuna

Fork Length(cm)	A-S		N-D		J-J	
	Number	Frequency	Number	Frequency	Number	Frequency
CM	550		737		391	
<30	1	0.18%	0	0.0%	8	2.05%
30-35	13	2.36%	50	6.8%	19	4.86%
35-40	12	2.18%	55	7.5%	19	4.86%
<b>&lt;40</b>	<b>26</b>	<b>4.73%</b>	<b>105</b>	<b>14.2%</b>	<b>46</b>	<b>11.76%</b>
40-45	103	18.73%	138	18.7%	45	11.51%
45-50	99	18.00%	264	35.8%	65	16.62%
<b>40-50</b>	<b>202</b>	<b>36.73%</b>	<b>402</b>	<b>54.5%</b>	<b>110</b>	<b>28.13%</b>
50-55	57	10.36%	95	12.9%	71	18.16%
55-60	133	24.18%	43	5.8%	58	14.83%
<b>50-60</b>	<b>190</b>	<b>34.55%</b>	<b>138</b>	<b>18.7%</b>	<b>129</b>	<b>32.99%</b>
60-65	125	22.73%	56	7.6%	42	10.74%
65-70	7	1.27%	25	3.4%	49	12.53%
70-75	0	0.00%	11	1.5%	15	3.84%
<b>&gt;60</b>	<b>132</b>	<b>24.00%</b>	<b>92</b>	<b>12.5%</b>	<b>106</b>	<b>27.11%</b>

Note: Number is the sample size, frequency is the result of Equation (1), the bold number is the

sum (Number and frequency) at the fork length group.

293

294 Table 1: WLRs between fork length (cm) and wet weight (g) over the three cruises

Class	J-J			A-S			N-D		
	a	b	$R^2$	a	b	$R^2$	a	b	$R^2$
CM	0.0039	3.3668	0.97	0.0058	3.2996	0.98	0.0066	3.2398	0.97
<40cm	0.0072	3.1704	0.75	0.0084	3.2048	0.85	0.0049	3.3069	0.69
40-50cm	0.0184	2.9664	0.7	0.0026	3.5226	0.95	0.0031	3.4449	0.91
50-60cm	0.0426	2.7687	0.66	0.0064	3.2841	0.77	0.0199	2.9696	0.74
>60cm	0.1015	2.5835	0.68	0.1681	2.481	0.59	0.9032	2.0441	0.61

295 CM, combine sex; a, intercept; b, slope;  $R^2$ , coefficient of determination

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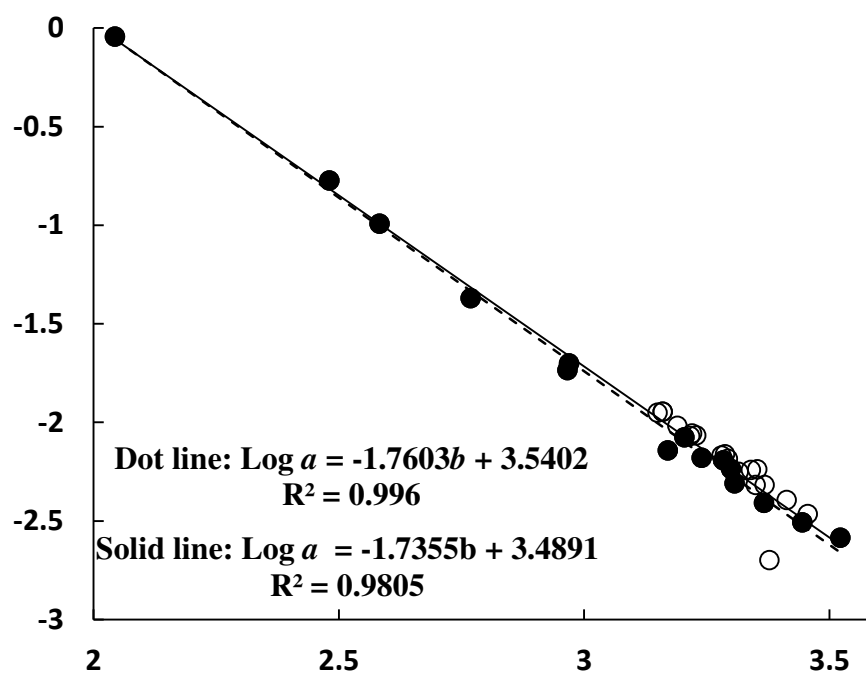


Figure 2: relationships between  $\log a$  and  $b$ . Dot line is the linear regression line of data from this study (solid dot); solid line is the linear regression line of data combined data in this study and data without sexed and doubted data from FishBase (circled dot).

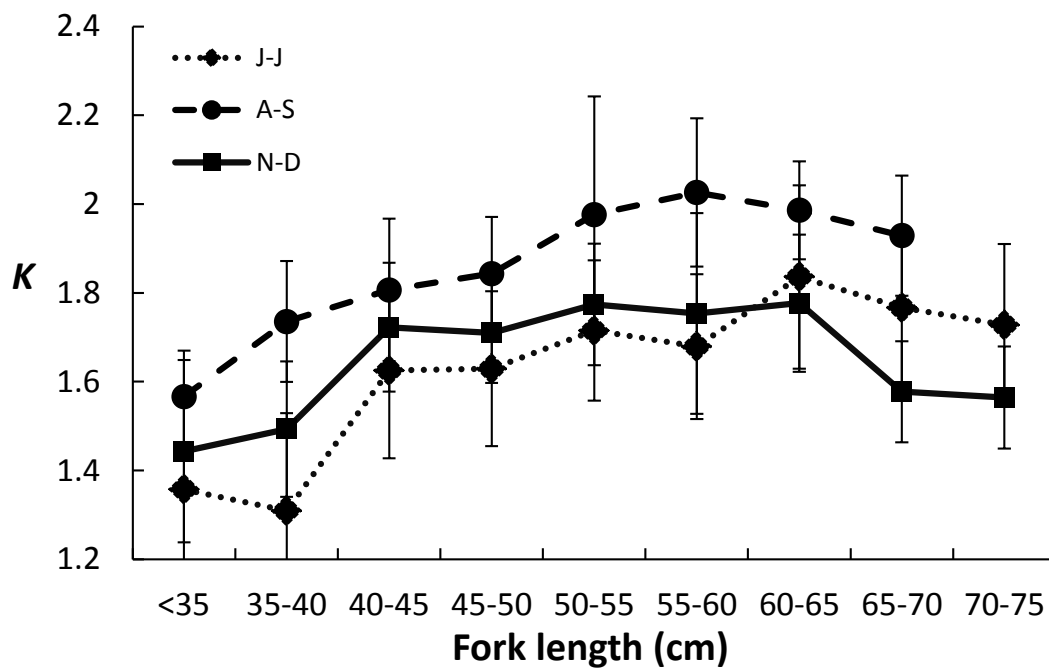


Figure 3: Condition factor ( $K$ ) per fork length (cm) class over all three cruises. Error bar is the standard deviation.