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Caracteristics of albacore (*Thunnus alalunga*) catches achieved by experimental fishing using instrumented longline in the French Polynesian Exclusive Economic Zone (EEZ)

P. BACH[*] , B. WENDLING[**] , R. ABBES[*] , E. JOSSE[**]

[*] ORSTOM, P.O. Box 529, Papeete, French Polynesia
[**] IFREMER, C/O ORSTOM, P.O Box 529, Papeete, French Polynesia

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INTRODUCTION

Longline fishery is a recent fishing activity used by French polynesian longliners in the polynesian EEZ since 1991. The size of the fleet has inceased regularly from 5 fishing units in 1991 to about 70 in 1995. Parallel to this development, three research institutes (*EVAAM: Polynesian Institute of research and development of marine activities, IFREMER: French Institute of research for the exploitation of the sea and ORSTOM: French Institute of research for the development in cooperation*) designed a research program to contribute to the management of fishing area and the development of fishing methods. With this aim, longline fishing experiments on field have been planned.
Principal objects of these experiments are:
i - studies of horizontal and vertical distributions of deep tuna resource in EEZ,
ii - behavior studies of deep tuna ressources in relation to the longline,
iii - studies of the movement of the fishing gear (longline) during the fishing,
iiii - effectiveness comparison of various baits regarding tuna target species.

For fishery biologists ans fishing professionals, the knowledge of the resource capturability is of importance. For the first ones, the determination of fishing mortality coeffcient depends on effective effort, proper correction of nominal efort. For the seconds ones, if we consider that the resource disponibility is constant, the increase of capturability will mean an improvement of the use of their fishing gear. For example, targeting specific depths can improve longline catches of desired species and reduce by catch for other species (Saito, 1975; Suzuki and Kume, 1982; Suzuki, 1989, Boggs, 1992). Several designs of our ffishing experiments have been planned according to this context.
The purpose of this paper is to expose the first results of fishing experiments using instrumented longline regarding alabacore catches. Catch variability will be discussed in relation to depth, temperature, fishing hour and main line conditions (rising, settled and sinking) variables.

MATERIALS AND METHODS

Fishing experiments using instrumented longline were conducted on board the ORSTOM oceanographic vessel N/O *Alis* in July and August 1993 (ECOTAPP cruise), July 1995 (ECOTAP01 cruise) and August 1995 (ECOTAP02 cruise). Sets were made in the French Polynesia EZ in the area delimited by the Societe Archipelago in the south and the limit of the EEZ in the north (Fig. 1).
Fishing gear, gear deployment, bait have been detailed in some reports published (Abbes et al., 1994; ECOTAP01, 1995; ECOTAP02, 1995). In general, longline was set in the morning (between 4:00 and 7:00 a.m.) and hauled in the afternoon (1:00 or 2:00 p.m.) The speed of main line deployment was about 200 m per minutes, the number of snap-on branch lines was 25 per basket and the number of baskets was variable between 7 (175 hooks) and 22 (550 hooks). Occasionally, some sets were made at night. In that case, the number of hooks deployed was lower than the one of daytime experiments. Hooks on the main line have a same spacing by timing precisely the attachment of snap-on branch lines on it.
Time intervals between two attachment varied between 12 and 16 seconds according to the set experiments planned.
Caracteristics of sets details are presented in the table 1.

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* ORSTOM, P.O. Box 529, Papeete, French Polynesia
** IFREMER, C/O ORSTOM, P.O Box 529, Papeete, French Polynesia

Table 1 - Caracteristics of fishing experiments during ECOTAPP, ECOTAP01 and ECOTAP02 cruises

Cruise	Date	Latitude S	Longitude W	Begin set	Basket Number	Hook number
ECOTAPP	24/06/93	14°06	145°13	06:20	15	370
"	25/06/93	13°14	144°07	06:05	16	397
"	26/06/93	12°22	143°02	06:10	16	390
"	27/06/93	11°35	142°06	06:00	16	389
"	28/06/93	10°48	141°03	06:05	16	387
"	29/06/93	09°57	140°03	06:00	15	371
"	30/06/93	09°18	139°18	06:00	15	359
"	01/07/93	08°01	137°41	06:00	20	496
"	02/07/93	06°46	137°17	06:12	20	496
"	03/07/93	07°22	136°55	06:00	19	455
"	04/07/93	08°41	138°29	06:01	20	498
"	05/07/93	09°40	138°26	06:00	20	500
"	09/07/93	09°52	138°58	06:15	16	399
"	10/07/93	09°22	140°15	05:59	15	361
"	11/07/93	09°30	141°10	06:00	15	371
"	12/07/93	08°12	141°04	06:00	15	372
"	13/07/93	08°43	140°21	04:01	15	375
"	18/07/93	08°32	139°17	06:00	17	423
"	27/07/93	15°34	146°30	06:42	8	185
"	29:07/93	14°51	147°39	06:07	8	180
"	02/08/93	16°38	151°04	22:38	8	197
"	07/08/93	16°26	152°11	04:18	7	175
"	08/08/93	16°27	151°54	23:31	8	191
"	10/08/93	16°53	151°36	00:37	10	237
"	11/08/93	16°33	151°24	00:27	10	237
"	13/08/93	17°32	149°12	06:19	6	133
ECOTAP01	11/07/95	19°19	150°31	06:30	18	450
"	12/07/95	19°20	151°26	06:10	23	570
"	13/07/95	19°31	152°29	06:07	22	549
"	14/07/95	18°29	153°04	06:05	22	549
"	15/07/95	17°05	152°31	06:12	19	461
"	16/07/95	17°05	153°10	06:01	22	542
"	17/07/95	15°45	152°25	06:06	22	549
"	18/07/95	15°45	151°51	06:05	21	527
"	19/07/95	16°06	149°48	06:00	21	521
ECOTAP02	28/07/95	12°37	145°20	06:12	20	499
"	29/07/95	11°56	144°51	05:44	20	500
"	30/07/95	11°42	143°06	05:36	20	499
"	31/07/95	11°22	142°20	05:37	20	500
"	01/08/95	09°43	143°17	05:34	20	499
"	02/08/95	08°26	143°36	05:32	20	500
"	03/08/95	07°06	143°13	05:46	20	500
"	04/08/95	06°14	142°20	05:35	20	500
"	05/08/95	05°15	141°00	05:36	20	500
"	06/08/95	06°04	141°04	05:34	20	500
"	07/08/95	07°45	141°15	05:32	20	500
"	08/08/95	08°30	140°50	05:26	20	499
"	12/08/95	07°59	139°49	05:33	20	500
"	13/08/95	07°09	139°50	05:33	21	524
"	14/08/95	05°25	138°57	05:34	22	550
"	15/08/95	07°59	138°17	05:31	22	550
"	16/08/95	06°48	137°26	05:30	22	550
"	17/08/95	07°30	137°21	05:31	22	551
"	18/08/95	09°37	136°26	05:31	22	550
"	19/08/95	10°36	137°19	05:36	22	550
"	20/08/95	12°11	138°40	05:31	22	550
"	21/08/95	12°30	139°59	05:37	22	550
"	22/08/95	12°55	141°30	05:32	22	550

Set depths

The maximum depth of the main line and therefore the fishing depth is modified by the action of different factors. A first group of factors correspond to the strategy of main line deployment and depends on the speed of the boat, the speed of the shooter (thrower speed) which have an effect on the slack of the main line. This slack may be quantified by the sagging rate equal to the horizontal disance between floats divided by the length of the main line per basket (Suzuki et al., 1977). A second group of factors are exogenous factors such as wind and currents (Boggs, 1992). Set parameters allow the calculation of the theoritical detph for each basket assuming a catenary shape (Yoshihara, 1954). As a matter of fact, is it proved that theoritical depth overestimate the true value of the depth (Boggs, 1992).
Then, the depth of several basket for each set was recorded with time depth recorders (Wildlife Computers, model MK3e and Micrel, model LL600) programmed to sample depth once per minute. In general, time depth recorders (TDRs) were attached to record the maximum depth between branch lines n° 12 and n° 13. To analyse the shape of the main line, two additionals TDRs were attached between branch lines n° 4 and 5, and branch lines n° 8 and 9. We assume the symmetry of the main line, then, shapes of the main line between hooks n° 1 to 12 and n° 25 to 13 are similar. For the basket without TDR, the maximum depth of the main line is estimated by the mean of values observed on TDRs located on baskets which flank it.
Moreover, TDRs records allow to calculate the fishing time of each hook, whichcan be used to calculate the fishing effort.

Hook depths

The hook depths have been estimated using a modelling of the shape of the main line (Wendling, 1994). This modelling is in progress and we describe here the principle of hook depth calculation.
The shape of the mainline is described for the basket equipped with three TDRs. Data are available for 5 baskets where distances between buoys were 800 meters to 900 meters and maximum depths were 220 meters to 500 meters (Fig. 2).
The aim of the modelling is to adjust a model to the depth values observed for the first half part of the main line. Depth values for the second half part of the curve is obtained by symmetry.
Five models were adjusted : power, exponential, logarithmic, parabolic and asymptotic with a non linear least squares method (NLIN procedure of SAS Software).

The best model f(D) in term of explained variance is the asymptotic model. Its algebric expression is:

$$f(d) = P_i = P_\infty * (1 - \exp(-K * d_i)) + \varepsilon_a \quad \textbf{(1)}$$

where:

P_∞ and K are the parameters of the model,
P_i = depth of the main line for the hook i at a linear distance from the buoy d_i,
d_i = linear distance between the hook i and the buoy,
ε = residual term of error.

The analysis of the graph between studentized residuals (ratio of the residual to its standard error) for the 5 models (one parametrization for each curve) and the distance shows a strong sinusoidal trend (Wendling, 1994). To avoid the estimation bias of the dependent variable, a model between studentized residuals and the distance has been adjusted.
The new expression g(D) of the depth D_i is:

$$g(d) = P_i = P_\infty * (1 - \exp(-K * d_i)) + f(s_{res}, d_i) + \varepsilon_b \quad \textbf{(2)}$$

where
s_{res} = mean of standard errors of residuals,
ε_b = errors normally distributed.

The calculation of the depth of a hook position using the asymptotic model is developed in appendix.

Hook timers

The hook timer is a little device on the branch which carry out to know the capture time of a fish or the
strike time caracterised by a triggered timer and the absence of the bait on the hook or the presence of bites on the bait. This device have been described by Boggs (1992) and those used in our cruise have been made using the same design. Hook timer is made of a plastic resin cast around a battery-powered microchip clock by a magnet and is attached between the snap and the branch line. When a fish strikes the hook, the magnet pulls out and triggers off the timer. During the ECOTAPP cruise the magnet holding in the resin were realised with a screw but it is very difficult to control the pressure of the screw on the magnet and for the next cruises a rubber band around the hook timer took the place of the screw (Fig. 3).

Fishing effort and catch data

To analyse the effect of the fishing time on catches, we have computed the fishing effort deployed for a given time interval. A time interval of one hour has been selected. The unit of the fishing effort is the number of active hooks per fishing hour. It is equal to the sum of the number of hooks that have been x minutes in the water. For a better understanding, a example is exposed below.

A longline with 12 baskets and 25 hooks per basket is deployed at 1 o'clock p.m.. Deployment and retrieval times for each basket are respectively 15 minutes and 10 minutes.
For the first fishing hour, the fishing effort is:
hook number per basket x fishing time for each basket/ periode of time (in this case 60 minutes) =
25 * (45+30+15+0) / 60 = 37.5 hooks.

For the second fishing hour, the fishing effort is:
the hook number in the water after the first hour and the hook number deployed during the second hour =
(25 * 4) + [25 * (45+30+15+0) / 60] = 137.5 hooks.

At the end of longline deployment, the number of hooks per hour is 300.

While rising, the inverse calculation is realised:

During the first hour of the longline recovery, the fishing effort is:
300 - [25 * (50+40+30+20+10)] = 237.5 hooks.

During the second hour of the longline recovery, the fishing effort is:
300 - (25 * 6) - [25 * (50+40+30+20+10)] = 87.5 hooks.

CPUE of albacore tuna using this fishing effort unit have been calculated to study their variability during fishing time.

Oceanographic data

For each set, environmental conditions in the fishing area are obtained from SBE19 SEACAT profiler casts. For each oceanographic station, the vertical structure of 4 parameters is recorded between the surface and 600 meters depth : temperature, salinity, oxygen and ligth intensity (PAR)
For the calibration of TDR pressure and temperature sensors, TDR have been attached to the profiler and deployed until 500 meters depths.

During the cruise, a thermosalinograph Sea-Bird SBE21 sample every 5 minutes the sea surface temperature (SST) and the sea surface salinity (SSS). Data collected are recorded on the hard disk of a portable computer.

FIRST RESULTS WITH EMPHASIS ON ALBACORE CATCHES

Catches and CPUE variabilities

Description of global catches (tabl. 2)

Twenty six longline sets caught a total of 259 fish (7,713 kg) in 1993 (ECOTAPP cruise). During ECOTAP01 and ECOTAP 02 cruises, a total of 338 fish (8,911 kg) has been caught by 32 longline sets. For ECOTAPP the hook number was 8,944 (6,700 hook timer). For ECOTAP01 and ECOTAP02 16,689 hook timers have been used. Sizes of albacore catches and theirs contributions for the total and tuna catches are reported in table 2.
Intervals of individual weights were 15 kg and 26 kg (ECOTAPP) and 12 kg and 31 kg (ECOTAP01 + ECOTAP02). Mean weights were 21 kg (ECOTAPP) and 22.2 kg (ECOTAP01+02) that corresponds to a focal length of about 100 cm.

Table 2 : Some results of ECOTAPP and ECOTAP01+02 cruises with regard to albacore catches

Cruise	Set Number	Hook Number	Total catch weight(kg) [number]	Albacore catch weight(kg) [number]	Albacore/Total % in weight [% in number]	Albacore/Tuna % in weight [% in number]
ECOTAPP	26	8,944	7,713 [259]	1,155 [55]	15 [21.2]	37.1 [45.5]
ECOTAP01+02	32	16,689	8,911 [338]	2,065 [93]	23.2 [27.5]	43.2 [47]

The catch per unit effort of albacore in number/100 hooks varies from 0.61 (ECOTAPP) to 0.55 (ECOTAP01 and ECOTAP02). CPUE in weight(kg)/100 hooks varies from 12.9 (ECOTAPP) to 12.37 (ECOTAP01 and ECOTAP02).
CPUEs (kg/100 hameçons) from ECOTAP cruises are similar. Difference with CPUEs from asiatic (Japan and Corea) longliner fleets is important, on an other hand, CPUE of Polynesian longliners are just listen higher (tabl. 3).

Table 3 : Comparison between albacore CPUEs (kg/100 hooks) in French Polynesia EEZ

ECOTAP cruises	Japanese longliners[1]	Corean longliners[1]	Polynesian longliners[2]
12.56	1.88	5.66	14.2

1 - Fishing statistics from 1984 to 1992
2 - Fishing statistics from 1991 to 1993 (from EVAAM)

A possible reason for explaining this variability of CPUE between fleets is the difference between the fishing area of these fleets (Nakano and Bayliff, 1993; Chabanne et al., 1993; Abbes et al., 1995, Thiriez, 1995). For Japanese longliners, the target species is the bigeye exploited in the North East of the Marquesas Archipelago in the EEZ. Corean longliners until 1991 were principally concentrated in the South and the North West of Marquesas Archipelago. En general, the yellowfin tuna was dominant in catches. The activity of Polynesian longliners is principally localised at the West of 144°W, but we observe too a spreading activity between Societe and Marquesas archipelagos. Our fishing experiments were conducted in the same area.Therefore it can explain the slight difference between Polynesian longliners and ECOTAP CPUEs.

Capture depths and temperatures

This analysis relates to albacore tuna of which the capture depth has been confirmed by the lecture of hook timer. Fish have been arranged in classes of 50 meters and 3°C. Results for each cruise are reported on the figure 4.

Distributions of the number of albacore caught by depth intervals during ECOTAPP and ECOTAP01+02 show a strong difference. The mean of capture depths obtained from data of ECOTAPP is lower (Fig. 4A). This result is independant of vertical temperature structure that have been homogeneous for the two cruises. According to that, the mean of capture temperatures for ECOTAPP is higher (Fig. 4B).

Interpretations of these results could be find in the analysis of either the variability of catches durind the fishing time or the variability of catches regarding to the condition of the main line (sinking, settled or rising).

For ECOTAPP, Wendling (1994) shows that the distributions of the fish number caught by depth intervals observed for bigeye and albacore are significatively differents (non parametric test of Kolmogorov-Smirnov), but for yellowfin and albacore the null hypothesis that the means of the two distributions are equal is accepted.

Variability of albacore CPUE during the fishing time

Effort (hook number/hour) distributions for ECOTAPP and ECOTAP01+02 are reported on the figure 5.

Effort distributions differ only by their scale higher for ECOTAPP for which some sets were made at night. CPUEs (fish number/hook/hour) distributions are presented on the figure 6. For ECOTAP01+02, CPUEs are more or less the same except for the class 3:00 to 4:00 hours p.m that could be an effect of the rising of the longline. Nevertheless, a trend of CPUE decrease when the line is settled is observed (between 9:00 a.m. to 1:59 p.m). This trend is not observed during ECOTAPP for which the variability of CPUE is high.

Albacore catches regarding to the mainline conditions (sinking, settled, rising)

ECOTAPP and ECOTAP01+02 results of the percentage of albacore catches regarding to the main line conditions (sinking, settled, rising) are approximately the same. Respectively 32% and 28% of albacore catch number have been obtained while sinking and rising. These contribtuions are more important if we consider that rising and sinking periods represent only an average of fishing effort.

Figure 6 shows too that the catch contrbition are higher during sinking period. Knowing that the longline was set early in the morning (between 4:00 and 7:00 a.m.), we think these results could be interpreted in relation to the vertical movement of tuna, pecularly at sunrise and sunset, as shown by acoustic telemetry tagging (Holland *et* al., 1990; Cayre and Marsac, 1993). If nightime and daytime depth distributions of albacore are differents as proved for yellowfin, then, variations of catch contributions between sinking and rising periods could be explained by the migration between habitat depths. Then, new fishing experiments can be conducted such as the sinking period correspond to the migration habitat depths at sunset.

Are there strong differences between tuna catch caracteristics

Tuna (albacore, bigeye and yellowfin) catches from ECOTAPP and ECOTAP01+02 have been considered regarding to 5 parameters describing their catch : fishing station (geographical criteria), depth, temperature, capture time, main line condition at the capture (settled, rising or sinking).

Only data from aytime fishing experiments have been analysed. This concerns 92 fishes for ECOTAPP (39 albacore, 24 yellowfin, 29 bigeye) and 156 fishes for ECOTAP01+02 (80 albacore, 21 yellowfin and 55 bigeye).

A discriminant analysis of these two data matrices has been performed. The higher value of the pseudo-F compared with the Fisher statistic confirms the homogeneity of the 3 species groups we choose as assumption regarding to the discriminant parameters (tabl. 4).

For ECOTAPP and ECOTAP01+02, the first two discriminant axis (that is a linear combination of parameters) explain 60% and 47% of the data variability respectively (tabl. 4). The total contribution of geographic and "habitat" parameters is about 80%. Figure 7A and B show individual and group coordinates on discriminant axis 1 and 2. Mahalanobis statistic confirms the homogeneity for the albacore group. For ECOTAPP and ECOTAP01+02, percentages of good arrangements for albacore are 79.5% and 74% respectively (tabl. 5).
In conclusion, results of discriminant analysis seems to confirm those obtained through observations of the spatial variability of tuna catches in polynesian EEZ (cartography of catch data of asiatic longliners, Chabanne *et al.*, 1993). Then, if we want show a possible effect of main line conditions or habitat migration on catches by species, spatial parameters can be eliminated in the analysis will perform in the future.

Table 4 : Pseudo-F and % of variance associated to the first two discriminant axis

	ECOTAPP		ECOTAP01+02	
Axis	% of variance	Pseudo-F	% of variance	Pseudo-F
1	46.6	21.2	30	23.1
2	12.5	5.2	17	13.2

Table 5 : % of good arrangements by species (=by group) obtained by the discriminant analysis

	ECOTAPP	ECOTAP01+02
ALBACORE	79.5	74
YELLOWFIN	45.8	47
BIGEYE	55.2	68

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APPENDIX

Calculation of hook depths using the aymptotic model

The depth of a hook position depends on the length of the main line that have been deployed until its attachment. Hook positions are controlled by timing the attachment of the snap, then, the length of the main line between them (lh) is constant and equal to:
lh = [lt/[number of hooks+1)] where lt = total length of a main line of a unit basket.

The linear distance that corresponds to the first half part of the curve describing the main line is D. This value is divided by n linear elements (for example n = 400). The linear distance of an element from the buoy is δ_k. For this distance, the depth of the main line is calculated using expression **(1)**:.

$$P_k = P\infty * (1 - \exp(-K * \delta_k)) + f(s_{res}, \delta_k) + \varepsilon_b \quad \textbf{(1)}$$

For the distance of the element k + 1, the depth of the main line is:

$$P_{k+1} = P\infty * (1 - \exp(-K * \delta_{k+1})) + f(s_{res}, \delta_{k+1}) + \varepsilon_b \quad \textbf{(2)}$$

The length $l_{k,\,k+1}$ of the deployed main line between element δ_k and δ_{k+1} is:

$$l_{k,\,k+1} = \sqrt{[\delta_{k+1} - \delta_k]^2 + [P_{k+1} - P_k]^2} \quad \textbf{(3)}$$

The length of the first half part of the main line deployed is equal to the sum of the length of elements
$l_{k, k+1}$:

$lt/2 = \Sigma\, l_{k, k+1}$ with k=0 to 399

Then; the length of the main line between hooks lh is equal to (4):

$lh = \sqrt{[\delta_{k+1} - \delta_k]^2 + [P_{k+1} - P_k]^2}$ **(4)**

The depth of each hook on the first half part of the main line will be calculated using the two expressions of lh:

a) lh = [lt/[number of hooks+1)] with $lt/2 = \Sigma\, l_{k, k+1}$

b) $lh = \sqrt{[\delta_{k+1} - \delta_k]^2 + [P_{k+1} - P_k]^2}$

The expression (4) has one value unknown which is δ_{k+1}.
lh is known as lh = [lt/[number of hooks+1)],

To resolve the equation (6), we need to estimate δ_{k+1}.
This estimation depends on the resolution of the equation (5)

$lh^2 = [\delta_{k+1} - \delta_k]^2 + [P\infty * (1 - \exp(-K * \delta_{k+1})) - P\infty * (1 - \exp(-K * \delta_k))]^2$ **(5)**

For the hook n°1, we have $\delta_k = 0$ and $P_k = 0$

The solution is calculated by an iterative process which minimize the difference
$T = \sqrt{A} - lh^2$
with
$A = [\delta_{k+1} - \delta_k]^2 + [P\infty * (1 - \exp(-K * \delta_{k+1})) - P\infty * (1 - \exp(-K * \delta_k))]^2$
$lh^2 = [lt/[\text{number of hooks}+1)]^2$ with $lt/2 = \Sigma\, l_{k, k+1}$

The value of δ_{k+1} at the iteration p corresponding to the solution is such as $0 < |T| < 0.1$.

The depth of the branch line attachment of the hook n°1 (P_1)is calculated using the expression (4). The depth of the hook is obtained by adding P_1 and the length of the branch line.

P1 and δ_{k+1} values are used to estimate coordinates values δ_{k+1} and P2 of the hook n°2.

This process is realized to calculate the depth of hooks n°1 to n°13. Depth values for the second half part of the main line are obtained by symmetry (n°14 replicates n°12, n°15 replicates n°11,........n°25 replicates n°1).