Chapter 8
Fishery Resource Management Challenges Facing Climate Change

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8.1 Introduction

Climate change is a natural cyclical phenomenon, with a frequency of approximately 70 years; and even when its effects and consequences are assumed, they are not clearly identified and characterized in the marine environment. The consideration of climate change effects for the management of living marine resources has not been incorporated into daily fishing practices. In the first instance, this has been due to the difficulty of identifying and separating the two sources of variation of stock abundances in a highly variable environment; second, the evidence of the effects of climate change has not been recognized in a timely manner. Although the regime shift was recognized by the late 1970s and early 1980s, it was not until 1984, at the World Conference on Fisheries Management and Development (FAO 1984), that the exploration of this phenomenon was suggested. Later, in 1995, Agenda 21 (ONU 1995) and the Code of Conduct on Responsible Fisheries (FAO 1995) included recommendations for governments to consider the effects of climate change on fishing activities; however, it was not until 2001, at the Reykjavik Declaration (FAO 2002), and in 2002, at the World Summit on Sustainable Development in Johannesburg (ONU 2002), that countries formally agreed to consider the climate change phenomenon within their policies, establishing a commitment to promote the implementation of measures to mitigate its effects. With this agreement, countries formally committed to attending to the effects of climate change, which, regarding fishing, was approximately 20 years after the regime change.

In this context, the state of knowledge of fisheries, the lack of background on the effects of climate change, and the absence of data, trends, and empirical evidence

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used by science have caused a delay in the provision of management advice. Additionally, before the 1980s, management practices were closely linked to the available science, which was, in general, based on the static nature of the models, assuming a stable population carrying capacity, and therefore of the ecosystems; consequently, fishing was assumed to be the main or only driver of changes in the trends of stock abundance. Under these conditions, if a stock is fully exploited, that is, harvested to the limit of its maximum capacity of production, the change in abundance caused by climate change was not recognized at that time, and such effects were attributed to fishing. In this way, since the stock declined due to a cause other than fishing and the high harvest rates were maintained at the level corresponding to the limit of the stock production capacity, a certain degree of overfishing was generated; the impact of that overfishing may be more or less severe, depending on the life history of the populations and the accumulation of this effect over time.

Under this scenario, a number of fish stocks around the world appear overfished; but now, we know that environmental conditions are a key factor inducing these abundance decreases. On the other hand, the fact that the global effect shows a decreasing trend for many resources is because, also in global terms, the warming trend is associated with a reduction in primary production (Roxy et al. 2016; Gu et al. 2017); and, if the tendency of the latter is to decrease over time, the abundance of the populations will also, in general, tend to decrease. Of course, since this process is propagated through the food web, some stocks will decrease, and others will increase in abundance, but global production is expected to decline. This is the case that is illustrated in Fig. 8.1, which represents the ecosystem evolution of the continental shelf of Campeche in the southern Gulf of Mexico from late 1950–2010.

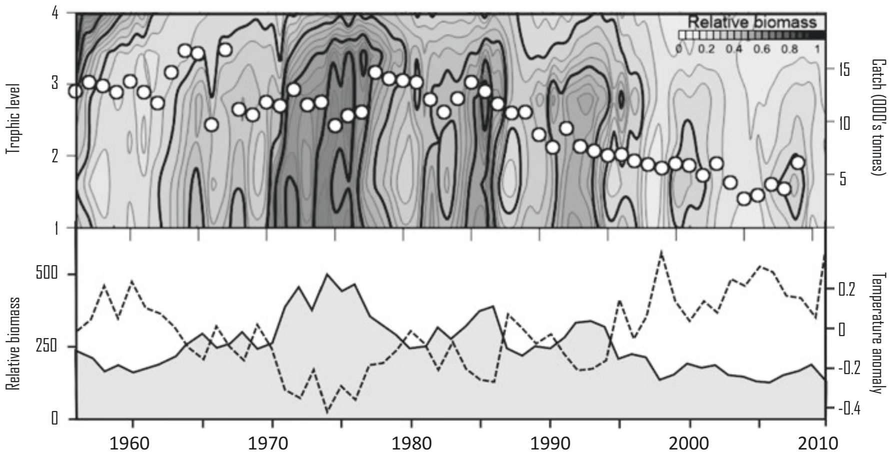

Fig. 8.1 Effect of climate change on the ecosystem of the southern Campeche Bank. Species in ecosystems are represented by their trophic level. Isolines reflect relative production along the ecosystem structure and through time. Note that maximum production occurs by the late 1980s with the regime shift when a cooling period ends and a warming period starts. Also note a decadal fluctuation that follows the long-term pattern of declining carrying capacity with a warming trend

The current challenge for science is to maintain the sustainability of exploited populations and ecosystems that change and evolve over time, defining adaptable management strategies by, for example, considering biological interdependencies, effects on habitat, changes in currents' circulation patterns, and metabolic stresses, among others. These types of questions require science that promotes active management actions, which allows for the continued generation of information and a continuous implementation of strategies in time and space in order to maintain sustainability independent of the evolution of stocks and ecosystems.

According to Arreguín-Sánchez (2012) and Arreguín-Sánchez et al. (2015), the Campeche Bank shows clear evidence of the effects of climate change, and in this region, consequences have been clearly reported for some of the main fisheries. In the following sections, three of the most significant regional fisheries are discussed: two of them have been negatively affected by climate change, with an official diagnosis of deterioration and overfishing, and one stock has been positively impacted, and yields have progressively increased. In all cases, we briefly discuss the consequences of adopting a management strategy based on an adaptability policy.

8.2 The Campeche Bank and the Evidence of Climate Change

One of the marine regions of Mexico that best reflects the effects of climate change on fisheries resources and that requires a new approach to fisheries management is undoubtedly the Campeche Bank (Fig. 8.2). In this region, a climate regime shift occurred in the late 1970s and the beginning of the 1980s, as shown by the anomalies of several environmental variables, such as temperature, salinity, primary production, mean sea level, and some climate indexes, such as the North Atlantic Oscillation, NAO, and the Atlantic Multidecadal Oscillation, AMO (Fig. 8.3) (Arreguín-Sánchez 2012; Arreguín-Sánchez et al. 2015). Additionally, the dominant effect of the 67-year harmonic component of temperature, which is characteristic of a climate change cycle, was demonstrated for this region, and this explains approximately 60% of the total variation in temperature (Del Monte-Luna et al. 2015).

The Campeche Bank behaves like a semi-closed marine system with respect to the rest of the Gulf of Mexico (Fig. 8.2). The bank contains an extensive continental shelf of approximately 140,000 km^2, which extends north and west of the Yucatan Peninsula for more than 200 km of coastline. In the peninsula, there are no rivers, except at the southern limit; its influence, because of the coastal currents, is manifested toward the western region outside the Campeche Bank. In this way, the contribution of terrestrial nutrients is limited to the adjacent area close to the mangrove systems along the coast; as a result, most primary production in the region comes from phytoplankton. The marine currents are, generally, of low intensity and provide a poor contribution to production because of the effect of turbulence that limits nutrient availability. On the other hand, the exchange of masses of water with the adjacent ocean, from the central Gulf of Mexico, is largely controlled by six eddies

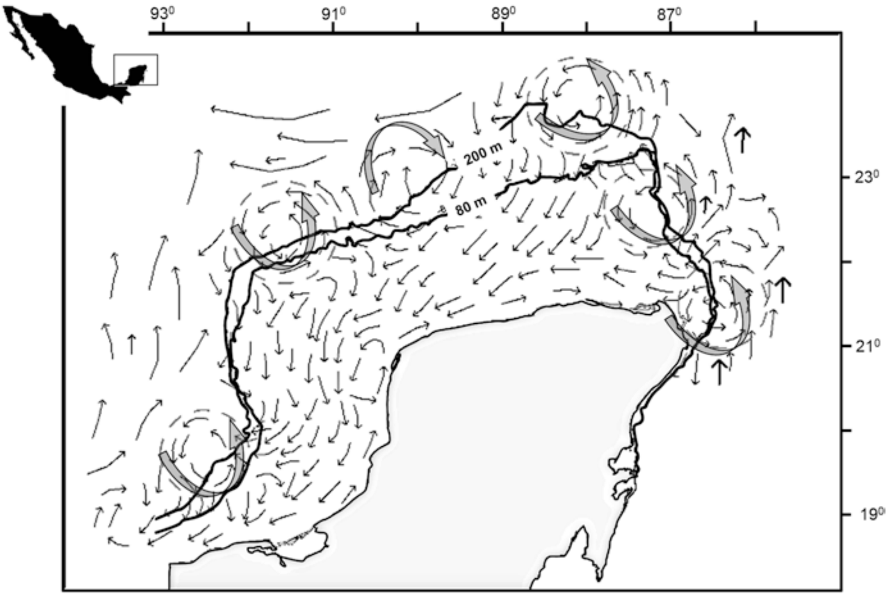

Fig. 8.2 Map showing the Campeche Bank indicating the limits of the continental shelf and the eddies around it (large transparent arrows). Thin arrows indicate Ixtoc I was the direction of the marine currents. It can be seen that most of the eddies act as a natural barrier with respect to the central Gulf of México

over the limit of the continental shelf, five of them anticyclonic gyres, which transport water outside the Bank of Campeche, and only one cyclonic gyre with the opposite effect (see Fig. 8.2). One important aspect to be taken into account for spatial and seasonal dynamics is that the entire system responds to seasonal pulses of primary production; one such pulse is associated with the region of the Laguna de Términos, is manifested just after the rainy season (July), and is characterized by the departure of a large number of species that migrate from the breeding areas to the sea (Yáñez-Arancibia and Day Jr 1988; Arreguín-Sánchez 1992; Zetina-Rejón 2004); another pulse is associated with the seasonal upwelling on the northeast of the continental shelf of the Yucatan Peninsula, occurring in April (Merino 1996; Pérez et al. 1999; Piñeiro and Giménez-Hurtado 2001). This dynamic results in east-west seasonal movements of many species; these are processes that have been documented by several authors (i.e., Arreguín-Sánchez 1992; Arreguín-Sánchez et al. 1995; Arreguín-Sánchez and Pitcher 1999; Pérez et al. 1999; Piñeiro and Giménez-Hurtado 2001).

The above processes explain ecosystem and population responses to climate change. In general, the warming period starting in the 1980s has caused a diminishing trend in primary production (Fig. 8.3) manifested as a general drop in the ecosystem carrying capacity (Fig. 8.1). This process has marked the evolution of the ecosystem over the last six decades and, in general, has led to a decreasing trend in global production.

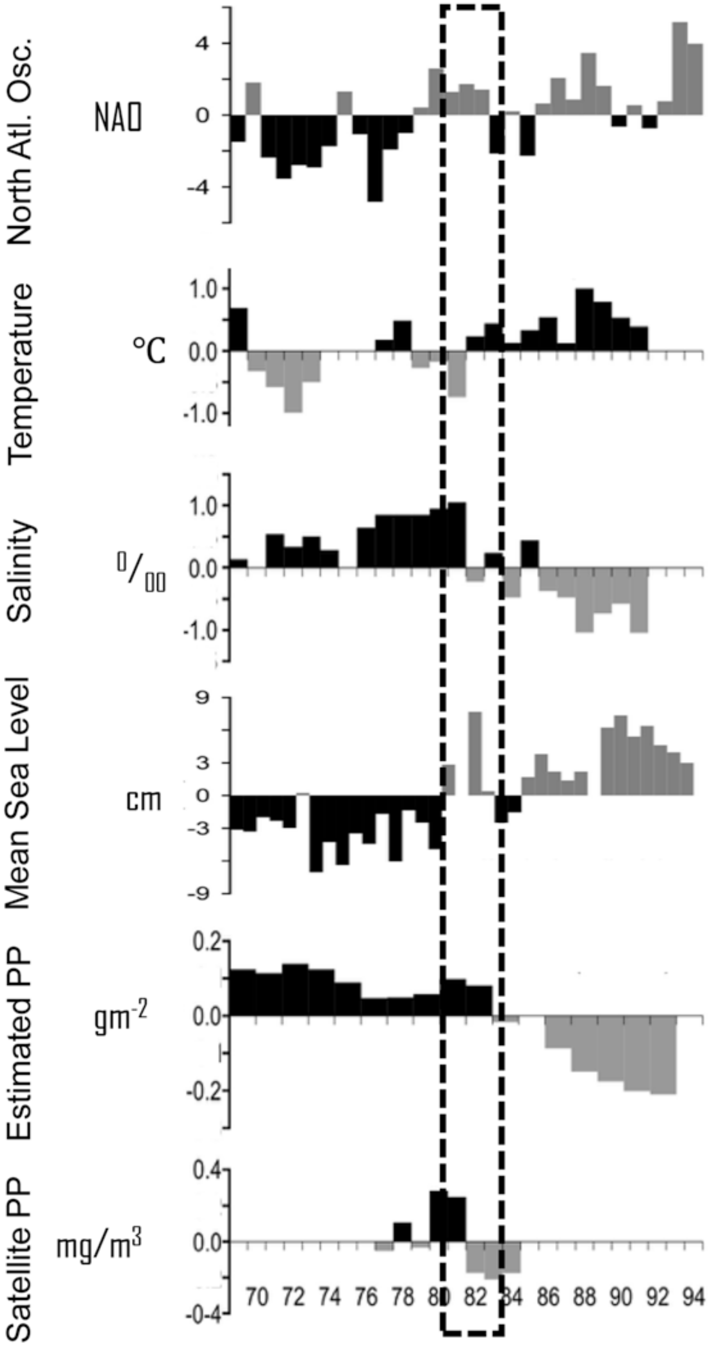

Fig. 8.3 Anomalies of several environmental variables affecting the Campeche Bank, where the change of phase indicates the regime shift moment

8.3 About the Management Tools

On the other hand, the management policies and tools are, conventionally, fixed, not dynamic. This is because fishery science has been conventionally based on the assumption of a stable carrying capacity and ecosystems. This assumption was acceptable for about six decades before the 1980s (Arreguín-Sánchez 2012), though it still persists in many cases, despite the evidence of the effect of climate change. The reason seems clear; the acceptance of climate change effects implies the commitment of governments to explicitly adopt management policies that incorporate dynamic management or an adaptable policy, which is a very complex process because it implies changes in the governance schemes that have been in place for many years. Additionally, the implementation of such a policy also depends on governments' scientific capacities to advise new forms of management. These tasks constitute a very strong challenge that must be faced. A recent approach to ecosystem-based management could help with this new form of management; such scientific developments suggest combining three interesting concepts: the harvest rate as a proportion of the stock that is retained by fishing; the noxicline, which defines the harvest rate limit before fishing affects ecosystem function; and the harvest rate that corresponds to the maximum production capacity of the resource (Arreguín-Sánchez et al. 2017a, b). In this sense, a constant harvest rate could be functional since it represents a proportion of the stock retained by fishing, that is, when the stock is large, a fishery can retain a certain proportion of that high biomass, and if the stock size is low, fishing will retain the same proportion of biomass.

In the following sections, three examples of the challenges imposed by climate change in this transition in the management approach are shown, using as an example some fisheries in the Campeche Bank.

8.4 The Pink Shrimp Fishery (*Farfantepenaeus duorarum*)

The current state of the pink shrimp fishery of the Campeche Bank is that it is collapsed and highly deteriorated (DOF 2012). Annual yields in the 1950s to the early 1970s averaged 18,000 t, while at present, they are lower than 2000 t. In 1995, when the state of the fishery was officially diagnosed as collapsed, the main hypotheses were overfishing and the disturbance of nursery and breeding habitats, among others. However, it has been shown that the decrease in the pink shrimp stock was strongly linked to climate change (Ramírez-Rodríguez et al. 2003, 2006; Arreguín-Sánchez et al. 2015).

Present knowledge indicates that the recruitment rate had been decreasing since the mid-1970s, following the same decreasing trend in primary production in the Campeche Bank, which was inversely related to the increasing trend in temperature (Arreguín-Sánchez 2012). Since fishing effort was not adjusted to the state that the shrimp stock acquired over time, the stock decreased, and the assumption was that

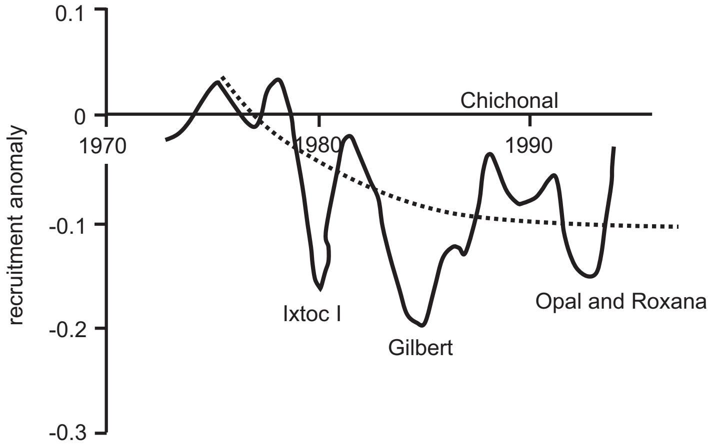

Fig. 8.4 Decreasing trend of the anomaly of the pink shrimp recruitment rate, over time, from the mid-1970s. Several falls in recruitment are shown, caused by hazardous phenomena: Ixtoc I was an oil spill; Gilbert, Opal, and Roxana were hurricanes; and Chichonal was an ash eruption. Recovery after each impact denotes the stock resilience. (Arreguín-Sánchez et al. 2008)

the decrease was the result of overfishing; however, the industry was not aware of this. This happened because, since January 1, 1980, Cuban and US shrimp trawlers ended their operations in Mexican waters, and after that, between 1982 and 1984, the Mexican fleet reduced its fishing efforts during the process of transferring fleet ownership from the private sector to cooperative societies. The net effect was a reduction in fishing mortality by approximately 50% by the mid-1970s; and the observed decreasing yields during the 1980s were attributed to these events. However, by the early 1990s, the fleet normalized its operations, and the low yields continued until 1995 when fishery collapse was recognized. Following the long-term trend in the recruitment rate, it can be observed that the decline started by the mid-1970s; during the 1980s, such decline in the recruitment rate was lower because of the reduction in fishing mortality, which returned to the long-term (higher) declining rate once the fleet operations were normalized (Fig. 8.4).

The management strategy implemented since the late 1990s was to avoid growth and recruitment overfishing; recovery was the main goal for the shrimp stock, which would be the first step toward returning the stock to the level of abundance that existed in the 1990s and, eventually, to the previous stock size that existed in the mid-1970s (DOF 2012). These measures have persisted from the mid-1990s to the present day, with no change in the stock abundance. In this context, the shrimp sector generated expectations of recovery. Of course, the measures were correct for maintaining the spawning stock in the best condition possible to maximize recruitment; however, since the shrimp stock has not been recovered after 20 years, it has generated distrust, which severely affects governance.

Currently, in terms of an ecosystem approach, an intensity of fishing equivalent to a harvest rate (the proportion of the available biomass taken by fishing) of

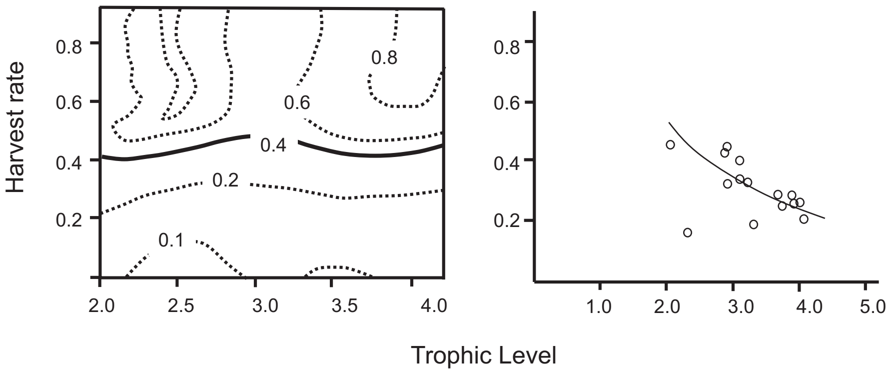

Fig. 8.5 Left, the bold isoline represents the noxicline, the limit reference level of fishing to affect ecosystem function given by the gain ecosystem entropy when biomass is extracted. The limit reference level can be defined by the harvest rate applied to each species (represented by their trophic level). Right, the isoline represents the balanced catch for the species within the ecosystem and the correspondent harvest rate. Both pictures represent the north continental shelf of the Yucatan

HR = 40% can be applied to the existing biomass, which meets both criteria: to use the maximum production capacity of the resource and to keep fishing mortality below the limit so as not to affect ecosystem function (Fig. 8.5).

In this case, there are three aspects to the management challenge: (i) generate the necessary knowledge about the contribution of climate change to the stock abundance trend and differentiate it, explicitly, from that induced by fishing; (ii) incorporate this information into fishery models to identify the harvest rate scenarios necessary to maintain the existing shrimp stock at its maximum production capacity, giving the stock the possibility of increasing when the environmental conditions are favorable; and (iii) communicate and involve the fishermen in this knowledge and in the management strategies to generate confidence and move, from the point of view of governance, toward a socially accepted condition.

8.5 The Red Grouper (*Epinephelus morio*) from the Campeche Bank

The grouper of the northern continental shelf of the Yucatan is one of the most important fisheries in the Gulf of Mexico, and it is currently diagnosed as deteriorated (DOF 2017). Three fleets to which a catch quota is assigned participate in the fishery: an artisanal fleet and a medium-sized fleet from Mexico and a Cuban fleet with greater autonomy. Toward the end of the 1970s, yields averaged approximately 18,000 t per year, while presently, they are approximately 8000 t. Red grouper is a species that presents reproductive concentrations in the winter in the eastern region of the continental shelf of the Yucatan with a hard bottom (Albañez-Lucero and

Arreguín-Sánchez 2009). The fleets took advantage of this behavior, which is when the resource is more vulnerable to fishing (Arreguín-Sánchez and Pitcher 1999), but the situation changed after the implementation of a closure aimed at protecting the reproductive process (DOF 2017).

There is an inherent risk for populations when reproductive concentrations are exploited (Sadovy 1999; Sadovy and Domeier 2005). For the red grouper, a closure to prevent recruitment overfishing was implemented by the mid-1990s; at that time, the stock did not yet display signals of overfishing, even though yields were lower than those in the previous decade. By the early 1990s, there were signals of a fully exploited stock, exhibiting the first evidence of interference from the fleets due to the catch-per-unit of effort trends. Despite the closure and the control of fishing effort, the stock continued decreasing. It has been documented that red grouper needs relatively low temperatures for a successfully reproductive period (Zupanovic and González 1975; Giménez-Hurtado et al. 2003), which has not the case because the influence of the warming period that began in early 1980s. The highest frequency of mature females occurred at of 22 ± 1 °C, while temperatures above 24.5 °C tend to inhibit gonadal maturation, which when accumulated over time, as during a warming period, will promote a decreasing trend in stock abundance.

On the other hand, catchability patterns indicate that vulnerability to fishing increases with size/age. In addition, before the late 1980s, these patterns could clearly be interpreted through the biological behavior of the species, evidencing bottom-up control (Arreguín-Sánchez and Pitcher 1999). Such patterns changed years later (Gimenez-Hurtado 2005), reflecting fleet behavior, changing to a top-down control (Fig. 8.6), which has been interpreted as a response to a diminished stock abundance, which was initially assumed to be a consequence of fishing but is now recognized as a combined effect of climate change (the warming period) and fishing.

Currently, management measures include a minimum legal size, a catch quota for the Cuban fleet, a limited number of fish permits, and a closure for all fleets; the

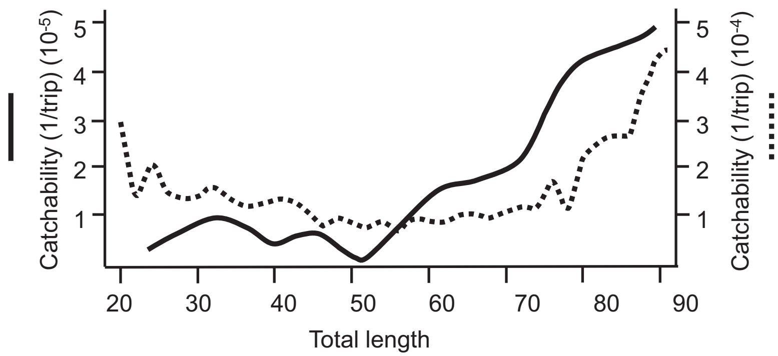

Fig. 8.6 Catchability patterns before and after the early 1990s, showing a shift from bottom-up to top-down control expressed by the interactions between the stock and the fleet. Such a change is associated with the change in the stock condition, which, in turn, is associated with the regime shift

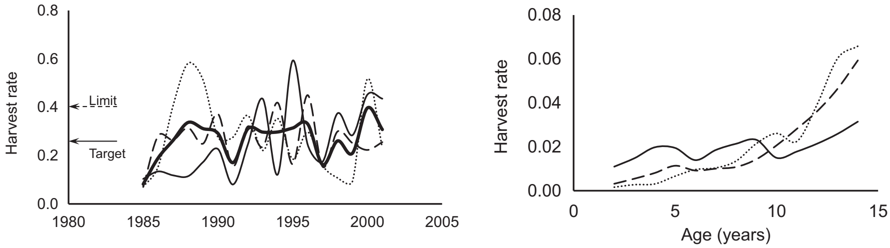

Fig. 8.7 Harvest rates for the red grouper fishery per fleet (thin black line for artisanal fleet, dashed line for mid-sized fleet, dotted line for Cuban fleet, and bold line for all fleets). Left historical trend; note that the historical pattern has been relatively stable; the thin arrow on the left indicates the target (recommended) harvest rate HR = 25%; the dashed arrow indicates the harvest rate corresponding to the limit reference point (see text for explanation). The right figure shows the average harvest rate per age, showing an increase for adult and older fishes

last measure is aimed at protecting the reproductive event. However, these measures are part of a static management scheme, in contrast with a population that is affected by climate change interfering, negatively, in the reproductive process. In this sense, the management challenge is to turn it into a dynamic management scheme that considers, in addition to the protection of the reproductive stock, a harvest rate that will be reviewed year to year and is coordinated with stock availability. In this sense, according to Arreguín-Sánchez et al. (2017a), a harvest rate of HR = 25% (meaning captures can be 25% of the existing biomass) that maximizes the productivity of the resource is suggested (Fig. 8.7), with a limit reference point represented by a HR = 40%, after which exploitation can affect ecosystem function. The values between both harvest rates imply a lower stock productivity level than the maximum that is possible.

8.6 The Red Octopus (*Octopus maya*) Fishery

The octopus fish resource in the Campeche Bank is currently composed of two species: the red octopus (*O. maya*), which is an endemic species (Voss and Solís-Ramírez 1966), and *O. vulgaris*, which began to be registered in the catches in 1998. The red octopus is captured by the artisanal fleet using sticks with strings at the end of which a crab is placed as bait. When the octopus accesses the bait, it is lifted on board. These operations do not require any technology, and many vessels operate without an outboard engine in shallow waters. The yields of the fishery in the 1980s were stable at approximately 8000 t per year; then, there was a gradual increase over time to approximately 20,000 t in the last two decades (Fig. 8.8).

It is known that the red octopus population is concentrated near the coast just after the rainy season (early August) where it searches for food, mainly crustaceans that migrate from inner waters to the sea. The change in feeding favors gonadal maturation and reproduction that occurs some few months later. According to

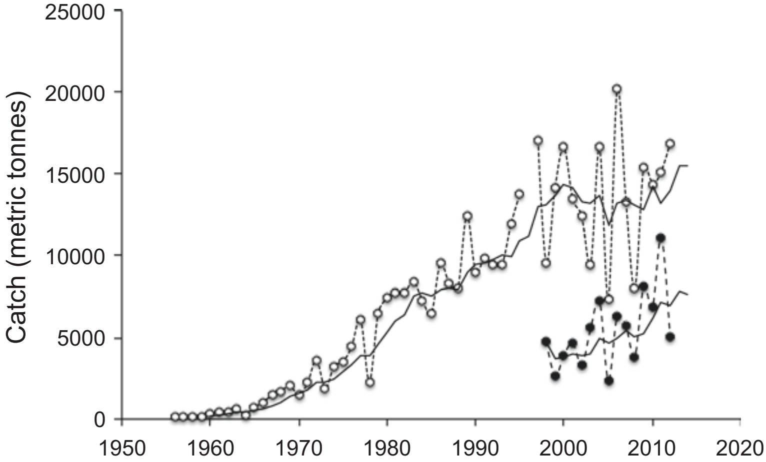

Fig. 8.8 Historical catch records of the octopus fishery in the Campeche Bank. White dots for *Octopus maya* and black dots for *O. vulgaris*

Arreguín-Sánchez (1992) and Solís-Ramírez et al. (1997), a similar event appears to occur toward the middle of the spring and is synchronized with the seasonal upwelling on the eastern edge of the continental shelf of the Yucatan (Merino 1996; Pérez et al. 1999; Piñeiro and Giménez-Hurtado 2001); the number of organisms that will aggregate in coastal waters the next year is based on the success of the reproduction of the spring cohort. According to laboratory experiments, increases in temperature and radiation favor the growth and robustness of *O. maya* (Van Heukelem 1976). In addition, a significant relationship has been found between these variables and fishing yields, which explains the continuous increase in stock abundance and the large increase in annual catches in the last three to four decades. This relationship is associated with the climate change trend documented for the Campeche Bank (Arreguín-Sánchez 2012; Arreguín-Sánchez et al. 2015). Another indirect effect is presumably the reduction of predation on *O. maya* by *E. morio* whose stock abundance has also declined as a result of climate change. Such a predation effect was demonstrated by Solís-Ramírez and Arreguín-Sánchez (1984) who indicate that predation can impact octopus yields up to 3000 t over the octopus' maximum sustainable yield.

According to Arreguín-Sánchez et al. (2017a), and using an ecosystem approach, a harvest rate of HR = 35%, which maximizes the stock production, is suggested with a limit reference represented by a HR = 40%, after which ecosystem function could be affected.

In terms of management, the access to the fishery is through fishing permits, which are limited in number based on the stock biomass. In this case, contrary to what happened in the previous examples, the red octopus population was favorably impacted by climate change; this consequence is reflected in the high yields obtained year after year. This condition caused a high demand for fishing permits, which, when granted in a limited manner, caused some governance problems in some fishing seasons since fishermen felt they could get better benefits.

The current state of management is rather precautionary, applying a minimum legal size, a closure from January to July, and fishing permits; it is estimated that the resource is being exploited to its maximum production capacity. The precautionary approach is applied because it is well known that the *O. maya* stock is highly sensitive to environmental changes and because it is highly important from the social point of view. The management challenge in this fishery is in maintaining a sustainable use of the stock given the uncertainty imposed by climate change. In such a case, a dynamic scheme with fishing mortality adapted, year to year, to the available biomass could be a good option.

8.7 About Management Challenges

Changes in the three fisheries mentioned above are linked to the effects of climate change. In the cases of pink shrimp and red grouper, the productivity of the resources has declined, while the productivity of red octopus has increased. The first two cases are critical because the effects of climate change were not identified until a couple of decades ago, though the effects are the result of a warming period that began in the early 1980s. Since both fisheries were fully exploited at that time, a certain and unknown degree of overfishing was caused because fishing mortality was not adjusted to the new stock sizes; this overfishing was not recognized at that time. Pink shrimp is a nice example of the necessity for clear management policy when facing climate change. When fishing mortality decreased approximately 50% for several years, the stock responded immediately, as expected of an “r-strategy” species; however, the long-term decreasing recruitment rate continued, but with a lower velocity. This suggests that the harvest rate should be continuously adapted to the new stock sizes year after year.

For the red grouper stock, changes in the interaction between the stock and fishing effort appear to be relevant since the stock tends to be highly vulnerable during warming periods since this condition reduces the efficiency of the reproductive success. The management’s suggestion to maintain a harvest rate of 25% could improve the fish stock. With this in mind, a simulation based on such a constant harvest rate suggests that the stock size could have been approximately 20% higher than the present size.

In the case of octopus, the management strategy, even when it is not explicitly defined, corresponds approximately, in a reserved manner, to maintaining a constant harvest rate, which was easily implemented through an increase in the number of fishing permits since the stock abundance was increasing. However, in recent years, annual yields have stabilized, showing a relatively high interannual variability. Under such conditions, it is highly relevant to formalize a management strategy, especially because fishermen must be prepared to reduce fishing mortality or to reduce access to the fishery when the stock size decreases.

Before the effects of climate change were recognized, the management strategy based on annual harvest rates seemed to be adequate. With such a definition of harvest rates, it will be possible to contend with climate change effects from the biological point of view. However, governance must be strengthened because, when stock abundance is clearly lower than that in other years, the access rules must change, the access rules must be clearly defined, the access must be provided equitably, and the strategy must be accepted by fishermen. All of this must be developed with enough time in order to permit the planning of alternatives. This is an unusual scheme at the moment, but it is of fundamental importance in order to avoid overfishing.

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