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 Ks 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 > 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 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 < 40cm ($P = 0.06$). However, *b* values at larger fishes 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.

Shaofei Jin[1, 2, 3*], Xiaodong Yan[4], Heng Zhang[3*], Wei Fan[3]

1. Key Laboratory of Regional Climate-Environment for Temperate East Asia (RCE-TEA), Chinese Academy of Sciences, Beijing, China
2. University of Chinese Academy of Sciences, Beijing, China
3. Key Laboratory of East China Sea & Oceanic Fishery Resources Exploitation and Utilization, Ministry of Agriculture, P. R. China (East China Sea fisheries Research Institute, Chinese Academy of Fishery Sciences) Shanghai, China
4. State Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing Normal University, Beijing China

*Corresponding author:
Shaofei Jin, No.40, HuayanLi, Chaoyang District, Beijing, 100029, China,
E-mail: jinsf@tea.ac.cn
Heng Zhang, No.300 Jungong Road, Shanghai, 200090, China.
E-mail: zhangziqian0601@163.com

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 assessmen[1] 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

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

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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 (>30cm) to 35cm (<= 35cm). The formula
71 for calculating the frequency is:

72

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

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 parameter 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

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

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

95 To connect the wet weight with the volume, one parameter representing density needed. Some
96 assumptions were settled below: 1) a mean density (ρ) 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):

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

100 Where ρ, k, k_2, k_3 is the measurable parameter for a given shape Skipjack tuna. Moreover, H is a
101 relative stable parameter, ρ 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:

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

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 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.

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: $b_{classes}=b_{CM}$, 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 illustrated 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), however the *b* values when fork length >60 cm were significant smaller than *b* values of fork length <40cm (P = 0.037).

165 **Discussion**

166

167 The parameters of WLRs in the confidence interval indicated the allometric growth (Froese, 2006),
168 and are effected by many factors from ecological to individual (Percin and Akyol, 2009). Only *b*
169 values were chosen commonly when compared with each other, although the WLRs had been uses
170 for nearly 90 years (see Froese (2006) for WLRs' historical detail). In this study, the WLRs of CM
171 class indicated positive allometric growth (3.302±0.064) for Skipjack tuna for all specimen in
172 WCPO, and these similar results had been showed by Wild & Hampton (1993), Sun & Yeh (2001),
173 and Froese and Pauly (2013). However, *b* values changed significantly (especially over the classes
174 that fork length > 60cm) when fork length classes were carried out that was also Froese (2006)
175 recommend. Thus, that *b* values from overall specimen for one individual cruise send one direct
176 understanding that the larger specimen were thicker than smaller specimen, and *b* values from
177 classes (e.g. fork length > 60cm, or fork length >40 cm in J-J) showed an opposite understanding
178 the allometric growth for a same population. Although our sample size was relative narrow
179 compared with some reports which occupied more than thousand samples (data from Fishbase,
180 2014), the sample size in our study still can obtain the acceptable *a*, *b* values (Froese, 2006).

181

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

187 similar with the results from Harley, Williams, & Hampton (2011) and we agreed that empty
188 stomachs can induce a lower *K* value for bluefin tuna (*Thunnus thynnus*) studies from Percin and
189 Akyol (2009). However, what Percin and Akol (2009) suggested that the declined *K* values for
190 large fishes were caused by health problem was not accepted by our studies. Although the *K*
191 values decreased at the large fish, the values were still larger than those on the other classes
192 (Fig.3). Similar argues occurred in Froese (2006). It is easy to imagine that the *K* value in A-S
193 should be similar with the *K* values in the other cruise if the large/old specimen were on a bad
194 health conditions. Hence, we suggested that *K* values decreasing on larger/older fishes were
195 caused possible by the sensitivities increasing to the ambient surroundings like the larval or young
196 fishes before the first mature (Stenseth et al., 2002).
197
198 To avoid the arguments about *K* values compared on different fork length, we combined the
199 WLRs and *K* values to estimate the population structures for Skipjack tuna in this study. For all of
200 the three cruises, more than 70% of specimens were smaller than 60 cm (fork length), and *b* values
201 had no significant differences when fork length < 60 cm. However, the significant difference
202 occurred when added the class that fork length > 60 cm (e.g. J-J cruise, see the results). Similarly,
203 *K* values had a turning point when fork length around 60 cm over the cruises. Furthermore,
204 dividing the population structure for Skipjack tuna into two stages (growing stage and old stage)
205 were benefit to focus on the specific growth and environmental condition sensitivity. For the
206 growing stage, *b* values were able to demonstrate the growth rate; for the old stage, *K* values were
207 able to show the sensitivities to ambient factors or health conditions.
208

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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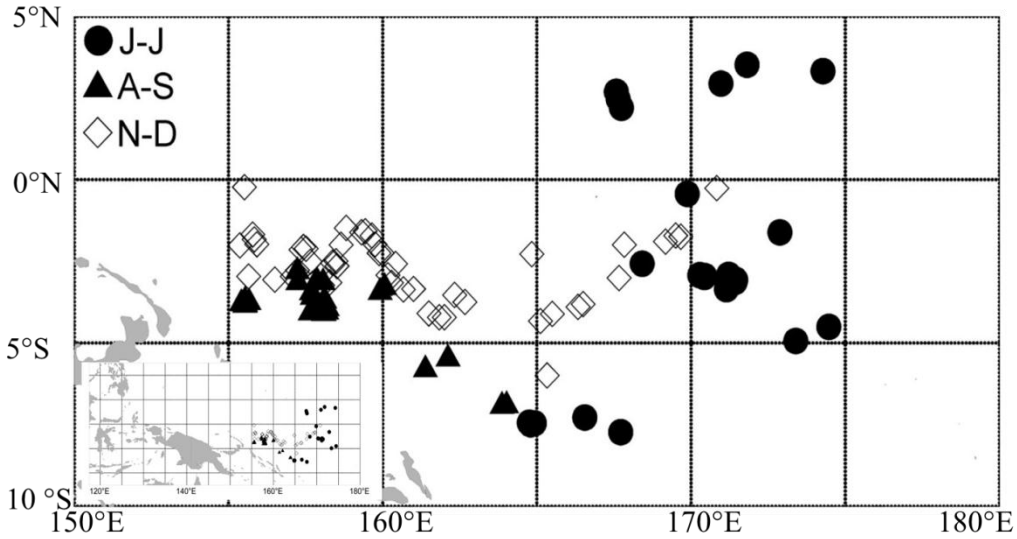

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279 Figure 1: sampling map during the three cruises. Black circle (J-J) symbol is the station in the

280 June-July cruise in 2013; black triangle (A-S) symbol is the station in August-September cruise in

281 2009; hollow diamond (N-D) symbol is the station in November-December cruise in 2012.

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283

284 Table 1 Frequency of different fork length group of skipjack tuna

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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%**

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

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

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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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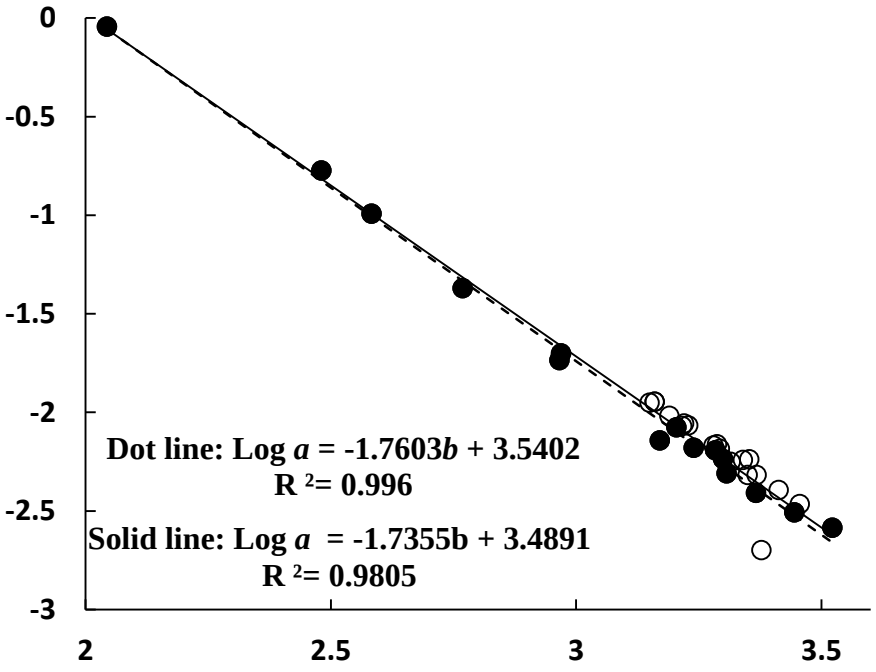

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298 Figure 2: relationships between log *a* and *b*. Dot line is the linear regression line of data from this

299 study (solid dot); solid line is the linear regression line of data combined data in this study and

300 data without sexed and doubted data from FishBase (circled dot).

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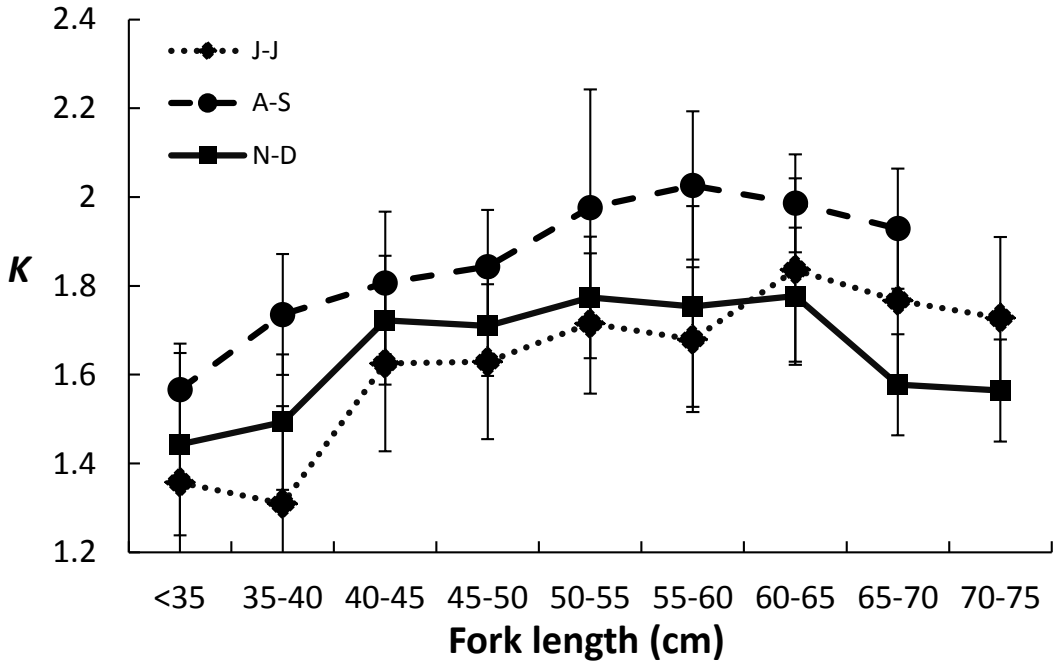

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304 Figure 3: Condition factor (*K*) per fork length (cm) class over all three cruises. Error bar is the

305 standard deviation.

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