SCIENTIA MARINA 86(3)
September 2022, e037, Barcelona (Spain)
ISSN-L: 0214-8358
https://doi.org/10.3989/scimar.05254.037

Using fisher's knowledge to estimate catch and effort in the large-scale octopus fishery on the eastern Campeche Bank (Mexico, NW Atlantic)

Otilio Avendaño [1,2], Iván Velázquez-Abunader [1], Francisco Rocha [3], Ángel Guerra [4]

[1] Centro de Investigación y de Estudios Avanzados del IPN, CP 97310, Merida, Yucatan, Mexico.
(OA) (Corresponding author) E-mail: otilio.avendano@unicach.mx. ORCID-iD: https://orcid.org/0000-0001-7644-8993
(IV-A) E-mail: jvelazquez@cinvestav.mx. ORCID-iD: https://orcid.org/0000-0003-3216-2007
[2] Universidad de Ciencias y Artes de Chiapas, Tonala, Chiapas, C.P. 30500, Mexico.
[3] Universidade de Vigo and Centro de Investigación Mariña. BA2, Departamento de Ecología y Biología Animal, Edificio Ciencias Experimentales, Campus de Vigo As Lagoas-Marcosende, 36310 Vigo, Spain.
(FR) E-mail: frocha@uvigo.es. ORCID-iD: https://orcid.org/0000-0001-6821-7394
[4] ECOBIOMAR, Instituto de Investigaciones Marinas, CSIC, 36208 Vigo, Spain.
(AG) E-mail: angelguerra@iim.csic.es. ORCID-iD: https://orcid.org/0000-0001-6716-3646.

Summary: The Mayan octopus (*Octopus maya*) and the American octopus (*O. americanus*) are the two species that support the octopus fishery on the Campeche Bank. The large-scale fleet catches both species. However, landings are recorded as American octopus in the official statistics, and this causes a problem for the management of the fishery. The large-scale octopus fishery on the Campeche Bank was studied using a model based on data from interviews with skippers. A total of 180 valid interviews were conducted in the base ports of Progreso and Yucalpeten (Yucatan), representing 51.1% of the skippers in the fleet in 2019. This information was used for the first time to estimate catch per unit effort (CPUE) and total catches for each octopus species. The mean CPUE ranged between 50 and 500 kg day^{-1}, with minimums of 10 kg day^{-1}. The mean estimated potential catches ranged from 5069 to 3456 t per year for *O. maya* and from 4113 to 2805 t per year for *O. americanus.* The relationship between official landings and estimated catches showed a significant correlation (rxy=0.898). The total estimated catches were on average 20% lower than the official landings of *O. americanus*. The origin of this discrepancy is discussed.

Keywords: *Octopus maya; Octopus americanus;* catch and catch per unit effort estimates; fishery statistics; survey methods; Campeche Bank; NW Atlantic.

Uso del conocimiento de los pescadores para estimar la captura y el esfuerzo en la pesquería de pulpo a gran escala en el este del banco de Campeche (México, Atlántico NO)

Resumen: El pulpo maya (*Octopus maya*) y el pulpo americano (*O. americanus*) son las dos especies que sustentan la pesquería de pulpo en el banco de Campeche. Aunque la flota industrial o de gran escala captura ambas especies, las descargas se registran en las estadísticas oficiales como pulpo americano. Esto significa un problema para la gestión de la pesquería. Con objeto de estimar, por primera vez, las capturas por unidad de esfuerzo (CPUE) y capturas totales de las dos especies por separado en el banco de Campeche, se utilizó un modelo basado en datos obtenidos a partir de entrevistas con patrones de pesca. Se analizaron un total de 180 entrevistas válidas en los dos únicos puertos donde la flota realiza sus descargas: Progreso y Yucalpetén (Yucatán). Las entrevistas representaron el 51.1% del total de patrones de la flota en 2019. La CPUE media osciló entre 50 y 500 kg día^{-1}, con mínimos de 10 kg día^{-1}. Las capturas potenciales medias estimadas variaron entre 5.069 y 3.456 t anuales para el pulpo maya, y entre 4.113 y 2.805 t anuales para el pulpo americano. La relación entre los registros oficiales y las capturas estimadas mostró una correlación significativa (r=0.898). Las capturas totales estimadas fueron en promedio un 20% inferiores a los registros oficiales de pulpo americano. Se discute el origen de esta discrepancia.

Palabras clave: *Octopus maya; Octopus americanus;* estimación de capturas y capturas por unidad de esfuerzo; estadística pesquera; método de encuestas; banco de Campeche; Atlántico occidental..

Citation/Como citar este artículo: Avendaño O., Velázquez-Abunader I., Rocha F., Guerra A. 2022. Using fisher's knowledge to estimate catch and effort in the large-scale octopus fishery on the eastern Campeche Bank (Mexico, NW Atlantic). Sci. Mar. 86(3): e037. https://doi.org/10.3989/scimar.05254.037

Editor: R. Villanueva.

Received: December 14, 2021. **Accepted:** April 28, 2022. **Published:** August 22, 2022.

INTRODUCTION

The international demand for octopus has increased during the last decade. The volumes caught have decreased significantly in traditional fishing areas of the Mediterranean and Sahara Banks off West Africa (DOF 2018, Coronado et al. 2020), positioning Mexico as one of the principal octopus producer countries (DOF 2018, Sauer et al. 2021).

The Campeche Bank, on the Atlantic coast of Mexico (Fig. 1), is the region that has commonly reported the highest levels of octopus catches, with the Yucatan and Campeche Mexican states as the principal producers (DOF 2018). On the Campeche Bank, two species are exploited: the Mayan octopus (*Octopus maya*, Voss and Solís 1966), an endemic coastal species (DOF 2018, Avendaño et al. 2019, 2020a), and the American octopus (*Octopus americanus,* Monfort 1802). *O. americanus* was previously recorded in official landings as *Octopus vulgaris* (Jereb et al. 2016, Amor et al. 2017, DOF 2018). Genetic results currently support the identification of *O. americanus* (formerly known as *O. vulgaris* type II) along the Campeche Bank, a new octopod extending from the north of Argentina to the northwest coast of the USA (Avendaño et al. 2020b).

Historically, the octopus fishery in the Campeche Bank has mainly been based on a single species, *O. maya*. With the development of new technological ca-

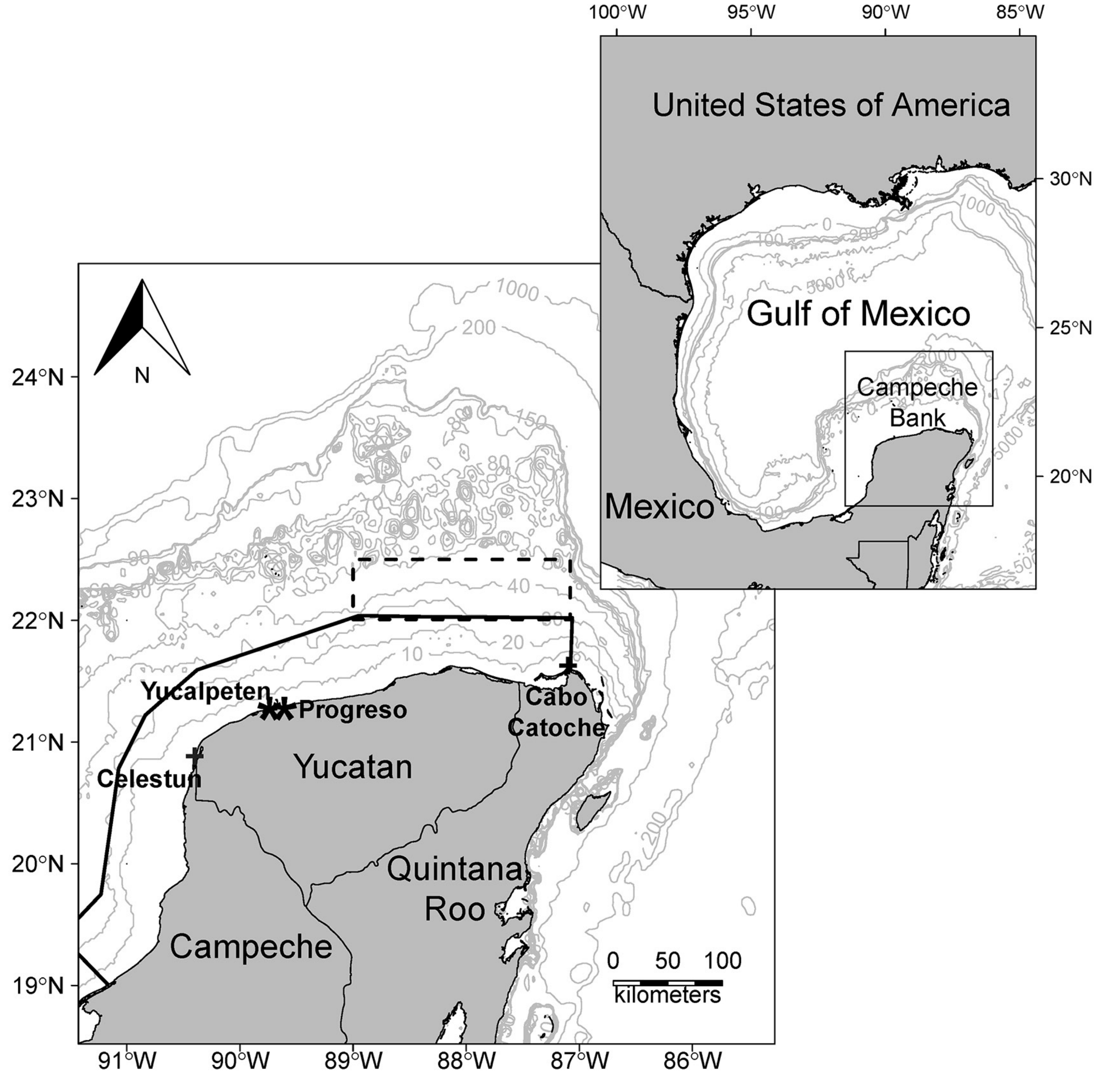

Fig. 1. – Campeche Bank and the location of the ports of Progreso and Yucalpeten, Yucatan, Mexico. Fishing area described for *O. maya* (continuous line) and *O. americanus*) (dotted line) (Source: DOF 2018, Sauer et al. 2021). The asterisk represents the ports where the interviews were carried out.

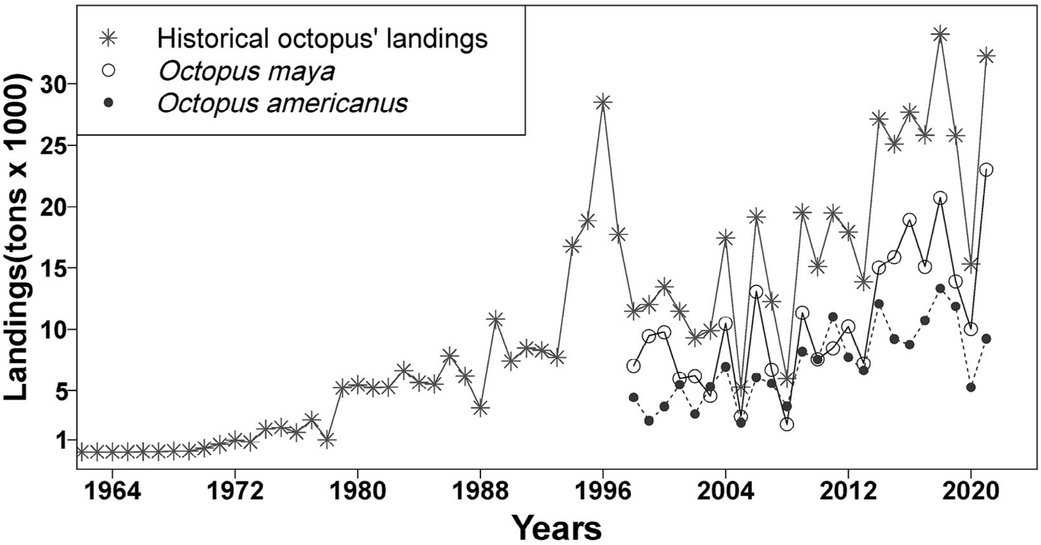

Fig. 2. – Historical official octopus landings in Yucatan from 1966 to 2021. Landings by fishery fleet from 1998 to 2021: *O. maya* (small-scale fleet), and *O. americanus* (large-scale fleet). (Source: Instituto Nacional de Pesca y Acuacultura, Yucalpeten, México. 2022).

pabilities (e.g. larger capacity outboard motors, storage holds in mother vessels and autonomy >20 days) that occurred around 1995, *O. americanus* landings came to represent approximately 40% of the total production for Yucatan in the first decade of the 21st century (DOF 2018). In the last two decades, both species together have recorded landings of over 20000 t (Fig. 2) (Velázquez-Abunader et al. 2013, DOF 2018).

Previously, the two species were considered to occupy different aggregation zones (Fig. 1), with *O. maya* being more abundant in shallow waters and "*O. vulgaris*" in deeper waters (>30 m depth) (DOF 2018, Sauer et al. 2021). For this reason, since 1998 small-scale fisheries landings have been recorded as *O. maya* and large-scale fisheries landings as "*O. vulgaris*" (DOF 2018, Sauer et al. 2021), which we have assigned to *O. americanus* (Fig. 2). However, since the two species occupy the eastern area of the Campeche Bank in similar abundances (Avendaño et al. 2020a), the scenario is different, and the large-scale fleet, which was thought to catch *O. americanus* exclusively, could be catching both species in similar proportions.

The octopus fishing season on the Campeche Bank extends from 1 August to 15 December each year (Salas et al. 2008, DOF 2018). During this period, the large-scale fleet operates with vessels of 18 to 25 m length that function as mother vessels transporting between 12 and 15 dories (~3 m long, locally called *alijos*), which fish far from the mother vessel. This fishing technique is called *gareteo* and consists of letting the *alijos* drift while fishing with lines tied to bamboo or wooden poles attached to the ends of the *alijos* (Salas et al. 2008, Sauer et al. 2021). The length of each line depends on the depth. At its lower end, bait is fixed, usually consisting of crab or fish pieces (*Callinectes* sp., *Libinia dubia, Diplectrum* spp., or *Haemulon plumierii*) (Galindo-Cortes et al. 2014, López-Rocha et al. 2021).

Owing to the lack of information about the octopus populations in areas far from the coastline, the octopus management plan in Mexico recommends analysing the trends in the catches of the large-scale fleet that operates in areas with depths greater than 30 m (Galindo-Cortes et al. 2014, DOF 2018). Among the methods used to manage cephalopod fisheries are production models that describe the relationship between surplus production and the stock biomass and an index of the stock biomass, generally expressed as catch per unit effort (CPUE). Applying these models requires time series data on landings and abundance (Pierce and Guerra 1994). However, these data do not exist or have significant biases for the octopus fishery in the study area.

A quick-fix alternative to the lack of this information in a fishery is to obtain data from interviews with fishers related to the fishery (Rocha et al. 2004). One of these models was proposed by Gómez-Muñoz (1990) and has proven beneficial for estimating the catches and CPUE of a fishing fleet during a fishing season in several cephalopods species, including squids (*Loligo vulgaris* and *L. forbesii*), cuttlefish (*Sepia officinalis*) and the common octopus (*O. vulgaris*) from fisheries located in the NE Atlantic (Galicia and Scotland) (Simón et al. 1996, Otero et al. 2005, Young et al. 2006, Rocha et al. 2006, Comesaña and Guerra 2019). In addition, this methodology was also applied to the monkfish (*Lophius* spp.) in the Grand Sole fishing ground (NE Atlantic) (Rocha et al. 2004), where the reliability of the model was tested by comparing catch estimates with data obtained from the fishers associations and official statistics.

The Gómez-Muñoz model was initially developed to aid the management of small-scale fisheries for which reliable catch and effort data may not be available. The method employs fishers' knowledge about catching trends obtained through interviews and is based on two simple assumptions. First, the CPUE is

Table 1. – Parameters and expressions used in the Gómez-Muñoz (1990) model.

Basic parameters	
S	Month in which the fishing season starts (January=1).
L	Length of fishing season in months.
I	Rate of decrease in catches after the peak (1, slow; 2, medium; 3, fast).
v	Number of fishing trips per month per boat (fishing effort).
N	Number of hauls per boat per trip.
M	The month of maximum catch (peak of the fishery).
C_{min}	Minimum catch in one haul (kg h^{-1}). Zero is not valid.
C_{max}	Maximum catch in one haul (kg h^{-1}).
B	Number of vessels engaged in this fishing per type of fishing gear.
V	Total number of trips made by the whole fleet (total fishing effort).
Expressions	
TE	An auxiliary variable expressing the time elapsed between the peak of the fishing and the beginning (left-biased, LB) or end (right-biased, RB) of the fishing.
x	The value used to calculate f(x).
f(x)	The bell-shaped function relating CPUE per trip to time in months.
Ct	CPUE per trip in month t.

assumed to provide an index of the stock size. Second, the trend in the CPUE throughout a fishing season is considered to follow a predictable pattern, in which the CPUE is initially low, then rises to a peak, and later falls off again. The model involves an interview survey of fishing sector personnel (e.g. ship owners, skippers and fishers) to obtain the data for the primary model parameters. The model generates estimates of the CPUE and total catches for a fishery (Rocha et al. 2004, Young et al. 2006).

The present study aimed to estimate CPUE and total catch levels of the two octopus species caught by the large-scale fleet that fishes along the NE coast of the Bank of Campeche. The results obtained will test whether or not there is a discrepancy between the total catch values estimated and the official landing records. They can also be used to advise one of the sectors that make up the fishery on the octopus resource of most significant commercial interest. This sector of private investment is the one that has shown the greatest interest in increasing its fishing effort (Salas et al. 2008, DOF, 2018).

MATERIALS AND METHODS

Study area

The study area comprises the eastern area of the Campeche Bank (Fig. 1). The length of the continental shelf of the Campeche Bank is ~260 km, with an average slope of 1 m km^{-1}, and its surface area is 175000 km^2. The Campeche Bank comprises cumulative low beach plains composed of mud, sand, shells and, in some areas, reef structures (Monreal-Gómez et al. 2004).

Interviews to calculate the Gómez-Muñoz model

The basic parameters for the Gómez-Muñoz model (Table 1) were obtained from interviews carried out with skippers in the fishing ports of Progreso and Yucalpeten (Yucatan, Mexico) (Fig. 1) in January and February 2018 (59%), November and December 2019 (29%), and December 2020 (12%). Progreso and Yucalpeten are the two ports where between 95% and 97% of the large-scale fleet vessels unload their catches. A total of 214 interviews were conducted with skippers of these vessels. The total number of interviews represented nearly 61% of the skippers from 352 vessels registered in 2019 with the National Aquaculture and Fisheries Commission (CONAPESCA) (Table 2).

After establishing a relationship of trust with the skipper, the interviewer skilfully asked questions and listened carefully. All interviews were personal. Their duration varied between 15 and 30 minutes. The interviews were always carried out by the same interviewer (O.A.). The interviewer created the right conditions for the respondent to talk extensively but kept in mind all the basic parameters of the model that he should obtain. In other words, it was a semi-structured interview, although the flow of the conversation was uninhibited. To avoid suspicion and not interrupt the rhythm of the conversation, the interviewer did not take notes. However, as soon as the interview ended, he wrote down the interviewee's answers that interested him in a notebook.

Table 2. – Data obtained from the interviews with skippers of the large-scale octopus fisheries in Yucatan, Mexico, used in the Gómez-Muñoz (1990) model.

Parameters from the model	*Octopus maya*	*Octopus americanus*
I: Rate of decrease in catches after the peak (1, slow; 2, medium; 3, fast)	1	3
S: Month in which the fishing season starts (January = 1)	8	8
L: Length of fishing season in months	5	5
v: Number of fishing trips in a month	1	1
N: Number of hauls per “mother vessel,” per day	2	2
M: Month of maximum catch	8	11
C_{min}: Minimum catch in one haul	12.5 kg total *alijo* day^{-1}	12.5 kg total *alijo* day^{-1}
C_{max}: Maximum catch in one haul	125 kg total *alijo* day^{-1}	125 kg total *alijo* day^{-1}
B: Total number of vessels	352 (to 2019)	352 (to 2019)

To this, he added observations about the plausibility of the explanations. The results from the interviews were analysed using measures of the central tendency to detect outliers, and surveys that exceeded 90% over a mean (N=34, 16%) were eliminated. Finally, 180 valid interviews were selected and used for the estimations and descriptions, representing 51.1% of the skippers in the fleet in 2019. The main parameters of the model are listed in Table 1.

In addition to asking the skippers for the model primary data, they were asked about a) the species they were fishing for (*O. maya* or *O. americanus*); b) areas of fishing for both species; c) the depth at which they fished; and d) the duration of the fishing hauls. We considered a haul as the action between moving the *alijos* away from the mother vessel to place them in their fishing spot and the moment the *alijos* were hoisted to deposit them in the mother vessel.

The values obtained with the interviews for the expected catches by all the mother vessels and the annual official landings were compared with an analysis of variance (ANOVA) and verified with the post hoc test of Tukey and Kramer (Nemenyi test), establishing α=0.05 (Zar 1999).

The Gómez-Muñoz model

The data obtained from the interviews (Table 1) were used to estimate the CPUE. As Rocha et al. (2004) suggested, the Gómez-Muñoz (1990) model was developed in two phases: in Phase 1, the main parameters for the model were determined through port interviews with skippers; and Phase 2, the values of these main parameters were used to estimate the catches for the main vessels and *alijos* and for the whole fleet.

Phase 1: variables and parameters

For all the data obtained through interviews, M, I, S and L are defined as the mode and C_{max} and C_{min} as the mean catch per haul. Assuming that these parameters are normally distributed, the mean or the mode of the interview data were used for estimation. A set of catch curves based on secondary variables and parameters was estimated from these main parameters. The data set was time-transformed [x(t)] to ensure that the month of the maximum catch coincided with the origin (xM=0). The curve showing the rate of decrease was calculated so that the rate was always between zero and +1. The type of curve was determined from the interview data and defined by their degree of asymmetry (Fig. 3), measured by the parameter TE in the model. TE is the relationship between the minimum and the maximum times to or from C_{max}. The rate of decrease in catches after the peak (I) can be slow (I=1), intermediate (I=2), or rapid (I=3) (Fig. 3).

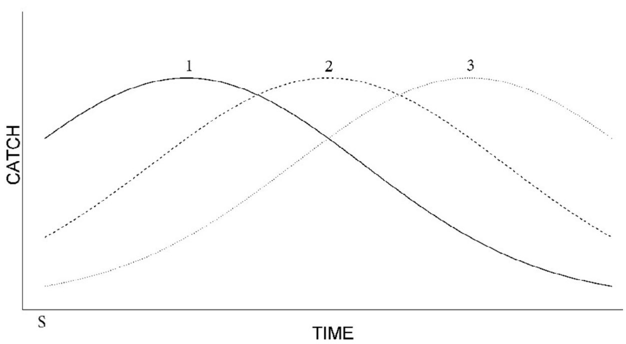

Fig. 3. – Types of rates of catch decrease from the peak during a fishing season. I=1, slow; I=2, intermediate; and I=3, rapid. S is the month when the fishing season starts (Rocha et al. 2004).

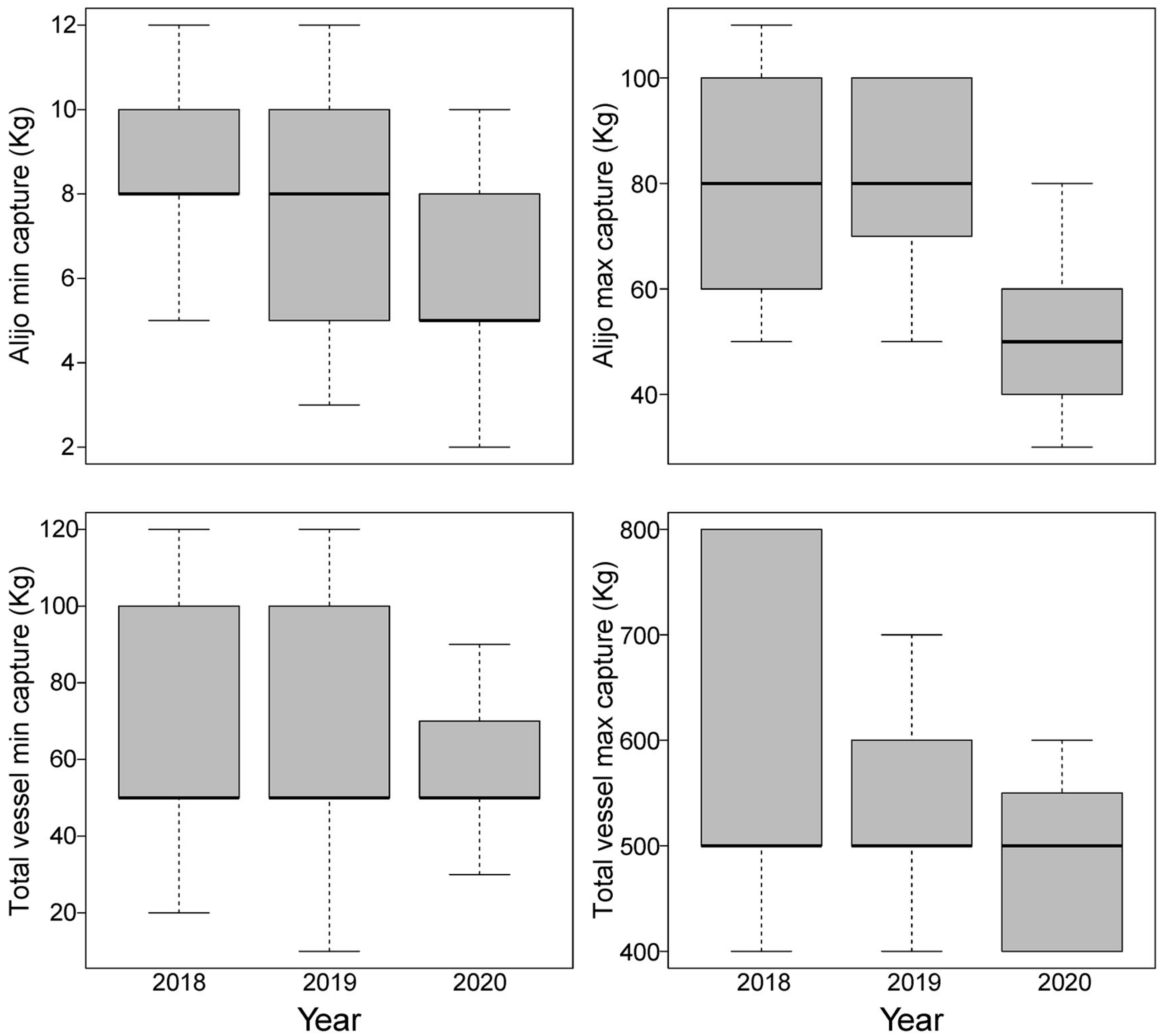

Fig. 4. – Scatterplot from the data obtained on the catches values per *alijo* and per vessel per day in 2018, 2019 and 2020.

If the decrease curve is type 1 (slow decrease), then

$$TE = \frac{(M-S)I}{S+L-1-M} \quad (1)$$

If the decreaseing curve is type 2 or 3 (intermediate or rapid decrease), then

$$TE = \frac{(S+L-M-1)I}{(M-S)} \quad (2)$$

where

$$TE = \left(\frac{Elapsed\ time\ from\ the\ maximum\ catch}{Elapsed\ time\ from\ the\ maximum\ catch}\right) * I$$

and I = type of curve.

The transformation is different for each type of curve. In the case of I=1 (slow), then

$$x = x(t) = \frac{(t-S)I + TE(t-S-L+1)}{L-1} \quad (3)$$

And in the case of I=2 or 3 (intermediate or rapid decrease),

$$x = x(t) = \frac{I(t-S-L+1) + TE(t-S)}{L-1} \quad (4)$$

This variable has different values for each month within the fishing season. The months were classified according to the number of the month in year (e.g. January = 1, February = 2, March = 3, etc.).

Phase 2: estimation of catch in kg per trip and per vessel (CPUE)

The CPUE (kg trip^{-1}) for each vessel corresponding to the large-scale fleet in Yucatan was estimated using the equation

$$CPUE = \frac{C_{max}\{f[x(t)]-f(I)\} + C_{min}\{1-f[x(t)]\}}{1-f(I)} \quad (5)$$

where

$$f[x(t)] = e^{-\{[(x1+x2)/x3]^2/2\}} \quad (6)$$

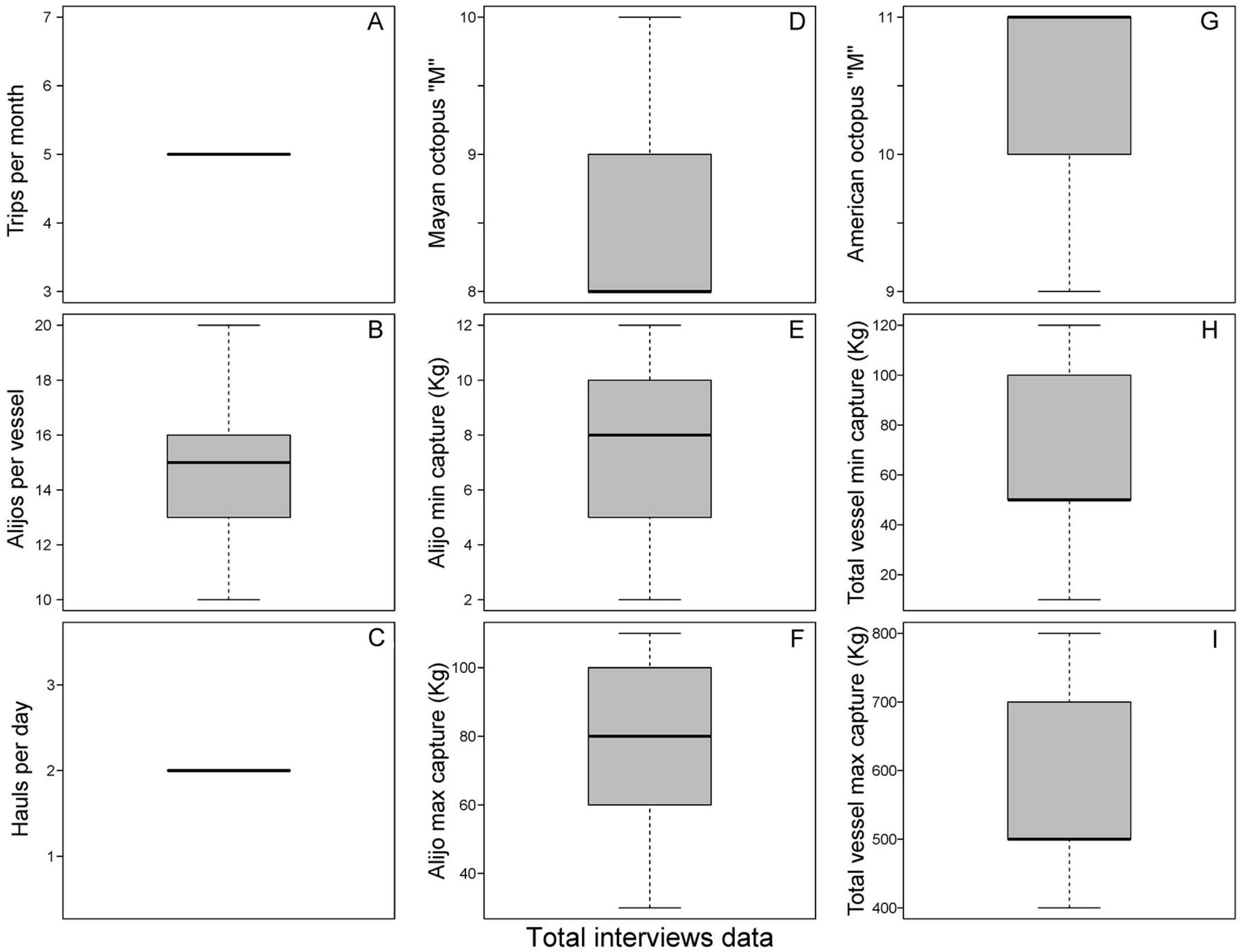

Fig. 5. – Distribution range from the parameters obtained from the total interviews with the skippers of the large-scale fleet targeting the *O. maya* and *O. americanus* in Yucatan, Mexico. A. Number of trips per month per mother vessel; B. Number of *alijos* per mother vessel; C. Number of hauls per day; D. *O. maya* "M"; E. *Alijo* minimum capture; F. *Alijo* maximum capture; G. *O. americanus* "M"; H. Total mother vessel minimum capture; I. Total mother vessel maximum capture. "M" means the month of maximum catch (peak of the fishery).

$$f(I) = e^{-(I)^2/2} \tag{7}$$

$$x1 = (\text{month number} - S - L + 1) \times I \tag{8}$$

$$x2 = (\text{month number} - S) \times TE \tag{9}$$

$$x3 = L - 1 \tag{10}$$

and the standard error of the CPUE ($s.e._{CPUE}$) was calculated by

$$s.e._{CPUE} = \frac{f(x) \times f(I) \times (CPUE_{max} - CPUE_{min})}{n+1} \times \sqrt{\frac{nf(I)^2 - 2f(I) + n}{n+2}} \tag{11}$$

where n is the number of surveys.

Subsequently, the total catch per month (C_t kg) was estimated as follows:

$$C_t = CPUE \times N \times v \tag{12}$$

where N is the average of hauls per fishing trip and v is the average number of fishing trips per month.

The standard error of C_t ($s.e._{Ct}$) was calculated using the following equation:

$$s.e._{Ct} = \frac{f(x) \times f(I) \times (Ct_{max} - Ct_{min})}{n+1} \times \sqrt{\frac{nf(I)^2 - 2f(I) + n}{n+2}} \tag{13}$$

The total catch (CT) by the large-scale fleet during the fishing season was calculated using the equation

$$CT = \left(\sum_l^L C_t\right) \times B \tag{14}$$

The summation includes from January (l=1) until December (L=12), and B is the effective number of vessels of the large-scale fleet whose exploitation is aimed at catching octopus on the eastern part of the Campeche Bank. This information was obtained from the records of CONAPESCA from 2007 to 2020.

Finally, the standard deviation of the total catch was calculated as the square root of the variance obtained from the catches per month.

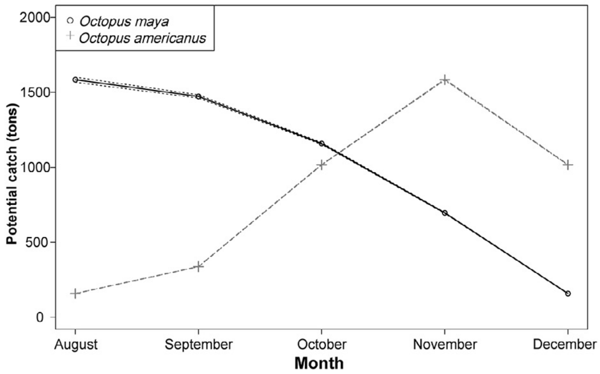

Fig. 6. – Monthly potential catch curves for the 2019 season of *O. maya* (black) (distribution type I=1) and *O. americanus* (grey) (distribution type I=3).

Comparison of the official landings with the results of the model

Only the official records of landings by the large-scale fleet of *O. americanus* were considered for this exercise. The National Institute of Fisheries and Aquaculture (INAPESCA) provided the official landings for the fishing seasons (August-December) from 1998 to 2018. This information was used to compare the results obtained with the Gómez-Muñoz model through a Pearson parametric correlation test (r_{xy}) using the R programming language (R Core Team 2020).

RESULTS

Table 2 shows the values of the basic parameters of the Gómez-Muñoz model obtained from interviews with skippers in Yucatan. Table 3 shows the catches calculated using the fleet model targeting *O. maya* and *O. americanus* from 2014 to 2020 and the official landings of *O. americanus* in Yucatan (Source: INAPESCA, Yucalpeten). This is the first time that octopus landings from the large-scale fleet have been estimated in Mexico. These data indicate that *O. maya* was caught in similar proportions to *O. americanus*.

Correlation analysis was performed between the estimated catches and official landings for *O. americanus* because official information on the large-scale fleet is attributed to this species. The result showed that the relationship between the official landings records and the catches estimated by the model and for that species was high: $r_{xy} = 0.898$. The data shown in Table 3 indicate that the official landings of *O. americanus* were on average 20% higher than the estimated catches.

The interviews showed that the volume catches per *alijo* and per total vessel were decreasing (Fig. 4) and were especially low in 2020 ($\alpha<0.05$ for all the comparisons, except for the minimum catch per vessel by trip).

The surveys allowed us to identify some peculiarities in the organization and conditions of the large-scale fleet targeting the octopus resource. The collected information showed that a) a mother vessel from the large-scale fleet typically travels to the fishing ground five times during the fishing season (once per month) (Fig. 5A); b) the skippers fish on average 18 days per trip; c) on each fishing trip the mother vessel transports between 10 and 20 *alijos*, most frequently 15 (Fig. 5B); d) fishing activity starts at 05:00 h and ends at 18:00 h; e) most skippers make two hauls per day (Fig. 5C), each lasting between 6 and 8 hours, and only some (6.5%) make three sets a day of about three hours each; f) the time it takes to release all the *alijos* carried by a mother vessel is approximately 40 minutes, and the same time is needed to collect them, so fishing time is usually four hours; g) catches per species vary with time, location and depth; h) each *alijo* can catch between 5 and 100 kg of octopus per day (Fig. 5E, F); and i) a vessel from the large-scale fleet catches 50 to 500 kg day^{-1}, although in periods of maximum abundance and favourable conditions a single vessel can catch a ~1000 kg day^{-1}, while in periods of low abundance the total catch falls to <40 kg day^{-1} vessel^{-1} (Fig. 5H, I).

According to the information obtained from the skippers, the areas with the highest abundance of both *O. maya* and *O. americanus* during the fishing season are zones with depths of less than 45 m. Consequently, fishing operations are carried out in areas between 15 and 35 m depth. As reported by the skippers, they do not have an exclusive fishing area to the northeast of the Campeche Bank but instead carry out their fishing operations across the entire continental shelf of the northern Campeche Bank, at 15 to 45 m depth. The skippers confirmed that they could catch off Celestún (west; Fig. 1) in areas between 25 and 35 m depth when the abundances of *O. maya* were high in western regions. In the limits of Quintana Roo (east; Fig. 1), the resource could be targeted in shallow areas, in a range between 15 and 40 m.

From the information provided by the interviewees, the following knowledge was obtained: i) at the beginning of the fishing season (August), the species with the highest abundance is regularly *O. maya* (Fig. 5D, and 6); ii) as the fishing season progresses and *O. maya* becomes less abundant, the fishing operations are directed to searching for *O. americanus* (Fig. 5G and 6); iii) *O. americanus* shows a maximum abundance towards the end of the season (November) (Fig. 6); iv) the areas of highest abundance of *O. maya* are towards the western portion of the Campeche Bank, whereas the areas of highest abundance of *O. americanus* are in the eastern zone of the Campeche Bank towards the border zone with Yucatan and Quintana Roo off Cabo Catoche; and v) in areas deeper than 45 m, the fishing gear is non-viable, because the current flow prevents the bait from sinking to the sea bottom.

DISCUSSION

Studies using interview data in several species have revealed that a large amount of valuable information for assessment purposes can be collected from fishers and their landing points (Simón et al. 1996, Rocha et al. 2004, 2006, Young et al. 2006, Comesaña and Guerra

Table 3. – Number of vessels (B) that reported octopus landings from 2014 to 2020. Official landings in tons (t) of American octopus in Yucatan by the large-scale fleet (Source: CONAPESCA and INAPESCA, Yucatan, Mexico), and estimated catches by mean of the Gómez-Muñoz model of the fleet for the Mayan octopus (*Octopus maya*) and the American octopus (*Octopus americanus*).±Var is the variance obtained from each year estimate in tons (t).

Year	No. vessels (*B*)	Official landings of *O. americanus* (t)	Total estimated octopus catches	Estimated *O. maya* catches		Estimated *O. americanus* catches	
			Annual total catch (t)	Annual catch (t)	± SD (t)	Annual catch (t)	**± SD (t)**
2014	312	12077	8139	4493±522		3646±511	
2015	290	9211	7565	4176±486		3389±475	
2016	308	8752	8035	4435±516		3599±505	
2017	326	10729	8504	4695±546		3810±534	
2018	350	13327	9130	5040±586		4090±574	
2019	352	11879	9182	5069±589		4113±577	
2020	240	5277	6261	3456±402		2805±393	
2021	320	9233	8344	4608±536		3739±525	

2019). Interviews with the skippers provide detailed information that increases the likelihood of precision and reliability in model estimates. Fishers can differentiate the two octopus species, *O. maya* and *O. americanus* on the basis of their morphological characteristics. Avendaño et al. (2020a, b) reported that both species were caught in the large-scale octopus fishery in Yucatan. This finding is corroborated by the information provided by the skippers interviewed in this study. However, official landing records do not separate landings by species (Galindo-Cortes et al. 2014). Landings are recorded in a single category corresponding to the American octopus (*O. americanus*), recorded as *O. vulgaris* because of the lack of studies (Avendaño et al. 2020b). With the help of the parameters of the Gómez-Muñoz model reported by the interviews (Table 2), we have been able for the first time to reconstruct the catches of both species in the last seven years (Table 3).

A minimum number of interviews by species and fisheries are required because the information is based on the fisher's appraisals and memory. As fishers have different interpretations of the variables used in the model, the interviewer must be able to interpret the data fairly. However, there should be no prior expectation of the interview result (Simón et al. 1996, Neis et al. 1999a, b, Rocha et al. 2004). The results provided in this article give some confidence that the outliers were rejected from the current analysis. Moreover, the number of valid interviews reached the minimum number of interviews necessary to obtain the main requirement for the model to be used optimally (51.1% of the official registered skippers). For the total catches in any port or the total fleet to be accurately estimated, the number of vessels fishing in each area or landing in a specific port must be known precisely. If vessels vary their port of landing, the target species change or the preferred fishing location varies, so the discrepancies between the estimated and actual catches will be considerable. To avoid invoking this bias, we were careful to determine the exact number of landed vessels, using data on the large-scale fleet fishing for octopus supplied by official Mexican fishing agencies (INAPESCA, Yucalpeten, Yucatan).

Although the bias between the landings and the estimated catches was minimized because the total catch was calculated for the whole fleet rather than the fleet representing each port, the discrepancy was low (20%; Table 3). As the results showed, the relationship between official landings and estimated catches was significant. The difference could be due to an imprecise estimate caused by the variability of the CPUEs used in the model as a calculation tool. Also, the catches represent two species, and the abundance of each species must depend on the development and environmental variables (Pierce et al. 2010). In this case, we were unable to verify the model's accuracy because of the lack of precise data on landings of each species, and the average of the catches is given with a relatively wide range of variation (Table 3).

However, the method used in this article showed optimal results in calculating the actual catches in this and other octopod fisheries, such as *O. vulgaris* in northeastern Spain (Rocha et al. 2004, Otero et al. 2005). The results obtained in this article allow us to know the potential fishing capacity of the large-scale fleet in Yucatan, an activity with no information available before this study.

The market demand and the pressure from the private sector to increase the fishing effort for this resource will continue (DOF 2018). The information obtained in this analysis of the fishery regarding the relative abundance of each species of octopus within the fishing season and the different abundances per fishing ground will serve to implement appropriate fishing management. However, it is necessary to advise the authorities to record the landings separately for each species. Furthermore, a more precise description of the number of vessels of the whole large-scale fleet targeting octopus resource in the region should be carried out.

The varying availability of the resource in different geographic regions could be related to migratory behaviour that octopods tend to show towards shallower areas for their reproduction, which generates aggregations near to the coast and therefore periods of maximum available abundance (Rosenberg et al. 1990, Faraj and Bez 2007, Leite et al. 2009, Emery et al. 2016). This scenario may be present in the octopus resource in the Campeche Bank. The skippers' knowledge showed that the fishing areas with the highest catches of both species were between 15 and 35 m depth. Regarding octopus fisheries on the Campeche Bank, Avendaño et al. (2020a, b) reported that the species that make up the octopus resource show a longitudinal change gradient parallel to the coast, with a greater abundance of *O. maya* towards the west and of *O. americanus* towards the East. This finding was also detected in the interviews with the fishing skippers. They also reported that the fishing effort is directed to *O. maya* at the beginning of the season because it offers better economic returns. However, towards the end of the season, the species representing the highest yields for the large-scale fleet in Yucatan is *O. americanus*.

CONCLUSION

The model applied in this article can be used as an independent tool for estimating catch and effort in the large-scale fishery of the Campeche Bank targeting *O. maya* and *O. americanus*. The model also tests the reliability of the official landing statistics, which is a crucial point when there are no catch and CPUE statistics, as occurs in the large-scale octopus fishery on the Campeche Bank. The interview model provides comprehensive and realistic knowledge of how this fishery works. The increase in abundance of *O. americanus* throughout the eastern part of the Campeche Bank should not be ignored in the management of this resource. This increase in abundance could indicate that it is an essential region in the development of the species's life cycle.

ACKNOWLEDGEMENTS

The authors thank Jesús Soto and Adrian Núñez for their support during the fieldwork.

FINANCIAL SUPPORT

The results of this study were obtained as part of the project "Distribución, reproducción, biomasa y patrones de movimiento del pulpo común *Octopus vulgaris* Cuvier, 1797 en la costa de Yucatán", with financial support from the Consejo Nacional de Ciencia y Tecnología de México (Grant number 237057).

REFERENCES

Amor M.D., Norman M.D., Roura A., et al. 2017. Morphological assessment of the *Octopus vulgaris* species complex evaluated in light of molecular-based phylogenetic inferences. Zool. Scr. 46: 275-288. https://doi.org/10.1111/zsc.12207

Avendaño O., Velázquez-Abunader I., Fernández-Jardón C., et al. 2019. Biomass and distribution of the red octopus (*Octopus maya*) in the north-east of the Campeche Bank. J. Mar. Biol. Assoc. U.K. 99: 1317-1323. https://doi.org/10.1017/S0025315419000419

Avendaño O., Hernández-Flores A., Velázquez-Abunader I., et al. 2020a. Potential biomass and distribution of octopus in the eastern part of the Campeche Bank (Yucatan, Mexico). Sci. Mar. 84: 133-142. https://doi.org/10.3989/scimar.05007.01A

Avendaño O., Roura Á., Cedillo-Robles C.E., et al. 2020b. *Octopus americanus*: a cryptic species of the *O. vulgaris* species complex redescribed from the Caribbean. Aquat. Ecol. 54: 909-925. https://doi.org/10.1007/s10452-020-09778-6

Comesaña N., Guerra A. 2019. Application of the Gómez-Muñoz model to estimate catch and effort in the squid *Loligo vulgaris* fisheries in the Ría de Vigo (NW Spain). Sci. Mar. 83: 305-316. https://doi.org/10.3989/scimar.04917.10A

Coronado E., Salas S., Cepeda-González M.F., Chuenpagdee R. 2020. Who's who in the value chain for the Mexican octopus fishery: Mapping the production chain. Mar. Policy 118: 104013. https://doi.org/10.1016/j.marpol.2020.104013

DOF (Diario Oficial de la Federación). 2018. Acuerdo por el que se da a conocer la actualización de la Carta Nacional Pesquera. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA), México. Retrieved from http://www.dof.gob.mx/nota_detalle.php?codigo=5525712&fecha=11/06/2018&print=true, (accessed 27 September 2021).

Emery T.J., Hartmann K., Gardner C. 2016. Management issues and options for small scale holobenthic octopus fisheries. Ocean. Coast. Manage. 120: 180-188. https://doi.org/10.1016/j.ocecoaman.2015.12.004

Faraj A., Bez N. 2007. Spatial considerations for the Dakhla stock of *Octopus vulgaris*: indicators, patterns, and fisheries interactions. ICES J. Mar. Sci. 64: 1820-1828. https://doi.org/10.1093/icesjms/fsm160

Galindo-Cortez G., Hernández-Flores Á., Santos-Valencia J. 2014. Pulpo del Golfo de México *Octopus maya* y *Octopus vulgaris*. In: Beléndez-Moreno L.F.J., Espino-Barr E., Galindo-Cortes G., et al. (eds), Sustentabilidad y Pesca Responsable en México, Evaluación y Manejo. INAPESCA. México, pp.177-207. ISBN: 978-607-8274-11-6.

Gómez-Muñoz V.M. 1990. A model to estimate catches from a short fishery statistics survey. Bull. Mar. Sci. 46: 719-722.

Jereb P., Roper C.F.E., Norman M.D., Finn J.K. 2016. Cephalopods of the world. An annotated and illustrated catalogue of cephalopod species known to date. Octopods and Vampire squids. FAO Species Catalogue for Fishery Purposes, N°4, Vol. 3. FAO, Roma. 370 pp. ISSN 10120-8682.

Leite T.S., Haimovici M., Mather J., Lins J.E.O. 2009. Habitat, distribution, and abundance of the commercial octopus (*Octopus insularis*) in a tropical oceanic island, Brazil: Information for management of an artisanal fishery inside a marine protected area. Fish. Res. 98: 85-91. https://doi.org/10.1016/j.fishres.2009.04.001

López-Rocha J.A., Ramos-Miranda J., Velázquez-Abunader I., et al. 2021. Artes y métodos de pesca de la península de Yucatán. Universidad autónoma de Campeche. Centro de Investigación y de Estudios Avanzados del IPN, Unidad Mérida. Universidad Nacional Autónoma de México. México, 70 pp. https://doi.org/10.26359/EPOMEX0121

Monreal-Gómez M.A., Salas-de-León D.A., Velasco-Mendoza H. 2004. La hidrodinámica del Golfo de México. In: Caso M., Pisanty I., Ezcurra E. (eds). Diagnóstico ambiental del Golfo de México Vol. 1. INE-SEMARNAT. Distrito Federal. México. 47-68 pp. ISBN:9688177059

Neis B., Felt L., Haedrich R.L., Schneider D.C. 1999a. An interdisciplinary methodology for collecting and integrating fishers' ecological knowledge into resource management. In: Newell D. and Ommer R. (eds), Fishing Places, Fishing People: Issues and Traditions in Canadian Small-Scale Fisheries, University of Toronto Press. 412 pp. pp. 217-238. https://doi.org/10.3138/9781442674936-013

Neis B., Schneider D.C., Felt L., et al. 1999b. Fisheries assessment: what can be learned from interviewing resource users? Can. J. Fish. Aquat. Sci. 56: 1949-1963. https://doi.org/10.1139/f99-115
Otero J., Rocha F., González A.F., et al. 2005. Modeling artisanal coastal fisheries of Galicia (NW Spain) based on data obtained from fishers: the case of *Octopus vulgaris*. Sci. Mar. 69: 577-585. https://doi.org/10.3989/scimar.2005.69n4577
Pierce G.J., Guerra A. 1994. Stock assessment methods used for cephalopod fisheries. Fish. Res. 21: 255-285. https://doi.org/10.1016/0165-7836(94)90108-2
Pierce G.J., Allock L., Bruno I., et al. 2010. Cephalopod Biology and Fisheries in Europe. Cooperative Research. ICES, Copenhagen. pp. 175. Report No. 303. ISBN 978-87-7482-078-9.
R Core Team. 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria. Retrieved from https://www.r-project.org/
Rocha F., Gracia J., González A. F., Jardón C. M., Guerra A. 2004. Reliability of a model based on a short fishery statistics survey: application to the Northeast Atlantic monkfish fishery. ICES J. Mar. Sci. 61: 25-34. https://doi.org/10.1016/j.icesjms.2003.10.006
Rocha F., Otero J., Outeiral R., et al. 2006. Modelling small-scale coastal fisheries of Galicia (NW Spain) based on data obtained from fisheries: the case of *Sepia officinalis*. Sci. Mar. 70(4): 593-601. https://doi.org/10.3989/scimar.2006.70n4593
Rosenberg A., Kirkwood G., Crombie J., Beddington J. 1990. The assessment of stocks of annual squid species. Fish. Res. 8: 335-350. https://doi.org/10.1016/0165-7836(90)90003-E
Salas S., Cabrera M., Palomo L., et al. 2008. Plan de manejo y operación del comité de administración pesquera de escama y pulpo. Informe Final. Cinvestav IPN Unidad. Technical Report. 162 pp. Mérida, México.
Sauer W.H., Gleadall I.G., Downey-Breedt N., et al. 2021. World Octopus Fisheries. Rev. Fish. Sci. Aquac. 29: 279-429. https://doi.org/10.1080/23308249.2019.1680603
Simón F., Rocha F., Guerra A. 1996. The small-scale squid hand-jig fishery off the northwestern Iberian Peninsula: Application of a model based on short fishery statistics survey. Fish. Res. 25: 253-263. https://doi.org/10.1016/0165-7836(95)00425-4
Velázquez-Abunader I., Salas S., Cabrera M.A. 2013. Differential catchability by zone, fleet, and size: the case of the red octopus (*Octopus maya*) and common octopus (*Octopus vulgaris*) fishery in Yucatan, Mexico. J. Shellfish. Res. 32: 845-854. https://doi.org/10.2983/035.032.0328
Young I.A.G., Pierce G.J., Murphy J., Daly H.I., Bailey N. 2006. Application of the Gómez-Muñoz model to estimate catch and effort in squid fisheries in Scotland. Fish. Res. 78: 26-38. https://doi.org/10.1016/j.fishres.2005.12.006
Zar J.H. 1999. Biostatistical analysis, 3rd ed. Prentice-Hall, Upper Saddle River, New Jersey, USA. 663 pp.