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WHY THE NUMBER OF HOOKS PER BASKET (HPB) IS NOT A GOOD PROXY INDICATOR OF THE MAXIMUM FISHING DEPTH IN DRIFTING LONGLINE FISHERIES ?

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SUMMARY

The effects of targeting in longline fisheries have major impacts on CPUE (catch per unit effort). To target large pelagic fishes in longline fisheries, fishermen deployed several tactics according to the target species. For a given species, the tactic depends on both the season and the fishing ground. One of major aims of the fishing tactic is to set the longline for optimizing the overlap between the distribution of hook depths and the supposed preferential vertical habitat of the target species. Thus, the maximum fishing depth (MFD) of the longline is recognized as a key parameter for estimating the distribution of hook depths and then to standardize fishing effort. In this context, the number of hooks per basket (HPB) is commonly used as a proxy indicator of MFD (this information has been collected for the Japanese longline fishery since 1975). Unfortunately HPB is not a good proxy indicator of MFD. In the first part of this work we illustrate why our previous affirmation is consistent from a theoretical point of view. Second, we analyse depth series recorded with time depth recorders (TRDs) at the deepest point of the mainline (data collected during instrumented longline experiments carried out in the French Polynesia EEZ, central South Pacific). We observe variations of depths recorded during the soak time and we compare the calculated mean depth of depth series with the theoretical MFD (catenary formula). The mean depth appears as the better proxy indicator of the MFD which can be used to estimate the distribution of hook depths. Finally, we discuss relevant data which must be collected by both observers and fishermen in order to improve analysis of the fishing effort in longline fisheries. These data are crucial to standardize appropriately longline CPUE and to correct for potential bias. Statistical models (even the most sophisticated, such as habitat based model, GLM, GAM, GLMM or neural networks) could not supplant for the lack of such input information.

RÉSUMÉ

La recherche d'espèces cibles dans les pêcheries palangrières a des conséquences majeures sur les estimations et les analyses de la capture par unité d'effort. Pour cibler les grands pélagiques avec une palangre, les pêcheurs déploient des tactiques de pêche qui dépendent de l'espèce recherchée. Pour une espèce donnée, la tactique mise en œuvre dépend de la saison et de la zone de pêche. Un des objectifs majeurs de la tactique sélectionnée consiste à filer la ligne pour optimiser la superposition entre les hameçons et l'habitat vertical de l'espèce. Ainsi, la profondeur maximale de pêche est considérée comme un paramètre clé pour l'estimation de la distribution de la profondeur des hameçons et la standardisation de l'effort de pêche. Dans ce contexte, le nombre d'hameçons par élément est généralement utilisé comme indicateur de la profondeur maximale de pêche (informations collectées par la pêcherie palangrière japonaise depuis 1975). Malheureusement, le nombre d'hameçons par élément n'est pas un bon indicateur de cette profondeur. Dans la première partie de ce travail, nous montrerons pourquoi cette affirmation est valide d'un point de vue théorique. Ensuite, nous analysons des données de profondeur collectées avec des enregistreurs de profondeur placées au point supposé mesurer la profondeur maximale de pêche (données collectées lors de pêches avec une palangre instrumentée réalisée dans la ZEE de Polynésie Française, Centre du Pacifique Sud). Les variations de la profondeur pendant le temps de pêche sont discutées et nous comparons la moyenne des profondeurs avec la profondeur maximale calculée à partir de la formule du

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modèle caténaire. Cette moyenne est le meilleur indicateur de la profondeur maximale de pêche qui peut être utilisé pour estimer la distribution des profondeurs des hameçons. Enfin, nous discutons sur la nature des données qui doivent être collectées par les observateurs embarqués et par les pêcheurs professionnels pour améliorer les analyses de l'effort de pêche des pêcheries palangrières. Ces données sont indispensables pour l'amélioration de la standardisation des captures par unité d'effort car la rigueur des approches statistiques utilisées dans le cadre de la standardisation de l'effort (modèles basés sur l'habitat, GLM, GAM, GLMM, réseaux neuronaux) ne peut remplacer la précision de l'information de base.

RESUMEN

El direccionamiento hacia especies objetivo en las pesquerías palangreras tiene consecuencias importantes en las estimaciones y los análisis de captura por unidad de esfuerzo. Para dirigir su actividad con palangre hacia los grandes pelágicos, los pescadores tienen que desplegar tácticas de pesca que dependen de la especie objetivo. Para una especie determinada, la táctica utilizada depende de la temporada y zona de pesca. Uno de los principales objetivos de la táctica seleccionada consiste en calar la liña para optimizar la superposición entre los anzuelos y el hábitat vertical de la especie. De este modo, la profundidad máxima de pesca se considera un parámetro clave para estimar la profundidad de los anzuelos y la estandarización del esfuerzo de pesca. En este contexto, el número de anzuelos por canasta (HPB) se utiliza generalmente como indicador de la profundidad máxima de pesca (información recopilada por la pesquería palangrera japonesa desde 1975). Lamentablemente, el número de anzuelos por canasta no es buen indicador de esta profundidad. En la primera parte de este trabajo mostraremos por qué esta afirmación es válida desde un punto de vista teórico. A continuación analizamos los datos de profundidad recopilados con registradores de profundidad (TRD) colocados en el punto en que se supone que se mide la profundidad máxima de pesca (datos recopilados durante operaciones de pesca con un palangre equipado con instrumentos en la ZEE de la Polinesia francesa, centro del Pacífico sur). En este documento se debaten las variaciones de profundidad registradas durante la pesca y se compara la profundidad media con la profundidad máxima teórica calculada mediante la fórmula catenaria. Esta profundidad media parece ser el mejor indicador aproximado de la profundidad máxima que puede utilizarse para estimar la distribución de profundidades de los anzuelos. Finalmente, se debate el carácter de los datos que deben recopilar los observadores embarcados y los pescadores profesionales para mejorar los análisis del esfuerzo de pesca de las pesquerías palangreras. Estos datos son indispensables para mejorar la estandarización de las capturas por unidad de esfuerzo del palangre y para corregir posibles sesgos, ya que el rigor de los enfoques estadísticos utilizados en el marco de la estandarización del esfuerzo (incluso los más sofisticados, como modelos basados en el hábitat, GLM, GAM, GLMM, redes neuronales) no pueden cubrir la ausencia de dicha información de base.

KEYWORDS

Longline, Targeting, CPUE, Fishing effort

1 Introduction

The pelagic longline is the oldest fishing gear targetting mostly tuna and swordfish in the pelagic environment around the world. Longlines are strings of hooks deployed along distances of several tens of miles and maintained at the surface by buoys regularly disposed along the mainline. The well known longline fishing unit called "basket" corresponds to a longline section delimited by two buoys. Several factors govern the efficiency of the fishing operation however one of major factors is the overlap between the vertical distribution of the hooks and the vertical distribution of the individual fishes targetted. Then, the interaction between the resource abundance and the longline fishing efficiency depends on the vertical distribution of hooks. This interaction corresponds to "the catchability coefficient": a major parameter in the quantification of the fishery impact on the exploited resources. The existence of possible variations in the longline catchability has stimulated the development of the habitat based model approach. In this approach the standardization of longline catch per unit effort (CPUE) takes into account the vertical habitat of the target species. The estimation of the impact of longlines on the resource is traditionaly related to the distribution of hook fishing depths as longline catch patterns clearly show that the species selectivity for longlines depends on the depths of the fishing operations (Yang and Gong, 1987; Boggs, 1992; Nakano et al., 1997).

In order to control the hook fishing depths into a specific fishing spatial and time strata fishermen try to reach a given maximum fishing depth (MFD). Different fishing tactics can be implemented in order to reach this objective:

(1) a modification of the length of floatlines and/or branchlines, however this modification has a minor impact on MFD variations (except for surface fisheries as swordfish fisheries).

(2) adjustments of the degree of the sagging of the mainline, the horizontal distance between floats (DBF) and the length of the mainline between floats (LLBF). The degree of sagging is measured by the shortening or sagging rate (SR) defined as the ratio between DBF and LLBF (*cf*. **Figure 1**).

Numerous works analysing longline catches according to the sampled habitat consider the HPB has a proxy indicator of the MFD. This approach is widely developed in the frame of habitat based model to estimate effective longline fishing effort (Hinton et Nakano, 1996; Bigelow et al., 2002; Goodyear et al., 2003) and then to infer the vertical variation of catchability for some large pelagic stocks (Ward and Myers, 2005).

The choice of the HPB as a proxy of the MFD is likely based on the fishing practice described in the Japanese longline vessels (Yamaguchi 1989a; 1989b). For a given set, it makes sense to assume that the MFD depends on the HPB. This assumption is quite well verified at small scale levels (from 1 to 3 baskets). At the set level local current shears may modify the expected result. However, this assumption can not be extrapolated at a fishery level composed by boats of different characteristics and using different fishing strategies (line materials, vessel speed, line setter speed, floatline length, branchline length, time interval between hooks) depending on fishing areas and oceanographic conditions. Some recent studies analysing the longline behaviour by using time depth recorders have shown that MFD is influenced by a large number of factors apart the HPB (Boggs, 1992; Mizuno et al., 1998, 1999).

With the aim to show why the HPB is a poor proxy indicator of the gear configuration used to quantify the distribution of hooks in the water column and to estimate effective longline effort, we have broken down this paper in the following sections. In section 2, we briefly present the well-known catenary formulation of a longline basket in order to show why from a theoretical point of view the HPB is a poor proxy indicator of the MFD. In section 3, we discuss on information of the fishing tactic. In section 4, from depth data coming from time depth records collected during longline fishing experiments we analyse "the behaviour" of the maximum fishing depth located at the mid-distance of the mainline for a given basket. Theoretical depths and parameters of distributions of depths recorded on field are compared in terms of robustness. Finally, in the last section we suggest what type of useful data must be collected routinely during longline fishing operations in order to estimate a proxy indicator of the maximum fishing depth during the soak time.

2 Maximum fishing depth and distribution of hook depths according to the catenary geometry

The theoretical depth of a hook j can be estimated by using the catenary geometry (Yoshihara, 1951, 1954; Suzuki et al., 1977):

$$D_j = LF + LB + (LLBF/2) * \{(1 + \cot^2 \varphi)^{1/2} – [(1 – (2j / N))^2 + \cot^2 \varphi]^{1/2}\} \qquad (1)$$

and

$$SR = DBF/LLBF = (\cot \varphi) * \ln [(\tan(45° + \varphi /2)] \qquad (2)$$

where D_j is the depth of the jth hook, LF is the length of the floatline, LB is the length of the branchline, LLBF is the length of the mainline between two consecutive floats (basket), N is HPB + 1, j is the jth hook from the floatline, φ is the angle between the horizontal and the tangential line of the mainline, SR is the sagging rate and DBF is the horizontal distance between floats. The angle φ is estimated by iteration of the sagging rate from the formula (2), (**Figure 1**).

The formula (1) can be modified in order to estimate the depth D_j for any hook j located at a distance dbf_j from the float. The depth D_j can be calculated by using the formula :

$$D_j = LF + LB + (LLBF/2) * \{(1 + \cot^2 \varphi)^{1/2} – [(1 – (2*dbf_j / DBF))^2 + \cot^2 \varphi]^{1/2}\} \quad (3)$$

At the mid-point of the basket mainline (i.e. the point where dbf_j = DBF/2 or j = N/2), expressions (1) or (3) are written as :

$$D_j = LF + LB + (LLBF/2) * \{(1 + \cot^2 \varphi)^{1/2} – (\cot^2 \varphi)^{1/2}\} \qquad (4)$$

or

$$\{(D_j – (LF + LB)\}/LLBF = \{(1 + \cot^2 \varphi)^{1/2} – (\cot^2 \varphi)^{1/2} \}/ 2 \qquad (5)$$

Assuming that the depth at the mid-point of the basket mainline corresponds to the maximum fishing depth (MFD), the formula (5) clearly shows that the ratio between the theoretical MFD and the length of the mainline between floats only depends on the angle φ (i.e., the sagging rate). Consequently, this implies that for given values of LF and LB, a sagging rate value defines one unique relative theoretical MFD according to the LLBF (**Figure 2A**). Then, an equivalent relationship can be drawn between the ratio MFD/LLBF and the sagging rate (**Figure 2B**).

3 The number of hooks per basket (HPB) and others gear configuration data: what type of data are useful to estimate the MFD ?

In this section we assume that only some parts of the fishing operation are registered.

A – Only HPB is available

As developed above, when FL, BL and SR are known the number of hooks per basket (HPB) can be estimated and used as a proxy of the theoretical maximum fishing depth only if HPB corresponds to a given value of the length of the mainline between floats (i.e. a constant distance of the mainline between hooks). In contrast, without data describing the configuration of the gear the estimation of the theoretical MFD according to HPB can not be obtained. A difference of 200 m between theoretical MFDs is calculated for extreme fishing tactics as showed in the example presented on **Figure 3**.

In such a situation, HPB is only useful for estimating the nominal fishing effort at a fishing set level and only when the number of baskets is available. However, the total number of hooks at the set level is a common data recorded on logbooks. This is the unit of the longline fishing effort commonly used by tuna fishing agencies for both analyses of time/space variations of tuna longline CPUE and abundance indices in stock management purposes.

B – HPB and SR information is available

The sagging rate (an indicator of the angle between the horizontal and tangential line of the mainline) is a dimensionless parameter which corresponds to (i) the ratio between the horizontal distance between floats and the length of the mainline between floats or (ii) the ratio between the speed of the boat and the line shooter speed.

This parameter is an indicator of the shape of the mainline (concavity), but unfortunately, even used with HPB information, it can not produce a proxy indicator of the MFD. Indeed, for a given SR the theoretical MFD depends on LLBF (**Figure 4**).

However, because modifications of SR are commonly used to target different depth strata, SR data could be helpful to classify set operations into large depth categories such as : surface (0.99 < SR < 0,9), intermediate (0,9 < SR < 0,7) and deep (0,7 < SR).

C – HPB and LLBF

The length of the longline between successive floats (i.e. the length of the longline per basket) can be informative in terms of the fishing distance prospected by the longline (if the number of baskets and/or the total number of hooks are available). Nevertheless, once again LLBF and HPB together can not be used to perform a proxy indicator of the MFD. Indeed, for a given LLBF the theoretical MFD depends on SR (**Figure 5**).

D – Others information of the gear configuration

The others two parameters involved in the theoretical formulation of longline depths are the length of the floatline and the length of branchline. According to the catenary shape (equation 4 or 5), the lack of these parameters are responsible of a relative error on the estimation of the theoretical MFD (which depends on LLBF for a given SR ; **Figure 6**). For both the length of the branchline (LB) and the length of the floatline (LF), these relative errors are LB/LLBF and LF/LLBF, respectively. From a theoretical point of view, it must be stressed that relative errors decrease as LLBF increases. In addition, for a given LLBF the relative error declines rapidly for SR values ranged between 0.99 and 0.8. This result is directly related to the shape of the relationship between MFD/LLBF versus SR (**Figure 2 B**). Otherwise, if the length of the floatline and/or the length of branchline are unknown, an error related to both LLBF and SR can be applied for the estimation of the MFD and hook depths.

4 The maximum fishing depth and hook depths during the soak time

In this section we analyse longline depths data recorded in the middle of the mainline of a basket which has been assumed as being the deepest point of the mainline. The "maximum fishing depth" can not be characterized by a constant but appears rather as a distribution of values ranged between a maximal and a minimal depth (**Figure 7**). Currents, sagging variations during the soaking time and movements of the fish after bitting the bait are major factors explaining the variability of this parameter (Boggs, 1992; Mizuno et al., 1998).

According to the variability of this parameter, it seems reasonable to consider that the mean depth of the depth distribution is more representative of the vertical amplitude of the longline fishing than the maximum fishing depth.

With these considerations in mind, we present TDRs data collected in the framework of instrumented longline experiments carried out in the South Pacific (French Polynesia) during the ECOTAP Research Program. For all these fishing experiments, 25 hooks per basket were deployed. In the first time we calculate variations of the depth recorded for the supposed deepest point of the mainline. Second, we compare the mean depth observed during the soak time and the theoretical maximum depth. Finally, we show that the catenary shape model appears as robust enough to describe the relationship between the mainline length, the sagging rate and the mean value of depths recorded in the middle of the mainline.

A – Presentation of longline fishing experiments and depth data

The instrumented longline deployed for fishing experiments was a nylon monofilament mainline with a 3.5 mm diameter stored on a drum and settled with a line shooter. During fishing operations a transmitter buoy was attached at each end of the mainline. At regular time interval, 20 m polypropylene floatlines were disposed on the mainline to maintain the gear at the sea surface. Monofilament branch lines of 2 mm diameter and 12 long were snapped at a constant time interval for a given set. For each set, at least 50% of baskets were equipped with TRDs programmed to record fishing depth once per minute. The TDRs were positioned with two snaps at the mid-point of the basket mainline. For each set, the distance between floats (DBF) has been calculated by the ratio between the great circle distance of the longline and the number of baskets. The longline length between

floats (LLBF) has been estimated by multiplying the shooter speed measured with a tachometer and the respective basket setting time, and for each basket the corresponding sagging rate value has been calculated.
For each set the number of basket per set, LLBF and SR were ranged from 20 to 26, from 1200 m to 1400 m and from 0.48 to 0.91, respectively. A total of 372 depth records coming from 124 longline sets is considered (3 records per set). Depth records per set are located on non-consecutive baskets. They concern baskets without capture in order to analyse the longline “behaviour” only without noises on depth series induced by vertical fish movements after hooking.

For each TDR series, we considered data recorded between the end of rising and the start of retrieving. For each depth series, we extracted both the highest (HFD) and the lowest (LFD) values and we calculated the corresponding mean (MeanFD).

B – Depth variations at basket and set levels

During our experiences, the amplitude of variations for MDF was ranged between 8 m to 345 m around an average value of 98 m. In terms of relative variations according to the highest depth value (HFD), minimal, maximal and average values are 2%, 64% and 24%, respectively. Logically, if we assume that the amplitude of variations for MDF is independent of the maximum fishing depth, it will be limited by the HFD value reached during the soak time (**Figure 8 A, B**). From our fishing experiments, it was showed that this limit corresponds to a relative variation of about 60% of HFD.

It must be stressed that LFD and HFD present highest within set variability (i.e., differences between lowest and highest values for each variable) than MeanFD. The three distributions are significantly different (Wilcoxon’s signed-rank test) and the ascending sort of the three variables in terms of within-set variations is MeanFD < HFD < LFD.

C - Confronting MeanFD and the theoretical MFD

As the MeanFD is the most representative of the maximum depth reached by the longline during the soak time we compare it with the theoritical MFD rather than HFD. Inspite HFD is commonly used for this purpose it must be stressed that it represents only an instantaneous information. As a result, the use of HFD may lead to an overestimation of the fishing effort in deepest strata.

For the fishing sets presented here, relative differences between the meanFD and the theoretical depth (these relative differences can be interpreted in terms of longline shoaling) are ranged between 5% and 44% around an average value of 18.3% (**Figure 9**). Obviously, vertical current shears were the main factors of shoaling and the calculated percentages of shoaling depended on current conditions during the experiments. Further analyses of shoaling in relation to small scale environmental conditions are necessary.

D – MeanFD and theoretical depth versus the angle φ

The relationship between the ratio MeanFD/LLBF and the angle φ observed during our experiments has been compared to the theoretical relationship (see equation 5). On account of shoaling mentioned previously, a shift between observed and theoretical relationships is observed. However, it can be noted that the shapes of these relationships are similar (**Figure 10**). This result could be a consequence of the robustness of the catenary formula for estimating depths reached by the longline.

According to that, the depth of a given hook can be estimated with the following formula by assuming an homogeneous effect of the vertical currents :

$$D_j = \cos(\alpha) * [LF + LB + (LLBF/2) * \{(1 + \cot^2\varphi)^{1/2} - [(1 - (2j / N))^2 + \cot^2\varphi]^{1/2}\}]$$

with $\cos(\alpha)$ = MeanFD (observed or estimated) / theoretical MFD

5 Discussion and conclusion

As mentioned previously, LLBF and SR are key parameters for estimating both the theoretical MFD according to the catenary geometry of the mainline and the average depth during the fishing time. HPB data is needed for the estimation of hook depths and then for the standardization of CPUEs. HPB is a variable easily recorded or calculated by observers on board and by fishermen. Unfortunately, HPB is few informative in terms of the fishing tactic and is not a relevant proxy indicator of the maximum fishing depth attained by the mainline. In contrast (in the other hand suit in one hand ou qq chose du genre), MeanFD presents some properties for being a good proxy (that is to say: representative of the maximum fishing depth during the soak time, with a reduced within-set variability, etc.) of fishing depths exploited by hooks.

Some authors have noted yet that the weakest link of the habitat-standardisation could lie in the adequacy of the gear model. The longline behaviour is a domain in which knowledge is still too weak for having robust standardizations of the longline fishing effort. Our attention must be paid on data describing the gear configuration and the fishing tactic. The priority concerns estimations of both the sagging rate and the length of the mainline per basket. For this purpose some essential information must be collected by observers or recorded on logbooks by fishermen in order to calculate at a minimum the sagging rate and the mainline length per basket (**Table 1**).

The sagging rate corresponds to the ratio of speeds (vessel ground speed/line shooter speed), or equivalent to the ratio of distances at the same scale (horizontal distance of the longline/total length of the mainline or horizontal distance between floats/length of the mainline between floats). It must be stressed that estimates of distances and mainline length could be biased due to various factors. For instance the horizontal distance of the longline is calculated as the great circle distance based on the geographical coordinates at the start and the end of the longline. Nevertheless, this distance is biased if the longline is not set along a straight line. For this reason, the best way to prevent this potential bias consists in equipping observers on board with a GPS portable for collecting (or recording with a data logger) several geographical coordinates and corresponding times during the setting. With this type of data at hand an average speed may be easily calculated. With the collaboration of fishermen (e.g., logbooks), geographical coordinates at the start and the end of the longline must be collected.

Currently, longliners are often equipped with a tachometer on the line shooter which gives directly the setting speed of the mainline. If this equipment is absent on board, or defective, some alternatives exist to estimate the setting speed of the mainline. The length of the mainline totally deployed can be obtained from fishermen who generally have a good knowledge of how their fishing gear behaves. Knowing times at the start and the end of the fishing operation, the line shooter speed is inferred. From observers on board, one possibility consists in estimating the time for deploying a segment of the mainline with know length or inversely. An alternative is to equip observers on board with a tachometer portable as realised with this objective in mind during the framework of the ECOTAP program (Bach et al., 2003).

To calculate LLBF from the line shooter speed, the time spent to deploy a basket unit must be known. From data collected by observer on board, this variable can easily be collected during the setting operation. From logbook data, information of the setting duration and the number of baskets (from data recorded directly or calculated) are necessary.

When the complete gear configuration data is available, the theoretical MFD can easily be calculated. However the estimated theoretical MFD and the maximum depth reached by the gear during the soak time are different (fishing depths are shallower than the theoretical MFD).

Two means allow to describe the longline behaviour during the fishing time: observation and proxy indicator. Observations can be collected from the deployment of time depth recorders by observers embarked or during instrumented longline surveys. This type of operations on field must be supported by international tuna commissions.

As proxy indicator, as we shown in this study, the MeanFD appears as robust enough to describe the average behaviour of the different baskets for a given set. The shape of the relationship between the MeanFD and the sagging rate is similar to the catenary shape.

Now, the next step is to quantify the shoaling in relation to environmental conditions in order to estimate the MeanFD knowing MFD and currents (or a proxy of current effects as the wind stress, the drift of the longline during the fishing time …). These analyses must be achieved in the framework of longline behaviour studies by collecting simultaneous small scale data of the gear behaviour and current (vertical profiles of both direction and speed). However, large oceanographic patterns of currents could probably be used for applying an estimated shoaling ranged from a minimal value of 5% in oceanographic areas as gyres to maximal value of 50% in equatorial areas.

The future of longline CPUE standardization study requires in priority research program devoted to the analysis of the fishing gear behaviour in different parts of the word ocean. Materials and technologies are currently available (e.g., Time Depth Recorders, Acoustic Doppler Current Profiler) to collect gear behaviour and oceanographic data and then to improve our knowledge of how the longline behaves according to both fishing tactic and oceanic environment. Nowadays, we have plenty of statistical approaches for standardize CPUE but wisdom to interpret available data is scarce. “The argument that statistics replaces wisdom is counterfeit in the face of an inexact science with poor data” (Rose, 1997).

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Table 1. List of variables to collect by observers embarked or on logbook to calculate the theoretical maximum fishing depth and estimate the mean depth expected during the soak time. Variables are sorted by their respective priority (from 1 = high priority to 3 = optional).

Variables to collect	Observers (*)	Logbook	Main variable of interest
Geographical coordinates of the start of setting	1	1	SR
Geographical coordinates of the end of setting	1	1	SR
Time of the start of setting	1	2	SR, LLBF
Time of the end of setting	1	2	SR, LLBF
Boat speed during setting	1	3	SR
Line shooter speed	1	3	SR, LLBF
Total length of the mainline	1	1	SR, LLBF
Total number of baskets	1	1	LLBF
Duration of a basket setting	1	3	LLBF
Length of floatlines	1	1 - 2	LF
Length of branchlines	1	1 - 2	LB
Total number of hooks	1	1	hook depths

SR = sagging rate, LLBF = length of the mainline between floats, LF = length of floatlines, LB = length of branchlines
(*) GSP portable, tachometer and TDRs if possible must be in the staple material of observers embarked.

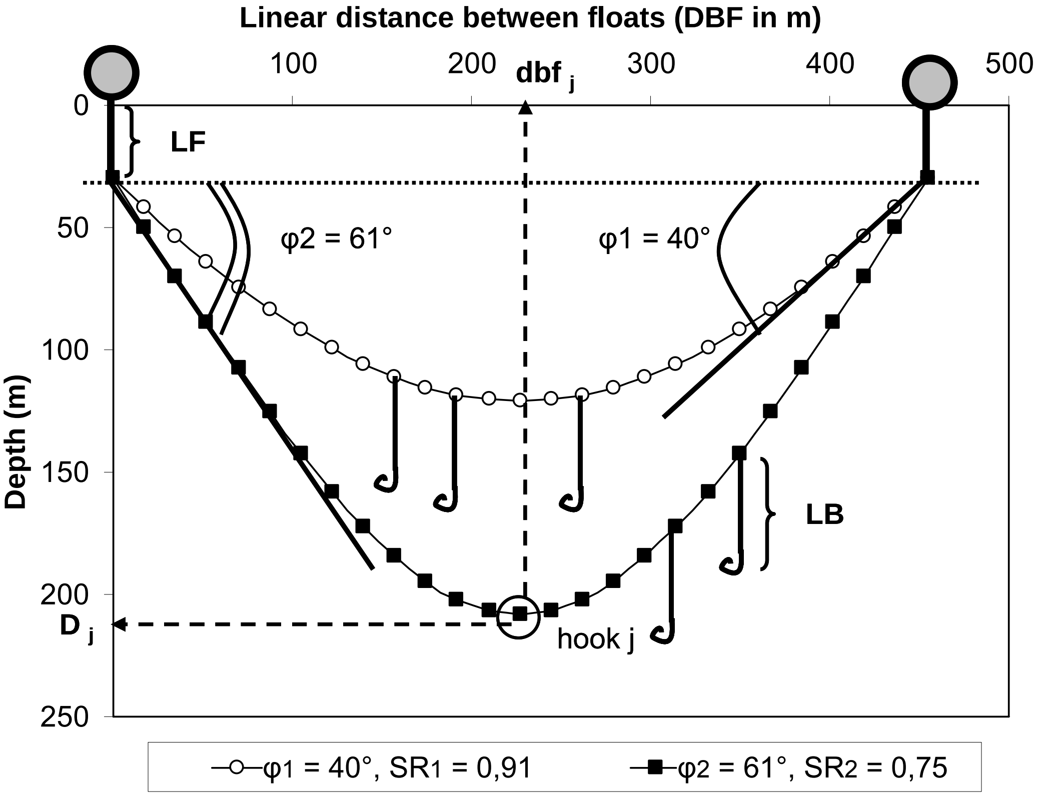

Figure 1. Theoretical catenary shape of two baskets defined by respective values of the sagging rate of 0,91 (φ1 = 40°) and 0,75 (φ2 = 61°). D_j is the depth of the hook j located at a distance dbf_j form the floatline, LF is the length of the floatline and LB is the length of the branchline (see text for the corresponding catenary equation).

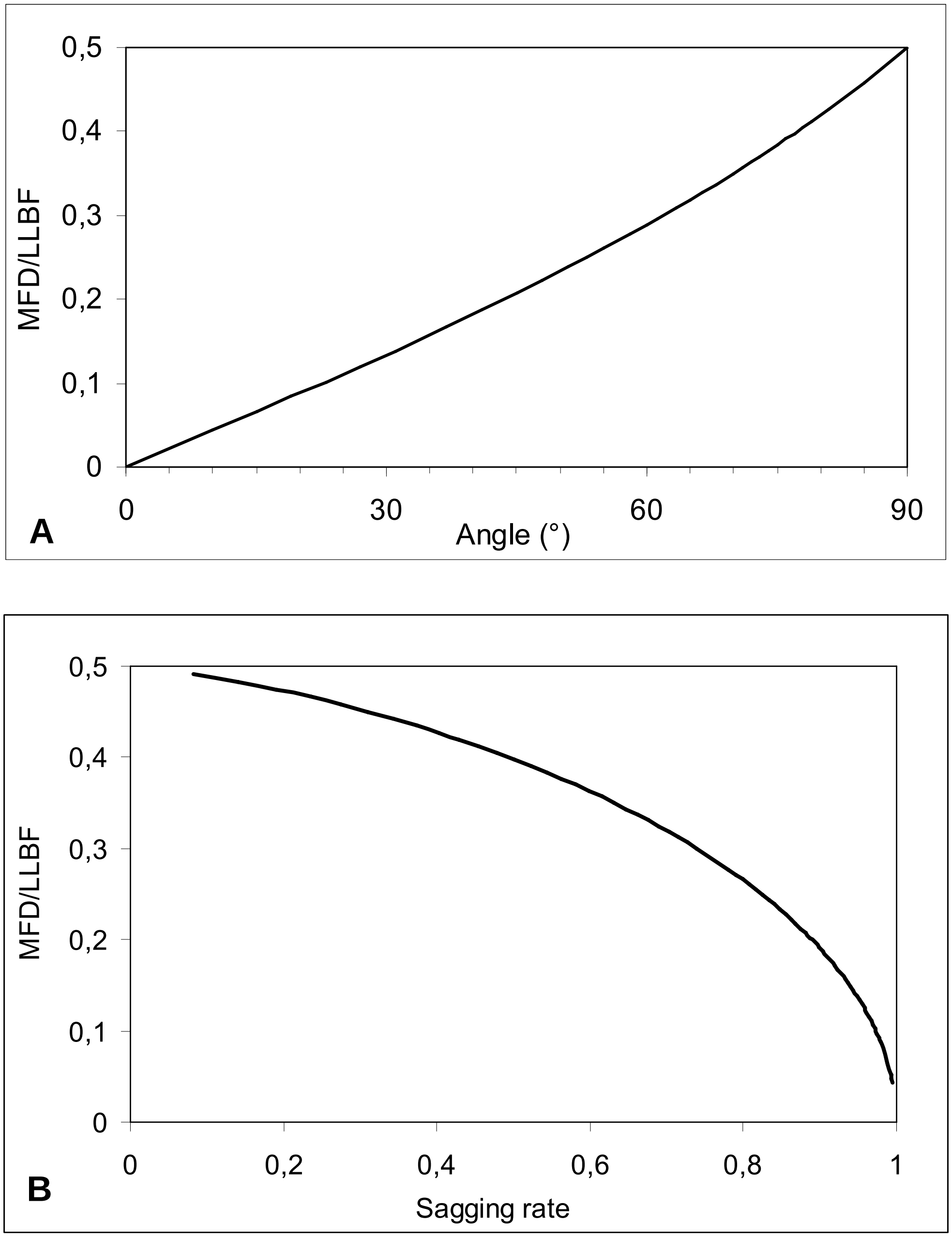

Figure 2. Theoretical relationship between the ratio MFD/LLBF and the angle (0° < φ < 90°), (panel A) and SR (0 < SR < 1), (panel B). MFD is the theoretical maximum depth, LLBF is the length of the mainline between floats and SR is the sagging rate. On this figures the value of the length of floatline (LF) and the length of branchline (LB) is supposed equal to zero.

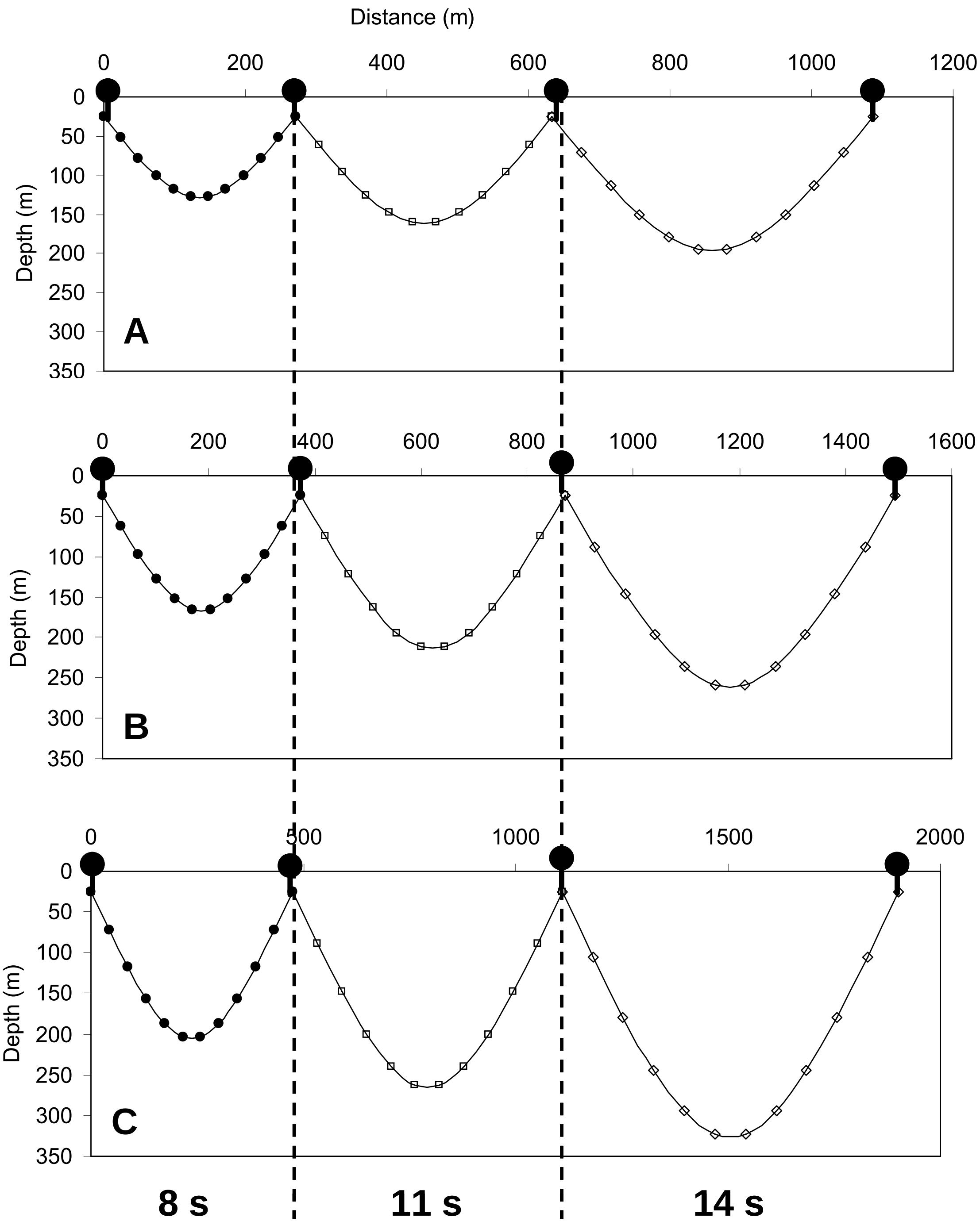

Figure 3. Variations of the theoretical maximum fishing depth of the mainline for similar baskets (10 hooks, sagging rate = 0.76) according to different time intervals between hooks (8 s, 11 s, 14 s) and setting speeds of boat (A = 6 knts, B = 8 knts, C = 10 knts).

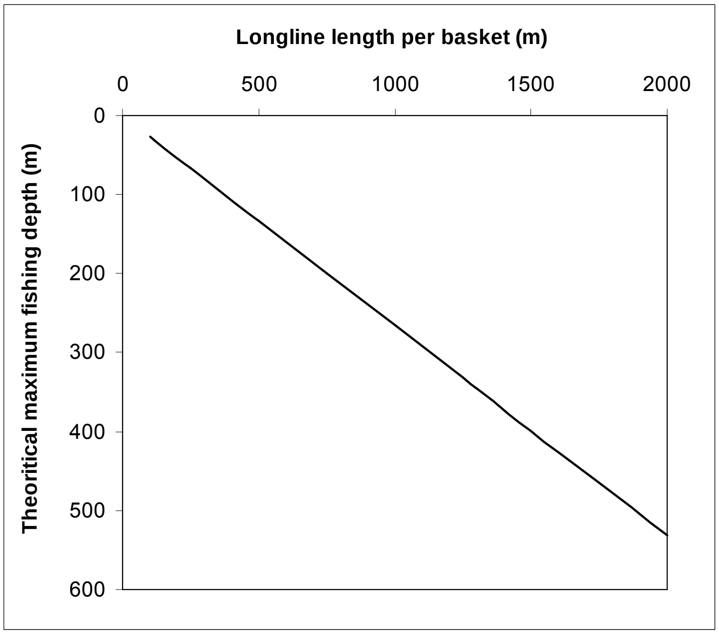

Figure 4. Relationship between the theoretical maximum fishing depth and the length of the longline between floats for a sagging rate of 0.8 (φ = 56°) according to a catenary geometry.

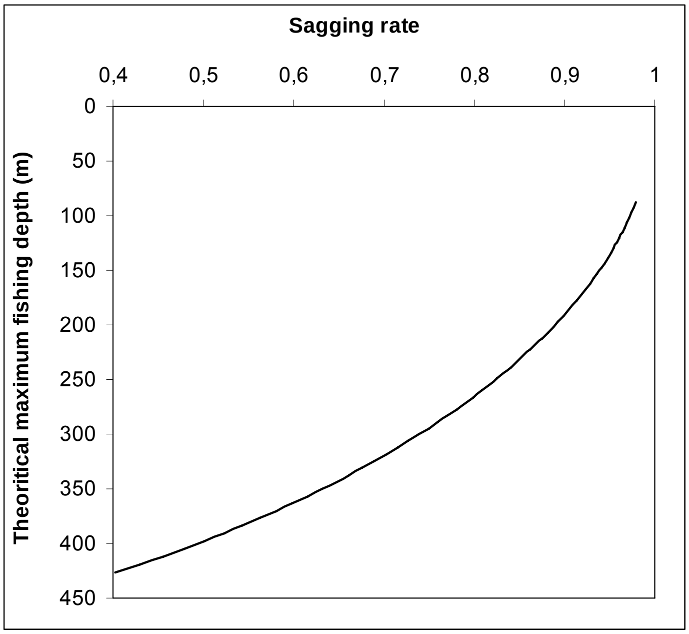

Figure 5. Relationship between the theoretical maximum fishing depth and the sagging rate for a longline length per basket of 1000 m according to a catenary geometry.

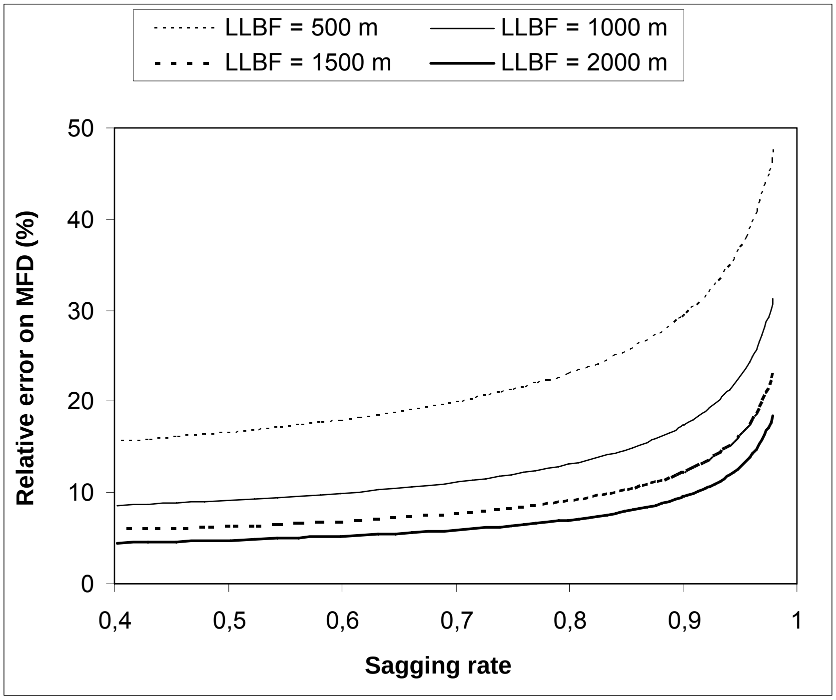

Figure 6. Relationship between the relative error on the theoretical MDF (%) and the sagging rate according to different lengths of the mainline per basket if the length of the floatline (LF = 40 m for this example) is unknown.

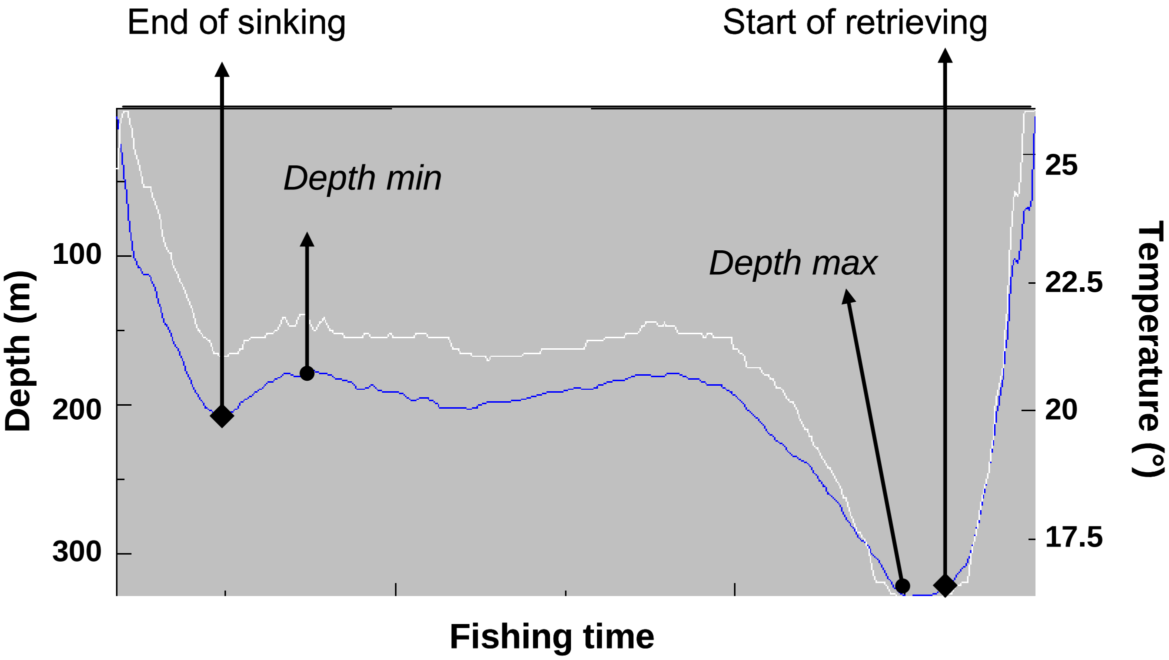

Figure 7. Depths (blue line) and temperature (white line) recorded during fishing time at the middle distance of the mainline.

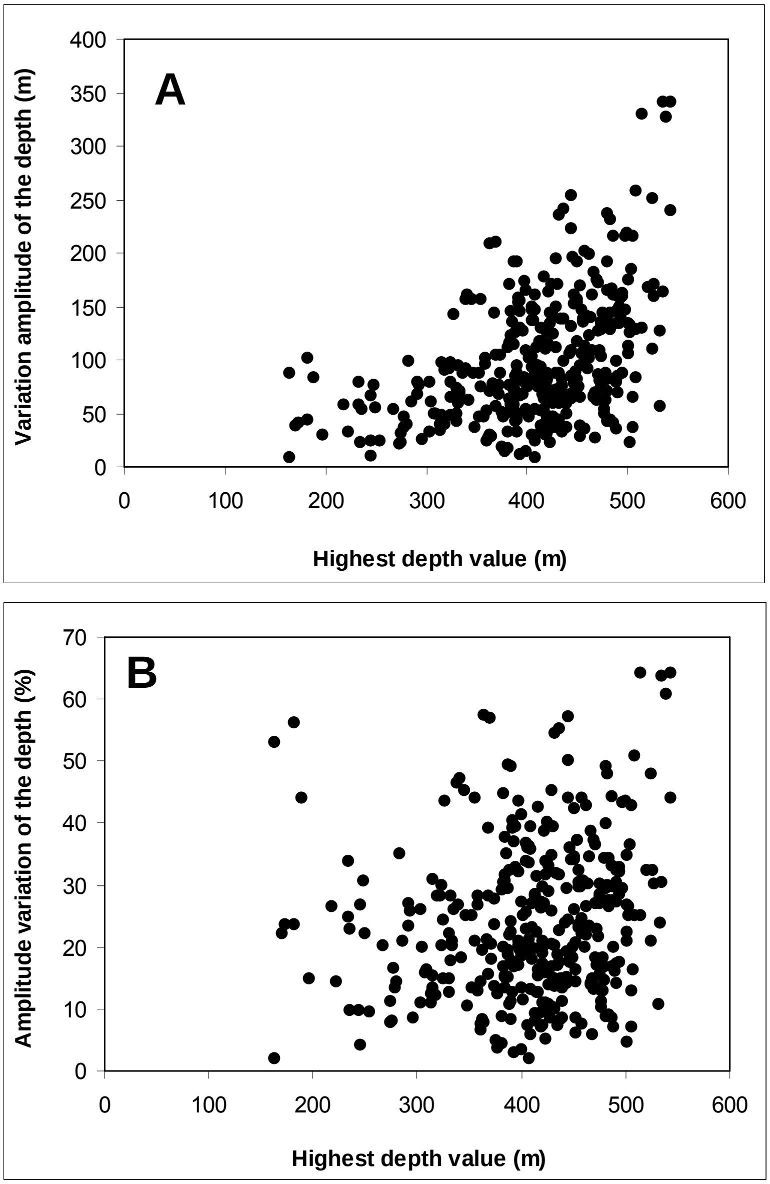

Figure 8. Variation amplitude of depths recorded during the soak time of longline fishing experiments according to the highest depth value (m) observed (A – Amplitude in m. B – Relative amplitude (%) according to the highest depth value).

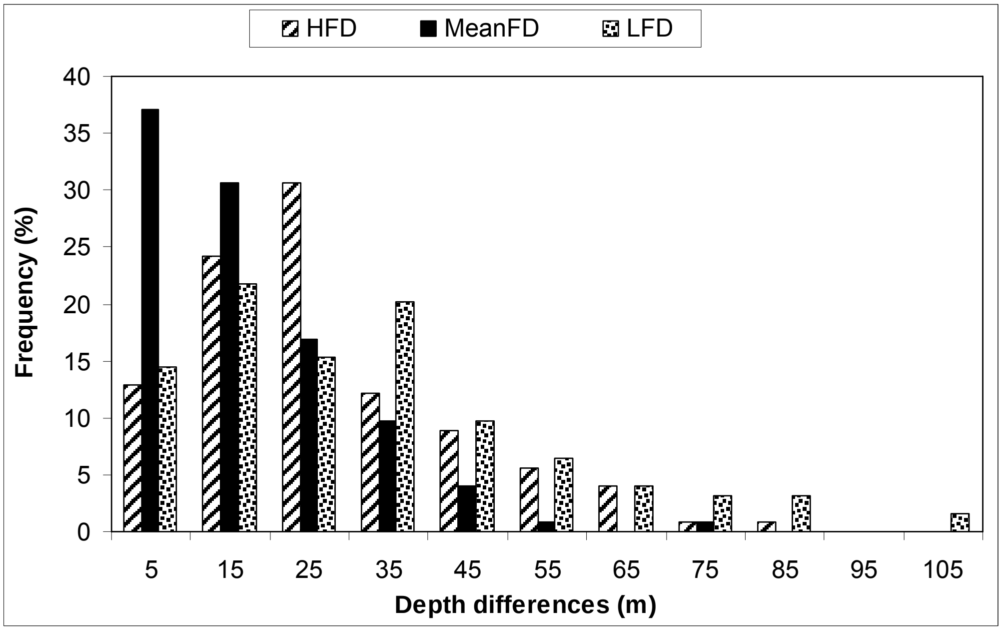

Figure 9. Frequency distributions of the maximal difference values observed for the three variables highest fishing depth (HFD), mean of the fishing depth (MeanFD) and lowest fishing depth (LFD) recorded on different baskets of a same set (3 depth series are recorded on non-consecutive baskets for 124 fishing sets).

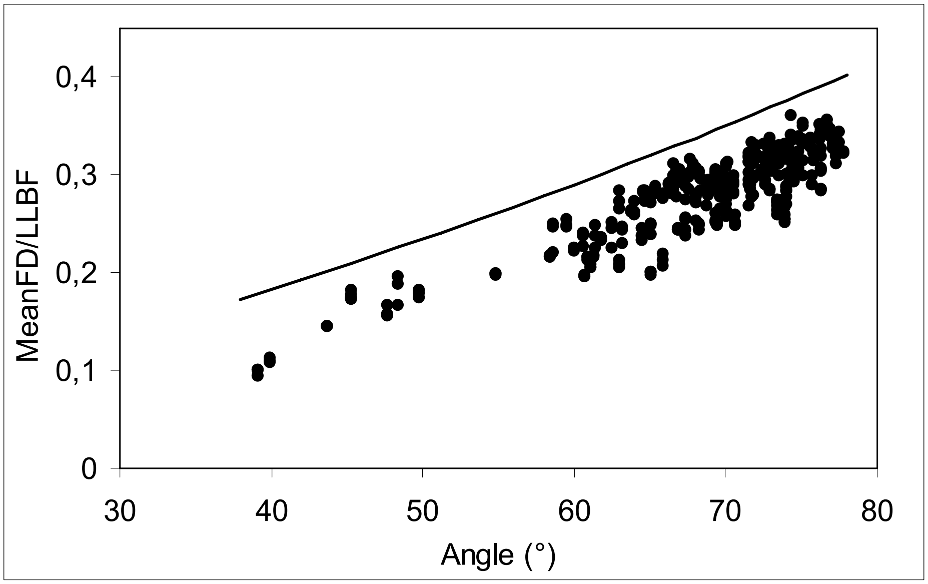

Figure 10. Confronting observations and theory. Comparison of the ratio between the observations of depths and the length of the longline between floats and the theoretical ratio (line) according to variations of the angle between the horizontal and the tangential line of the mainline.