Capacity Building in Marine Protected Areas and Connectivity in the Mesoamerican Barrier Reef System: Larval Fish Recruitment

Fomento de Capacidades en Areas Marinas Protegidas dentro del Arrecife Mesoamericano: Reclutamiento de Larvas de Peces

Renforcement des Capacités dans les Aires Marines Protégées et de la Connectivité dans le Système de Barrière de Corail Mésoaméricaine : Recrutement de Larves de Poisson

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ABSTRACT

The Mesoamerican reef (MAR) connects Mexico, Belize, Guatemala, and Honduras. The MAR shares a rich cultural heritage and ecological resources amongst its people. Although crucial resources such as reef health and fisheries have declined steadily, the region depends on ecotourism and fisheries to thrive. In this region, multiple marine protected areas (MPAs) have been established as a conservation strategy, yet little is known about trends in recruitment of reef fishes into these MPAs. Monitoring recruitment is fundamental but difficult in remote areas, thus local capacity-building is the first step to assess reef fish recruitment. An innovative capacity and research effort was carried out in 10 MPAs during the new moon in September 2013, February 2014 and August 2014 to assess the arrival of juvenile fishes into MPAs. First, training was provided to enhance local expertise during capacity workshops in May 2010, and March 2012. Collection efforts utilized water column collectors deployed overnight for at least 5 days at each site, and were sampled in the morning. 947 fish were captured during three simultaneous collection efforts from 23 families, and at least 48 species have been identified. Active recruitment into MPAs was documented, as most fish were post-larvae to early juveniles with pelagic dispersal strategies. The most abundant families were jacks, wrasses, filefishes, and pufferfishes. Jacks were represented by six species; the most abundant was the Atlantic bumper (C*hloroscombrus chrysurus*). Results of the first three connectivity exercises were successful with widespread participation and improved capacity among neighbor countries. As a result of our capacity building efforts, additional exercises have been incorporated by managers to increase activities related to connectivity research to support conservation and management of reef fishes in the Mesoamerican Region.

KEY WORDS: Mesoamerican reef system, marine protected areas, connectivity

INTRODUCTION

The Mesoamerican Reef (MAR) runs parallel to the Yucatan peninsula's coastline and is the second largest barrier reef in the world spanning approximately 1,000 km along the shores of Guatemala, Honduras, Belize and Mexico (Mcfield and Kramer 2007). Besides supporting extraordinary biodiversity in a relatively small space, the reefs support ecotourism economies and provide 10% of the world's fisheries production (Salm et al. 2000, Chiappone 2001, Vásquez-Yeomans et al. 2011). In the MAR and adjacent coastal areas, there are more than 30 protected areas to manage and preserve natural resources (Mcfield and Kramer 2007). Many of the MPA within the region provide nursery habitats critical for the life history of reef fishes and many other species that are targeted in the region (lobster, conch, among others). Connectivity in marine fishes is important in the MAR because it pertains to exchange of individuals coming from different places (Grober-Dunsmore and Keller 2008). Fish families of commercial value that utilize coral reefs throughout their life cycles include snappers, groupers, wrasses, and over 180 species that are harvested in the Caribbean (Chiappone 2001) in addition to many more species that are harvested as by-catch.

Recruitment refers to the number of planktonic survivors (larval fish) that find suitable settlement benthic habitats (Chiappone 2001). The recruitment of larval fishes into nursery areas is a combination of biophysical factors such as behavior, dispersal, and retention mechanisms (D'Alessandro et al. 2007, Paris and Cowen 2004). Although adult fishes are mostly sedentary, the life history of a coral reef fish is typically divided into a larval pelagic (planktonic) stage, a juvenile stage, and an adult benthic stage (Leis 1991). During the larval stage, fishes may be dispersed along as part of the plankton and transported by ocean currents for variable distances or they may be retained relatively close to their point of origin by oceanographic mechanisms such as gyres and convergences. The settlement stage begins when larval fish end their planktonic stage by establishing themselves into benthic habitats. These now post-larval reef fish (also referred to as pre-settlement stage (Leis 1991), must cross the reef or go through reef channels to be able to settle to the appropriate benthic habitats. Several studies have observed that larval fish fluctuate with moon phases and that colonization peaks at night especially during moonless nights (Dufour and Galzin 1993).

Larval fish assemblages are studied to gain an understanding of recruitment processes for the replenishment of stocks (Fuiman 2002) and with repeated surveys can be used to derive an index of stock abundance for fisheries (Pepin 2002). One of the many challenges in the conservation and management of these critical habitats is the inherent patchiness of larval and juvenile fishes. Despite an increase in the published literature on larval fish ecology in the Gulf and Caribbean region (Llopiz et al. 2014, Flores-Coto et al. 2014, Lyczkowski-Shultz et al. 2013, Muhling et al. 2013, Vasquez-Yeomans et al.

1998, Vasquez-Yeomans et al. 2011) additional investigations are needed to enhance connectivity research and highlight the biodiversity of the Caribbean region.

The first step in understanding connectivity within a region is to identify the larval fish assemblages within the study area. To describe the variability of incoming fish larvae into the various MAR MPAs, this study aims to characterize the larval fish within selected nursery habitats in each MPA simultaneously over a consecutive time period. The "exercises in connectivity in the Mesoamerican reef" were regarded as "ECOME" and had three objectives:

i) Build local capacity among MPA managers,
ii) Standardize and assess the distribution of larval and young juvenile fishes, and finally
iii) Establish a baseline of fish families that utilize and recruit to the MPA's nursery habitats within the MBRS region with an emphasis on families that have importance in ecology, tourism, and fisheries.

METHODS

To develop a network of local MPA practitioners trained on larval fish collections, hands-on training was provided during two capacity-building workshops (May 17 - 19, 2010, and March 13 - 14, 2012) in Chetumal and Xcalak, Quintana Roo, Mexico. The methodology for the systematic sampling of larval and juvenile reef fishes was introduced during these workshops to simultaneously sample MPAs during the same time period. Standardized working protocols were developed in English and Spanish and were distributed to MPA managers and workshop participants. Due to limited resources, collection equipment was provided to each MPA; however the infrastructure required for deployment and sampling (small boat, personnel) was arranged by each MPA in the Mesoamerican Reef.

To assess the larval and juvenile fish distribution and abundance in the MAR, three simultaneous sampling efforts took place in ten MPAs around and during the new moon (see Figure 1) to optimize collections. The first exercise in connectivity in Mesoamerica (abbreviated as *ECOME* 1) took place in September 1 - 9, 2013, the second (ECOME 2) in February 27 to March 6, 2014 and the third (ECOME 3), in August 22 - 28, 2014. Water column collectors (modified from Steele et al. 2002, Yam 2013) are passive devices made of plastic fencing material and screen netting (see Figure 2). Each station consisted of two water column collectors (WCC) moored with an anchor and floated by a buoy deployed at a distance of approximately 150 m apart from one another in nearshore coastal areas with at least 2 m depth immediate to coral reef environments and devoid of strong currents or rough sea conditions. During ECOME 1, 2 and 3, sampling locations were previously selected with input by local managers and WCCs were successfully deployed in tandem at 10 stations within each MPA. The WCCs were joined together, and were deployed at sunset and sampled at sunrise from a small boat using a large mesh bag operated by a snorkeler at each station. Participants from Guatemala MPAs utilized SCUBA to deploy and recover the WCCs. Fishes were collected and preserved in 95% ethanol for further analysis in the lab. Whenever multiple species were collected at any given MPA, only a representative subsample was preserved for analysis.

After each sampling exercise, substantial coordination was necessary to obtain each station's coordinates and total abundance data from each MPA in the four MAR countries and even more organization efforts to successfully identify fishes. Ultimately, larval and juvenile fish were counted, measured when possible (nearest 1 mm) and all measurements were entered into a standardized database.

Identification of larval and juvenile fishes to lowest taxonomic level took place using multiple techniques that included examination under a dissecting microscope as well as reviewing digital images and data provided by ECOME participants. Taxonomic keys were utilized (Richards 2006, Baldwin 2013) to create a hierarchical classification of the species collected. Genetic identifica-

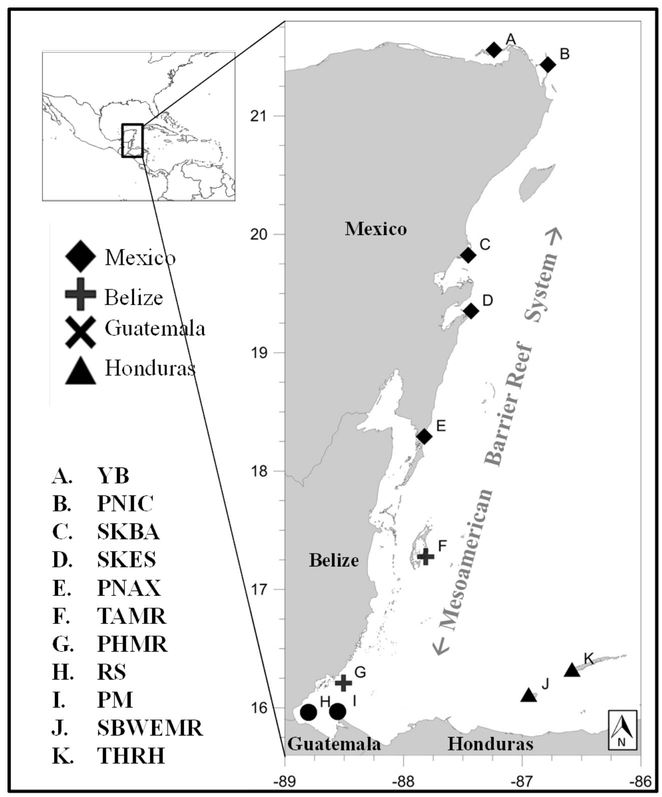

Figure 1. Eleven marine protected areas in the Mesoamerican Barrier Reef System that participated in ECOME 1, 2 and/or 3 in 2010-2014. From North to South and East to West: (A) Area de Proteccion de Flora y Fauna Yum Balam, YB; (B) Parque Nacional Isla Contoy, PNIC; Reserva de la Biosfera Sian Ka'an: (C) Bahía Ascensión, SKBA, (D) Bahía Espiritu Santo, SKES; (E) Parque Nacional Arrecifes de Xcalak, PNAX; (F) Turneffe Atoll Marine Reserve (TAMR); (G) Port Honduras Marine Reserve (PHMR); (H) Área de Uso Múltiple Rio Sarstún, RS; (I) Refugio Vida Silvestre Punta Manabique, PM; (J) Sandy Bay West End Marine Reserve, SBWEMR, and (K) Zona de Protección Especial Marina Turtle Harbour - Rock Harbour, THRH.

Figure 2. Water column collector deployed (left) and collection effort (right) in Zona de Protección Especial Marina Turtle Harbour - Rock Harbour, Honduras during ECOME 1 in 2013.

tion of several individuals took place with the collaboration of El Colegio de la Frontera Sur's Barcode Laboratory. Tissues were extracted from individual specimens and fixed in 96% ethanol. Identifications were made by amplifying the mitochondrial COI gene which is then aligned with COI sequences available from Genbank (See Richardson et al. 2007 and Valdez-Moreno et al. 2010 for detailed methodology).Once the tissue was sequenced; it was compared to adult sequences of confirmed species archived at the Barcode of Life website (www.boldsystems.org) and were added to the ECOME databases.

Comparisons and baselines were created using total abundance of larval and young juvenile fishes collected during the three sampling efforts. Abundances were calculated and plotted at each MPA by family and species.

RESULTS

A MAR *connectivity network* stemmed from the first capacity building workshop attended by 20 local and regional managers that work directly with MPAs. The second workshop was attended by 24 individuals and had a training component directed at collection and data acquisition. At least 70 reported individuals were involved in executing ECOME1-3.During ECOME-1, nine MPAs participated including at least one or more MPA from each MAR country. In ECOME-2, Turneffe Atoll Marine Reserve in Belize joined the simultaneous collection efforts and brought the total of participating MPAs to eight. Finally for ECOME-3, Área de Protección de Flora y Fauna Yum Balam joined the collection effort, and nine MPAs participated. The relative locations of the collection efforts in 2013 and 2014 are show in Figure 1 with specific coordinates detailed on Table 1 when available. Mexican MPAs were represented by Parque Nacional Isla Contoy, within the Reserva de la biósfera Sian Ka'an, both Bahía Ascensión and Bahía Espiritu Santo, Área de Protección de Flora y Fauna Yum Balam, and Parque Nacional Arrecifes de Xcalak. In Belize, Port Honduras Marine Reserve, and Turneffe Atoll Marine Reserve participated. In Guatemala, Área de Uso Múltiple Rio Sarstún and Refugio de Vida Silvestre Punta Manabique and in Honduras, Sandy Bay West End Marine Reserve, and Zona de Protección Especial Marina Turtle Harbour and Rock Harbour.

Fish abundance was variable at each MPA, however the most specimens were collected in Guatemala at the Refugio Vida Silvestre Punta Manabique, even though they participated in only ECOME-1 and 3, followed by Mexico's Parque Nacional Arrecifes de Xcalak , which participated in all three exercises. In at least two MPAs zero collections took place although fish were visually observed. ECOME-1 collected the largest number of specimens and had the most complete participation, followed by ECOME-3 and lastly by ECOME-2 (Figure 2). Difficult seas, limited access to equipment and lack of personnel restricted access to some MPAs, however despite difficulties encountered, a total of 947 post-larval and juvenile fishes were captured belonging to 23 families, and represented at least 48 species (see Table 2). The three most abundant species were the Atlantic bumper (*Chloroscombrus chrysurus*, n = 241), the social wrasse (*Halichoeres socialis*, n = 207) and the slender filefish (*Monacanthus tuckeri*, n = 114). The most commonly collected fishes in four of the MPAs during the same collection effort were the Caribbean sharp-nose puffer (*Canthigaster rostrata*) and the slender filefish correspondingly. The latter are reef-associated species that employ floating-like strategies to camouflage themselves with their surroundings and also have relatively low swimming speeds (compared to snappers or wrasses) which likely facilitated their collection in the field. Abundances for all members of a unique taxonomic family are plotted for an assemblage comparison of fish collected during ECOME1-3.

While twenty five species were unique to a given MPA, overall collections were variable between and within locations. Fish abundances were patchy and variable without an apparent gradient.

DISCUSSION

The temporal scale for arrival of larval fishes into MPAs is not well known, as most studies examine monthly or seasonal averages. Although valuable, seasonal studies can miss pulses of recruitment which are common in the highly variable conditions that influence dispersal and settlement. This study was carried out on a fine temporal scale (4 - 10 days) in order to identify pulses of larval and juvenile fishes to coral reefs and associated nursery habitats in the MAR. The daily collections that took place over the course of 2013 and 2014 provided a snapshot of biological conditions as it pertains to the recruitment stages of fishes. In order to obtain a more complete picture, measurements of physical variables are needed to quantify the current field around each MPA to include the average direction, variability and the speed .

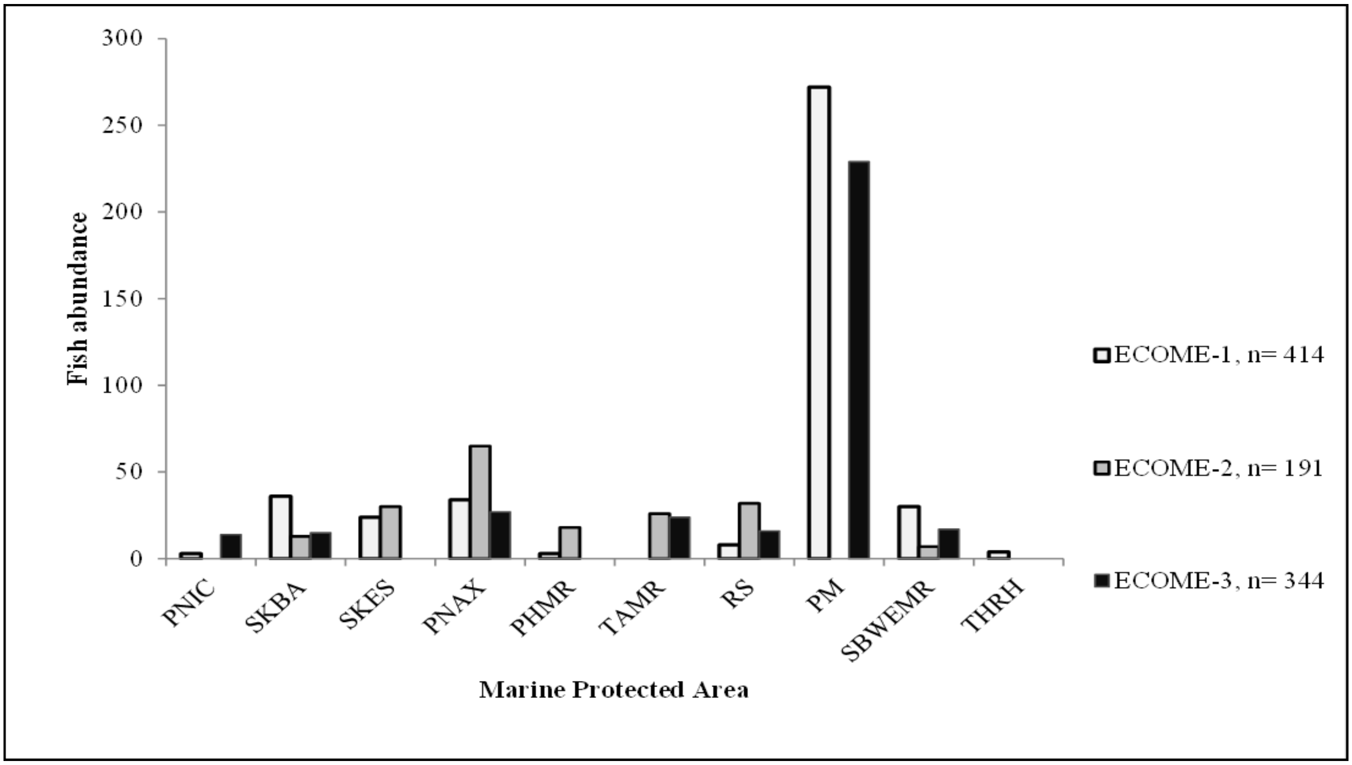

Figure 3. Plot of the total abundance of larval and young juvenile fishes in the marine protected areas that participated during Collection exercises ECOME 1 (September 2013), ECOME 2 (February/March 2014) and ECOME 3 (August 2014). Parque Nacional Isla Contoy, PNIC; Reserva de la Biosfera Sian Ka'an Bahía Ascensión, SKBA, Bahía Espiritu Santo, SKES; Parque Nacional Arrecifes de Xcalak, PNAX; Port Honduras Marine Reserve (PHMR), Turneffe Atoll Marine Reserve (TAMR); Área de Uso Múltiple Rio Sarstún, RS, Refugio Vida Silvestre Punta Manabique, PM; Sandy Bay West End Marine Reserve, SBWEMR, and Zona de Protección Especial Marina Turtle Harbour - Rock Harbour, THRH.

Table 1. Coordinates provided by participants from eight individual marine protected areas that participated in the ECOME 1,2 and 3 exercises. Parque Nacional Isla Contoy, PNIC; Reserva de la Biosfera Sian Ka'an: Bahía Ascensión, SKBA, Bahía Espiritu Santo, SKES; Parque Nacional Arrecifes de Xcalak, PNAX; Área de Uso Múltiple Rio Sarstún, RS; Refugio Vida Silvestre Punta Manabique, PM; Sandy Bay West End Marine Reserve, SBWEMR, and Zona de Protección Especial Marina Turtle Harbour - Rock Harbour, THRH.

Station	**Decimal Longitude**	**Decimal Latitude**	**Decimal Longitude**	**Decimal Latitude**	**Decimal Longitude**	**Decimal Latitude**	**Decimal Longitude**	**Decimal Latitude**
MPA	**PNIC**		**SKBA**		**SKES**		**PNAX**	
1	-86.7819	21.4330	-87.4541	19.8231	-87.4315	19.3510	-87.8247	18.2910
2	-86.7820	21.4346	-87.4545	19.8207	-87.4326	19.3521	-87.8254	18.2876
3	-86.7814	21.4357	-87.4547	19.8213	-87.4346	19.3531	-87.8280	18.2771
4	-86.7821	21.4365	-87.4548	19.8214	-87.4366	19.3545	-87.8271	18.2702
5	-86.7823	21.4379	-87.4550	19.8206	-87.4367	19.3574	-87.8258	18.2615
6	-86.7826	21.4386	-87.4550	19.8188	-87.4375	19.3594	-87.8261	18.2611
7	-86.7815	21.4386	-87.4553	19.8178	-87.4385	19.3621	-87.8261	18.2586
8	-86.7866	21.4553	-87.4553	19.8166	-87.4402	19.3637	-87.8275	18.2570
9	-86.7866	21.4586	-87.4560	19.8166	-87.4417	19.3644	-87.8312	18.2364
10			-87.4566	19.8156	-87.4432	19.3674	-87.8319	18.2338
Station	RS		PM		SBWEMR		THRH	
1	-88.8005	15.9603	-88.5541	15.9683	-86.5801	16.3250	-86.9451	16.1126
2	-88.8014	15.9598	-88.5533	15.9687	-86.5790	16.3255	-86.9454	16.1128
3	-88.8008	15.9590	-88.5518	15.9675	-86.5774	16.3260	-86.9458	16.1118
4	-88.8015	15.9584	-88.5514	15.9674	-86.5707	16.3331	-86.9459	16.1108
5	-88.8063	15.9575	-88.5511	15.9688	-86.5692	16.3340	-86.9478	16.1096
6	-88.8071	15.9569	-88.5454	15.9644	-86.5685	16.3344	-86.9485	16.1098
7	-88.8076	15.9562	-88.5433	15.9579	-86.5674	16.3356	-86.9494	16.1089
8	-88.8084	15.9556	-88.5437	15.9576	-86.5661	16.3360	-86.9120	16.1188
9	-88.8092	15.9553	-88.5528	15.9672	-86.5638	16.3379	-86.9114	16.1182
10	-88.8101	15.9594					-86.9111	16.1174

Table 2. Taxonomic classification of larval and young juvenile fishes collected during the 3 connectivity exercises (ECOME 1, 2 and 3) collected during 2013 - 2014.

Common name	Family	Species	Abundance
flyingfish	Exocoetidae	*Cheilopogon* sp.	1
trumpetfish	Aulostomidae	*Aulostomus maculatus*	4
brotula	Bythitidae	*Ogilbia* sp.	1
pipefish	Syngnathidae	*Bryx* sp.	1
dwarf seahorse		*Hippocampus zosterae*	1
pipefish		*Syngnathus* sp.	1
bridle cardinalfish	Apogonidae	*Apogon aurolineatus*	18
cardinalfish		*Apogon* sp.	4
horse-eye jack	Carangidae	*Caranx latus*	3
jack		*Caranx* sp.	50
Atlantic bumper		*Chloroscombrus chrysurus*	241
mackerel scad		*Decapterus macarellus*	4
		Decapterus sp.	1
bigeye scad		*Selar crumenophthalmus*	5
schoolmaster snapper	Lutjanidae	*Lutjanus apodus*	17
lane snapper		*Lutjanus synagris*	4
yellowtail snapper		*Ocyurus chrysurus*	3
mojarra	Gerreidae	*Eucinostomus* sp.	2
porkfish	Haemulidae	*Anisotremus virginicus*	7
blue striped grunt		*Haemulon sciurus*	5
chere-chere grunt		*Haemulon steindachneri*	33
		Haemulon sp.	11
spotted goatfish	Mullidae	*Pseudupeneus maculatus*	1
sergeant-major	Pomacentridae	*Abudefduf saxatilis*	7
night sergeant		*Abudefduf taurus*	1
twinpost bass	Serranidae	*Serranus flaviventris*	16
bass		*Serranus* sp	1
dwarf wrasse	Labridae	*Doratonotus megalepis*	6
slippery dick		*Halichoeres bivittatus*	1
social wrasse		*Halichoeres socialis*	207
bluehead wrasse		*Thalassoma bifasciatum*	2
green razorfish		*Xyrichtys splendens*	1
parrotfish	Scaridae	*Scarus* sp.	3
parrotfish		*Sparisoma* sp.	4
frillfin goby	Gobiidae	*Bathygobius soporator*	1
goby		*Coryphopterus* sp.	2
flarenostril clingfish	Gobiesocidae	*Acyrtops amplicirrus*	2
clingfish		*Gobiesox sp.*	1
surgeonfish	Acanthuridae	*Acanthurus sp.*	2
marbled blenny	Labrisomidae	*Paraclinnus marmoratus*	7
occidental blenny		*Starksia occidentalis*	1
blenny	Blenniidae		1
flat needlefish	Belonidae	*Ablennes hians*	2
needlefish		*Strongylura* sp.	1
great barracuda	Sphyraenidae	*Sphyraena barracuda*	3
orangespotted filefish	Monacanthidae	*Cantherhines pullus*	2
slender filefish		*Monacanthus tuckeri*	114
fringed filefish		*Monacanthus ciliatus*	30
Caribbean sharpose-puffer	Tetraodontidae	*Canthigaster rostrata*	80
pufferfish		*Canthigaster* sp.	4
unidentified or damaged			27
		Total fish abundance	**947**

During the three field exercises, the MAR *connectivity network* included a heterogeneous group of professionals: biologists, park rangers, boat captains, fish taxonomists, oceanographers, fisheries biologists, as well as students, volunteers and NGO staff. One of the main goals of the "ECOME" exercises was to utilize in-house knowledge from participants and take advantage of their access to each particular location to maximize sampling opportunities. Field exercises differed in the number of days with some MPAs starting collections on a slightly different day (no more than one day before or after). For Guatemala MPAs, the use of SCUBA to recover samples proved highly successful as there was collected the largest number of specimens, although lower species diversity was observed. Most MPAs successfully carried out their ECOME activities and shared information amongst participants. Even with financial constraints faced during the preparation and execution of the two exercises, it is important to recognize the enthusiasm and the initiative of cooperation by the responsible participants in the different areas, without them, these collections would not have been possible, , as well as to recognize the important role of MAR-Fund in the regional logistics coordination. Despite the logistical challenge and large geographical distance covered in this study, these results demonstrate the cooperative work necessary to gather information on fundamental aspects of biological and physical connectivity in the Mesoamerican Reef

Finally, additional work is necessary for research efforts to establish a coupled biophysical yet standardized monitoring in the region. Given the success of the ECOME exercises and the utility of the WCC in the field, we recommend that the monitoring of incoming larval recruits be assimilated into MPA management plans to establish an initial baseline in at least two contrasting seasons (winter – summer) with duration of at least 10 days to capture smaller temporal events. We should stress the importance of simultaneous and continuous monitoring, including the logging of temperature and salinity. These physical data will help potentially untangle events such as an observed mass fish kill in Roatan Honduras during May 2014 (Gisselle Brady, Sandy Bay West End Marine Reserve, Personal communication) and the observed intrusion of freshwater into marine environment that caused the loss of hundreds of kilos of live lobsters in February, 2014 at Punta Herrero in the Sian Ka'an Biosphere Reserve (Denisse Angeles, Comisión Nacional de Áreas Naturales Protegidas, Personal communication) which resulted in economic losses to fishermen in the area. These episodic mortality events in the MAR highlight the need for baseline information to determine possible causes.

Locally, recruitment and connectivity studies improve management by enhancing the available baseline information of the diversity of the MAR region and documenting what (if any) MPAs are recruitment refuges needing scientific data to further justify their importance and stability as management tools. The MAR region can benefit greatly from establishing ecological recruitment baselines as biodiversity and ecosystem-oriented policy take on a larger role.

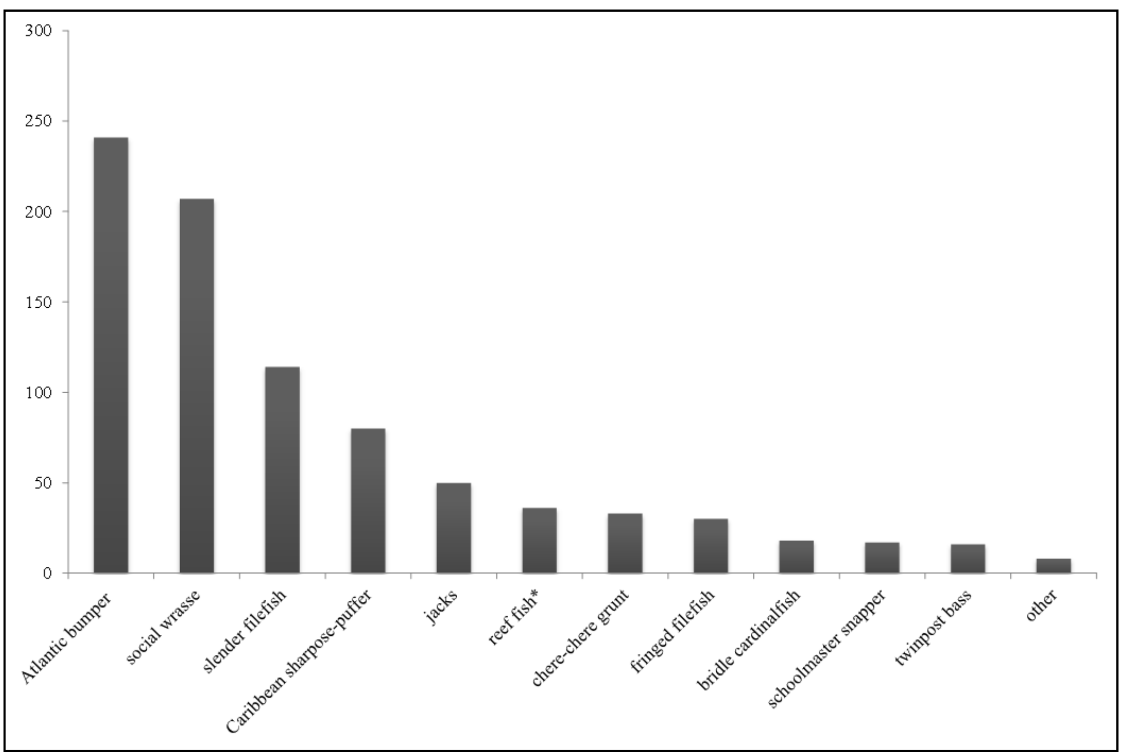

Figure 4. Most abundant fishes for ECOME 1, 2 and 3 collections from September 2013 through August 2014

ACKNOWLEDGEMENTS

We are appreciative to personnel from each Marine Protected Area from Mexico, Honduras, Guatemala and Belize. We are especially grateful to CONANP-SEMARNAT and to personnel from ECOSUR's Zooplankton Laboratory: S. Morales and G. Yam Poot. This project was funded by MARFUND, NOAA Coral Reef Conservation Program #20528, NOAA SEFSC, ECOSUR, and University of Miami.

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