Modeling Larval Transport from Snapper (Lutjanidae) Spawning Aggregations in Cuba

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ABSTRACT

Historical spawning aggregations of mutton (*Lutjanus analis*), lane (*L. synagris*), cubera (*L. cyanopterus*), dog (*L. jocu*), and gray (*L. griseus*) snappers on the insular shelf of Cuba are examined in terms of the probability of larval dispersal from the source populations to coastal habitats in the Mesoamerican region and different ecological provinces of the island of Cuba. In particular, we examine how dispersal and recruitment vary intra- and inter-annually with oceanographic regimes, shelf configuration, and spawning sites. Our modeling approach is based on a coupled biophysical model incorporating a high-resolution ocean circulation model (MICOM), a Lagrangian scheme with larval sub-grid turbulent motion, larval sensory capabilities, and the availability of settlement habitat. Sequential runs centered on particular months and lunar phases were used to estimate the likelihood that each spawning event contributes large numbers of larvae to foreign downstream populations or to neighboring populations on the complex Cuban shelf. The model results are discussed with regard to historical data. This innovative approach of estimating larval dispersal from spawning aggregations can enhance stock-based conservation recommendations and optimize the design of marine reserve networks.

KEY WORDS: Larval transport, snappers, spawning aggregations, Cuba

Modelando el Transporte Larval desde las Agregaciones de Desove de los Pargos (Lutjanidae) en Cuba

Se analizan las agregaciones históricas de desove de los pargos (*Lutjanus analis, L. synagris, L. cyanopterus, L. jocu y L. griseus*) de Cuba, en términos de la probabilidad de dispersión de las larvas desde el origen de la población hacia los hábitat costeros de la región mesoamericana y las provincias ecológicas de la isla de Cuba. Se investigó en particular, la variación anual e interanual de la dispersión y el reclutamiento en relación con el régimen oceanográfico, la configuración de la plataforma y los puntos de desove. Nuestro modelo biofísico incorpora un modelo de circulación oceánica de alta

resolución (MICOM), un esquema Lagrangian con turbulencias de rejilla secundaria para describir el movimiento de las larvas, las capacidades sensoriales de estas y la disponibilidad de hábitat para el asentamiento. Se ejecutaron varias secuencias del modelo centradas en determinados meses y fases lunares, y fueron utilizadas para estimar la probabilidad de contribución de larvas de cada evento de desove hacia poblaciones distantes de otros países, u otras zonas de la plataforma cubana. Los resultados del modelo se analizan a la luz de los datos históricos. Esta forma innovativa de análisis de la dispersión de larvas desde las agregaciones de desove, puede contribuir a los esfuerzos de conservación basados en las poblaciones, y además ayudar en la optimización de la red de reservas marinas.

PALABRAS CLAVES: Dispersión de las larvas, pargos, agregaciones de desove, Cuba

INTRODUCTION

The snapper family (Pisces: Lutjanidae) include Caribbean-wide, reef fish species known for forming predictable spawning aggregations. Historically, large groups of snappers have been spawning periodically at specific sites within the insular shelf of Cuba (Claro and Lindeman 2003). Snapper fishery is the principal finfish fishery in Cuba with the lane snapper as primary fishing target, being mostly fished in the Golfo de Batabanó in the southwest of Cuba. Mutton snapper catches rank second with largest catches in the northeastern coast. Large decreases in catches from as early as 1975 have been reported (Claro et al. 2002a) and may be attributed from fishing in spawning aggregations.

The Cuban platform consists of a main continental island with many smaller islands. The geomorphology of the Cuban shelf is very distinct in that it has a large and shallow insular shelf surrounded by fringing keys and reefs forming a series of lagoons, while the shelf edge is abrupt and formed by a series of submerged terraces (Claro et al. 2002b). The Cuban platform can be divided in four wide shelf regions separated by areas of narrow shelves: the North West (NW), North Central (NC), South East (SE) and South West (SW). The reproductive strategy of snappers is species-specific and rather complex. Spawning aggregations occur at promontories (e.g. Cabo Cruz, C. Corrientes), at the shelf edge (Cayo Bretón), or even in the inner-shelf (Golfo de Cazones). A single or multiple sites may be shared by several species simultaneously or with different inter- and intra-specific spawning schedules. Spawning occurs during a narrow window in time (usually of a couple of months) and centered on a lunar phase (Table 1). However, intra-specific variations in peak spawning occurs among regions (Claro and Lindeman, 2003). In addition, snapper have highly variable within and among species planktonic larval durations (PLDs), ranging from 15 - 48 days (Lindeman et al. 2000).

Table 1. Subset of spawning aggregation sites for larval transport modeling: priority site/species combinations in yellow.   * - peak spawning month (modified from Claro and Lindeman 2003)

Spawning Site	Coordinate	Species	Spawning Peak	Moon
Southeast region				
Cabo Cruz	19°49'24" 77°44'36	Lane snapper	June	Before full
		Mutton snapper	May*-June	Full to 4
		Cubera and gray snapper	July*-August.	Full
Cayo Bretón	21°07'36" 79°31'24"	Cubera snapper	July-Augus	Full
		Dog snapper	July*-August.	Full
		Lane snapper	June*-July	Before full
Southwest region				
C. Diego Pérez	22°02'00 81°30'25	Lane snapper	May*	Before full
C. San Felipe	21°55' 83°36'	Mutton snapper	May*	Full to 4
		Lane snapper	May-June*	Before full
		Spiny lobster	Feb.-May	Full
Cabo Corrientes	21°44'43" 84°32'05"	Nassau grouper	Dec.-Jan.	Full
		Mutton snapper	May-June*	Full to 4
		Cubera and Dog snapper	July*-August	Full
Northwest region				
Corona de San Carlos	22°54'24" 83°36'12"	Mutton snapper	May-June*	Full to 4
		Gray and cubera snappers	July*-August.	Full
North-Central region				
Punta Hicacos-Mono	23°17' 81°05'	Mutton snapper	May-June*	Full to 4
		Lane snapper	May-June*	Before full
C. Caimán Grande	22°45'12" 78°52'48"	Mutton snapper	May-June*	Full to 4
		Lane snapper	May-June*	Before full

Marine reserves have been suggested as a tool to conserve economically and ecologically valuable species fish species like snappers. However, snappers may require particular protection since they are highly vulnerable to fishing activities during spawning (Luckhurst 2002). Thus, information on the potential larval pathways likely to occur from specific spawning aggregations may serve to guide reserve design for maximum effectiveness at ensuring population replenishment. Only studies that incorporate accurate information on the currents, physical forcing, spawning locations, and larval behaviors can make such predictions.

APPROACH AND METHODS

Data Source

It is important to recognize two major sources of information regarding those spawning aggregations. First, information may come from patriarch fishers, which knowledge of the spawning sites (e.g. where and when) is usually associated with observations of adult biology. Fishers can in fact become the most credible of advocates for the protection of those sites (e.g. Riley's Hump, Florida; Banco Chinchorro, Mexico). Another source of information comes from local scientists. They take a critical part in keeping track of historical data and in studying the ecology of local fish populations as well as the physical attributes of the region (e.g. Claro et al. 2002c).

Spawning Aggregations Sites

The spawning sites on the insular shelf of Cuba were reported by Claro and Lindeman (2003) and listed in Table 1 for the mutton (*Lutjanus analis*), lane (*L. synagris*), dog (*L. jocu*), cubera (*L. cyanopterus*), and gray snapper (*L. griseus*). Six major spawning aggregation sites were selected for the mutton snapper (one in the NW and the SE, two in the SW and the NC) as well as for the lane snapper (two in the SE, SW, and NC). The cubera, dog, and gray snappers were treated as a species complex because they share both locations and peak spawning times; for this species complex, four major spawning aggregation sites were selected (one in the NW and the SW, two in the SE).

Larval Transport Model

Spawning output dispersal and larval trajectories from known spawning sites within the insular shelf of Cuba (Table 1) was simulated for several species of snapper (*Lutjanus analis* (mutton), *L. synagris* (lane), *L. jocu* (dog), *L. cyanopterus* (cubera), and *L. griseus* (gray). For this purpose, we used the high resolution (9 km mesh) Miami Isopycnal Coordinate Ocean Model (MICOM) and a variety of larval behavior scenarios (e.g. passive and active; Cowen et al. 2003) to compute a range of likely transport outcomes under varying winds and currents associated with seasonal conditions. Larval behavior incorporated to the model is based on observed biophysical retention mechanisms (i.e. ontogenetic vertical migration in low flow regions; Paris and Cowen, In review) as well as on known swimming (Stobutzki and Bellwood

1999) and sensory capabilities (Kingsford et al. 2002). These factors served to define a Retention Zone (RZ) for pelagic larvae of which the boundaries correspond to the geographical extent of the biophysical mechanisms experienced by snapper larvae (see Sponaugle et al. 2002) and were set within 9 - 18 km of the suitable settlement habitat. Mortality at the end of the transport scenario occurs at 100 % for simulated larvae that are found outside the RZ. Larval transport is performed under various levels of larval behavior. For example, in the quasi-passive scenario, transport is passive throughout the pelagic phase and the recruits are those particles that are at found within the RZ at the end of the PLD. In the active scenarios, the onset of active behavior occurs at day 7, 14, or 30 of the pelagic phase, whereby simulated larvae are allowed to be retained if they are found within the RZ. Otherwise, they continue their trajectories until they reach a RZ or until the end of the PLD, whichever comes first. Finally, Spawning Production (SP) is simulated using sequential runs of 3-day frequency around a moon phase and during peak spawning months.

RESULTS AND DISCUSSION

Sensitivity Analysis
Sensitivity analysis was performed on the onset of active behavior and on the width of RZ around settlement habitat. The percentage of SP recruiting locally decreased exponentially with delay of active behavior, while the width of the RZ did not have a significant effect on recruitment levels. Similarly, the export levels (% SP non-locally recruiting) decreased with delay of active behavior, especially for close-by locations (e.g., Bahamas, Cay Sal Bank). For more distant locations (e.g. Mexico, Jamaica, Florida), the export levels were constant for the early onset of active behavior (day 7 and 14), but decreased drastically in the quasi-passive scenario.

Local Recruitment
Results indicate that most of the spawning aggregations benefited their own region (self-recruitment), except for the mutton snapper spawning aggregation site from the NW which was mostly a source to the NC region. It was also clear that some regions were more productive than others. For example, the SE sites contributed to most of the local recruitment of the cubera-dog-gray complex, while the SW and NC sites were more important in terms of local recruitment for the mutton snapper. The NW region was consistently a poor source of local recruitment for all the species, which corroborated with lowest historical catches by region (Claro et al. 2002c). There were also site differences within a region, where some sites represented a better source of local recruitment than others (e.g. in the SW region, Cabo San Felipe produces more local recruits than Cabo Corrientes).

Export by Region
Results indicate that export is about an order of magnitude lower than local recruitment. In general, sites from the northern regions may be connected

to the southern Bahamas, and may contribute to a significant part of the replenishment for the mutton snapper populations of Cay Sal Bank. Sites from the SW region are connected to Mexico, Cayman, and Jamaica, and to a lesser extent to Belize, while those from the SE are connected to Hispaniola and the eastern Bahamas. Despite the proximity of the Florida Keys from the NW sites, none of the spawning aggregations seemed to contribute to the Florida Keys snapper populations. There are however interspecific differences in the exports.

PRELIMINARY CONCLUSIONS

i)   Temporal variability such as a lag in spawning schedules leads to spatial variability in recruitment.

ii)   Spawning production from the insular shelf of Cuba contributes mostly to local recruitment to the insular shelf of Cuba – total export is an order of magnitude lower than local recruitment.

iii) Spawning aggregations are sources of recruitment to the region -the NW region is an exception to self-recruitment – consistent with lowest historical catches by region & the geomorphology of the shelf,

iv)   The larval transport model is sensitive to the onset of active behavior in terms of recruitment but not in terms of dispersal distances - early larval behavior increases survival for both local recruitment and export. The quasi-passive scenario produces such low level of recruitment that it hampers detection of any possible spatial variation in recruitment levels.

v)   Estimating larval dispersal from spawning aggregations can enhance stock-based recommendations and optimize design of marine reserves.

vi)   The sustainability of snapper populations in Cuba may largely depend on the conservation of the spawning aggregations.

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