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Comparison of condition factor between FADs-associated and unassociated schools of skipjack tuna Katsuwonus pelamis on the Western and Central Pacific Ocean

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Comparison of condition factor between FADs-associated and unassociated schools of skipjack tuna *Katsuwonus pelamis* on the Western and Central Pacific Ocean

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Abstract

The use of drifting fish aggregation advices (FADs) by tuna purse seine fleets has greatly expedited tuna catches since the 1990s. The large increase in the number of FADs calls for studies to evaluate potential negative impacts on tuna stocks, such as reduced fitness. We explored the differences in condition factor (K) for skipjack tuna (*Katsuwonus pelamis*) in the Western and Central Pacific Ocean (WCPO). This study shows that (1) The log dressed weight (DW)-fork length (FL) relationships for the free swimming school and associated schools were significantly different, the DW tended to be higher for free swimming schools than for associated schools at a given size class (p <0.001); (2) the bootstrapped 95% CIs for the standardized K values for the free swimming schools was significantly higher than that for the associated schools for all fish ([1.8387, 1.8533] vs [1.6766, 1.6811]) and fish between 45-75cm ([1.8493, 1.8630] vs [1.7145, 1.7222]), implying that the fish in the free schools were in better conditions. Though our study cannot provide the direct connection between poorer K of skipjack in associated schools to worse habitat quality, we cannot rule out the reasonable possibility that worse conditions of tuna were the reflection of the negative consequence of an association with FADs.

Key words: purse seine, skipjack tuna *Katsuwonus pelamis*, drifting fish aggregation devices, condition factor

Introduction

Tropical tunas and other pelagic fishes are often attracted to floating objects and form aggregations under or around them. This behavior is used in developing fish aggregation devices (FADs) for aggregating tuna in purse seine fisheries. In the past 30 years, this fishing model has greatly improved the catch and fishing efficiency. However, many controversies and unanswered questions arise in fisheries ecology and management (Fonteneau et al. 2000). For example, why are tuna attracted to FADs and what are the potential ecological consequences of widespread of use drifting FADs (Fréon & Dagorn 2000; Marsac et al. 2000)? Lack of answers to these questions may increase uncertainty in understanding of tuna population dynamics and developing management strategies for sustainable fisheries.

Studies have evaluated the potential impacts of FADs on tuna biology in addition to the impacts on behavior patterns. These studies have compared biological indicators of fish aggregating around the FADs to conspecifics in unassociated schools (i.e. free swimming schools). Concerns have been raised regarding alterations in feeding patterns (Ménard et al. 2000; Hallier and Gaertner 2008; Jaquemet et al. 2011), reduced plumpness and growth rates (Marsac et al. 2000; Hallier and Gaertner 2008), and changes in migration direction (Hallier and Gaertner 2008) and pattern (Wang at al. 2014). These studies demonstrated that the presence of FADs may negatively affect the life history of tuna and inferred that reduced biological indicators of tuna associated with FADs are a result of poor habitat quality (Marsac et al. 2000; Hallier and Gaertner 2008).

Condition factors are commonly used biological indicators to measure fish well-being (condition) which are assumed to reflect the environmental conditions (i.e., prey availability) (Blackwell et al. 2000). Various measures of fish condition have been widely used in previous studies to infer the habitat conditions for FAD-associated fish (Marsac et al. 2000; Hallier and Gaertner 2008; Robert et al. 2014).

The objective of this study is to explore potential impacts of FADs on skipjack condition factor (*K*) in the Western and Central Pacific Ocean (WCPO) and the causal relationship between differences in *K* and habitat choice. We hypothesize that the *K* for free swimming schools would be different than that for associated schools. This study can improve our understanding of potential impacts of FADs on skipjack tuna.

Material and methods

Tuna purse seine observer survey data

Data were collected from three survey cruises by the Chinese Tuna Purse Seine Fishery Observer Program from 2007 to 2011(Table 1). The tuna purse seiners, Pohnpei No.1, Jinhui No.6 and Jinhui No.7, caught skipjack from both free swimming schools and associated schools in the WCPO (Fig.1). Data for thirty-two free swimming schools were collected including both pure schools of skipjack and mixed schools of both skipjack and yellowfin tuna (*Thunnus albacares*) that were not associated with any type of floating objects. Data for eighty-three associated schools were collected including seventy-nine aggregations associated with sole drifting FADs and four drifting FADs attached to naturally occurring debris (i.e., branches or iron buckets). The observers recorded the date, sampling station position, and total weight of catch (tones) for each set. Ten to fifteen individuals were sub-sampled randomly in a set for fork length (*FL*), dressed weight (*DW*), gender, and stomach fullness.

Table 1. The survey cruises, date, fishing days, number of total sets, number of successful sets, number of observed sets, and sample size by types of schools

Voyage	1		2		3	
Dates	2007.10-2008.1		2010.10-2011.5		2011.10 -2011.11	
Fishing days	73		182		56	
School type	Free school	Associated school	Free school	Associated school	Free school	Associated school
The number of total sets	52	14	35	133	60	24
The number of successful sets	22	13	15	116	19	12
The number of observed sets	10	11	6	66	7	6
The number of fish for condition factor	108	224	91	913	79	78

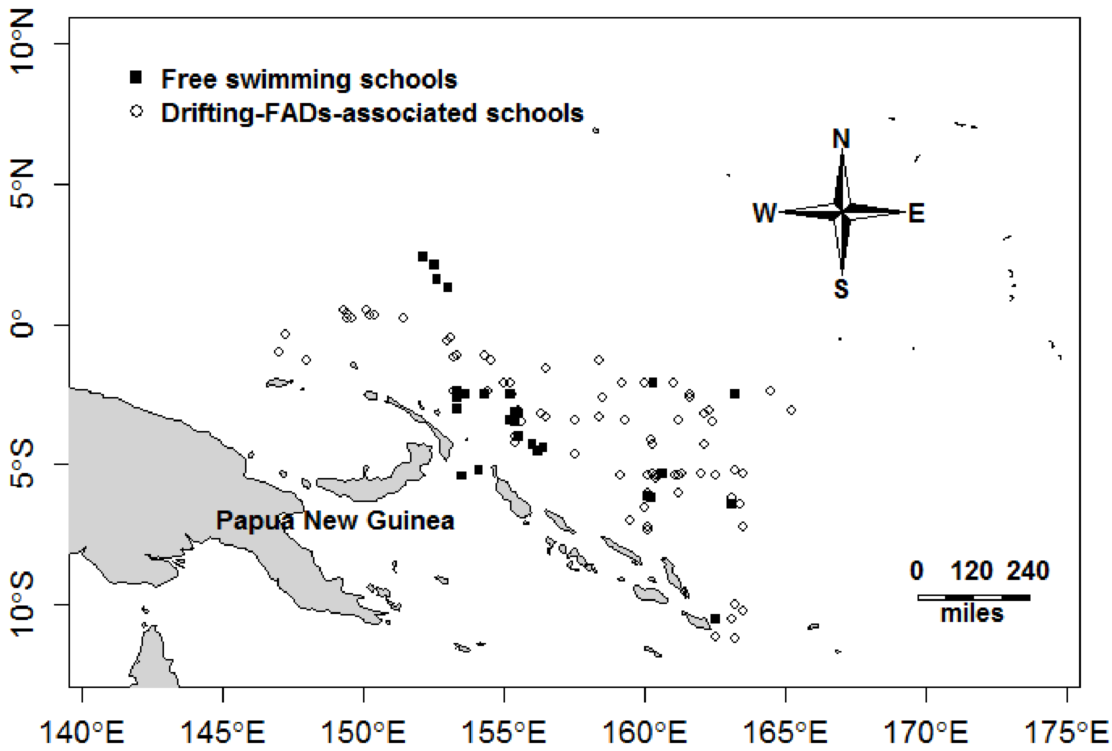

Fig 1. Location of sampling stations in the Western and Central Pacific Ocean.

Condition factor

Fulton's condition factor (*K*) (Carlander 1950) was used to quantify fish condition. Fulton's *K* takes into consideration the influence of length (*L*) and body shape (^3) relative to weight as a measure of plumpness or condition. The *K* value was calculated as

$$K = (DW/FL^3)*100$$

(1)

where *DW* is dressed weight (g), *FL* is fork length (cm).

Initially, total weights for individuals were recorded for sampled skipjack tuna. However, stomach fullness data showed the proportion of empty stomachs for associated schools tended to be much higher (94.5%) than that for free swimming schools (only 33.2%), which is consistent with findings in the other studies (Ménard et al. 2000; Potier et al.2001; Hallier and Gaertner 2008). Due to the large discrepancies in stomach fullness we concluded that total weight would not provide a true measure of *K*. It was decided that *DW* would provide a standard weight measure by removing consumed prey biomass to avoid overestimating *K* for individuals with full stomachs, especially those in free swimming schools. The *DW* refers to somatic body weight after the removal of all internal organs, and is weighed to 5 g using an electronic scale.

Sample size ranges of *FL* and *DW* are shown in Table 2. The size distribution for associated schools includes a larger proportion of smaller fish than the free swimming schools (Table 2). Associated schools have been shown to attract tuna of a wide size distribution while free swimming schools tend to be more size selective (Wang et al. 2012). This phenomenon was noted in our study as well. The free swimming school in our study was dominated (90.01%) by skipjack with a *FL* of 45-75cm (Table 2). To determine the influence of the difference in size distributions data sets for associated and free swimming schools were truncated at 45cm, which created a size distribution of 45-75cm for the two schools (Table 2).

Table 2. Sample sizes and ranges of fork length (*FL*) and dress weight (*DW*) for the free swimming schools and drifting-FADs-associated schools

Full size range	Drifting-FADs-associated school	Free swimming school
Number of fish	1215	278
Length range (cm)	27.8 - 73.3	22.8 - 74.6
Average length (cm)	44.9±7.8	51.7±7.7
Weight range (g)	280 - 8,305	220 - 8,140
Average weight (g)	1698.2±962.4	2752.0±1222.3
Size range 45-75 cm		
Proportion > 45cm	54.07%	90.01%
Length range (cm)	45-73.3	45-74.6
Average length (cm)	50.54±4.9	53.34±5.2
Weight range (g)	1,335-8,305	1,558-8,140
Average weight (g)	2310.2±883.6	2936.2±1108.2

A linear model was used to determine the effects of various factors on the log-transformed *K* values. The linear model can be expressed as

$$\mathrm{Log(K)} = \beta_0 + \beta_1 \mathrm{F} + \beta_2 \mathrm{Y} + \beta_3 \mathrm{M} + \beta_4 \mathrm{Lat} + \beta_5 \mathrm{Long} + \varepsilon$$

(2)

where *F* is fishing method/ aggregation type (associated school = 1, free swimming school = 2) with associated school as the reference level; *Y* is year (2007, 2008, 2010, 2011) with 2007 as the reference level; *M* is month (January, February, March, April, May, October, November, December) with January as the reference level; *Lat* is latitude; *Long* is longitude; β_0 is the intercept term; β_i, $i = 1, 2, 3, 4, 5$ are unknown parameters and ε is an error term assumed to follow normal distribution. In equation (2), variables *Lat* and *Long* are continuous variables, and *F*, *Y*, and *M* were treated as categorical variables.

Akaike's Information Criterion (AIC) was used to select the best model from all candidate models. The predicted value from the best fit model was used to calculate the bootstrapped CIs. CIs were calculated based on the bootstrap method described above.

Results

Size distribution

We measured 278 individuals for 32 unassociated schools. The FL ranged from 27.8 to 73.3 cm and average FL was 51.69±7.66 cm. We measured 1215 individuals for 83 associated schools. The range of FL was 22.8-74.6 cm and average FL was 44.95±7.75 cm. Associated schools tended to attract more individuals smaller than 45 cm compared with free swimming schools (Fig.2).

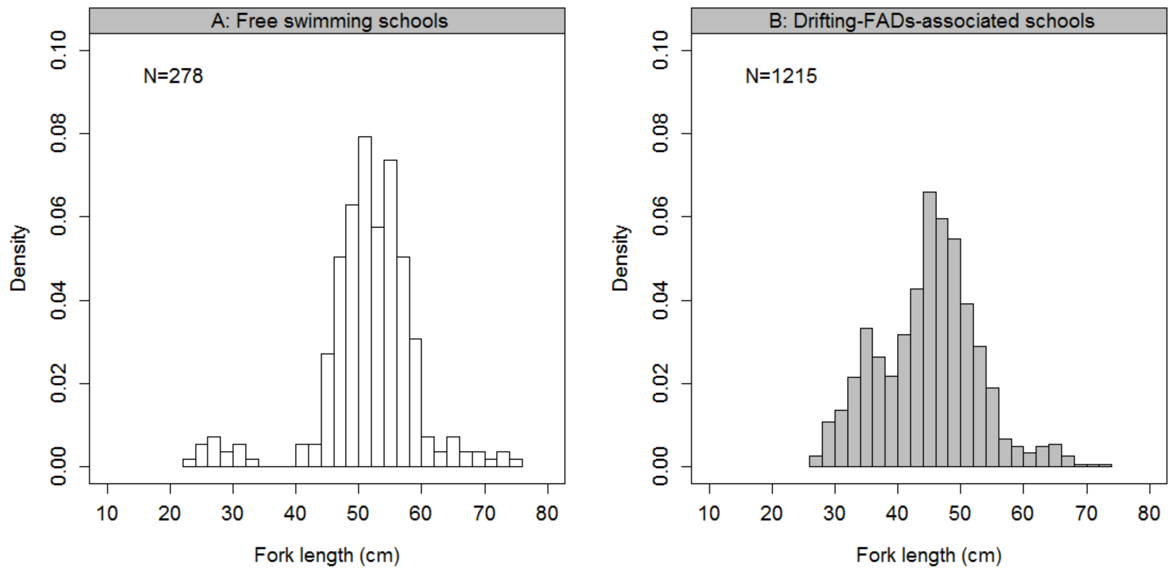

Fig. 2 Size distributions for skipjack (A) associated to drifting fish aggregation devices (FADs), and (B) caught on free swimming schools

The relationship of dressed weight and fork length

The log *DW-FL* relationships for the free swimming school and associated schools were significantly different (Fig. 3A and B); the *DW* tended to be higher for free swimming schools than for associated schools at a given size class, for all fish and fish between 45-75cm (Fig. 4A and B). Although the regression lines for the free swimming model and the associated model appear to be close together, the 95% CIs do not overlap and ANCOVA tests of significance show these populations to be significantly different (p <0.001).

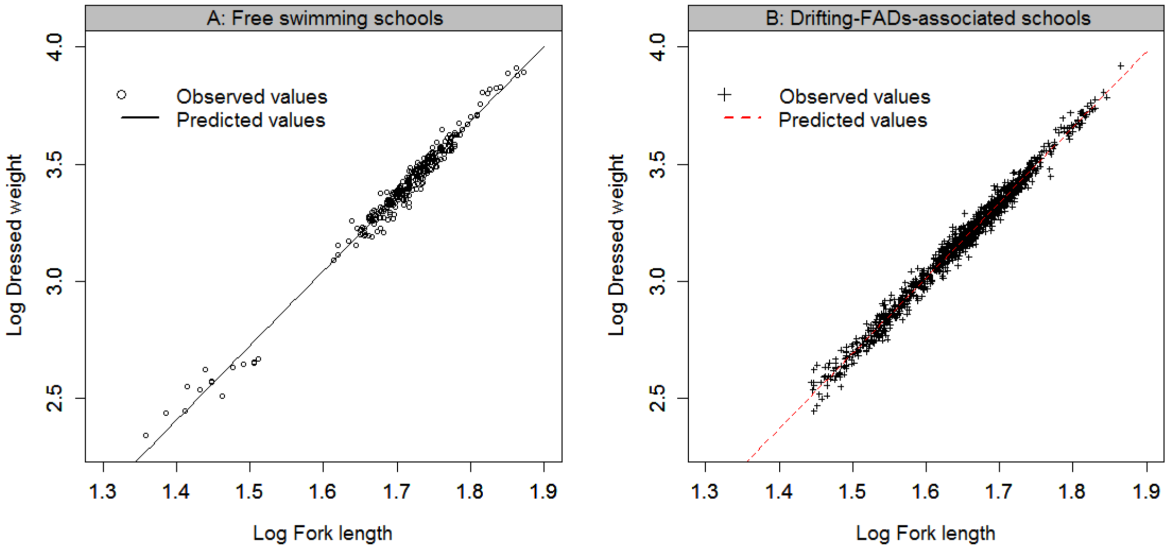

Fig. 3 Log dressed weight (*DW*) as a function of log fork length (*FL*) for skipjack (A) associated to drifting fish aggregation devices (FADs), and (B) caught on free swimming schools

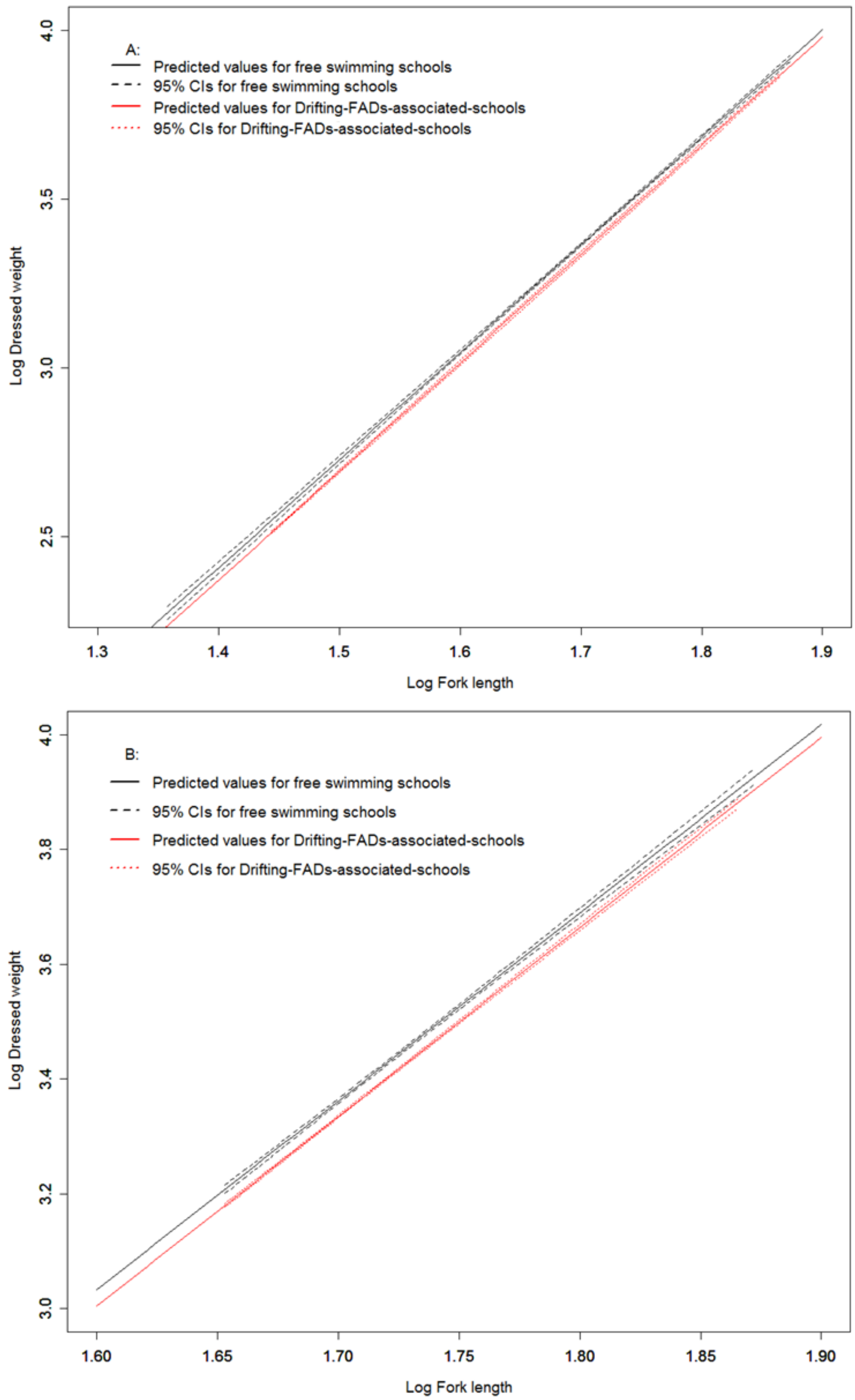

Fig. 4 The comparison of two Log *DW*-*FL* models for skipjack associated to drifting fish aggregation devices (FADs) and caught on free swimming schools for (A) full size range and (B) 45-75 cm

Condition factor (K)

An initial run of the model showed that the full model was the best fit model as the AIC value increased when any given variable was removed. All variables were significant; therefore association type, year, month, latitude and longitude were included in the final model (Table 3). The parameter estimate for variable "association type" was positive, 0.0929 (p <0.001), which suggests that FAD-caught skipjack were slimmer than those caught in free swimming schools.

Table 3. An ANOVA table for the linear model used to standardize *K* for condition factor. Variables were fishing method/ aggregation type (*F*), year (*Y*), month (*M*), latitude (*Lat*) and longitude (*Long*). The levels for each variable were contrasted with a reference level, which is associated school for *F*, 2007 for *Y,* and January for *M*. *Df* was "Degree of freedom"; "Sum Sq" was "Sum of Square"; "Mean of Sq" was "Mean of Square"; Significance code were *** (P < 0.001), ** (P < 0.01) and * (P < 0.05).

Variable	*Df*	Sum Sq	Mean Sq	*F* value	*Pr*(>*F*)	Significance code
F	1	2.0131	2.0131	345.3705	$2.2*10^{-16}$	***
M	7	0.3131	0.0447	7.7174	$3.47*10^{-9}$	***
Lat	1	0.2955	0.2955	50.9829	$1.46*10^{-12}$	***
Long	1	0.0741	0.0741	12.7886	0.00036	***
Y	3	0.3535	0.1178	20.3350	$6.49*10^{-13}$	***

The range of observed *K* values was 1.2512 to 2.1815, with a mean of 1.6836 (± 0.1331) for associated schools; while the range for free swimming schools was 1.3326 to 2.3113, with a mean of 1.8508 (±0.1514). Standardized *K* values were estimated from this model. The bootstrapped 95% CIs for the standardized *K* values for the associated schools [1.6766, 1.6811] were cleanly separated from the free swimming schools [1.8387, 1.8533] (Fig. 5A). Larger skipjack in the size range between 45 and 75cm showed similar separation in the bootstrapped 95% CIs for the standardized *K* values for the associated schools [1.7145, 1.7222] and the free swimming schools [1.8493, 1.8630] (Fig. 5B).

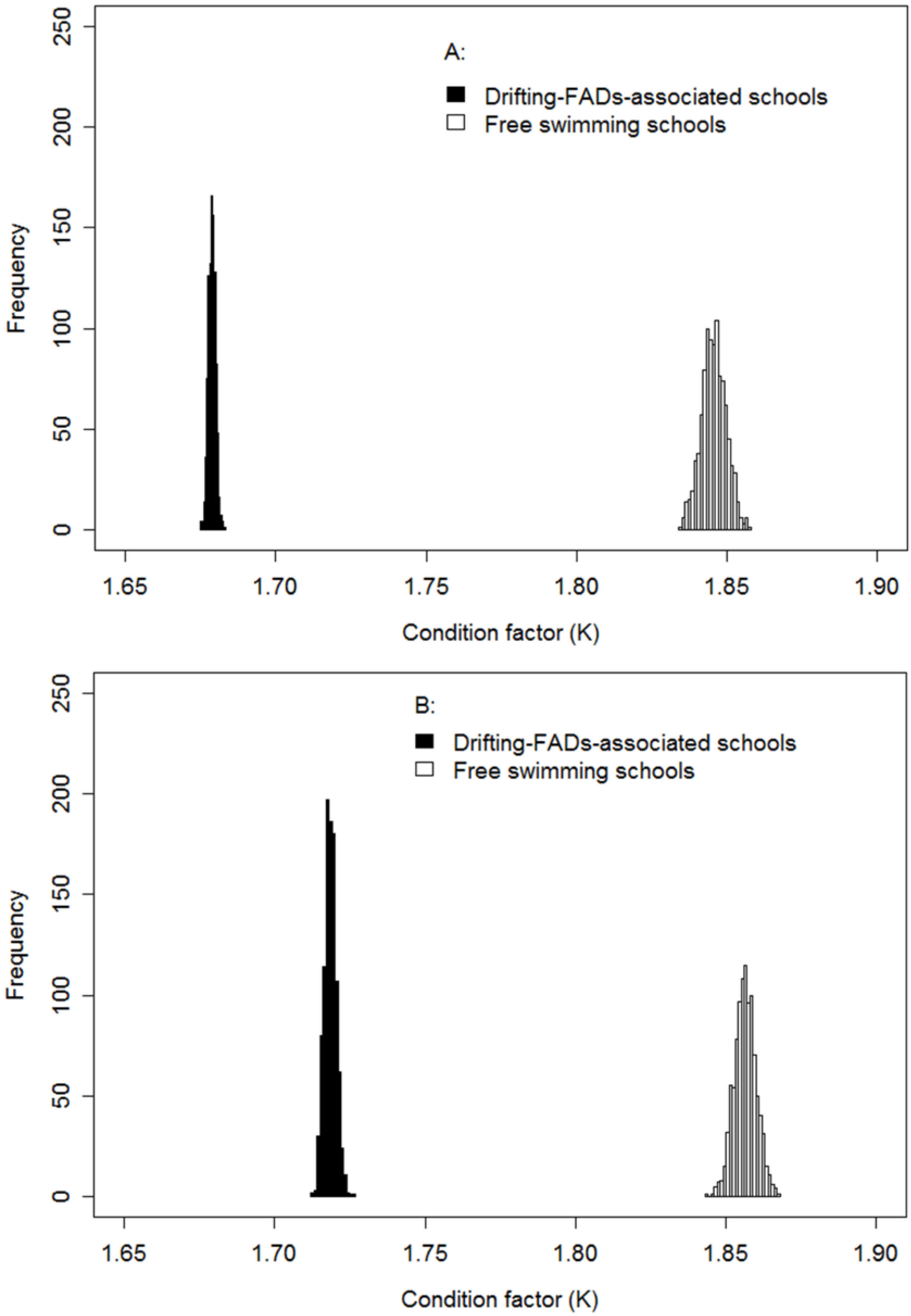

Fig. 6 Range of bootstrapped condition factor (*K*) for skipjack associated to drifting fish aggregation devices (FADs) and caught on free swimming schools for (A) the full size range and (B) for fish between 45-75cm

Discussion

Skipjack condition factor for associated and free swimming schools

Our results show that skipjack in free swimming schools and associated schools have a significantly different condition factors (Fig. 4 A and B). For our study, the amount of time for which a given tuna associated with a FAD is unknown making the exact cause of worsen condition for associated schools indiscernible. We hypothesized three possible explanations for the differences in *K*: (1) isometric assumptions are violated, (2) FADs worsen the condition of fish, and (3) fish in poor condition are attracted to FADs.

Fulton's condition factor (*K*) assumes isometric growth for the animal which can be assessed by determining if the slope (*b*) of the length-weight relationship is close to three (Blackwell et al. 2000). If *b* is greater than 3 then the assumption of isometric growth is not met and individuals of similar lengths should only be compared (Blackwell et al 2000). When testing for this assumption we determined that free swimming schools and associated schools did not meet the assumption of isometric growth as *b* was greater than 3 in both cases (free = 3.1872; FAD = 3.2184). For this reason, we evaluated *K* for fish of similar length by truncating the data to remove small skipjack. The mean length for free swimming (53.34) and associated schools (50.54) were similar after removing small individuals from both data sets (Table 2), with the same coefficient of variance (CV) of 0.097. This length range could then be compared, showing that free swimming schools still maintained a better condition than FAD associated schools (Fig. 4B). We can effectively rule out that violation of the model assumption did not unduly influence the better condition of free swimming schools.

Studies in the Indian and Atlantic oceans attributed the lower condition factors to the association of FADs (Marsac et al. 2000; Hallier and Gaertner 2008). Marsac et al. (2000) and Hallier and Gaertner (2008) found the thorax girth, as the condition factor, for yellowfin and skipjack tuna associated with FADs was lower than for those individuals in free swimming schools. These studies inferred that the habitat quality was poor because of low condition factors but quantifying habitat quality is also needed to determine the impact of FADs on tuna condition.

Skipjack conditions were evaluated in the Mozambique Channel and found that the condition of skipjack associated with naturally occurring logs was also lower than for those in free swimming schools (Robert et al. 2014). Skipjack tuna behavior in the Mozambique Channel is thought to be representative of their ancestors before the heavy use of FADs in fishing practices, which are not widely used in this area. This study set out to determine if poorer conditions of tuna associated with FADs was a function of these devices or an evolutionary behavior of fish already in poor condition. Consequently, if this associative behavior is inherent of tuna in poor condition, then high densities of FADs cannot be solely responsible for negative impacts on tuna conditions.

Robert et al. (2014) suggest that the poor condition of tuna drives the aggregation behavior around floating objects. If a free swimming school is having low foraging success their condition will be reduced, possibly encouraging aggregation behavior around floating objects to seek out conspecifics to increase their foraging capacity (Dagorn and Fréon 1999; Fréon and Dagorn 2000; Robert et al. 2014). To help verify this hypothesis however, habitat quality needs to be quantified within the study.

Previous studies rarely considered specific habitat conditions for the survey area when inferring the relationship between biological indicators and the environment. Consideration of the specific habitat would be helpful in interpreting the conflicting conclusions from studies with similar objectives. Previous studies using stomach fullness as an indication of condition found that the proportion of empty stomachs for drifting FAD associated schools tended to be significantly higher than that for free swimming schools (Ménard et al. 2000; Potier et al. 2001; Hallier and Gaertner 2008). However, Jaquemet et al. (2011) did not observe these differences in either type of school during times of extremely high prey abundance. Buckley and Miller (1994) also observed that the larger yellowfin tuna associated with anchored FADs had higher stomach content than unassociated conspecifics in both the Philippines and French Polynesia waters. This can be attributed to anchored FADs generally being deployed in near-shore areas around islands where prey availability is likely to be naturally higher than what the free swimming school counterparts would encounter offshore (Bromhead et al. 2000).

Our study cannot provide the direct connection between poorer conditions (*K*) of skipjack in associated schools to worse habitat quality. Making this direct link would require a time series of condition values with associated environmental conditions to identify a causal relationship for reduced condition (Robert et al. 2014). However, our findings cannot rule out the reasonable possibility that worse conditions of tuna were the reflection of the negative consequence of an association with FADs.

The necessity of considering the habitat conditions

The controversies arise in a series of studies involving impacts of FADs on tuna habitat selection. Some studies propose that FADs mislead tunas to inappropriate habitat (Marsac *et al.*, 2000; Hallier and Gaertner, 2008). In instance, FADs were deployed on a large-scale in the Gulf of Guinea in the westbound equatorial currents, transporting the drifting FADs to offshore areas of poor trophic conditions (Marsac *et al.*, 2000). Marsac *et al.* (2000) propose that skipjack instead migrated with the FADs in the westbound equatorial currents, explaining the higher catch rates of skipjack in offshore areas in the Gulf of Guinea. These increased catches may also be explained by FAD increasing vulnerability of free swimming schools in the offshore areas because they are easier to locate (Marsac *et al.*, 2000). It is difficult to test whether FADs have negative impacts on habitat choice of tuna without data on habitat conditions at catch locations.

Specific habitat conditions for study areas inferring the relationship between biological indicators and the environment are also rarely quantified. Studies in the Indian and Atlantic oceans attributed the lower condition factors to the association of FADs (Marsac *et al.*, 2000; Hallier and Gaertner, 2008). They found the thorax girth, as the condition factor, for yellowfin and skipjack tuna associated with FADs was lower than for those individuals in free swimming schools. These studies inferred that the habitat quality was poor because of low condition factors (Marsac *et al.*, 2000; Hallier and Gaertner, 2008).

By contrast, Robert *et al.* (2014) suggest that the poor condition of tuna drives the aggregation behavior around floating objects. They observed that the condition of skipjack associated with naturally occurring logs was lower than for those in free swimming in the Mozambique Channel, and proposed that if a free swimming school is having low foraging success their condition will be reduced, possibly encouraging aggregation behavior around floating objects to seek out conspecifics to increase their foraging capacity (Dagorn and Fréon, 1999; Fréon and Dagorn, 2000; Robert *et al.*, 2014). In the case that this associative behavior is inherent of tuna in poor condition, high densities of FADs cannot be solely responsible for negative impacts on tuna conditions.

In addition, previous studies using stomach fullness as an indication of condition found the proportion of empty stomachs for drifting FAD associated schools tended to be significantly higher than for free swimming schools (Ménard *et al.*, 2000; Potier *et al.*, 2001; Hallier and Gaertner, 2008). However, Jaquemet *et al.* (2011) did not observe these differences in either type of school during times of extremely high prey abundance. Thus, consideration of specific habitat is needed to interpret conflicting conclusions from studies with similar objectives.

Tracking studies for tuna associated with FADs similarly need to consider habitat conditions. Studies observing the behavioral pattern of tunas around FADs concluded that individual fish have varying tendencies of continuous residence time around a FAD(s) (Klimley and Holloway, 1999; Ohta and Kakuma, 2005; Dagorn *et al.*, 2007) and leaving a FAD area (Dagorn *et al.*, 2007; Schaefer and Fuller, 2010). The different behavioral tendencies were conducted in different areas and did not consider habitat quality around the FADs (Dagorn *et al.*, 2007). Future studies need to take into account environmental factors to better understand different behavioral phenotypes of fish.

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