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 describe~~d~~ WLRs and Ks of Skipjack tuna (*Katsuwonus pelamis*) samples in Purse Seine fisheries from three cruise~~s~~ (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 > 60cm 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 cruise~~s~~ 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 < 40cm (*P* = 0.06). However, *b* values ~~at~~ larger fish~~es~~ were significantly ~~smaller~~ than those of fork length <40cm. We suggest ~~to combine~~ WLRs and *K* values at different growth phases ~~for evaluating~~ population structure for skipjack tuna.

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Introduction

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

Some studies had focused on the biological parameter such as Weight-Length Relationship (WLR) for Skipjack tuna in the CPWO (Wild & Hampton, 1993; Sun & Yeh, 2001; Froese & Pauly, 2013), however, all of them concentrated the relationship from all of specimen of Skipjack tuna. Thus, the information covered by different age/body classes could not be identified obviously. Moreover, from the report of status of stocks of skipjack tuna in the WCPO (Harley, Williams, & Hampton, 2011), the size range between 40cm and 60 cm (between 1 and 2+ year-old fish) dominated the catch, while the medium-large (60cm-80cm, older than 2+) fishes occupied a large proportion in the PS fisheries. However, few about the biological parameters were known at different growth phases currently. Besides, confuses could be came out when *a* and *b* (regressed parameters of WLR) were used to compare the differences among different stages of one observation, different *in situ* observations, because *a* values can deeply affect *b* values and a higher *b* value associated with a small *a* value (Froese, 2006). Additionally, few studies worked on the Fulton's condition factor (*K*) for skipjack tuna ~~recently.~~ Previous studies ~~had shown~~ that *K* values changed seasonally (see Froese, 2006 and references therein) - ~~S~~kipjack tuna was strongly affected by macro-marine conditions, e.g. El Niño and La Niña (Lehodey et al., 1997, 2013; Loukos et al., 2003)- and changed with ~~the~~ growth phases. However, ~~none of these had been~~ reported for skipjack tuna.

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

Materials & Methods

Study area

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

Length frequencies

In this study, the fork length frequency was calculated by a 5 cm fork length interval between 30 cm and 75 cm. For each interval, the left boundary was closed, take the interval of 30-35 cm as an example, the fork length of this interval is from 30 cm (>30cm) to 35cm (<= 35cm). The formula for calculating the frequency is:

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

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

WLRs

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

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

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

Condition factor (*K*)

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

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

For a given form, ~~the~~ volume can be calculated ~~as the multiplication by~~ one constant parameter ~~with the~~ one measurable parameter cubic function, e.g. for the sphere, $V = 4/3\pi r^3$; for a cube, $V = l^3$. ~~For a general style,~~ the volume ~~style~~ can be written as $V = P*M^3$, where *P* is the constant parameter determined by the form, and ~~the~~ *M* is a measurable length/diameters which ~~have~~ a relative correlations with other measurable biometric parameters. For Skipjack tuna, the volume can be written as the form of equation (4):

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

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

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

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

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

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

Result

1 Frequency distribution of fork length

Table 1 showed the frequences 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 illustrate~~d~~ 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~~ found~~ed~~ ~~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: $b_{classes}=b_{CM}$, H_1: $b_{classes} \neq b_{CM}$, as the same as below), and had the difference by P = 0.075 (*b* from the groups without the class of fork length > 60cm). 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 > 60cm). 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 > 60cm).

3 distributions of K value over the cruises

Figure 3 illustrate~~d~~ the distributions of *K* value ~~over~~ the three cruises. The ranges of ~~K value of~~ J-J, A-S, and N-D were~~:~~ from 1.3 to 1.84 (1.62±0.18); from 1.57 to 2.02 (1.86±0.15); from 1.44 to 1.78 (0.65±0.13), respectively. ~~All of the~~ *K* values in ~~an~~ individual cruise have an increasing trend over one fork length range ~~firstly and then declining after~~ the fork length. ~~The~~ turning point for J-~~J~~ ~~was~~ 60-65 cm, ~~for N-D was~~ 60-65 cm, ~~for A-S was~~ 55-60cm. Among the cruises, all ~~of the~~ *K* values of specimen ~~form~~ A-S cruise were ~~larger~~ than those ~~in~~ the other two cruises. ~~For the other two cruises, the~~ *K* values of N-D were higher when fork length < 60cm than *K* values in J-J, ~~while,~~ the trend ~~changed~~ when fork length > 60cm.

Comparisons over the three cruises with combined WLRs and *K* values

The minimum *K* values ~~of the class of~~ fork length >60 cm were significant higher than those of the groups ~~of~~ fork length < 40 cm ~~from the three cruises~~ (*P*=0.06), ~~h~~owever ~~the *b* values~~ when fork length >60 cm were significant smaller than *b* values of fork length <40cm (*P* = 0.037).

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±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.

Conclusion

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

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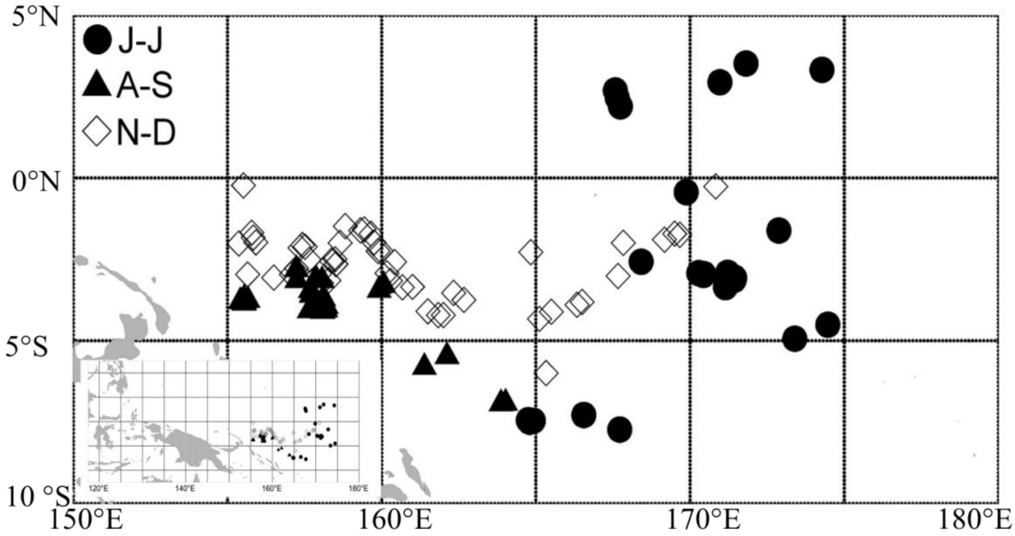

Figure 1: sampling map during the three cruises. Black circle (J-J) symbol is the station in the June-July cruise in 2013; black triangle (A-S) symbol is the station in August-September cruise in 2009; hollow diamond (N-D) symbol is the station in November-December cruise in 2012.

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%
<40	**26**	**4.73%**	**105**	**14.2%**	**46**	**11.76%**
40-45	103	18.73%	138	18.7%	45	11.51%
45-50	99	18.00%	264	35.8%	65	16.62%
40-50	**202**	**36.73%**	**402**	**54.5%**	**110**	**28.13%**
50-55	57	10.36%	95	12.9%	71	18.16%
55-60	133	24.18%	43	5.8%	58	14.83%
50-60	**190**	**34.55%**	**138**	**18.7%**	**129**	**32.99%**
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%
>60	**132**	**24.00%**	**92**	**12.5%**	**106**	**27.11%**

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.

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

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

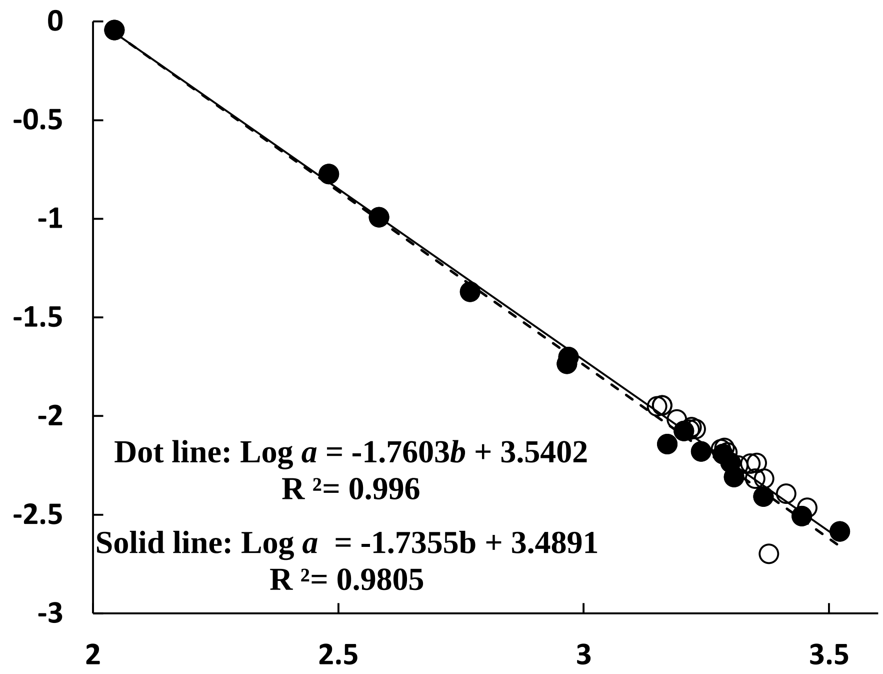

Figure 2: relationships between log *a* and *b*. Dot line is the linear regression line of data from this study (solid dot); solid line is the linear regression line of data combined data in this study and data without sexed and doubted data from FishBase (circled dot).

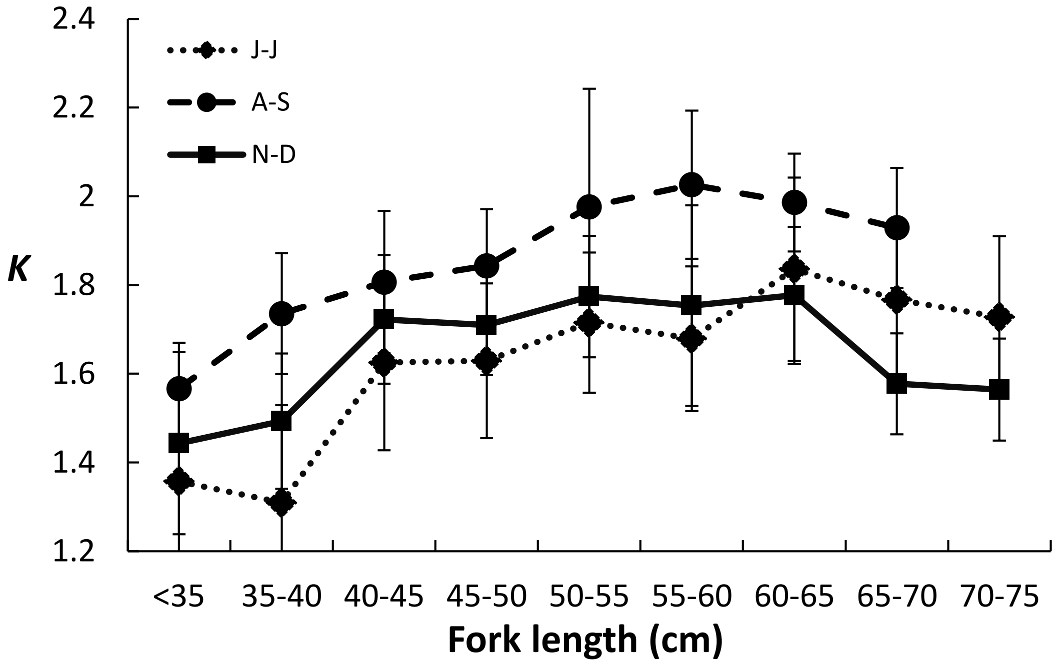

Figure 3: Condition factor (*K*) per fork length (cm) class over all three cruises. Error bar is the standard deviation.