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Environmental variability and governance: The fishery of *Octopus maya* in Yucatan, Mexico

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In the socio-ecological system of the Mayan octopus, climate change, natural variability and human decisions impact the dynamics and population structure of the octopus. Since fishing decisions have been made out of synchrony concerning the octopus's natural response, the system's sustainability is put at risk. Sustainability is a socially desirable, environmentally necessary, and economically viable goal; since it contributes positively to food security, ways, and lifestyles. The objective of this work is to deepen the study of the perception of the fishermen of Progreso, Yucatán regarding the interactions between the Mayan octopus, the variability in the environment, the governance system, and fishing decisions. It was developed from a qualitative and quantitative approach, and bonds of trust were created for a year adopting an ethnographic approach to deepen the use of language, feelings, and emotions. To obtain information, open and semi-structured interviews, participant observation, and documentary research were carried out. For the analysis and evaluation of perceptions and fishing decisions, a non-parametric test was used through the modeling of structural equations with Partial Least Squares (PLS). It was found that, although the quantity to be captured is strongly influenced by the market, the strong incidence of changes in the environment on capture decisions stands out among the results. The experiences and knowledge of the fishermen about the marine environment represent an opportunity to contribute to the process of evolution of the socio-ecological system of the Mayan octopus, towards the establishment of norms and agreements between the different actors and contribute to the construction of resilience and sustainability against the overexploitation and environmental variability.

KEYWORDS

governance, environmental variability, socioecological system, Mayan octopus, Yucatan fishermen, fishing decisions

Introduction

In 1974, according to the FAO (2022), 10% of the fishing *stocks* were exploited at biologically unsustainable levels, a situation that has been increasing until reaching 35.4% in 2019. Added to the pressure on fishery resources is climate change, which may influence the redistribution of fish stocks and their catches, predicting an increase in high latitudes and a decrease in low latitudes with repercussions for developing countries in the tropics (Porter et al., 2014; FAO, 2020). One of the physical factors observed is the sea's surface temperature, which in the Gulf of Mexico oscillates between 22 and 30°c. Current scenarios suggest increases between 0.2 and 0.3°C per decade, which implies increases of 1 to 2°C in the next 50 years (IPCC, 2014). Knowing the thermal tolerance of some fishing species is necessary to establish the most appropriate way to manage them (Rosas et al., 2021), and how fishermen interact with some species such as *Octopus maya* in the context of environmental variability. It becomes relevant since it is likely that they will be forced to migrate to deeper areas or to the north, which would imply a change in the structure of the fishing communities (Rosas et al., 2021). This change could occur gradually and irreversibly as part of climate change (Orellana, 2009) in the next 30 to 50 years.

The Mayan octopus fishery takes place off the coast of the Yucatan peninsula in the States of Campeche, Yucatan, and to a lesser extent in northern Quintana Roo. The capture is subject to a series of regulations that regulate the actions of the fishermen: NOM-008-SAG/PESC-2015 establishes the closure of the Mayan octopus capture season from December 16 to July 31 and NOM-008-PESC-1993 establishes the minimum capture size in mantle length of 110 mm or 450 grams of weight, and the permitted capture method known as "gareteo" (the fishing method that consists of drifting the boat and the ropes with the bait, generally crabs, and that simulate a movement as if they were alive).

Given the complexity of small-scale fisheries (i.e., many fishers, species caught, and habitats exploited) and the lack of reliable data, classical tools such as setting catch limits based on stock assessments are unlikely to be practical or effective (Selgrath et al., 2014). This is the case of the Mayan octopus in Yucatan whose catch quota suggested by INAPESCA is constantly doubling. In this fishery, the norms and rules constitute an essential element for its operation since it integrates biophysical and social components as a system. The integration of the social system and ecosystems is what Ostrom (2009) called socio-ecological systems. When natural systems are related to social systems, mutual feedback processes occur, characterized by their interdependence and complexity at different spatial, temporal, and functional scales (Cox, 2011). On the one hand, the authorities establish limits (for example, fishing regulations) to make fishing sustainable, as shown by the objectives of the Program for the Promotion of Fisheries and Aquaculture Productivity in Mexico (DOF, 2019). On the other hand, fishing decisions are related to factors such as income, distance, and security that influence the movement of fishermen (Selgrath et al., 2014) and involve where, how, when, and how much to fish. However, fishing decisions can be modulated by the influence of physical (e.g., wind, sea surface temperature) and biological (e.g., reproduction, feeding) factors. Both play a fundamental role in the distribution and abundance of marine species (Pabon, 1998).

To facilitate the study of fisheries such as the Mayan octopus, the Social and Ecological Systems Analysis Framework (MASS) allows the identification of components, relationships, and variables that facilitate their analysis (Ostrom, 2009; Ospina, 2012; McGinnis and Ostrom, 2014). However, an imbalance of this theoretical approach, inherited from the theory of common resources, is characterized by the absence of visualization of biophysical factors, even though the social system does perceive these changes and they are part of ecological knowledge (Ruddle, 1993; Epstein et al., 2013; Binder et al., 2013). This theoretical approach is complemented by concepts such as scale, self-organization, emergent properties, irreversibility, and resilience (Levin, 1999) that contribute to the understanding of socio-ecological systems. For example, for resilience, nonlinearity is often seen through threshold effects, while irreversibility means that the system has changed to such an extent that it can no longer return to its original state (Berkes et al., 2003).

In the case of the variability of physical factors, it is important to distinguish in which of the scales of climatic variability they occur since they can be perceived by fishermen. Climate Variability (VC) responds to climate fluctuations on various scales of time and space, refers to variations in the average state compared to normal values, and can be expressed in precipitation, temperature, or humidity, among other parameters. These deviations from normal values are known as climatic variability, they are quantified by calculating anomalies and are evident in short periods (Montealegre and Pabon, 2000). While climate change implies the non-return of the average conditions of the normal values of the atmosphere, a process that occurs in the long term and irreversibly, mainly attributable to human activity (IPCC, 2014; Orellana, 2009). According to Boshell et al. (2011) and Orellana, (2009), the following scales of climate variability are recognized: a) intra-seasonal scale (summers, and intensification of rains), seasonal (rainy and dry) short periods of months, seasons and years, concerning the annual cycle it is common to recognize seasons (winter, spring, summer, and autumn) in mid-latitudes, in tropical latitudes the frequent thing is the alternation between rainy and dry seasons. On the interannual scale, there are cycles of more than one year in duration, typical examples of interannual VC are the phenomena framed within the cycle known as El Niño or La Niña (ENSO); b) interdecadal or episodic scale of decades, on this scale climate fluctuations manifest themselves for decades (Montealegre, 2009); c) secular or centuries-long variations and d) variations in thousands of years. It is the intra-seasonal climatic variability that, according to field observations, is perceived and recognized by fishermen.

In the case of the Octopus maya, the already mentioned physical factors and others such as light, precipitation, or the hard bottom, have an important influence on the biology of the octopus in aspects such as its development, growth, reproduction, and distribution (McGowan et al., 1998; Harley et al., 2006). Consequently, in the establishment of norms and rules whose objective is to regulate the behavior of the actors (e.g., fishermen and distributors) in their interactions with the resource unit (Mayan octopus) and the resource system (coastal marine space as the habitat of the Mayan octopus) (Ostrom, 2005; Dietz et al., 2013). The design and implementation of norms underlie the governance system that moves between the monocentric and the polycentric (hierarchical and horizontal), which refers to the way decisions are made by the authorities of the federal/central government mainly (Berkes et al., 2001; Whittingham, 2010).

Achieving and maintaining the sustainability of the socio-ecological system of the Mayan octopus implies facing complex challenges such as knowing the possible interactions between its components. Depending on the physical state of the environment and the response of the species, the system of agreements that underlies the management and governance of the Mayan octopus can be favored, threatened, or broken. Hence, the present work aims to know the perception of the fishermen of Progreso on biophysical aspects relevant to the Mayan octopus fishery, environmental variability, and the governance system.

Materials and methods

Two methodological approaches were used to understand Maya octopus fishing as a socio-ecological system: the first was slow and exploratory, at this stage the establishment of trust allowed us to deepen the use of language, feelings, and emotions of the fishermen (Woodruff and Aoki, 2004, Drew, 2005); the second approach was quantitative, using the SmartPLS software (Ringle et al., 2015) and with the support of socio-ecological systems theory (Ostrom, 2009; Cox, 2011). This allowed the ranking of complete sentences that the fishermen themselves revealed as general ideas and that was significant for new working hypotheses and explanations of the previous ones. Both forms of approach in an ethnographic and grounded theory (Glaser and Strauss, 1999) and conventional process, in which the socio-ecological system was deeply reflected for at least one year (2020) before the fieldwork carried out in 2021. The conversations with the fishermen were analyzed from a human ecology perspective (McCay, 1978; Berkes et al., 2001).

Ethnography and the conversational method (Delin, 2000; Woodruff and Aoki, 2004; Drew, 2005) were conducted from August 1 to December 15, 2021 (Mayan octopus harvest period). Open, semi-structured interviews and participant observation were used. To obtain information, the qualitative research cycle was followed according to Creswell (1994), who suggests that once the study area is defined, it is necessary to 1) manage access and establish rapport; 2) establish sampling strategies; 3) operationalize the measurement instrument for which Likert-type scales were used (scalar measurement: low, medium, high) with ordinal type variables to perform quantitative analysis, to obtain data a semi-structured interview, participant observation, and documentary research were carried out and; 4) ordering, capturing, storing and processing information, a process that allowed cyclical adjustments through learning.

An intentional type of sampling was applied (Aldridge, 2001), taking artisanal Mayan octopus fishermen as the target population. The cyclical nature of this work made it possible to comply with the saturation principle (Taylor and Bogdan, 1996), which establishes that between 30 and 60 interviews the answers are usually repetitive, so no more relevant information will be obtained after exceeding this number (Crouch and McKenzie, 2006; Mason, 2010), 41 interviews were conducted (n=41; Progress=19, Chuburná=10, Chicxulub=10, Chelém=2) (Figure 1).

The information obtained was classified and captured in Word and Excel format, and it was evaluated through categorization and frequency analysis with the support of the SPSS program. With the SmartPLS, a second-generation multivariate analysis was carried out to increase the confidence level in the empirical research, allowing to simultaneous examine a series of dependency relationships between independent and dependent variables. This non-parametric test of structural equation modeling was carried out using analysis of variance with Partial Least Squares (PLS), whose objective is to increase the explanatory and predictive capacity of the empirical verification of the theory (Henseler et al., 2016; Hair et al., 2017; Martínez and Fierro, 2018).

In this way, by induction and deduction, the reactions, impressions, and local knowledge of the artisanal fishermen who fish during the permitted period (four and a half months of the year) and the closed season (for seven and a half months), the understanding of that environmental variability is part of the socioecological system of the Mayan octopus.

Valuation criteria for the estimation of the structural and measurement models

For model estimation, the PLS algorithm (partial least squares) was calculated. This statistical technique is characterized by two basic components: the structural model and the measurement model. The structural model contains the relationships between exogenous (independent) and endogenous (dependent) variables, while the

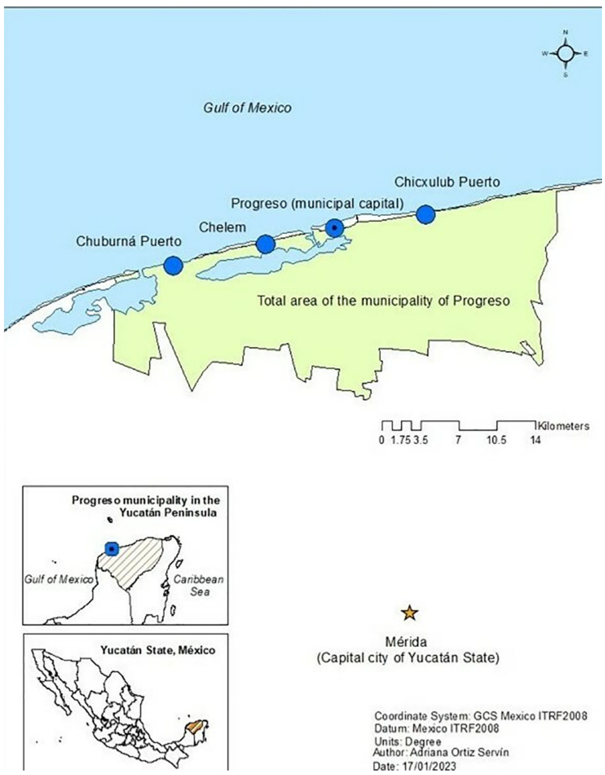

FIGURE 1
Study area. The municipality of Progreso and localities studied, in the central portion of the Yucatan coast, Mexico.

measurement model represents the relationships between the constructs (latent variables) and the indicators (observable variables).

The PLS approach was developed to reflect the theoretical and empirical conditions applied in the social sciences and behavioral sciences. The PLS mathematical procedures are robust and rigorous, but at the same time, they are flexible because they do not establish rigid premises in the distribution of data, measurement scales, or sample size (Martínez and Fierro, 2018).

The values obtained with the estimation of the model, in general, allowed us to analyze and quantify the relationship between variables and the quality criteria, among which stand out: a) the loads or factorial weights (pf), which show the relationship between the observable variables and the latent variables, considering those higher than 0.7 adequate (Carmines and Zeller, 1979); b) the *path* coefficient (Cp), which allows evaluating the level of causality between constructs, applying the range from -1 to 1, where values close to 0 (zero) show less convergence and values $\geq$ 0.7 show a strong relationship, according to Bagozzi (1994) and Chin (2010); c) the coefficient of determination (R^{2}) reflects the amount of variance of the construct that is explained by the other constructs, also called predictor variables. The parameters that show a strong, moderate or weak relationship oscillate around 0.67, 0.33, or 0.10 respectively, according to Falk and Miller (1992) and Chin (1998); d) the value of f^{2} allows assessing the impact of a construct when another construct is omitted from the model, where values of 0.02, 0.15 and 0.35 indicate a small, medium and large effect respectively (Cohen, 1998); e) internal consistency, shows the reliability of the construct, in SmartPLS the Composite Reliability Index (IFC) is generated. It is suggested to consider this index as valid when it reaches values of 0.7, 0.8, or 0.9, which mean modest, adequate, and high levels, respectively (Nunnally and Bernstein, 1994). The IFC is more suitable for PLS than Cronbach's alpha as it does not assume that all indicators receive the same weight (Chin, 1998); **f**) the evaluation of the model, in general, was carried out with a single criterion, the normalization of the residual root mean square (SRMR), in which a correct model implies values >0.06 (Henseler et al., 2016).

Results

Environmental factors in the abundance of the Mayan octopus in the perception of fishermen during 2020

In the understanding of the components, attributes, and interactions of the socio-ecological system of the Mayan octopus, the value and importance of environmental variability as an attribute of the system, was found. For example, a merchant-fisherman from the town of "El Playón" in Progreso expressed the following:

"… last year there were many hurricanes, storms, and "northern" events, this influenced the octopus to store it earlier, the excess rainfall and colder water made it take refuge earlier. What usually happens between November and December, but last season it happened between September and October, the egg was already too big for those dates and that's why it was scarce.

This perception was shared by 95% of those interviewed and it was possible to verify that precipitation reached 1802.2 mm/m ^{2} in 2020, while the average recorded in the period 2014-2019 was 1051.2 mm/m^{2}, representing an increase of 42% (CONAGUA, 2022).

Another factor was the interruption of operations due to the impact of COVID-19, which influenced the low catches and the market-price subsystem. The low price that octopuses reached in the season encouraged some demand from the local market and seafood packers. In this context, the fishing sector requested an extension of the capture period, to which the authorities granted a 15-day extension, an agreement published on December 15, 2020 (DOF, 2020). The catches recorded in 2020 were 29% less than the quota established as the maximum catch, unfortunately, this limit has been exceeded by more than 100% systematically for several years.

Estimation of the measurement and structural models for the understanding of the socio-ecological system of the Mayan octopus

In the fieldwork carried out in 2021, the fishing decisions related to the most frequently observable variables were observed, as well as the level of influence (Table 1).

In addition, the observed variables were quantitatively assessed using the factor loadings (measurement estimate) and the structural estimate (Figure 2). To facilitate the understanding of the results, the factor loadings of the model were included in Table 2.

Reproductive capacity and natural closure, its influence on the abundance and governance of the Mayan octopus according to the perception of the fishermen

According to the perception of the fishermen, the high reproductive capacity of the octopuses and the care of the mother over the eggs guarantee the abundance of the resource. This could be perceived in the interviews, for example:

"…the octopus will never end, there are many octopuses, and they lay thousands of eggs, up to 5,000"

"…it will not end, it lays thousands of eggs, imagine a single octopus lays thousand and there are thousands of octopuses".

The apparent abundance and high price that octopus reached during the season increased fishing efforts. In the estimation of the measurement model, the natural closure and the reproductive capacity directly affect the perception of the fishermen with values of 0.96 and 0.80 (Table 2). Whose fishing decision of all the actors is oriented to increase the fishing effort (Table 1). In contrast, fishing permits (pf=0.57) and regulatory issues (pf=0.95) (Table 2) had a weak effect (Cp= -0.18) on capture decisions (Figure 2).

Physical factors of the environment and their influence on fishing decisions

The physical factors identified in the interviews were turbidity, sea surface temperature (SST), wind, and marine currents, as those

10.3389/fmars.2023.1018728

TABLE 1 Observable variables and fishing decisions.

Observable Variables	Influence level	Proportion (%)	Fishing decisions observed in the field
Competition for other anglers	3 (strong)	75.6	Increase in fishing effort
Knowledge about dribbling	3	70.7	Determine the type of bait, length, and control of ropes, location, perception of the physical environment, orientation, and use of the brake on the boat.
Illegal fishing	3	78	Increase in fishing effort.
Fishing standards (regulations)	1 (weak)	78	Start of the fishing season, approach the fishing quota as a goal and use weight (450 grams) as a criterion to assess the price in the market.
Capture permissions	1	82.9	A condition that determines the way of working: independent, employer, boat owner, cooperative, assistant.
Turbidity	2 (moderate)	58.5	Location to fish
Sea surface temperature	two	48.8	Location to fish
Wind	3	92.7	Location, length, and control of ropes. Orientation of the boat and use of the brake. Increase or reduction of the working day.
Ocean currents	3	97.6	Location, length, and control of ropes. Orientation of the boat and use of the brake. Increase or reduction of the working day.
Octopus High Price	3	95.1	Increase in fishing effort and capture of non-standard specimens.
Reproductive capacity	3	92.7	Increase in fishing effort and capture of non-standard specimens.
Natural closure	3	97.6	Indicates the end of the permitted fishing period.

with the greatest influence on fishing decisions (Figure 2). Its factor loading (pf) was 0.42, 0.29, 0.92, and 0.95 (Table 2). As a construct, Physical Factors (Figure 2) strongly influenced the perception of the fishermen (Cp=0.87). The two physical factors that most strongly influenced the fishing operations of fishermen at sea were the wind in 92.7% and sea currents in 97.6% of the interviewees (Table 1). The factors that influenced weakly and moderately were the temperature and the turbidity of the seawater related to the wind and

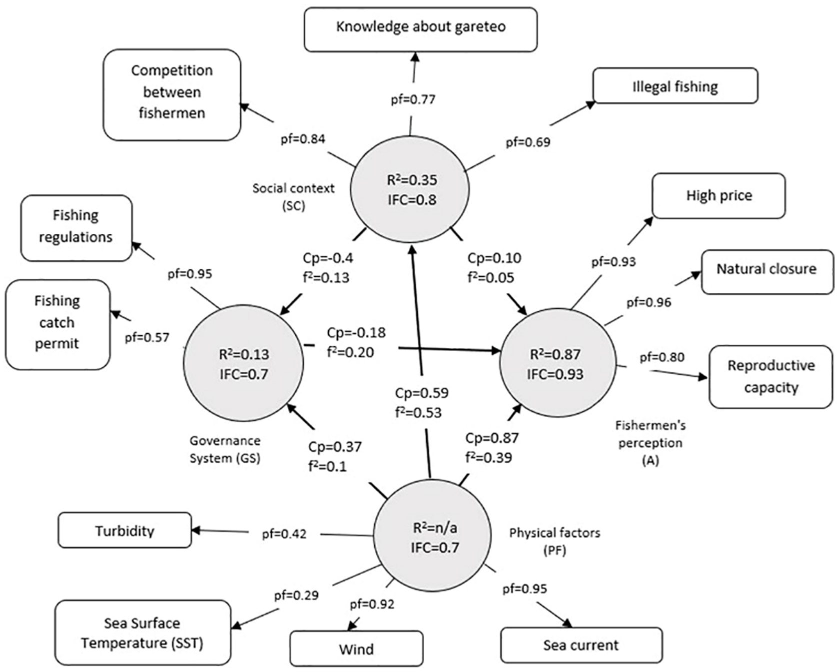

FIGURE 2
Estimation of the structural (grey) and measurement (white) model; each circle represents a latent variable, and a rectangle represents the observable variables; Determination coefficient (R^2), Composite Reliability Index (IFC), *Path coefficient* (Cp), effect index in R ^{2} (f^2), loads or factorial weights (pf); analysis method using PLS algorithm; own elaboration based on SmartPLS software.

TABLE 2 Estimation of the measurement model (factorial loadings).

Observable variables	Latent variables			
	SC	GS	PF	A
Competition for other anglers	0.84			
Knowledge about dribbling	0.77			
Illegal fishing	0.69			
Fishing standards (regulations)		0.95		
Capture permissions		0.57		
Turbidity			0.42	
Sea surface temperature			0.29	
Wind			0.92	
Ocean currents			0.95	
Octopus High Price				0.93
Reproductive capacity				0.80
Natural closure				0.96

SC, "Social Context"; GS, "Governance System"; PF, "Physical Factors"; A, "Actors".

marine currents which influenced 58.5 and 34.1% of the interviewees (Table 1).

Precipitation is a factor that can directly influence the closed season and reproductive nature as perceived by fishermen, but it is not a determining factor in fishing decisions to increase or decrease fishing effort or how, where, and when to catch the octopuses The wind and sea currents are the determining factors. For this reason, it was not included in the model, but it could be a sensitive variable for future analysis, due to its interaction with the natural closure.

Discussion

In this work, Mayan octopus fishermen are recognized as the first link in the value chain that not only contributes catches or a product to the international market. This fishery has also contributed to the well-being of 12,000 fishermen and their families directly and to other economic sectors indirectly in the region. The accumulation of empirical and scientific knowledge made it possible to validate and identify the variables studied, difficult to measure, but identified by the fishermen that together can contribute to the advancement of the adaptive ocean and climate governance processes. This fishery is complex and dynamic and is approached for study as a system.

The socio-ecological system of the Mayan octopus is dynamic and unpredictable, although the governance system tends to be static. Failure to recognize the non-linearity and limits of the system could lead the fishery to a point of no return, towards a significant decrease in octopus abundance, or lead it from a stable to an undesirable state (Berkes et al., 2003; Hughes et al., 2005) with effects on ecosystems and social actors (Wiber et al., 2009). From this approach, the Mayan octopus system does not reflect proper functioning, gradually heading towards an uncertain state. Although to date this fishery is not considered at risk (Ramos-Miranda et al., 2021), it has been constantly subjected to high levels of uncertainty.

Uncertainty as a system attribute can be caused by natural conditions such as environmental variability, such as atypical rainfall, or by human decisions such as estimating inappropriate catch quotas (Charles, 2001; Gunderson and Holling, 2002). Non-linearity can be observed through threshold effects, which determine inflection points that lead ecosystems to changes in their original characteristics to give way to degraded ecosystems or alternate states (Berkes et al., 2003). For example, the Newfoundland cod fishery (Charles, 2007). Cod exploited since 1950 and overexploited in the 1970s, attempts were made to recover using conventional technical resources such as the establishment of quotas. However, it collapsed in 1992 (Chantraine, 1993; Walters, 2007). With the near disappearance of the cod, the seabed changed from a stable state to a different one. Currently, this seabed is characterized by a fauna of invertebrates (crabs, shrimps, and lobsters). Due to its high price, the value added by fishing activity has not diminished. However, the losing actors were the artisanal fishermen, since they did not have the technical capacities to access invertebrate fishing (Wiber et al., 2009; Berkes, 2010). Management oriented toward the political-economic system, the discarding of fishermen's knowledge and the misinterpretation of population trends led to the collapse of the cod fishery (Chantraine, 1993; Walters, 2007).

Collapses do not happen from one day to the next, they are the result of multifactorial processes in which human decisions play a transcendental role. Over time, fishermen have generated detailed knowledge of their activity and environment, resulting from innumerable observations under changing environmental conditions; this knowledge governs their behavior (Johannes, 1993; Ostrom, 2000; Ostrom, 2008). During 2020, the fishermen perceived a population decrease of the octopus, which was attributed to abundant and anticipated rains. In this case, the availability of the resource could have been altered by biophysical factors (e.g., rain and/or nutrient availability) or as part of a natural response of the species. The octopus population sometimes seems to increase and in others to decrease, it is still not known with certainty what influences these population changes, if they are cyclical or if a state of the population leads to an alternate state. Population variability is a characteristic present in many marine species such as sockeye salmon (Oncorhynchus nerka) whose biological similarity with the Mayan octopus is that they reproduce only once in their lives, that is, they are semelparous organisms. The population of sockeye salmon, and probably also of the Maya octopus, can drop dramatically at any given time (McCay, 1978; Holling and Meffe, 1996). Unpredictability and change are part of natural variation and are an important part of species resilience processes (Idem). These types of processes are generally not considered by decision-makers, which contributes to increasing the uncertainty of the systems, putting their governance and governability at stake (Charles, 2001; Gunderson and Holling, 2002), as well as the social adaptive capacities of fishermen.

In a normal cycle, the laying and incubation phase of the Maya octopus takes place between November and December (Figure 3), when the females go into their caves or hiding places to lay their eggs. Once this process has started, they no longer feed and dedicate themselves completely to the care of the eggs until the moment of hatching, then the mothers die. This process is an indicator of change in the behavior of the Mayan octopus and means that it "hides" or "refuges" giving rise to a kind of "natural closure", preceded by the gradual growth of the ovary until it reaches its maximum size, a process constantly monitored by the fishermen (verified in the field), and coincides with the period of intensification of the winds coming from the "north" (Figure 3). In response, 97% of the fishermen interviewed decided to increase the fishing effort (Table 1). The argument found for said conduct or fishing decision was:

"... *it's the last chance of the season before the octopus is sold*".

During the season of winds coming from the north, the knowledge and skills of the fishermen are put to the test, this is because the permitted capture method known as "gareteo" implies a detailed and deep knowledge of the behavior of the wind and marine currents (Table 2). It was verified in the field that, if both environmental factors are aligned with each other in the same geographical direction, the capture possibilities increase considerably. But, to the extent that the direction of the wind changes in a different direction than the sea currents, the possibilities of capture decrease. When the synchrony between the wind and the sea currents occurs, the speed of the boat is controlled using a technical adaptation in their boats known as a "brake" (Table 1). In this sense, the capture maneuvers are not only determined by the seasonal abundance of fish or shellfish, but also by the effect of biophysical factors and local knowledge (Ruddle, 1993; Ehuan-Noh et al., 2020).

Strong winds and sea currents can influence fishermen not to go fishing. However, the northerly winds are valued and desired, if they are not so frequent since they help remove the "garbage" from the seabed near the coast and clean the caves where the octopuses hide. The term garbage refers to remains of algae, seagrass (Ehuan-Noh et al., 2020), and solid waste of human origin. The term that begins to be changed among fishermen to "sargassum". In addition, the recirculation of the water contributes to lowering the temperature and turbidity, which according to the fishermen is preferred by the octopuses. Thus, once the "northern" event has removed the garbage from the bottom, eventually the octopuses approach the coast again to occupy the liberated shelters, and with them, the fishermen also come to resume their activities with less risk and cost, especially those who lack the technical and material capabilities to venture offshore.

Conclusions

Variability has characterized the uncertainty of socio-ecological systems, proof of this is that fishing decisions are modulated based on environmental variability, the market and the agreements reached as a group and on some occasions together with the authorities. For this reason, fishermen have reiterated for decades that fishing bans must be reviewed from time to time (Fraga et al., 2008) and not leave it in perpetuity. However, the rigidity of the governance system compared to the ability of fishers to adapt to the variability of the system opens the doors for the emergence of conflict, social dilemmas, and perverse problems (Grundmann, 2018). For example, the catch quota recommended by the authorities is perceived more as a goal to be exceeded than a limit, which implies a problem since for years it has been conveniently perceived in the name of economic growth.

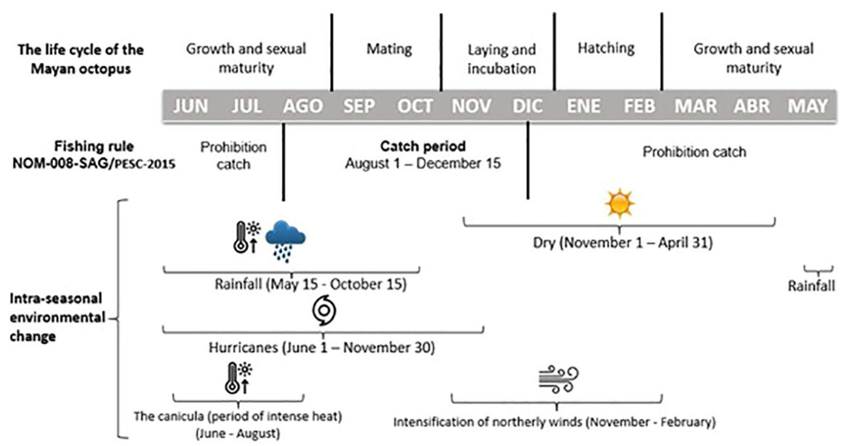

FIGURE 3
The life cycle of the Mayan octopus, intra-seasonal environmental variability, and NOM-008-SAG/PESC-2015. Own elaboration based on Solís-Ramírez et al., 1997; DOF, 2019; CONAGUA, 2022.

The normative conditions established to regulate the Mayan octopus fishery show a bias towards the economic-political system, ruling out environmental variability, fishermen's knowledge, and non-linear processes, which can considerably increase the level of risk and uncertainty of the fishery. As was shown with the Newfoundland cod fishery that collapsed in 1997.

It is recognized that governance is another way that can induce cooperation between the actors to achieve the resilience and sustainability of the socio-ecological system of the Mayan octopus. But it is necessary to consider the accumulated knowledge and learning of fishermen in the face of environmental variability in the design and implementation of regulations. Given this scenario, emerging governance models, such as adaptive governance (Folke et al., 2005) and interactive governance (Kooiman et al., 2005), can provide key elements to guide the course of a highly dynamic fishery with increasing levels of uncertainty, such as that of the Mayan octopus.

Recommendations

Deepen the study of the socio-ecological system of the octopus through different approaches and multidisciplinary research techniques (awareness workshops, accompaniment in the tasks, monitoring and evaluation of indicators beyond concentrating only on fishing catches per unit of effort).

Review the methods for estimating recommended catch quotas.

Encourage productive alternatives in closed seasons for species such as the Mayan octopus.

Evaluate the relationship between physical factors such as precipitation, salinity, and temperature with primary production in the coastal zone of the Yucatan peninsula.

Deepen the study of spawning and incubation timing and its relationship with physical factors to identify its variability and how it can affect regulations while considering the experiences and knowledge of fishermen.

Disseminate principles of bioethics among actors and consumers of any nationality, age, or style of consumption on the importance of respecting the closed periods for octopus and other target species to contribute to the sustainability of resources.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding authors.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

The research design, data collection and information processing were carried out by JS. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Aldridge, A. E., and Levine, K. J. (2001). *Surveying the Social World: Principles and Practice in Survey Research*.

Bagozzi, R. (1994). Structural equation models in marketing research: Basic principles. *Bagozzi (Ed) Principles marketing Res.*, 317–385.

Berkes, F. (2010). Perspectivas cambiantes sobre la gestión de recursos. resiliencia y reconceptualización de los 'recursos naturales' y la 'gestión'. *MÁSTIL* 9 (1), 13–40.

Berkes, F., Colding, J., and Folke, C. (2003). *Navigating social-ecological systems: building resilience for complexity and change* (Cambridge: Cambridge University Press).

Berkes, F., Mahon, R., McConney, P., Pollnac, R., and Pomeroy, R. (2001). *Managing Small-Scale Fisheries*. Otawa: International Development Research Centre.

Binder, C. R., Hinkel, J., Bots, P. W. G., and Pahl-Wostl, C. (2013). Comparison of frameworks for analyzing social-ecological systems. *Ecol. Soc.* 18 (4), 1–39. doi: 10.5751/ES-05551-180426

Boshell, F., León, G., and Peña, A. (2011). "Methodologies to generate and use meteorological information at the subnational and local levels in the face of climate change. manual series / manual no. 4. AACC program," in *Adaptation of agriculture and* *agricultural water use to climate change in the Andes* (Peru: Andean Countries 2010-2013).

Carmines, E., and Zeller, R. (1979). "Reliability and validity assessment," in *N. 07-017, sage university paper series on quantitative applications the social sciences* (Beverly, Estados Unidos: Sage).

CCPY (2022) *Fluctuation and climatic variability*. Available at: http://www.ccpy.gob.mx/cambio-climatico/fluctuacion-variabilidad-climatica.php.

Chantraine, P. (1993). *The last cod* (Montreal: Robert Davies).

Charles, A. (2001). "Sistemas pesqueros sostenibles," in *Libros de noticias de ciencia pesquera* (Oxford: Blackwell).

Charles, A. (2007). "Adaptive co-management for resilient resource systems," in *Adaptive cogestión British Vancouver*. Eds. D. Armitage, F. Berkes and N. Doubleday (Columbia Press), 83–102. https://www.ubcpress.ca/asset/9067/1/9780774813839.pdf

Chin, W. (1998). "The partial least square approach to structural equation modeling," in *Modern methods for business research*. Ed. G. Marcoulides (Mahawah, Estados Unidos: Lawrence Erlbaum), 295–369.

Chin, W. (2010). "How to write up and report PLS analyses," in *Handbook of partial least squares: Concepts, methods, and applications*. Eds. E. Vinzi, W. Chin, J. Henseler and H. Wang (Berlín, Alemania: Springer-Verlag), 655–690.

Cohen, J. (1998). *Statically power analysis for the behavioral sciences* (USA, New York: Laurence Erlbaum Associates).

CONAGUA (2022) *Monthly precipitation and temperature summaries*. Available at: https://smn.conagua.gob.mx/es/climatologia/temperaturas-y-lluvias/resumenes-mensuales-de-temperaturas-y-lluvias.

CONAGUA (2022). Portal de datos abiertos: Resúmenes mensuales de temperaturas lluvia. https://smn.conagua.gob.mx/es/climatologia/temperaturas-y-lluvias/resumenes-mensuales-de-temperaturas-y-lluvias. México.

Contreras, D., Vazquez, E., Romero, Y., Pardo, J., Guevara, M., and Rivera, R. (2019) *Strategic plan: Mayan octopus technology platform for the development of high value-added products.CIATEJ*. Available at: https://ciatej.mx/files/divulgacion/divulgacion_5f593a994e3c3.pdf.

Cox, M. (2011). Advancing the diagnostic analysis of environmental problems 1. introduction: Complexity and panaceas. *Int. J. Commons* 5 (2), 346–363.

Creswell, J. (1998). *Qualitative Inquiry and Research Design. Choosing Among Five Traditions* (Thousand Oaks, California: Sage Publications).

Crouch, M., and McKenzie, H. (2006). The logic of small samples in interview based qualitative research. *Soc. Sci. Inf.* 45 (4), 483–499. doi: 10.1177/0539018406069584

Delin, J. (2000). *The language of everyday life* (Londres: Sage publications).

Diario Oficial de la Federación (2019) *Agreement establishing a catch quota octopus maya*. Available at: https://dof.gob.mx/nota_detalle_popup.php?codigo=5338727.

Diario Oficial de la Federación (2020) *Agreement establishing a catch quota octopus maya*. Available at: https://dof.gob.mx/nota_detalle.php?codigo=5607231&fecha=10/12/2020&print=true.

Dietz, T., Ostrom, E., and Stern, P. (2013). The struggle to govern the commons. *Science* 302, 1902–1912.

Drew, P. (2005). "Conversation analysis," in *Handbook of language and social interaction*. Eds. K. L. Fitch and R. E. Sanders (N.J. Lawrence Erlbaum), 71–102. https://psycnet.apa.org/record/2004-21251-004

Ehuan-Noh, R. G., Mariaca, R., Sáenz-Arroyo, A., and Espinoza, A. (2020). *Tácticas y saberes: los capitanes de la pesca ante la variabilidad ambiental del mar sociedad y ambiente, núm* Vol. 23 (El Colegio de la Frontera Sur: México Disponible), 1–22. Available at: https://www.redalyc.org/articulo.oa?id=455765022004. doi: 10.31840/sya.vi23.2199

Epstein, G., Vogt, J. M., and Cox, M. (2013). Missing ecology: integrating ecological perspectives with the social-ecological system framework. *Int. J. Commons* 7 (2), 432–453. doi: 10.18352/ijc.371

Falk, R., and Miller, N. (1992). *A primer for soft modeling* (Akron, Estados Unidos: University of Akron Press).

FAO (2022). "El Estado mundial de la pesca y la acuicultura," in *Hacia la transformación azul* (Roma: FAO), 48–53. doi: 10.4060/cc0461es

FAO. (2020). *El estado mundial de la pesca y la acuicultura 2020*. La sostenibilidad en acción. Roma. doi: 10.4060/ca9229es.

Folke, C., Hahn, T., Per, O., and Norberg, J. (2005). ADAPTIVE GOVERNANCE OF SOCIAL-ECOLOGICAL SYSTEMS. *Annu. Rev. Environ. Resour.* 30, 441–473. doi: 10.1146/annurev.energy.30.050504.144511

Fraga, J., Salas, S., and y Mexicano-Cintora, G. (2008). La Pesca en Yucatán: de la abundancia a la escasez, a la fragilidad de las estructuras institucionales (Parte 3). En Descentralización y manejo ambiental: gobernanza costera en México. Coordinadores: Fraga, Villalobos, Dayon y García. 1a. Edición. 2008. 142-160.

Glaser, B., and Strauss, A. (1999). "Discovery of grounded theory," in *Strategies for qualitative research* (New York: Routledge).

Grundmann, R. (2016). Climate change as a wicked social problema. *Nature Geoscience* 9(8), 562–563. doi: 10.1038/ngeo2780

Gunderson, L., and Holling, C. (2002). "Panarchy," in *Understand transformations in human and natural systems* (Washington dc: Island Press).

Hair, J., Hult, G., Ringle, C., and Sarstedt, M. (2017). *A primer on partial least square structural equation modeling (PLS-SEM)* (USA, California: Sage).

Harley, C. D.G., Hughes, A. R., Hultgren, K. M., Miner, B. G., Cascade, J. B., Thornber, C. S., et al. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters* 9, 228–241. doi: 10.1111/j.1461-0248.2005.00871.x

Henseler, J., Hubona, G., and Ray, P. (2016). Using PLS path modeling new technology research: updated guidelines. *Ind. Manage. Data Syst.* 116 (1), 2–20. doi: 10.1108/IMDS-09-2015-0382

Henseler, J., Ringle, C., and Sarstedt, M. (2016). Testing measurement invariance of composites using partial least squares. *Int. Marketing Rev.* 33 (3), 405–431. doi: 10.1108/IMR-09-2014-0304

Henseler, J., Hubona, G., and Ray, P. (2016). *Using PLS Path Modeling in New Technology Research: Updated Guidelines. Industrial Management & Data Systems*. 116, 2–20. doi: 10.1108/IMDS-09-2015-0382.

Holling, C., and Meffe, G. (1996). Command and control and pathology of natural resources administration. *Biología la conservación* 10, 328–337.

Hughes, T., Bellwood, D., Folke, C., Steneck, R., and Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends Ecol. Evol.* 20 (7), 380–86. doi: 10.1016/j.tree.2005.03.022

Intergovernmental Panel on Climate Change (IPCC) (2014). *Climate change 2014 synthesis report summary chapter for policymakers* Vol. 31 (IPCC). doi: 10.1017/CBO9781107415324

Johannes, R. E. (1993). *Integrating traditional ecological knowledge and management with environmental impact assessment* (Ottawa, Canada: Concepts and Cases Ed. Julian T Inglis), 33–39.

Kooiman, J., Bavinck, M., Jentoft, S., and Pulin, R. (2005). *Fish for life: interactive governance for fisheries* (Amsterdam: Amsterdam University Press).

Levin, S. (1999). *Fragile dominion: Complexity and the commons* (Reading, MA: Perseus).

Martínez, A. M., and Fierro, M. E. (2018). Aplicación de la técnica PLS-SEM en la gestión del conocimiento: un enfoque técnico práctico. *RIDE. Rev. Iberoamericana para la Investigación y el Desarrollo Educativo* 8 (16), 130–164. doi: 10.23913/ride.v8i16.336

Mason, M. (2010). "Sample size and saturation in Ph.D. studies using qualitative interviews," in *Forum qualitative sozial for Schung/Forum qualitative social research*, vol. 11. , 8.

McCay, B. J. (1978). Systems ecology, people ecology, and the anthropology of fishing communities. *Hum. Ecol.* 6 (4), 397–421. doi: 10.1007/BF00889417

McGinnis, M., and Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges. *Ecol. Soc.* 19 (2), 1–30. doi: 10.5751/ES-06387-190230

McGowan, J. A., Cayan, D. R., and Dorman, L. M. (1998). *Climate-Ocean Variability and Ecosystem Response in the Northeast Pacific*. http://science.sciencemag.org/ Downloaded from Science 281 (5374), 210–217. [doi: 10.1126/science.281.5374.210].

Montealegre, J., and Pabon, J. (2000). Interannual climate variability associated with the El niño-la niña–southern oscillation cycle and its effect on the rainfall pattern in Colombia. *Meteorol. Colomb.* 2, 7–21. ISSN 0124-6984. Bogotá, D.C. – Colombia.

Montealegre, J. E. (2009). Estudio de la variabilidad climática de la precipitación en Colombia asociada procesos oceánicos atmosféricos de meso gran escala. Obtenido en: https://www.minambiente.gov.co/images/AsuntosMarinosCosterosyRecursosAcuatico/CUNDINAMARCA.pdf, 08/07/2021

Nunnally, J., and Bernstein, I. (1994). *Psychometric theory. 3a ed* (Nueva York, USA: McGraw-Hill).

Ospina, D. (2012). *Actualización del marco para el estudio de sistemas socioecológicos*. Producto II. Instituto Alexander von Humboldt.

Orellana, R., Espadas, C., Conde, C., and Gay, C. (2009). *ATLAS ESCENARIOS DE CAMBIO CLIMÁTICO EN LA PENÍNSULA DE YUCATÁN*. Unidad de Recursos Naturales Centro de Investigación Científica de Yucatán Centro de Ciencias de la Atmósfera de la Universidad Nacional Autónoma de México, México. Pp 1–6. (Retrieved December 2, 2022) http://www.ccpy.gob.mx/pdf/Regional/escenarios-cambio-climatico/introduccion.pdf

Ostrom, E. (2000). Crowding out citizenship. *Scandinavian Political Stud.* 23 (1), 3–16. doi: 10.1111/1467-9477.00028

Ostrom, E. (2005). *Understanding institutional diversity* (Nueva York: Princeton University Press). doi: 10.3200/ENVT.50.4.8-21

Ostrom, E. (2008). "Institutions and the environment," in *Institute of economic affairs 2008* (Blackwell Publishing). doi: 10.1111/j.1468-0270.2008.00840.x

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science* 325 (5939), 419–422.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., et al. (2014). "Food security and food production systems". E. C.B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, et al, eds. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribución del Grupo de Trabajo II al quinto informe de evaluación del Grupo Intergubernamental de Expertos sobre el Cambio Climático*, págs. 485–533. Cambridge (Reino Unido) y Nueva York (Estados Unidos de América), Cambridge University Press.

Ramos-Miranda, J., Cabrera, M., Salas, S., López-Rocha, J., and Flores Hernández, D. (2021). "Commercial species of artisanal fishing in the Yucatan peninsula," in *Universidad autónoma de campeche. centro de investigación y de estudios avanzados del IPN unidad mérida* (Universidad Nacional Autónoma de México), 176.

Ringle, C. M., Wende, S., and Becker, J. M. (2015). "SmartPLS 3," in *Boenningstedt: SmartPLS GmbH*. Available at: http://www.smartpls.com.

Rosas, C., Caamal-Monsreal, C., Rodríguez, F. G., Mascaró, M., Galindo, C. E., Díaz, F., et al. (2021). Capacidad adaptativa a los cambios de temperatura de diversas especies de crustaceos, moluscos y peces de importancia pesquera ante escenarios de calentamiento en el golfo de méxico. *Resiliencia Costera. CICESE y UGM. Geos* 40 (1), 158.

Ruddle, K. (1993). "The transmission of traditional ecological knowledge," in *Concepts and cases*. Ed. J. T. Inglis(Ottawa, Canadian Museum of Nature and IDRC), 17–31. https://www.academia.edu/357980/3._The_Transmission_of_Traditional_Ecological_Knowledge

Selgrath, J. C., Kleiber, D., and O'Donnell, K. P. (2014). *Understanding tradeoffs in fishers decision making: Catch, distance, and safety influence where fishers fish. project seahorse* (Vancouver, Canada: University of British Columbia), 36–44. Available at: https://www.researchgate.net/publication/265336514.

Solís-Ramírez, M. J., Arreguín-Sánchez, F., and Seijo, J. (1997). "Cephalopod fisheries," in *Analysis and diagnosis of the critical fishing resources of the gulf of Mexico*. Eds. D. Flores-Hernández, P. Sánchez-Gil, J. C. Seijo and F. Arreguín-Sánchez(Mexico), 61–80, 496.

Taylor, S. J., and Bogdan, R. (1990). Introducción los métodos cualitativos de investigación. *La búsqueda de significados*. México: Paidós. Cap. 1

Walters, C. J. (2007). Is adaptive management helping to solve fisheries problems? *Ambio* 36, 304–307. doi: 10.1579/0044-7447(2007)36[304:IAMHTS]2.0.CO;2

Whittingham Munévar, M. V. (2010). ¿Qué es la gobernanza para qué sirve?. *Revista Análisis Internacional (Cesada a Partir De 2015)*, (2), 219–236. Recuperado a partir de https://revistas.utadeo.edu.co/index.php/RAI/article/view/24. 12/0772021

Wiber, M., Charles, A., Kearney, J., and Berkes, F. (2009). Improve community empowerment through participatory fisheries research. *Mar. Policy* 33, 172–179. doi: 10.1016/j.marpol.2008.05.009

Woodruff, A., and Aoki, P. M. (2004). Conversation analysis and the user experience. *Digital Creativity* 15 (4), 232–238. doi: 10.1080/1462626048520184