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Is it sustainable fishing for *Octopus maya* Voss and Solis, 1966, during the breeding season using a bait-based fishing technique?

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ABSTRACT

The fishery supported by *Octopus maya* Voss and Solis, 1966, has been managed with season closure, minimum legal size and gear restrictions. The opening of the fishing season occurs during the breeding season of this species, which could create concerns regarding sustainability. To analyse the implication of this regulation, the dynamics of the fishery was modelled using an age-structured dynamic model, accounting for females' behaviour for parental care. Four scenarios were tested to evaluate the performance of potential changes in the scheduling of the time span of the fishing season. The response variables were total biomass, spawning biomass, recruitment, and catch, assuming no changes in the fishing technique. In scenarios one and two, when fishing season opened earlier than current dates (status quo), there was a significant reduction of catch and the spawning biomass in the third year. When simulations postponed the opening of the season (scenarios three and four), the annual catches and spawning stock experienced an increase in the third year regarding the status quo. The results of the analysis showed that the use of a selective gear (bait-based) and the behaviour of parental care of females during reproduction, offer a buffer to maintain the stock, despite the fishing season operating in part of the reproductive period.

1. Introduction

Among the regulations established for the octopus fishery in Yucatan, Mexico (*Octopus maya* Voss and Solis, 1966), the fishing season was defined during the breeding and rearing of this species, which last from August to mid-December (Díaz de León and Seijo, 1992; Arreguín-Sánchez et al.,2000). Despite of the coincidence of the period of the fishing season and the breeding season, the catches have been sustained for more than 30 years (Markaida et al., 2016). Several authors argue that this regulation, along with minimal legal size and gear restrictions (avoiding harpoon) has been balanced by the use of a selective and unique fishing technique. This technique operates with the use of a gear named locally "jimba", which is based on baited lines, described elsewhere (Jurado-Molina, 2010; Velázquez-Abunader et al., 2013; Gamboa-Álvarez et al., 2015; Emery et al., 2016; Markaida et al., 2016).

The fishing gear and techniques used in octopus around the world, range from trawling to hooks (Boyle and Rodhouse, 2005). These gears can be grouped into five broad categories: i) traps, ii) pots, iii) spears and gaffs with autonomous and semi-autonomous diving, iv) jigging hooks, and v) baited lines (Emery et al., 2016). According to Bjordal (2002), using size and species selectivity criteria, a general ranking on the performance of fishing gear for different species shows that the most favourable one is diving, followed by pots, then traps and handlines with jigging hooks.

Octopus maya has been reported to be at its maximum fishing capacity (DOF, 2012). as the majority of octopus stocks around the world (FAO, 2011); average annual catches for *O. maya* are around 11000 tons, fluctuating between 8000 and 20000 tons (DOF, 2012). The legal fishing technique allowed in this fishery is highly selective in terms of the sex and reproductive stage of the organism captured, as it considers the voracious habits of the species and the reproductive behaviour of females.

Octopus species are semelparous (Boyle and Rodhouse, 2005) and females of some species exhibit a peculiar characteristic behaviour during breeding; they stop feeding because they remain in rock cavities to care for the eggs (Sarvesan, 1969; Mangold, 1983; Cortez et al., 1995; Hanlon and Messenger, 1996; Silva et al., 2002); *O. maya* females also exhibit this behaviour (Solís-Ramírez, 1997; Rosas et al., 2006). During the time that the embryonic development lasts (Solís-Ramírez, 1967; Van Heukelem, 1983; Rosas et al., 2006), the breeding females are not vulnerable to fishing gear that uses bait, because the bait is not

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attractive to them (Guerra et al., 2015). However, breeding females can be caught in fisheries that allow the use of pots (Faraj and Bez, 2007; Sobrino et al., 2011), gaffs and spears by diving (Cabrera et al., 2012; Markaida et al., 2016). The catch of breeding females could represent a serious threat to the recruitment of *O. maya* because it is a holobenthic species (Leporati et al., 2009).

The aim of this study is to determine the performance of current regulations of *O. maya* fishery in Yucatán under different scenarios, accounting for the behaviour of octopus females and the fishing gear selectivity. Within these regulations, it is of special interest the establishment of a fishing season closure. The performance of these scenarios was approached through an age-structured dynamic bioeconomic model, whose response variables were: total biomass, spawning biomass, recruitment, catch and quasi-profits, assuming no changes in the fishing technique. The joint role of female reproductive behaviour and the sexual selectivity of the fishing gear were analysed in terms of their impact on the sustainability of the fishery.

2. Material and methods

2.1. Source of information

A biological monthly sampling scheme was defined to collect data of *O. maya* at the four most important ports in Yucatan, Mexico between August 2007 and January 2011, (Fig. 1). The information recorded on each of the fishing trips was: mantle length (mm), body weight (g), and sex of the individuals captured. The landings of the two fleets that participated in the fishery were sampled. One of the fleets is artisanal and uses fiberglass boats (7–9 m long) that make one-day trips. Each boat carries two smaller wooden boats ("alijos") that operate in shallow waters (< 12 m depth); the fleet is composed of ~ 4000 boats. The second fleet is semi-industrial and consists of 385 large vessels or motherships (> 12 m long) with hulls made of wood, steel or fibre glass, that carry up to 13 alijos and make up to 20-day trips (Coronado and Salas, 2012; Velázquez-Abunader et al., 2013). Both fleets use the same gear and fishing technique.

Other information obtained was total catch, species captured as by-catch, number of alijos and jimbas, trip costs and total revenues per trip. Official records of total landings per month for the same period (2007–2011) obtained from the Fisheries Department Office were also analysed. The official record of landings of 2009 from the relevant ports was used to fit the model.

2.2. Data analysis: building the model

An age-structured bioeconomic model was used to test the impact of changing the fishing season closure dates. Four scenarios were tested, assuming no changes in the fishing technique. Performance variables were biomass, catch and recruitment. The components of the model are explained in the following sections.

2.3. Virtual population analysis

The Von Bertalanffy growth equation (VBGE) parameters were calculated using the ELEFAN module from the software FiSAT II (Gayanilo and Pauly, 1997) splitting growth pattern by sex component. Age was measured in months with a maximum age of 18 months (Arreguín-Sánchez, 1992; Arreguín-Sánchez et al.,2000). Age of *O. maya* has been validated by increments in the beak rostrum sagittal sections (Bárcenas et al., 2014). The length-weight relationship was calculated to obtain the parameters of the VBGE expressed in terms of weight (Haddon, 2001). The parameters obtained in the present study were compared with those published by other authors by means of the ϕ' index (Pauly and Munro, 1984).

Two catch matrices per length were obtained, one for each sex and for each of the four months that the fishing seasons lasted per year; the class interval was defined by 10 mm. With the VBGE parameters and the weight of the catch recorded per month, the catch-at-age matrix was assembled following the method outlined in Quinn and Deriso (1999). Using the catch-at-age matrix, a cohort analysis was performed assuming that the recruitment age for the fishery was of five months. An age vector was established, from five to 18 months, and it was assumed that once they reached this age, all individuals died from natural causes or from fishing. The Pope approximation (Pope, 1972) was applied to

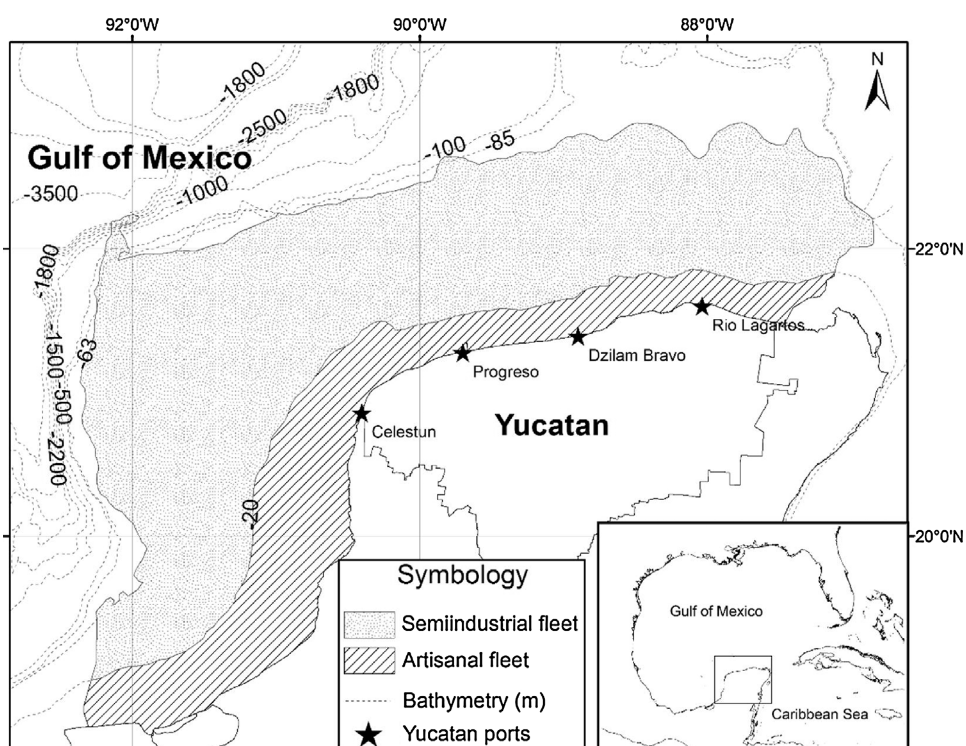

Fig. 1. Area of distribution of *Octopus maya* in Yucatan continental shelf indicating the landing sites were samples were taken.