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The role of bait type on pelagic longline efficiency

P. BACH[1], L. DAGORN[1], C. MISSELIS[2]

Abstract

Longline catches depend on the responses of individuals to baited hooks. Pelagic longlining is an old fishing method targeting tuna around the world tropical area. The choice of bait can considerably affect hooking responses of large pelagic fishes. However, studies of the effect of bait type on pelagic longline efficiency are scarce. In this context, we analyse three kinds of hooking responses (hooking contact, global hooking success and tuna hooking success) from experimental fishing sets carried out with a monitored longline equipped with hook timers. Forty one fishing sets were conducted in a homogeneous area in terms of both physical and biological (prey) environments within the northern part of the French Polynesian EEZ. For each fishing set, the gear was deployed in order to uniformly sample the pelagic habitat in the vertical dimension (maximum fishing depth ranged from 300 m to 500 m with regards to physical characteristics of the habitat) at a same fishing time. More than 20,600 baited hooks were settled. Hooking responses are considered according to the timer status and the hook status. Three kinds of bait (squids, herrings and sardines) were used alone or mixed, which leads to distinguish six bait types : large squids, squids mixed with herrings, herrings mixed with squids, herrings mixed with sardines, sardines mixed with herrings and sardines used alone. The three kinds of hooking responses for each bait type are compared at the fishing set level and according to the fishing periods.

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Introduction

Tuna longlining is an old fishing method that lands between 380,000 and 480,000 tons of tunas and billfishes yearly since 1980 (Carocci and Majkowski, 1998). Tuna longline fisheries occur mainly in tropical and subtropical waters where they mainly target bigeye tuna (*Thunnus obesus*), yellowfin tuna (*Thunnus albacares*) and albacore tuna (*Thunnus alalunga*). While tuna surface fisheries as purse seine and pole and line fisheries mainly exploit juveniles and subadults, longline fisheries mostly catch adults with high marketable value.

Fishery biologists have traditionally used the capture per hook and per species as an index of the stock abundance. Although this index has the advantage of being simple, it might not always be appropriate as it does not take into account the complexity of the capture process. In the last years, an effort has been made to consider the role of fishing strategy (soak time, fishing effort at the set level, number of hooks per basket as maximum fishing depth index) and/or environment in the calculation of abundance indices (Polachek, 1990; Hinton and Nakano, 1996; Hampton et al., 1998).

The capture of a fish by a longline is a complex process (Skud, 1978), especially due to the need of active movements of a fish towards the fishing gear. It involves four stages (Bjordal and Løkkeborg, 1996): (i) the availability of the resource, (ii) the accessibility of the resource within the range of the bait odour plume, (iii) the location of the baited hooks, (iv) biting (attack of the baited hooks), hooking and retention of the fish by the hook. Therefore, the longline catching efficiency mainly depends on factors ranged into three categories (Skud, 1978), (A) bait (chemical and visual attractiveness, time efficiency), (B) natural behaviour and density of the target resource, interactions between catches and environmental conditions (mostly prey environment), and (C) gear and fishing techniques including hook size, hook-spacing, lengths of both mainline and branch line, fishing period, soak time and mainline and branch line materials. Although the capture process of demersal fish by bottom longlines has been studied for years (see Bjordal and Løkkeborg, 1996 for a review), very few scientific studies on tuna behaviour in relation to pelagic longlines have been carried out.

The bait is recognised as a major factor affecting longline catches in terms of efficiency and species targeting. The bait is a source of amino acids dispersed in the water that triggers the fish to search it (Atema, 1980; Olsen and Laevastu, 1983, Bjordal and Løkkeborg, 1996). Recently, Mana *et al.* (1998) described a functional olfactory organ for some large pelagic fishes (*Thunnus obesus*, *Thunnus albacares*, *Thunnus alalunga*, *Tetrapturus audax*, *Coryphaena hippurus*, *Lampris guttatus*) reflecting an ecostructural adaptation to pelagic life. As observed from both ultrasonic telemetry experiments and longline catches, the vertical habitat of most of the large pelagic fishes during daytime corresponds to deep waters (Suzuki *et al.*, 1997; Carey, 1990; Carey and Scharold, 1990; Nishi, 1991; Boggs, 1992; Dagorn *et al*., 2000). In these deep layers where light conditions are very low, the chemoreception is likely to be essential for locating prey or bait. More, the bait attractiveness decreases while fishing time (Lokkeborg, 1990). The release rate of chemical attractants depends on the bait quality (bait type, condition) and affects fishing efficiency for a given soak time (Lokkeborg and Johannessen, 1992). Chemoreception is not the only sense involved in the longlining catch process. Vision may play an important role in a second step when the fish is close to the bait. The texture, the shape and the size of dead baits affect the longline efficiency and selectivity in terms of both species and capture sizes (Lokkeborg, 1990; Hart, 1993; Johannessen *et al.*, 1993).

In this article we present preliminary results in order to examine the role of bait on the pelagic longline efficiency. In this context, the bait type efficiency is measured according to three kinds of longline hooking responses: the hooking contact, the global hooking success and the tuna hooking success. These hooking responses are analysed for each bait type at the fishing set level and at homogeneous fishing periods within the fishing set.

Materials and methods

To extract the role of bait on longline efficiency, noise from external factors was reduced as much as possible. Then, fishing sets were conducted in an homogeneous oceanographic area and the same fishing material and the same fishing strategy were used (hook size, number of hooks per set, hook-spacing, proportions and vertical distributions of hooks baited with two kinds of baits, fishing period, soak time and maximum fishing depth).

The monitored longline

The monitored fishing gear (Figure 1) included a 3.8 mm-diameter nylon monofilament mainline settled using a line thrower. The mainline was maintained at the surface by vertical 19-m polypropylene float lines with one or two 10-l floats at the top. Monofilament snap-on branch lines of 2 mm-diameter were 12-m long equipped with one EZ-hook Mustad n°8/0. For each set, 40% to 60% of baskets were equipped with time depth recorders (TDRs, model MK3e from Wildlife Computers, model LL600 from Micrel). TDRs were programmed to record depth data once per minute. They were placed at mid-point on the basket mainline, which corresponds to its maximum depth (Mizuno *et al.*, 1997). Each branch line was equipped with a hook timer (Somerton *et al.*, 1988) similar to those used by Boggs (1992). A hook timer starts running when the timer attached to the a baited hook is tripped. Hook timers indicate elapsed time in minutes between the attack of the baited hook and its recovering on board. Time data from tripped timers either with fish or without fish were considered. For tripped timers without fish, only hooks or branch lines suggesting a contact with the bait were accounted. A contacted hook corresponds to a tripped timer for which (i) the bait on the hook is absent or damaged, (ii) the hook is lost or (iii) tripped or untripped timers with fish on hooks, i.e. capture success.

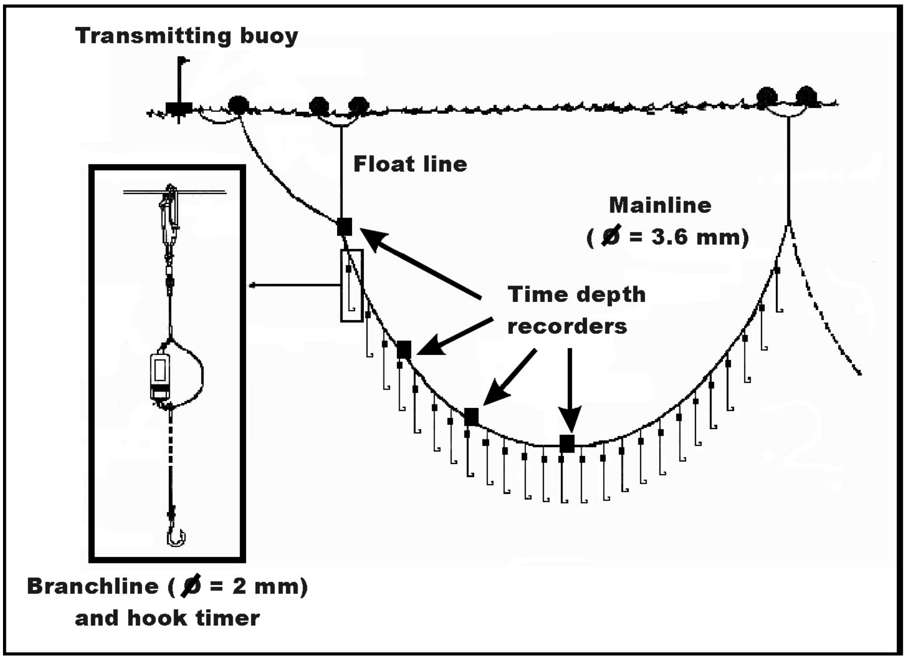

Figure 1 – Longline basket unit and instruments used in the fishing experiments.

Fishing area

The forty one fishing sets used in this work took place from 9°S to 14°S latitude within the northern part of the French Polynesian EEZ (Figure 2). For each set, oceanographic conditions were sampled, either after setting or before hauling, using a Seacat SBE19 multiparameter probe. Acoustic survey from the surface to 500 m depth was carried out above the longline from rectangular layout for describing the biological environment (micronekton structure and biomass). The homogeneity of this area in terms of both physical and biological environments has been demonstrated (Bertrand *et al.*, 1999; Bertrand *et al.*, in press). The hydrological environment is characterised by a surface layer homotherm in the first 60 m depth with an average temperature of 28° C. Below this layer, the temperature regularly decreases to reach 10°C at the depth of 370 m. Dissolved oxygen ranges between 3.7 $ml.l^{-1}$ and 3.2 $ml.l^{-1}$ in the first 220 m below the surface. Oxycline fluctuates from 220 m to 380 m where oxygen concentration decreases from 3.2 $ml.l^{-1}$ to 1.5 $ml.l^{-1}$. Micronekton biomass is higher than in the surrounding areas (from 20°S to 14°S and from 9°S to 4°S) with some aggregated structures located in the upper 200 m.

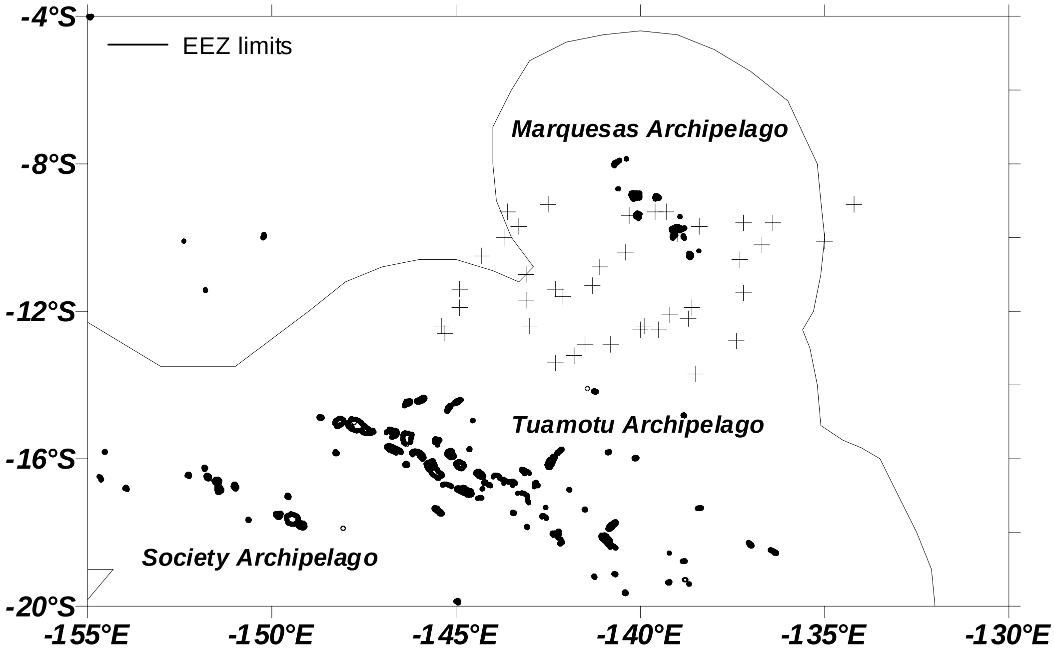

Figure 2 –Locations of the 41 longline fishing experiments (+) carried out in the northern part of the Exclusive Economic Zone (EEZ) of French Polynesia.

Fishing sets and baits details

Characteristics of fishing sets according to the bait type are summarised in table 1. Fishing sets including an average of 500 hooks were realised during daytime. Each set includes a basket series of 25 hooks. From 15 (about 375 hooks) to 24 (about 600 hooks) baskets were settled at each fishing experiment. The longline was deployed early in the morning (start setting ranged from 3:00 to 6:13 local time) and retrieved in the afternoon (start hauling ranged from 12:02 and 14:02 local time), (Figure 3). The average duration of setting and hauling periods was 1.95 hours and 3.30 hours respectively. The average soak time corresponding to the difference between the setting midtime and the hauling midtime was 8.70 hours (Table 1, Figure 3). The vessel speed during setting ranged from 3.5 to 6 knots and the line-thrower speed controlled with a tachymeter ranged from 168 to 269 m/min. The mainline shape quantified as the sagging rate (Suzuki *et al.*, 1977) corresponds to the ratio between the vessel speed and the line-thrower speed. It varies from 0.48 (highest slack) to 0.91 (lowest slack) around a mean value of 0.61. The time interval between hook attachments was constant for each fishing set (from 12 s to 16 s). Hook spacing on the mainline depends on the time interval between hooks and the mainline speed, and varied from 23 m to 45 m. Assuming a theoretical catenary shape of the mainline (Yoshihara, 1954), these values correspond to the highest distances between hooks in the water column. Highest distances are located close to the mid-point of baskets which reaches highest fishing depths. Maximum fishing depths of the longline observed from time depth recorders varies from 302 m to 486 m. For a given fishing set, although the mainline length per basket was constant, the maximum fishing depth during fishing varied within a range of about 50 m.
The frequency distribution of the maximum fishing depth per fishing set according to the bait type is presented on figure 4.
Large squids (*Notodarus sloani*) with 25 cm (225 g) body length were used alone for seven fishing experiments (2836 hooks). The body length of small squids (*Illex sp.*), European herrings and Californian sardines was about 18 cm (140 g), 17 cm (110 g) and 14 cm (90 g), respectively. Some experiments were done with sardines used alone (five fishing sets totalising 2500 hooks) while herrings with small squids and herrings with sardines were used mixed by pairs of baskets. The herrings/squids combination was tested during 15 fishing sets (4345 and 3834 hooks baited with herrings and squids, respectively) and the herrings/sardines combination was used during 14 fishing experiments (3574 and 3545 hooks baited with herrings and sardines, respectively). The average proportion of herrings in herrings/squids and

herrings/sardines combinations was 53% and 51%, respectively. When two bait types are mixed, hooking responses are considered for each bait separately.
Then, six different bait types are distinguished : (1) large squids = LS, (2) small squids mixed with herrings = S(Her), (3) herrings mixed with small squids = Her(S), (4) herrings mixed with sardines = Her(Sar), (5) sardines mixed with herrings = Sar(Her) and (6) sardines = Sar.

Table 1 – Summary of monitored fishing sets sets with averages and ranges (in parentheses) of the principal parameters for the total sets and sets according to the bait type.

	Total	Squids	Squids and herrings	Herrings and sardines	Sardines
Set number	41	7	15	14	5
Begin setting	4:50 (3:00 – 8:00)	5:48 (5:29 – 6:10)	5:24 (3:57 – 6:13)	4 :05 (3 :00 – 5 :31)	4 :02 (3 :00 – 8 :00)
End setting	6:47 (4:44 – 9:46)	7:31 (6:59 – 8:00)	7:33 (6:06 – 8:18)	5 :57 (4 :48 – 7 :16)	5 :47 (4 :44 – 9 :46)
Setting duration (hrs)	1.9 (1.4 – 2.3)	1.7 (1.4 – 2.1)	2.2 (2 – 2.3)	1.9 (1.7 – 2.2)	1.75 (1.7 – 1.8)
Begin hauling	13:00 (12:02 – 14:26)	12:36 (12:02 – 13:02)	13:04 (12:47 – 13:16)	13 :05 (12 :53 – 14 :02)	13 :25 (12 :57 – 14 :26)
End hauling	16:23 (15:05 – 18:06)	16:33 (15:59 – 16:57)	16:20 (15:43 – 16:44)	16 :07 (15 :05 – 17 :02)	17 :02 (16 :22 – 18 :06)
Hauling duration (hrs)	3.3 (2 – 4.6)	3.9 (3.4 – 4.6)	3.3 (2.8 – 3.7)	3 (2 – 4.1)	3.6 (3.3 – 3.8)
Soaking time (hrs) *	8.9 (7.4 – 11.3)	7.9 (7.6 – 8.3)	8.2 (7.4 – 9.8)	9.6 (8.4 – 10.9)	10.3 (7.4 – 11.3)
Basket number	20 (15 – 24)	16 (15 – 20)	22 (20 – 24)	20 (18 – 23)	20
Hooks per set	500 (361 – 600)	405 (361 – 500)	545 (499 – 600)	509 (450 – 576)	500
Hook spacing on the mainline (m)	34 (23 – 53)	34 (31 – 38)	32 (23 – 38)	29 (23 – 36)	51 (50 – 52)
Line par basket (m)	1307 (1106 – 1443)	1297 (1290 – 1306)	1307 (1184 – 1375)	1305 (1106 – 1443)	1332 (1320 – 1372)
Linear distance between buoys per basket (m)	813 (604 – 1007)	886 (810 – 990)	841 (604 – 1007)	769 (619 – 943)	754 (713 – 819)
Sagging rate (ratio)	0.62 (0.48 – 0.76)	0.68 (0.62 – 0.76)	0.64 (0.51 – 0.74)	0.59 (0.48 – 0.76)	0.57 (0.52 – 0.62)
Max. fishing depth (m) **	396 (302 – 486)	362 (326 – 396)	386 (358 – 418)	410 (302 – 486)	430 (401 – 463)

* The soaking time corresponds to the difference between the hauling midtime and the setting midtime.
** The highest fishing depth corresponds to the mean of depth records recorded at the mid-point of instrumented baskets of a given set without considering both sinking and rising periods.

Definition of fishing periods and estimation of active hooks

Analyses of hooking responses at the fishing set level does not take into account some factors as gear saturation, bait loss and temporal efficiency of bait that can interact while soak time. The analysis of hooking responses within the soak time requires information of hooking response times. More, these information allow to estimate the number of baited hooks that remain active during different periods of the fishing. For each fishing period, we considered the number of hooking responses relative to the number of active hooks.

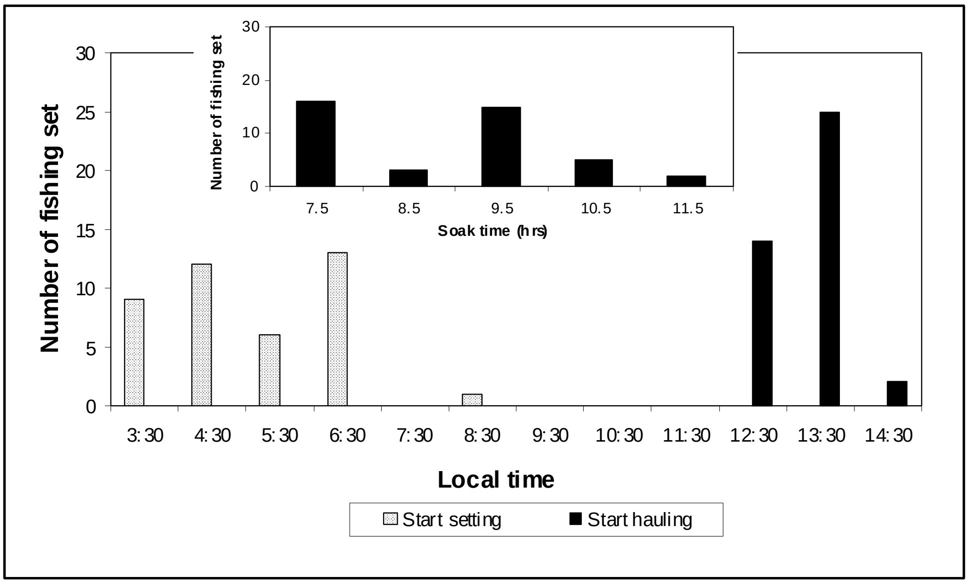

Figure 3 – Frequency distributions of longline fishing sets according to both the local time when setting and hauling and the soak time (difference between the setting midtime and the hauling midtime).

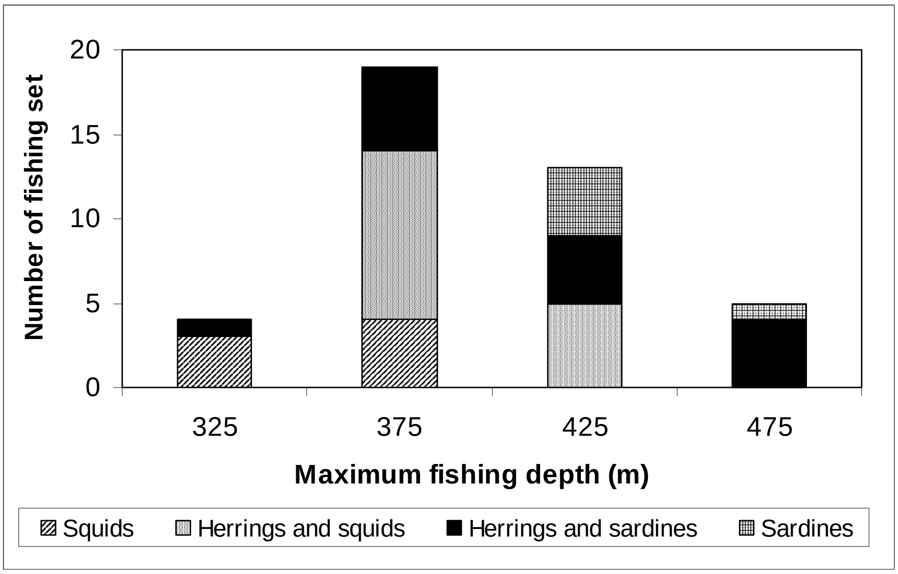

Figure 4 – Frequency distribution of the maximum fishing depth (m) of fishing sets according to the bait type.

For each fishing period, distributions of the hooking contact, the hooking success and the tuna hooking success observed for each bait type were compared.

As soak time between fishing sets was not constant, we considered seven homogeneous fishing periods. Periods 1 and 2 correspond to the beginning and the end of setting. The duration of each of them was 1 hour approximately according to the number of hooks per set and the time interval between hooks. Period 3 was defined as the period during which hooks descent until they reach their maximum fishing depth. The fishing time corresponding to hooks staying at the same depth in the water column is divided into two equivalent periods from 1.5 to 3 hours each depending on the fishing set (periods 4 and 5). Periods 6 and 7 correspond to the beginning (first 50% of the hooks) and the end (last 50% of the hooks) of the retrieval of the longline.

The number of active hooks N_t for each fishing period is estimated as follow. For period 1, N_t corresponds to the number of settled hooks. For period 2, N_t is estimated as $N_{t-1} - C_{t-1} + S_t$ where S_t is the number of new baited hooks added at time t. For periods 3, 4 and 5, $N_t = N_{t-1} - C_{t-1}$. During periods 6 and 7, N_t is estimated as $N_{t-1} - C_{t-1} - R_t$ where R_t is the number of baited hooks removed at time t.
Some of the clock times of hooking responses were unknown because of hook timer malfunctions. Some of the unknown clock times associated to tripped hook timers could be estimated from observations of time records of the mainline depth (TDRs): we observed that jerk and rush movements of fish after an hook attack produce a well marked signature on the depth profile of the mainline. Nevertheless, this signature depends on (i) the distance between the attacked hook and the time depth recorder, and (ii) the predator species and/or size. For tuna and billfish with fork lengths up to 1 m, movements of the mainline related to the behaviour of hooked individuals could be identified for hooks localised up to 100 m from the time depth recorder. Other unknown clock times were allocated among valid clock times by prorating them according to the observed clock time. This calculation was operated only for fishing sets for which less than 20% clock times information was unknown. Consequently, 16 fishing sets were eliminated for the fishing periods analysis (3 fishing sets for LS, 5 for S(Her), 2 for Her(S), 2 for Her(Sar), 1 for Sar(Her) and 3 for Sar).

Statistical analyses

Differences between distribution means of hooking responses according to the bait type were tested with an analysis of variance (ANOVA, the STATISTICA 5.5 software was used for statistical processing). When a significant difference was found, a multiple comparison test was applied (Scheffé's test) to identify the main distributions responsible for these differences. We assume that hooks were independent with each other and therefore assume a binomial distribution for each studied hooking response. According to this assumption, the variance of a ratio is only a function of this ratio and is not constant. In consequence, ANOVA was performed for transformed data by applying the formula T(Y), (Tomassone *et al.*, 1993) :

$$TR(Y) = (\mathbf{180} / pi) * \arcsin(\sqrt{Y})$$

where Y = the variable ratio, TR(Y) = transformed ratio expressed in degrees.
The homoscedaticity of variances of transformed data distributions compared between them was previously tested by performing the Bartlett's test.

Results

Presentation of hooking responses per set

We first present the frequency distributions of hooking responses per set without distinguishing the bait type used in the sets. Three types of hooking responses are considered (Figure 5): (i) hooking contact (HC = the number of biting and captures relative to the number of baited hooks), (ii) global hooking success (GHS = the number of captures relative to the number of baited hooks), and (iii) tuna hooking success (THS = the number of tuna captures relative to the number of baited hooks). The characteristics of these hooking response distributions according to each bait type are presented in table 2. Distributions have a well marked right skewness. However, compared to the range between the lowest and the highest distribution values (between 3.4% and 23.7% for HC, between 0.4% and 9% for GHS and between 0% and 8% for THS), the range between the first and third interquartiles values is low, which traduces a relative homogeneity of hooking responses per set.
Relations between these different hooking responses are then analysed (Figure 6). The correlation between the GHS and the HC per set is highly significant (coefficient of determination = 45.2%, $p < 0.001$) with a slope of the adjusted regression line of 0.24 indicating a constant relationship between HC and GHS: 24% of contacted hooks end to a capture. Similarly, the THS is highly correlated to the GHS (coefficient of determination = 75.4%, $p < 0.001$). The slope of the adjusted regression line is equal to 0.73, which means that the average tuna success contribution in the global success is 73%.

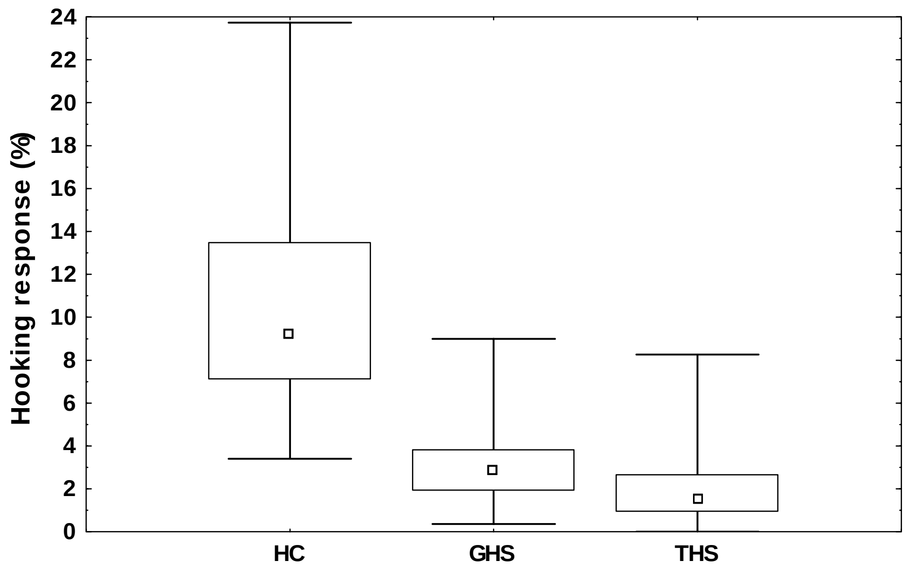

Figure 5 – Box plots of hooking responses (HC = Hooking Contact, GHS = Global Hooking Success, THS = Tuna Hooking Success) observed during fishing sets.

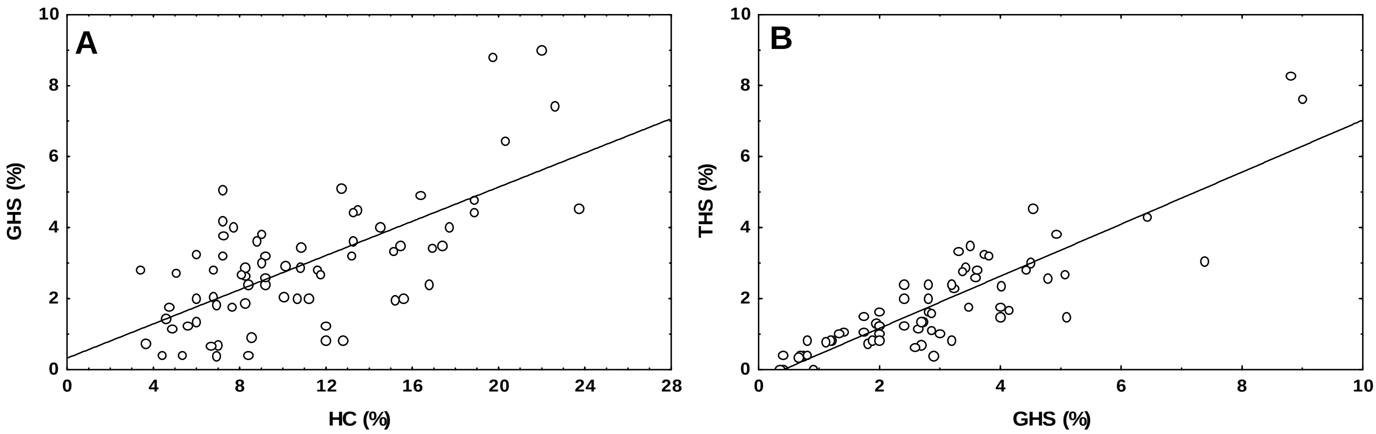

Figure 6 – Observed (O) and expected (line) hooking responses for the fishing trials (A : Global Hooking Success (GHS) versus Hooking Contact (HC) , B : Tuna Hooking Success (THS) versus Global Hooking Success (GHS)).

Hooking responses according to the bait type at a fishing set level

The distributions of hooking responses (HC, GHS, THS) per fishing set according to each bait type are described in Figure 7 and Table 2. Results of both variance analysis and multiple comparisons between bait type distributions for a given hooking response are summarised in tables 3 and 4, respectively.

Hooking contact: Range values are less extended for squids (LS and S(Her)) than for other bait types. Except for Sar, the range between the first and the third interquartiles follows a similar trend, which shows higher variations of hooking contact between fishing sets for Her(S), Her(Sar) and Sar(Her). Median values are lower for squids bait types (7.2% and 7.1% for LS and S(Her), respectively) than for fish bait types (between 9% for Sar and 13.2% for Her(S)). The hypothesis of the homoscedacity of variances can not be rejected (Bartlett's test, $p = 0.34$, Table 3). The analysis of variance applied for distributions of transformed data values confirms an highly significant difference ($p<0.001$) between hooking contact distributions (Table 3). However, the Scheffé's test application shows that these differences are essentially due to differences between squids (LS and S(Her)) and Her(Sar), with p = 0.007 and p = 0.0075 respectively, (Table 4).

Global hooking success: As observed for HC, the range of GHS values is higher for fishing sets achieved with Her(S), Her(Sar), Sar(Her) and Sar than with squids (LS and S(Her)), (Figure 7 B). Nevertheless, the range between the first and the third interquartiles values are quite low traducing a relative homogeneity of GHS samples whatever the bait type. More, these ranges overlap, except for S(Her) which presents the lowest interquartiles values. The homoscedaticity of variances is accepted (p = 0.47). While the difference between the means of the distributions (transformed data) is significant (p = 0.017, Table 3), the multiple comparison does not allow to identify which distributions explain this difference (Table 4).

Tuna hooking success: The highest ranges between the lowest and the highest THS are observed for Her(S) and Sar. They are two or three times higher than for the other bait types (Figure 7 C). The range values delimited by the first and the third interquartiles overlap, except for S(Her) and Sar distributions for which these ranges are respectively lower and higher than the others. The assumption of the equality of variances can not be rejected (p = 0.55). There is a significant difference between THS distributions (transformed data): p = 0.047 (Table 3). The multiple comparison shows one significant difference between the S(Her) and Sar distributions (p = 0.04, Table 4).

Table 2 – Statistical parameters of hooking response distributions analysed in the study (N = number of fishing sets, n = number of baited hooks, median, mean (in italics), lowest and highest values (in parenthesis), LS = large squids, S (Her) = squids mixed with herrings, Her (S) = herrings mixed with squids, Her (Sar) = herrings mixed with sardines, Sar (Her) = sardines mixed with herrings, Sar = sardines).

		Hooking responses		
		Hooking contact (%)	Global hooking success (%)	Tuna hooking success (%)
Bait type	All bait types (N = 70, n = 20,664)	9.2 / *10.8* (3.4 – 23.7)	2.8 / *2.9* (0.4 – 9)	1.5 / *1.8* (0 – 8.3)
	LS (N = 7, n = 2,836)	7.2 / *6.2* (3.4 – 7.8)	3.8 / *3.6* (1.8 – 5.1)	1.8 / *2.1* (1.5 – 3.3)
	S(Her) (N = 15, n = 3,834)	7.1 / *7.6* (3.6 – 12.7)	1.5 / *1.9* (0.4 – 5.1)	0.8 / *0.9* (0 – 2.9)
	Her(S) (N = 15, n = 4,345)	13.2 / *12.1* (4.6 – 19.7)	2.8 / *3.1* (0.8 – 8.8)	2 / *2.3* (0.4 – 8.8)
	Her(Sar) (N = 14, n = 3,574)	12.3 / *13.5* (6.7 – 23.7)	2.5 / *2.7* (0.4 – 6.4)	1.2 / *1.8* (0.3 – 4.5)
	Sar(Her) (N = 14, n = 3,545)	10.4 / *12* (4.4 – 22.6)	2.9 / *3.2* (0.4 – 7.4)	1.7 / *1.8* (0.4 – 3.5)
	Sar (N = 5, n = 2500)	9 / *11.2* (7.2 – 22)	3.6 / *4.4* (2.6 – 9)	2.6 / *3.3* (0.6 – 7.6)

Table 3 – Results of variance analysis performed to test differences between hooking response distributions according to the bait type (HC = hooking contact, GHS = global hooking success, THS = tuna hooking success).

	Bartlett's test	D.o.F(*) effect	Mean square of effect	D.o.F(*) error	Mean square of error	Observed F	Probability level
HC	0.18	5	78.02	64	15.85	4.92	0.0007
GHS	0.78	5	24.26	64	8.06	3.01	0.017
THS	0.24	5	30.61	64	8.12	3.77	0.0047

(*) D.o.F = degree of freedom

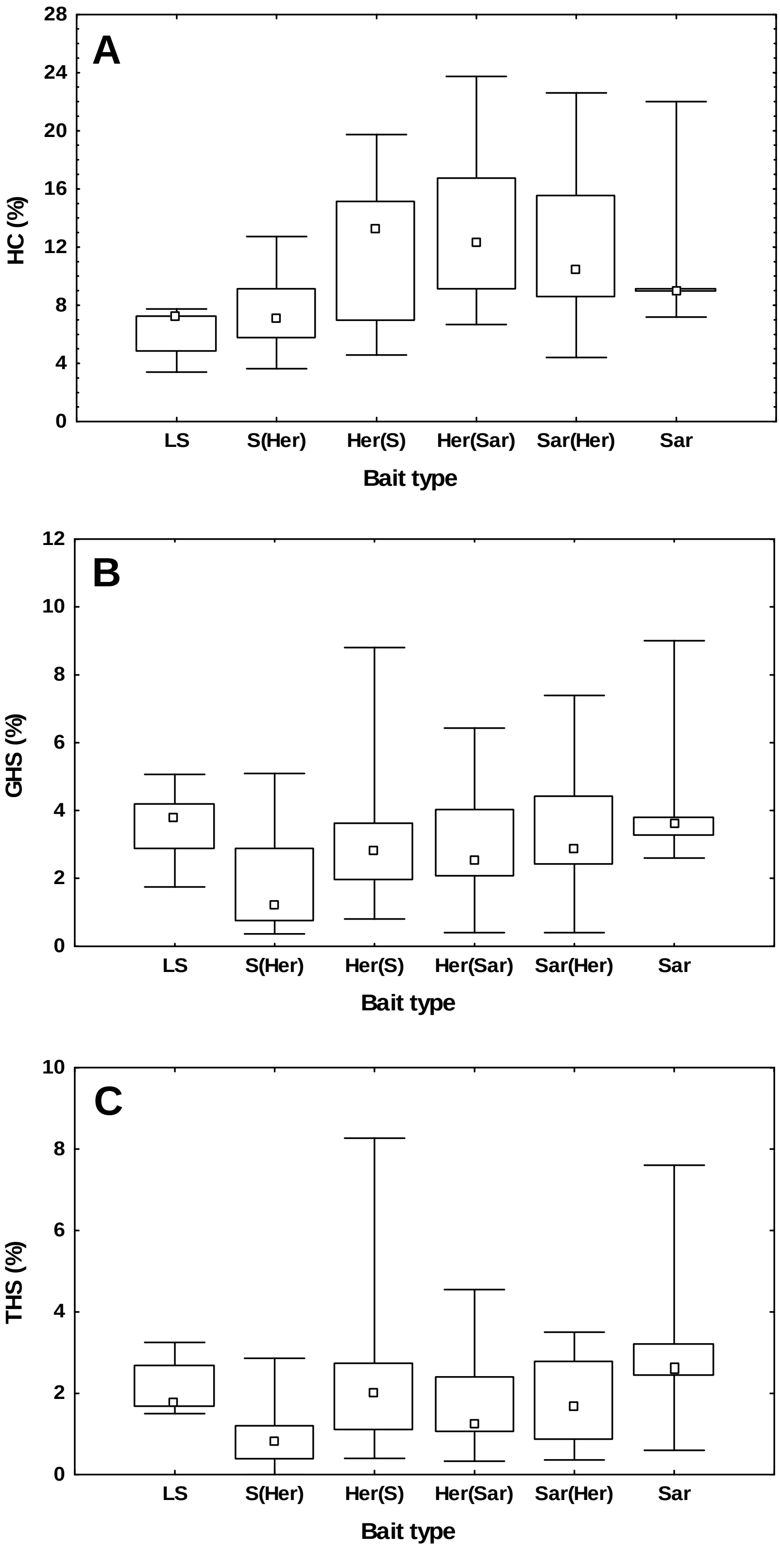

Figure 7 - Box plots of hooking responses according to the bait type (LS = large squids, S (Her) = squids mixed with herrings, Her (S) = herrings mixed with squids, Her (Sar) = herrings mixed with sardines, Sar (Her) = sardines mixed with herrings, Sar = sardines).
A - Hooking Contact (HC), B - Global Hooking Success (GHS), C - Tuna Hooking Success (THS).

Table 4 – Statistical differences between hooking response distributions according to the bait type estimated from multiple comparison (Scheffé's test). (O = no significant difference, + = significant difference, significance level α = 0.05). (Hooking response : HC = hooking contact, GHS = global hooking success, THS = tuna hooking success, Bait type : LS = large squids, S (Her) = squids mixed with herrings, Her (S) = herrings mixed with squids, Her (Sar) = herrings mixed with sardines, Sar (Her) = sardines mixed with herrings, Sar = sardines).

HC	S(Her)	Her(S)	Her(Sar)	Sar(Her)	Sar
LS	O	O	+ (p = 0.022)	O	O
S(Her)		O	+ (p = 0.031)	O	O
Her(S)			O	O	O
Her(Sar)				O	O
Sar(Her)					O

GHS	S(Her)	Her(S)	Her(Sar)	Sar(Her)	Sar
LS	O	O	O	O	O
S(Her)		O	O	O	O
Her(S)			O	O	O
Her(Sar)				O	O
Sar(Her)					O

THS	S(Her)	Her(S)	Her(Sar)	Sar(Her)	Sar
LS	O	O	O	O	O
S(Her)		O	O	O	+ (p = 0.04)
Her(S)			O	O	O
Her(Sar)				O	O
Sar(Her)					O

Hooking responses versus bait according to the fishing period

Hooking contact: Distributions of HC values relative to fishing periods for all the bait types considered together are presented on figure 8 A. Only two fishing periods (periods 1 and 4) have been chosen as examples to present HC data according to the bait type (Figure 8 B). HC range from 0 to 10.8%. Compared to these ranges, differences between the first and the third interquartiles values are lower than a maximum of 3.4% observed during the period 1. For the other fishing periods, this difference is about 2%. Then, for a given fishing period, HC are quite similar. The highest median value occurs for fishing period 1 while the lowest one is observed for period 7. For this last period, 70% of hooking contacts are null and all HC values for LS, Sar(Her) and Sar equal zero. Then, no ANOVA was performed for this fishing period.
A significant difference is calculated only for period 1 while the multiple comparison is not significant (Table 5). For period 1 (highest HC values), the dispersion of the HC values is less extended when squids (LS and S(Her)) are used than when other bait types are used (Figure 8 B). This result is analogous to those observed at the fishing set level. For period 4 for which the ANOVA is not significant, the data dispersion for Sar(Her) and Sar is reduced and resembles to those observed for squids.

Global hooking success: Distributions of GHS values relative to fishing periods are presented on figure 9 A. Only two fishing periods (periods 4 and 6) have been chosen as examples to present GHS data according to the bait type (Figure 9 B). The temporal variation of the median differs from those observed for HC (in particular for fishing period 1). For HC, the median value is maximal during period 1 (Figure 8 A) while it is minimal with a null value for GHS (53% of GHS value equal zero, Figure 9 A). More, the GHS median value is also null for periods 3 and 7.
Fishing periods 1 and 7, for which the GHS distribution variance is null for some bait types, were not considered for statistical analyses. Among the other fishing periods, the ANOVA application shows a significant difference between the distributions means for period 6 while the multiple comparison is not significant (Table 5 B, Figure 9 B).

Tuna hooking success: Distributions of tuna hooking success relative to fishing periods are presented on figure 10 A. Only fishing periods 4 and 5 have been chosen as examples to present THS data according to the bait type (Figure 10 B). The lowest and the highest values for fishing period distributions are 0% and 4%, respectively, while range values vary from 1.5% (period 7) to 4% (period 1). The highest median values are observed for fishing periods 4 and 5 while the median is null for the other periods. More than 70% of the THS values equal zero for periods 1, 6 and 7. Consequently, no ANOVA was performed for these fishing periods. The ANOVA is significant (p = 0.048) for period 4 while the multiple comparison is not significant (Table 5 C).

Table 5 – Results of variance analysis and multiple comparison (Scheffé's test) performed to test differences between hooking response distributions observed during fishing periods according to the bait type (A : HC = Hooking Contact; B : GHS = Global Hooking Success, C : THS = Tuna Hooking Success).

A – HC	Bartlett's test probability	Test F (probability level)	Scheffé's test probability
Period 1	0.15	0.018 (*)	No significant
Period 2	0.22	0.32	-
Period 3	0.18	0.44	-
Period 4	0.15	0.09	-
Period 5	0.08	0.41	-
Period 6	0.11	0.43	-
Period 7	No tested		

B – GHS	Bartlett's test probability	Test F (probability level)	Scheffé's test probability
Period 1	No tested		
Period 2	0.81	0.07	-
Period 3	0.32	0.13	-
Period 4	0.47	0.47	-
Period 5	0.44	0.12	-
Period 6	0.47	0.027 (*)	No significant
Period 7	No tested		

C – THS	Bartlett's test probability	Test F (probability level)	Scheffé's test probability
Period 1	No tested		
Period 2	0.61	0.07	-
Period 3	0.20	0.22	-
Period 4	0.58	0.048	No significant
Period 5	0.88	0.27	-
Period 6	No tested		
Period 7	No tested		

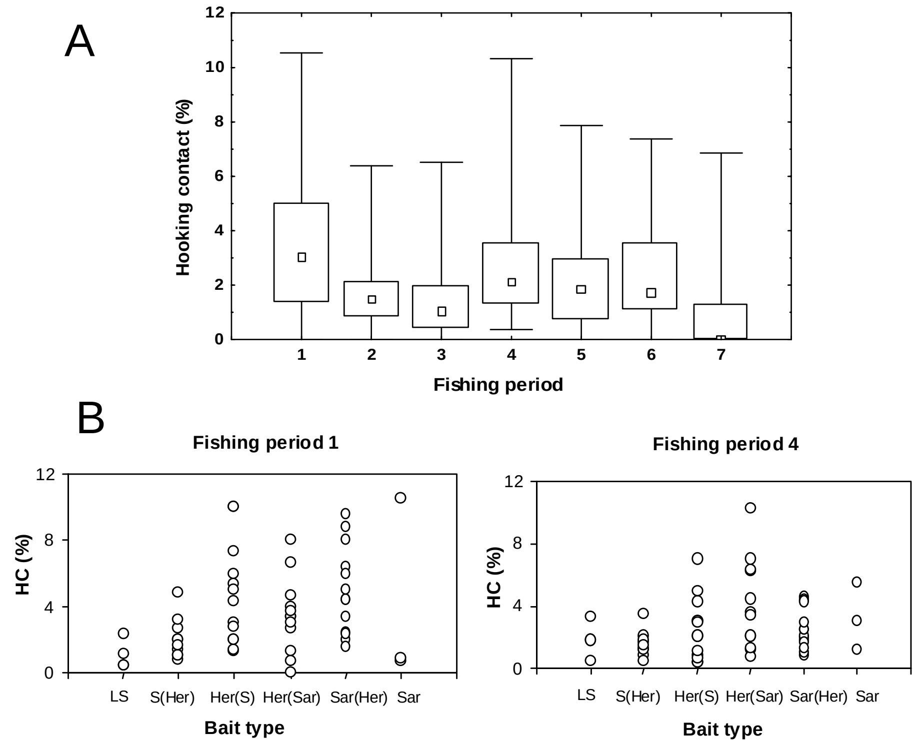

Figure 8 – A : Box plots of the hooking contact (HC in %) according to fishing periods.
B : Exemples of HC distribution values according to the bait type for fishing periods 1 and 4 (LS = large squids, S (Her) = squids mixed with herrings, Her (S) = herrings mixed with squids, Her (Sar) = herrings mixed with sardines, Sar (Her) = sardines mixed with herrings, Sar = sardines).

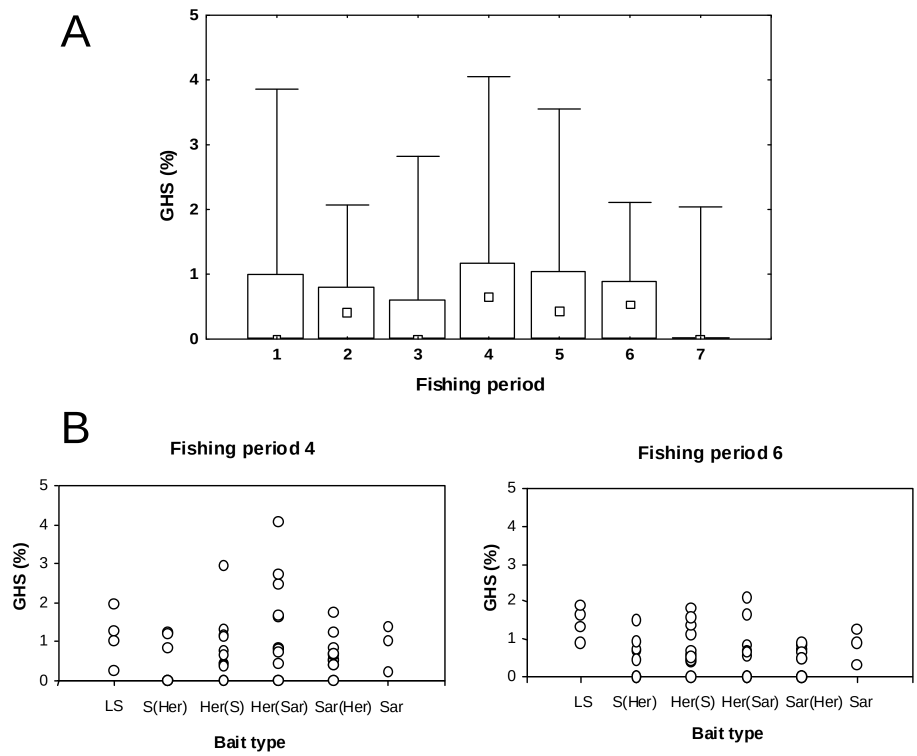

Figure 9 – A : Box plots of the global hooking success (GHS in %) according to fishing periods.
B : Exemples of GHS distribution values according to the bait type for fishing periods 4 and 6 (LS = large squids, S (Her) = squids mixed with herrings, Her (S) = herrings mixed with squids, Her (Sar) = herrings mixed with sardines, Sar (Her) = sardines mixed with herrings, Sar = sardines).

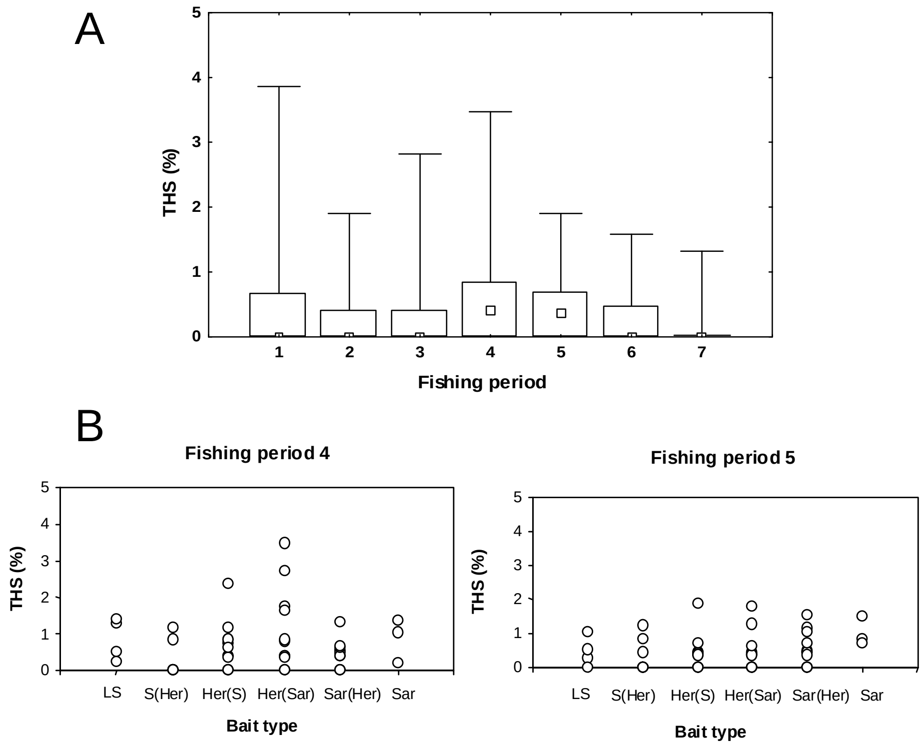

Figure 10 – A : Box plots of the tuna hooking success (THS in %) according to fishing periods.
B : Exemples of THS distribution values according to the bait type for fishing periods 4 and 5 (LS = large squids, S (Her) = squids mixed with herrings, Her (S) = herrings mixed with squids, Her (Sar) = herrings mixed with sardines, Sar (Her) = sardines mixed with herrings, Sar = sardines).

Discussion

The capture of an animal by a longline involves two main processes: (1) attraction by the bait through chemical and visual stimuli, (2) capture by the baited hook. The role of chemical stimuli in longline fishing efficiency and species selectivity has been shown by several authors (Yamaguchi *et al.*, 1983; Løkkeborg and Bjordal, 1992; Løkkeborg and Johannessen, 1992). When the fish is near the bait, its visual appearance (shape, size, mobility) determines the fish motivation to attack the bait (Sivasubramaniam, 1961; Atema *et al.*, 1980; Johannessen *et al.*, 1993). We therefore consider that the HC mainly represents the attraction process by chemical and visual stimuli from the bait, while the hooking success corresponds to the efficiency of the baited hook to effectively capture the predator after biting. The THS is a special case of GHS to examine if the pelagic longline is adapted to capture the target species of this fishery (*i.e.* tunas).
Combining all the different types of baits used in our study, our data show that an average of 10% of the baited hooks are contacted by predators. Results show that the different bait types tested in this study provide the same HC results, except for Her(Sar) that seem to attract more predators than LS and S(Her). This trend can be explained by the different textures of squids and fishes: fishes (sardines and herrings) might release more chemical stimuli than squids, which can lead to a lower attractive power of squids compared to fishes. Compared with other fishing gears in general, and with the bottom longline in particular, the pelagic longline does not appear to be an efficient fishing method. From bottom longline experiments with 845 hook timers, Sigler (2000) found a HC of 79%. Are these differences between bottom and pelagic longlines HC due to (i) different abundance or behaviour of predators, or (ii) different diffusion processes of chemical stimuli when baits are on the bottom or in pelagic waters? Independent observations of fish in the fishing area, from echosounding for instance (Bertrand and Josse, 2000), and captures by a longline would greatly contribute to better interpret this poor encounter rate between predators and fishing gear.

Among the contacted hooks, only 24% of them lead to a capture in average, among which 73% are tunas. Range values of our hooking successes (0.4-9% for the GHS and 0-8% for the THS) are in accordance with Boggs (1992) and Campbell *et al.* (1997) results.

There is no major difference in GHS or THS between the different types of baits used in this study. The fact that Her(Sar) attracts more fish than LS and S(Her) does not lead to more catches by this type of bait. The very high proportion of tunas captured in this study, as compared to other species, clearly shows that in the studied area (French Polynesia) and considering the setting strategy adopted during the experimental fishing sets, this fishing gear is well adapted to target tunas. No particular type of baits leads to more catches of tunas, which is not in accordance with old experiments (Shimada and Tsurudome, 1971).
However, our result can be explained by the fact that tunas are known to be opportunistic feeders (Kornilova, 1980; Sund *et al.*, 1981), which has been verified in the studied area, *i.e.* French Polynesia, from stomach content analyses (Bertrand, 1999). This is also confirmed by our observations of several baits in tuna stomachs: during fishing sets achieved with mixed bait types (herrings/squids and herrings/sardines), several tuna stomach contents comprised the two kinds of bait.
Considering that the different types of baits used in this study do not affect the hooking responses, the next step would consist in examining what other factors might affect the longline efficiency. For a given local predator abundance and given attractive stimuli by the bait, the feeding motivation of a predator can be considered as the major cause of variations of HC. It is very likely that the local prey abundance and its dynamics affect the feeding motivation of predators, and therefore the HC. Studies are clearly needed to further investigate the role of local prey abundance on HC. We assume that the HS might mainly depend on the shape of the hook, the texture of the bait and the predator behaviour. The selection of the shape of hook by fishermen results from a long term process and we can assume that fishermen have selected one of the most efficient shapes to capture large predators. The texture of the bait does not seem to play a major role as shown by our study. However, fine-scale observations of hooking processes are needed in order to determine the main factors responsible for success or failure in capture. Such fine-scale observations have been developed for demersal fishes (Løkkeborg *et al.*, 1989; 1995) but never for tunas or other large pelagic fishes. As the process of a longline catch necessitates an active behaviour of the predator, fishery biologists need to determine the different factors that affect the attraction then the capture of a predator by a hook in order to better interpret the commercial catches of longlines and find appropriate indices of abundance.

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