

## Comparing condition indices of skipjack tuna (*Katsuwonus pelamis*) associated with natural floating objects and those from free-swimming schools in the Mozambique Channel

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### Abstract

The objective of this study is to compare condition indices of skipjack tuna (*Katsuwonus pelamis*) (plumpness, bioelectrical impedance) caught in schools associated to natural floating objects with fish caught in free-swimming schools. All samples were collected in the Mozambique Channel within 3 weeks (April 2010) assuming that all skipjack tuna were experiencing the same environmental conditions. The Mozambique Channel was chosen as it is a major fishing area that has not been hardly modified by the introduction of FADs (artificial floating objects), then representing the natural habitat of tuna before the use of FADs. All samples come from 6 free-swimming schools and 21 log-associated schools. For both indices, skipjack tuna around logs revealed lower conditions than in free-swimming schools. We propose two possible interpretations of our results that can help better understand the reason why tuna aggregate under floating object. Differences could come from different feeding success (foraging strategies) between fish around logs and those in free-swimming schools. Considering that in average, tuna stay associated to floating objects for a few days only, it would mean 1) that condition indices rapidly change (within a week) and 2) that the reason for which skipjack tuna has developed this associative behavior is not linked to feeding behavior but to other major component of their behavior, such as schooling (see the meeting point hypothesis). The other interpretation is that the observed difference is not the consequence of the association but the cause why tuna aggregate under logs. Skipjack tuna would associate to floating objects after some bad feeding success in free-swimming schools. Associating to floating objects could be a behavioral strategy for fish in free-swimming schools that are in low conditions to save energy, form larger schools that could be more efficient when foraging, etc. Our results are not in favor of the ecological trap hypothesis as they tend to represent the conditions of tuna before the introduction of FADs and it is difficult to assume that animals could have developed a behavior that would lead to lower fitness. However, before concluding, further analyses are needed to better understand what the absolute values of condition indices represent and to measure the differences of condition indices in areas that are highly modified by FADs.

## Introduction

Natural floating objects such as logs or branches naturally drift at the surface of the ocean and attract various species of tropical fishes (Castro et al. 2002, Taquet et al. 2007). Since the end of the 80's, fishers have been intensively using this behavior to enhance their catch of tropical tuna by constructing and deploying bamboo rafts with nets hanging underwater, called Fish Aggregating devices (FAD), equipped with positioning buoys to locate them (Moreno et al. 2007). In the sequel, we will use the term log to refer to any natural floating object (even those that have been reinforced by fishers – deployment of underwater net or addition of positioning buoys), and the term FAD to refer to any man-made floating object (bamboo rafts), released by fishermen for the purpose of fishing.

The release of thousands of such FADs in the tropical oceans obviously represents a change in the natural habitat of tropical pelagic fish (see Fauvel et al. 2009 for the Western Indian Ocean) and some scientists considered that it could lead to major changes in the behavior and biology of tuna (Marsac et al. 2000, Hallier and Gaertner 2008). This has raised concerns by fisheries managers as this fishing strategy has been responsible for more than 50% (Fonteneau et al. 2000) of the world's catches of tropical tuna in the world. For more than 10 years, many studies have been investigating the behavior, biology and movement of tuna around floating objects but the exact role of those floating structures in the ecology of tuna has not been elucidated yet.

Many hypotheses have been advanced to explain why tropical tuna associate with floating structures (see review in Fréon and Dagorn 2000). One of them is the indicator log hypothesis (Hall 1992). It stipulates that natural floating objects could be indicators of productive areas, either because most natural floating objects originate in rich areas (e.g. river mouth, mangrove swamp) and remain within these rich bodies of water, or because they aggregate in rich frontal zones. The association of tuna with floating objects may then result from an evolutionary process where tuna use these indicators to stay in contact with rich waters. If the indicator log hypothesis (Hall 1992) is the reason why tuna developed their association to floating objects, several authors (Marsac et al. 2000, Hallier and Gaertner 2008) has suggested that FADs could act as an ecological trap. According to the biological concept of ecological trap (Dwernychuk and Boag 1972, Battin 2004), the sudden habitat modification induced by FADs could act as an ecological trap for tropical tuna (i) if fish do not make any distinction between natural objects and man-made FADs, (ii) if FADs alter the correlation between habitat attractiveness and habitat quality misleading tuna's habitat choice and (iii) if this non appropriate behavior negatively affects the biology of tuna (growth rate, reproduction, survival), ending to lower fitness.

Regarding the last point, Hallier and Gaertner (2008) suggested that conditions of tuna are poorer under floating structures than in free-swimming schools. More, Ménard et al. 2000 and Hallier and Gaertner 2008 reported large proportions of empty stomach for fish associated with floating objects. Nevertheless, in both studies the authors neither indicated if the floating objects were natural or artificial, nor they provided information on the ratio between logs and FADs in the areas from which their samples were taken from.

Assessing the impacts of FADs on the biology of tuna is of primary importance. We here propose to study this impact by a first study that would represent a reference point. According to the ecological

trap, FADs would be responsible for lower fitness of tuna, but it is recognized that before the introduction of FADs, logs certainly provided some benefits to fish that have developed this associative behavior. We compare the condition indices of tuna caught around natural floating objects and in free-swimming schools, at the same time in a same area where logs are naturally abundant and which has been poorly modified by the addition of FADs: The northern part of the Mozambique Channel (Fauvel et al. 2009). We test the hypothesis that in such an area, conditions of tuna under logs would be similar to those of tuna in free-swimming schools.

## Materials and methods

### Sampling Zone:

Since the beginning of the fishery, the Mozambique Channel has always been a major fishing ground with floating objects. In this area, fishers do not seed a lot of new FADs because the density of logs is already high in this quite small area (at the scale of industrial tuna purse seiners fishing). Consequently, the increase in numbers of floating objects due to FADs is quite low (10% maximum) (Fauvel et al. 2009). The Mozambique Channel therefore appears as a good candidate to compare conditions of tuna under logs and in free-swimming schools, considering that this area has not been modified by the introduction of FADs.

### Condition indices:

For this study, we have selected two condition indices known to be sensitive to malnutrition: the plumpness (measured through the thorax girth) and the bioelectrical impedance (called Bioelectrical Impedance Analyses -BIA).

The thorax girth measures the plumpness of the fish. It is an index commonly adopted by many studies assessing health condition of fish (see Hallier and Gaertner 2008 for instance).

The BIA has not been used frequently in our field. Recent works suggest that bioelectrical impedance of biological tissues is a low cost, easy used, nonlethal and accurate condition index which could be a tradeoff between rough morphometrical condition indices and costly, time consuming biochemical indices (Cox and Hartman 2005, Willis and Hobdays 2008). Impedance (resistance  $R$  and reactance  $X_c$ ) is measured by passing an alternating electrical current at high frequency (50 kHz) and low intensity (800  $\mu$ A) through an organism. The BIA has been used for more than 20 years in medicine field as an important predictor of survival and recovery in a number of human diseases, which are conditional on the body's capacity to take advantage of food intake (Wirth and Miklis 2005). More than resistance and reactance, the use of phase angle (PA), a derived index of impedance (equation 1), has been of increasing interest in recent years and is now considered to be a possible global marker of health (Barbosa-Silva et al. 2005).

$$\text{Equation 1. Phase Angle (PA)} = \left(\arctan\left(\frac{X_c}{R}\right)\right) * 180/\pi$$

Malnutrition is characterized by changes in cellular membrane integrity, body cell mass and alterations in fluid balance, all of which being detected by the phase angle (Barbosa-Silva 2003, Mika et al. 2004). Low phase angles appear to be consistent either a breakdown in the selective

permeability of the cell membrane and cell death (Schwenk et al. 2000, Cox and Heintz 2009) whereas high phase angles are consistent with large quantities of intact cell membranes and body cell mass (Foster and Lukaski, 1996). Fusiform geometric shape of fish approximates a cylinder with a majority of the mass located in the thorax (Jobling 1995). The thorax accommodates all major body composition components and likewise is the main region for hypertrophic or hypotrophic growth. Since volume is proportional to the impedance and the length between detecting electrodes, a single impedance measurement represents the whole body and likewise compositional changes that occur within (Cox and Hartman 2005). Therefore, a strong predictability and accuracy is expected in these fish data as a result of the body geometry of fish being more simplified than the higher vertebrates used in previous BIA studies (Berg and Marchello 1994; Marchello et al. 1999, Cox and Heintz 2009).

Samples were collected on skipjack tuna (*Katsuwonus pelamis*) during one commercial fishing cruise onboard a Spanish purse seiner in the Mozambique Chanel between the 4<sup>th</sup> and the 25<sup>th</sup> of April 2010. An average of 15 fish by set was sampled on 6 sets on free-swimming schools and 21 sets on natural floating objects. Data were collected between 12°58' and 15°46' south and between 42°05' and 47°06' east (Fig 1).

#### Plumpness:

452 skipjack tuna (121 in free-swimming schools and 331 under logs) were measured in fork length (FL) at the inferior centimeter and thorax girth (TG) at the half inferior centimeter. The objective was to assess the effect of school type on the thorax girth. We derived a covariance analysis to address whether or not the relationship between thorax girth and fork length was identical whatever the school type (free-swimming school and natural floating object school). We tested differences between slopes and intercepts.

#### Bioelectrical impedance analysis (BIA) of tissue:

BIA measurements, resistance (R) and reactance (Xc) and fork length were taken on 402 skipjack tuna, (117 in free-swimming schools and 285 under logs) according to the sampling protocol suggested by Willis and Hodbay (2008). Two sets of needle electrodes (Terumo corporation Leuven Belgium 19 G 1.1\*25mm needles.), each consisting of a signal and detecting electrode, were inserted to a depth of 1 cm within the fish. One set was placed midpoint between the first dorsal fin and the lateral line and the second set was placed midpoint between second finlet dorsal and lateral line (see Willis and Hobday 2008 for detailed description). The four electrodes were placed in a generally linear manner along the side of the fish. Variables that could introduce error in R and Xc measures (e.g. varying the depth and gauge of needles, placement on the fish, temperature and time between capture and measure) were standardized to negate bias.

Independence between fork length and PA was checked (Fig 2) and PA between logs and free-swimming schools were compared thanks to a test of student. Due to strong heteroscedasticity and bimodal distribution of logs schools PA data (second smaller mode for low values) only PA higher than 24 were selected to derive the analysis (Fig 3).

Statistics were performed with R (2.9.0) available on the web ([www.r-project.org](http://www.r-project.org)). We considered tests to be statistically significant at an  $\alpha$  of 0.05.

## Results

### Plumpness:

Within the range of fork lengths, a straight line model between log transformed thorax girth and log transformed fork length appears to be adequate (Fig 4 and 5). Figure 4 shows that thorax girth increases with fork length (Pearson' coefficient of correlation of 0.72 and 0.96 for free-swimming schools and logs schools respectively). Covariance analyses showed that slopes are distinct between the two regressions (Table1. ANCOVA, p-value of the interaction term is inferior to 0.05 with a value of 0.025) meaning that the type of school affects the rate at which thorax girth increases with fork length. Table 2 provides strong evidence that log-caught skipjack tuna were significantly thinner than those caught in free-swimming schools (estimated coefficient for logs school= -0.91, p-value= 0.018).

### Bioelectrical impedance analysis (BIA) of tissue:

T-test showed a significant difference in PA values ( $t = 6.407$ ,  $df = 255.046$ ,  $p\text{-value} = 7.108e-10$ ) between free-swimming schools and log associated schools. Figure 6 shows that PAs are higher for free-swimming fish, average PA being 29.85 for free-swimming schools and 28.64 for logs schools. Sensitivity analysis to the reduction of data set was performed. The significant difference in PA is maintained when comparing the entire data set (without selection of PA superior to 24) with both parametric (student test,  $t=7.44$ ,  $df=292.049$ ,  $p\text{-value}=1.1e-12$ ) and non parametric rank tests (Wilcoxon Mann Whitney,  $p\text{-value} 5.45e-11$ ).

## Discussion

Although the reason for which tuna developed their associative behavior with natural floating objects has not been found yet, logs have always been natural components of the habitats of pelagic fish and one can assume that this evolutionary associative behavior contributed to increase their fitness (at individual or population level). One possible benefit for tuna to associate with natural floating objects, often advanced in the literature, could have been to increase (or maintain) good nutritional status. If logs are indeed spatially correlated to rich body waters (if we refer to the indicator log hypothesis, Hall 1992), logs would then allow tuna to stay in contact with rich waters. Based on this assumption, Hallier and Gaertner (2008) interpreted the lower condition of tuna caught under floating objects in comparison to tuna caught in free-swimming schools as a proof that FADs (e.g. artificial floating objects) act as ecological traps for tropical tuna. However, the authors did not specify if their samples came from artificial or natural objects. More, they sampled three distinct areas of the Indian Ocean: The Mozambique Channel, East Somalia and North West Seychelles, which are characterized by different ratios between artificial and natural objects (Fauvel et al. 2009). Hallier and Gaertner (2008) did not provide detailed results and interpretation on the differences according to the area of sampling.

Following the reasoning of Hallier and Gaertner (2008), we therefore decided to try to measure a "reference point", i.e. the condition of tuna in the two types of schools (associated and not associated) in an area that has not been (or very little) modified by human activities (no FADs, only

logs). The Mozambique Channel in the South Western Indian ocean appeared to be a good candidate as [Fauvel et al. \(2009\)](#) estimated that only 10% of the floating objects in this area were FADs (90% being natural floating objects). In such an area, our results show that skipjack tuna caught under free-swimming schools are in better conditions both in terms of plumpness and nutritional status than skipjack tuna caught under natural floating objects. This result first shows that without major anthropogenic modifications of the “floating object” environment, skipjack tuna associated with logs naturally exhibit lower conditions than those in free-swimming schools. Therefore, one should be careful before concluding that a difference between condition indices of associated and non associated fish could correspond to a negative consequence of the introduction of FADs. Our results reject the hypothesis that in an area that has not been modified by FADs, conditions of fish around logs and in free-swimming schools are similar.

Recent electronic tagging studies of tuna around floating structures clearly show that tuna alternate between associated and non associated phases: [Ohta and Kakuma \(2005\)](#), [Dagorn et al. \(2007\)](#), [Schaefer and Fuller \(2010\)](#), [Govinden et al. \(2010\)](#), [Matsumoto et al. \(2006\)](#). [Schaefer and Fuller \(2010\)](#), from archival tag data (98 recoveries), estimated quite short average durations of associative events by bigeye tuna with floating objects (an average of 2–3 days, although few longer events have been recorded - up to 24 days). The authors also found that the total proportion of time during which bigeye tuna are associated with floating objects (versus non associated phases) are from 8.8% to 18.9%, depending on size classes (the bigger the fish, the smaller the proportion of time associated to floating objects). Nevertheless, it is not excluded that the high proportion of natural floating objects in the Mozambique Channel modifies the patterns observed for bigeye tuna ([Schaefer and Fuller, 2010](#)) in the Eastern Pacific Ocean. Such information on durations of associated and non associated phases is available from archival tag data on bigeye tuna as their vertical behavior could be considered as a proxy for these two different phases. Skipjack tuna and yellowfin tuna do not exhibit such strong different vertical behavior when associated or not to floating objects. [Dagorn et al 2007](#), from acoustic tagging at drifting FADs, describe association periods of the order of a few days for yellowfin tuna (N=55, mean 1.04 (0.24-15.22)). Several studies have provided estimates of residence times of skipjack tuna at drifting FADs from acoustic tagging but the total number of skipjack tuna tagged around drifting FADs is still quite small (13). All results more or less converge towards association periods of the order of a few days ([Dagorn et al. \(2007\)](#) N=10, mean 0.91 days (0.13-7.03) ; [Govinden et al. \(2010\)](#) N=3, mean 4.47 days (0,09 - 18,33)). Even if information on the duration of non associated phases for skipjack tuna is not available yet, we can refer to [Schaefer et al. \(2010\)](#) who consider that bigeye tuna have a greater affinity for associative behavior than do skipjack tuna or yellowfin tuna, and therefore assume that non associated phases of skipjack tuna could be longer than those observed by [Schaefer and Fuller \(2010\)](#) on bigeye tuna.

We propose two possible interpretations of our results that can help better understand the reason why tuna aggregate under floating object. First, differences could come from different feeding success (foraging strategies) between fish around logs and those in free-swimming schools if (i) as suggested by recent literature we assume an average residence time of skipjack tuna around drifting floating objects of the order of a few days and (ii) conditions indices are sensitive to short term changes in the diet (e.g. a few days). Our results could be explained if feeding success (in terms of quantity or quality) is higher for fish in free-swimming schools than fish associated with floating objects. The differences observed could be a direct consequence of a change in foraging strategy or

feeding success of skipjack tuna when associated to floating objects or in free-swimming schools. As this is observed in an area highly dominated by natural floating objects (as opposed to other studies such as [Ménard et al. 2000](#), [Marsac et al 2000](#), [Hallier and Gaertner 2008](#)) it would mean that the reason for which skipjack tuna associate to floating objects would not be related to a trophic function. One hypothesis is that skipjack tuna could associate with floating objects to enhance the formation of larger schools (see the meeting point hypothesis [Dagorn and Fréon 1999](#), [Fréon and Dagorn 2000](#), [Soria et al. 2009](#)). While “waiting” for other schools to join the floating object, skipjack tuna could “accept” to be less efficient in terms of foraging success (losing energy), as forming large schools could represent (in their behavioral strategy) a necessity. It is believed that schooling behavior enhance individual foraging through faster location of food, more time for feeding, more effective sampling, information transfer, and opportunity for learning by social facilitation (see reviews in [Pitcher and Parrish, 1993](#); [Fréon and Misund, 1999](#)). Losing energy at the FAD for a few days would simply be a part of the compromise to be efficient on a long term.

The second possible interpretation of our results is that skipjack tuna associate to floating objects when they are in a poor condition. Instead of considering that the lower condition of fish associated to floating objects would be a consequence of their association with floating objects, another interpretation would be that it is the reason why tuna aggregate around them. The association with logs would then be an adaptation to situations when fish in free-swimming schools have a low success in terms of feeding. Associating to logs could be a behavioral strategy to save energy or to form larger schools (see [Fréon and Dagorn 2000](#)) in order to be more efficient when foraging in free-swimming schools.

As we have seen, our results could change the interpretation of studies concluding that FADs could act as ecological traps (e.g. [Hallier and Gaertner 2008](#)). However, we consider that it is risky to conclude at this stage as complementary results are needed. In order to go further, two types of studies are now necessary. The first type of study is to better understand what the values of the condition indices represent. Because no references points are available in the literature regarding the two condition indices used in this study, only relative comparisons between conditions of fish belonging to different types of schools can be derived. This gap in the knowledge precludes us from saying if the range of values observed for both types of schools corresponds to poor or good conditions for tuna. Thus, we cannot conclude whether tuna caught under logs show a real depressed condition or if both school types are actually in good conditions, but where associated schools are just in lower conditions than free-swimming schools. However, phases angle values assessed in this study are consistent with those collected by [Willis and Hodbay \(2008\)](#) on southern bluefin tuna. To go further in the interpretation of such data, there is a clear need to specify the threshold under which a tuna is declared in poor condition. Chemical analyses can provide very useful information on fish conditions by assessing the amount of fat (reserve and structure) in the white muscle of fish. Samples from our study are currently being analyzed by the IRD lab in Sète (France). It is also important to assess the time evolution of the condition indices when the quality or quantity of diet changes. If a fish does not feed properly for 2-3 days, is there a change in the thorax girth, BIA and fat content? The only way to answer this is to conduct controlled experiments on captive fish. This is underway in Hawaii, using the facilities of the Hawaii Institute of Marine Biology. The second type of study is to conduct the exact same experiment presented in this study in an area that has been highly modified by the introduction of artificial FADs, in order to examine if the

differences between the condition indices of fish when associated or not to floating objects are bigger (or not) than the differences observed in a non modified area such as the Mozambique Channel. It was planned to conduct this study in the Somalia area as this area is mainly dominated by FADs (Fauvel et al. 2009). However, due to the presence of pirates, the next experiment will likely be done in the Atlantic Ocean.

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## Figures and Tables

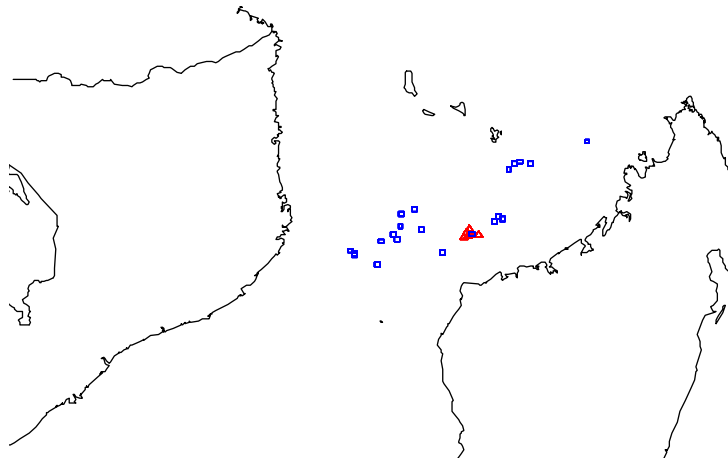


Figure 1. Map of the fishing set sampled in the northern part of the Mozambique Channel between the 4<sup>th</sup> and the 25<sup>th</sup> of April 2010. Red triangles represent set on free-swimming schools (n=6) and blue square set on logs (n=21).

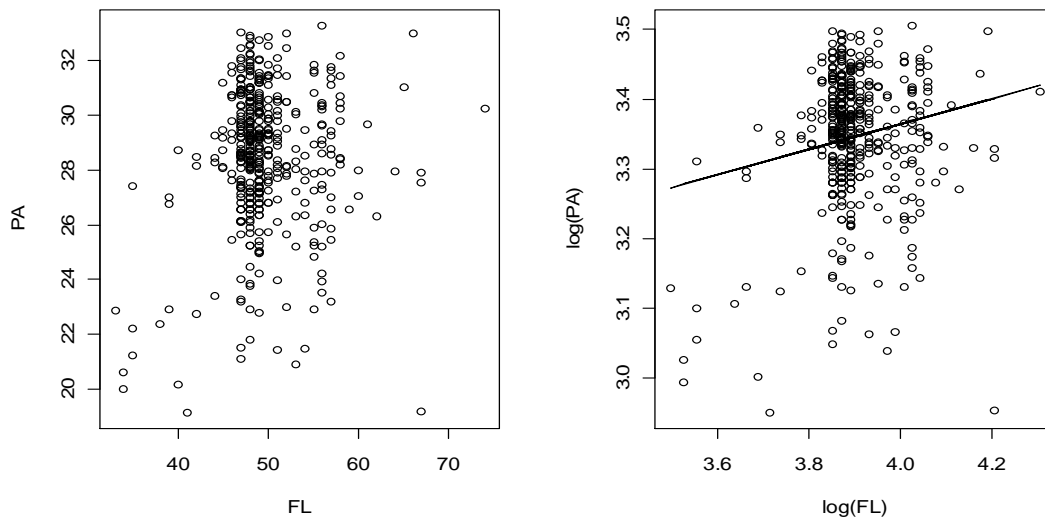


Figure 2. Left panel: Plot Phase Angle (PA) function of fork length (FL). Right panel: Plot log transformer PA function of log transformer FL. No relationship appears between the two variables. Solid black line represents fitted linear relationship. Pearson correlation coefficient of 0.13.

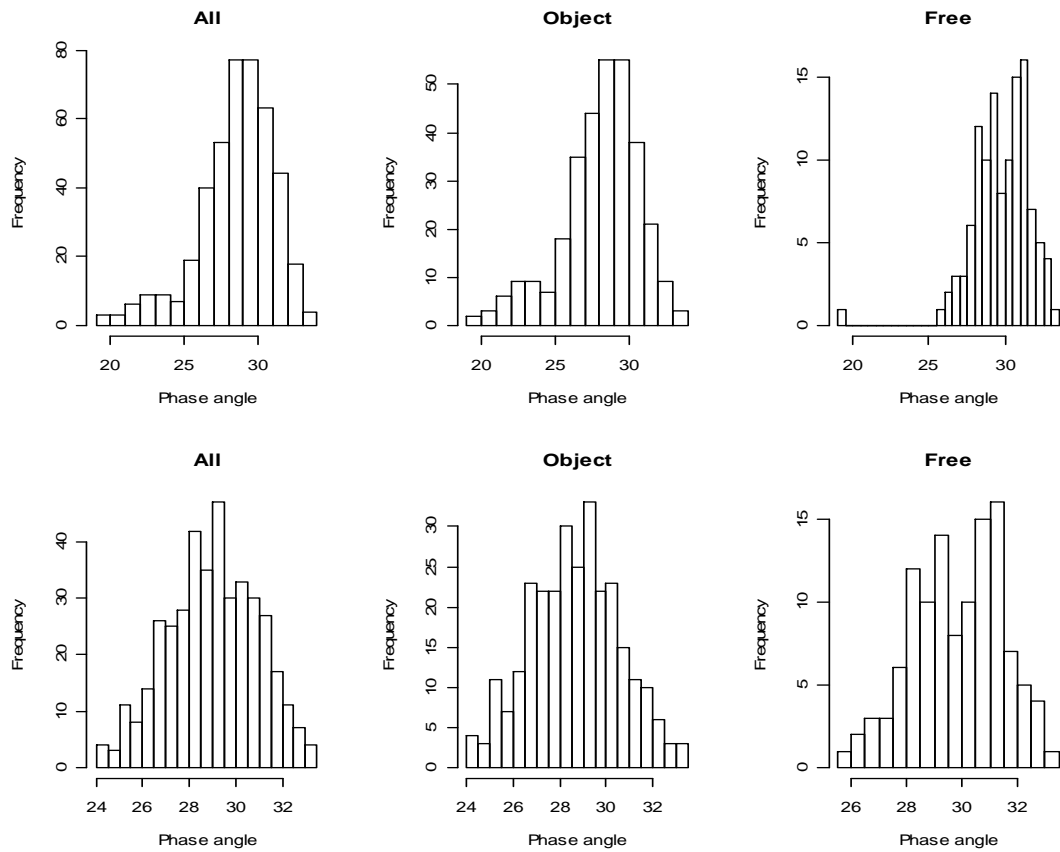


Figure 3. Histogram of phase angle values (PA). From left to right: All data set, logs schools data and free-swimming school data. On the first line, we see a bimodal distribution for logs school with a smaller second mode around 23. Selection of PA superiors to 24 allows removing the second mode and reducing heterosedasticity between the two fishing mode.

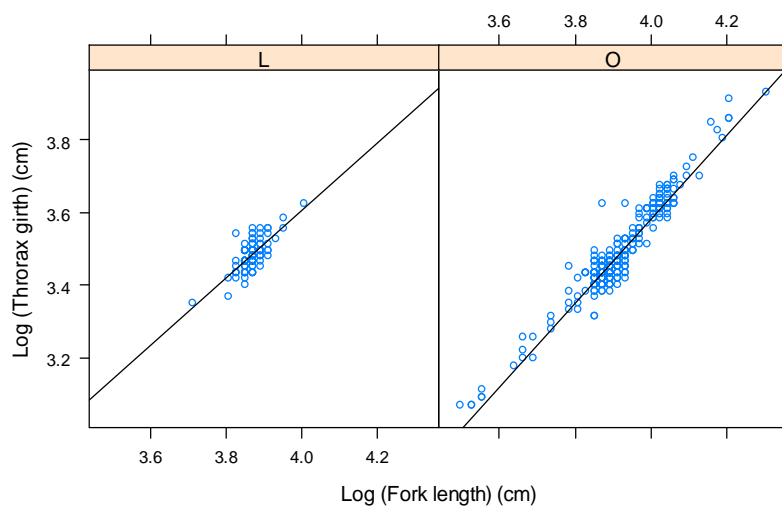


Figure 4. Linear relationship between fork length and thorax girth on a logarithm scale. Left panel for free-swimming schools and right panel for logs schools.

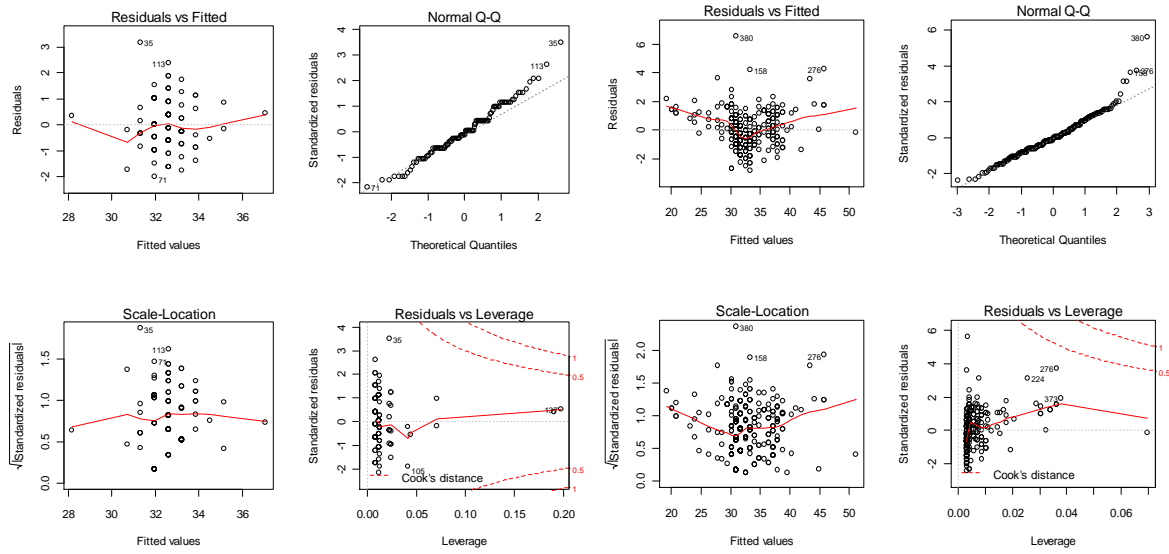


Figure 5. Diagnostic of the linear relationship between log-transformed thorax girth and log-transformed fork length for free-swimming school data (left panel) and for logs' schools (right panel).

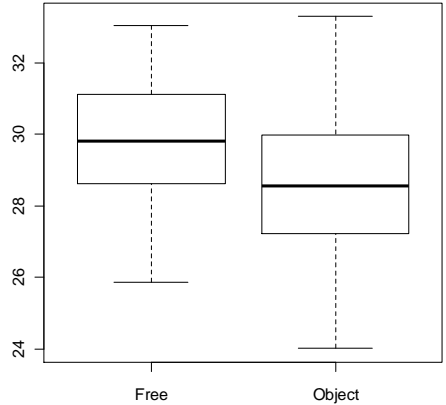


Figure 6. Boxplot of phase angle for free-swimming school (left side) and log school (right side).

Table 1. Analysis of variance table of the model, where Y is the log transformed thorax girth (log(TG)), and the explanatory variables are : the log transformed fork length (log(FL)), the fishing mode (FM: free-swimming school and logs school) and interaction between fishing mode and fork length (FM:log(FL)). Since the interaction term is significant (p-value= 0.025) we conclude that the two separate slopes are required in the model.

Model	Df	Sum Sq	Mean Sq	F value	Pr(>F)
FM	2	5474.3	2737.2	2.5120e+06	< 2e-16
log(FL)	1	4.6	4.6	4.2427e+03	< 2e-16
FM:log(FL)	1	0.005473	0.005473	5.0228e+00	0.02550
Residuals	448	0.5	0.001090		

Table 2. Estimated coefficient of the linear model where y=log(Thorax Girth) and explanatory variable are : the log transformed fork length (log(FL)), the fishing mode (FM : free-swimming school or logs school) and interaction between fishing mode and fork length (FM:log(FL)).

	Estimate	Std. Error	t value	Pr(> t )
(Intercept)	-0.1279442	0.37765873	-0.3387827	7.349322e-01
FM Object	-0.9118984	0.38411320	-2.3740355	1.801545e-02
log(FL)	0.9330805	0.09759955	9.5602954	7.857664e-20
FL Object:log(FL)	0.2223945	0.09923153	2.2411673	2.550429e-02