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Linking temporal changes in the demographic structure and individual growth to the decline in the population of a tropical fish

Charlotte Sirot [a,*], Audrey M. Darnaude [a], François Guilhaumon [a], Julia Ramos-Miranda [b], Domingo Flores-Hernandez [b], Jacques Panfili [a]

[a] UMR 9190 MARBEC, IRD-Ifremer-CNRS-UM2, Université de Montpellier, CC 93, Place Eugène Bataillon, 34095 Montpellier Cedex 5, France
[b] Instituto de Ecología, Pesquerías y Oceanografía de Golfo de México (EPOMEX), Universidad Autónoma de Campeche, Av. Héroe de Nacozari #480, C. P. 24029, Campeche, Mexico

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ABSTRACT

The exceptional biodiversity and productivity of tropical coastal lagoons can only be preserved by identifying the causes for the decline in the populations living in these vulnerable ecosystems. The Terminos lagoon in Mexico provided an opportunity for studying this issue as some of its fish populations, in particular the Silver Perch (*Bairdiella chrysoura*), have declined significantly since the 1980s. Fish sampling campaigns carried out over the whole lagoon area in 1979–81 and again in 2006–2011 revealed the mechanisms which may have been responsible for this decline. Based on biometrical data for 295 juveniles and adults from the two periods and on somatic growth derived from 173 otoliths, a study of the temporal changes in the demographic structure and life history traits (individual growth and body condition) made it possible to distinguish the causes of the decline in the *B. chrysoura* population. Growth models for the lagoon in 1980–1981 and 2006–2011 showed no significant change in the growth parameters of the population over the last 30 years with a logistic model giving an accurate estimate ($R^2 = 0.66$) of the size-at-age for both periods. The decline in the *B. chrysoura* population could not be explained by an overall decrease in individual size and condition in the lagoon, the average standard length (SL) and Fulton index (FI) having increased slightly since 1980–1981 (4.6 mm and 0.02 for juveniles and 5.42 mm and 0.07 for adults). However, the size structure of the population in the lagoon has changed, with a significant shift in the size distribution of juveniles with a marked reduction in the proportion of juveniles $\leq$ 60 mm in the captures (90.9% fewer than in 1980–1981). As the otolith growth rate of fish during the first 4 months also decreased significantly between the two sampling periods (-15%), it is suggested that the main reason for the decline in the abundance and biomass of *B. chrysoura* within this system may be that its habitats are less suitable for fish growth and survival in the initial months after settlement. Environmental conditions in the lagoon appear to allow compensatory growth of the individuals that survive this early demographic bottleneck. The key for the conservation of *B. chrysoura* probably lies in the identification and restoration of the habitats required by its larvae and juveniles.

1. Introduction

Identifying the factors and mechanisms that cause global biodiversity loss and local demographic fluctuations of species is a primary challenge for conservation biology, especially in tropical lagoons and estuaries (Hutchings and Baum, 2005; Lotze et al., 2006; Halpern et al., 2008). Due to their location at the land–sea interface, these habitats are among the most productive but also the most vulnerable ecosystems in the world (Costanza et al., 1997; Rochette et al., 2010; Layman et al., 2011). During the last century, their environmental conditions have been significantly modified by the combined effects of local human activity and climate change (Costanza et al., 1997). The changes observed in their biological communities (Jackson et al., 2001; Lotze and Worm, 2009) require a better understanding of the factors driving demographic responses to environmental changes.

* Corresponding author.
E-mail address: charlotte.sirot@free.fr (C. Sirot).

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There are many reasons for fluctuations or decline of fish populations, with complex interactions between external and internal drivers (Fonseca and Cabral, 2007). However, life history traits have a determining effect on the three main components of individual fitness, i.e. survival, growth and reproduction (Hutchings, 1993; Violle et al., 2007), and can be used to predict the vulnerability status of individual species (Chessman, 2013) and differences in demographic trajectories between species (Sirot et al., 2015). Therefore, evaluating variations in life history traits and linking their temporal changes to population dynamics is essential for understanding demographic responses of fish to environmental perturbations (Winemiller, 2005).

This study evaluated the changes in the population structure (size distribution) and the life history traits (growth and body condition) of a tropical fish species, the American Silver Perch *Bairdiella chrysoura* (Lacépède, 1802), with a declining population in a very large tropical lagoon (Laguna de Terminos, Mexico). This lagoon, the third largest in the world, is of great biological, ecological and economic importance (Ramos-Miranda et al., 2005b). However, intensification of human activities within its catchment area and in the nearby marine coastal zone has caused major environmental changes in the lagoon since the 1980s (Ramos-Miranda et al., 2005a, 2005b; Villéger et al., 2010; Sirot et al., 2015), resulting in a significant decrease in both global fish abundance (−41%) and biomass (−58%) (Sirot et al., 2015). *Bairdiella chrysoura* is illustrative of this community collapse as this fish species was listed as one of the most abundant and widely distributed of the Gulf of Mexico in the 1980s (Chao and Musick, 1977), and has since suffered a decline of ~90% in both its abundance and biomass within the lagoon (Sirot et al., 2015).

Despite a short life-span (<6 years) and a small maximum size (250 mm total length) (Waggy et al., 2006), *B. chrysoura* is of commercial and recreational importance in the Gulf of Mexico (Ayala-Pérez et al., 2006) and is a key component of local coastal ecosystems as the normal prey for several large estuarine predators (Luczkovich et al., 2000; Heupel and Hueter, 2002; Blewett et al., 2006; Grammer et al., 2009). Knowledge of the mechanisms responsible for its recent decline is required so that appropriate conservation actions can be taken. In order to identify these mechanisms in the Terminos lagoon, the changes since 1980–1981 in both its demographic structure (size of cohorts and percentage of juveniles *vs.* adults) and life history traits (somatic growth rate and body condition) were studied. Growth rate and body condition are generally included in studies assessing demographic fluctuations of fish where there are environmental perturbations (Ashfield et al., 1998; Amara et al., 2007) as they are considered proxies for individual fitness, in particular in early life stages (Houde, 1987; Cushing, 1990; Smith and Shima, 2011). Establishing the relationships between the growth rate and body condition on the one hand with changes in the population structure on the other in the light of the environmental changes observed in the Terminos lagoon since 1980–1981 should provide a better understanding of the ongoing processes leading to the decline of this fish in this ecosystem.

2. Materials and methods

2.1. Study area

The Terminos Lagoon (90°00' − 90°20′ W 18°25' − 19°00′ N) is the largest estuarine system along the coast of Mexico. Located in the southwest part of the Gulf of Mexico (Fig. 1), it communicates with the sea through two wide channels, located at either end of Carmen Island, the Puerto Real outlet to the east and the Carmen outlet to the west. The lagoon is shallow (mean depth = 2.5 ± 1.0 m) and the water temperature is high throughout the year (mean = 27.8 ± 2.7 °C), with a minimum of 20 °C and a maximum of over 32 °C (Villéger, 2008). Freshwater inputs to the lagoon originate mainly from three rivers located on its southern edge (Rio Palizada in the west and Rio Chumpan and Rio Candelaria in the east). As the water in the lagoon generally circulates from east to west, the southwestern part of the lagoon tends to have brackish water while the salinity of water in the northwestern part is close to marine levels (Carvalho et al., 2009; Villéger et al., 2010). The tropical climate in the area has three distinct seasons: a dry season from February to May and a wet season from June to September with the 'nortes' season, characterized by strong winter storms coming from the north which bring rain and low temperatures, from October to January (Yañez-Arancibia and Day Jr., 1982). As a result, the water salinity in the lagoon also varies throughout the year, with the highest levels in the dry season and the lowest levels during the rainy season.

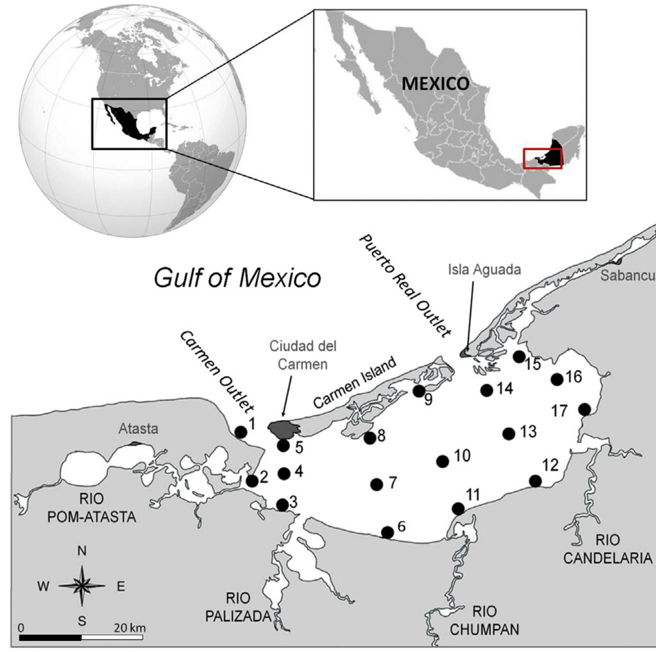

Fig. 1. Study area (Southern Gulf of Mexico) with the 17 sampling sites (black spots) in the Terminos lagoon and the main cities (dark gray).

2.2. Temporal changes in demographic structure and body condition

To compare the demographic structure and the body sizes and condition of juveniles and adults of *B. chrysoura* in 1980–1981 and 2010–2011, fish were collected throughout the year in 1980–1981 and in 2010–2011, by monthly sampling at 17 fixed stations distributed over the whole lagoon area (Fig. 1). The same method was used for all sampling dates and stations. A 5 m long shrimp trawl net with 2.5 m mouth and 19 mm mesh was towed for 12 min at a speed of 2.5 knots (i.e. 4.6 km/h), giving a sampled area of 2000 m^2. All the individuals captured during the two annual sampling campaigns (Table 1) were measured (standard length, SL, and total length, TL, in mm), weighed (total weight, W, in mg). Their individual body condition was evaluated using the Fulton index (FI, Ricker, 1975), defined as:

$$FI = \frac{W}{SL^3} \times 100$$

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