El Colegio de la Frontera Sur

Reclutamiento de peces arrecifales en el Parque Nacional Arrecifes de Xcalak, análisis comparativo de métodos de muestreo.

TESIS
Presentada como requisito parcial para optar al grado de
Maestra en Ciencias en Recursos Naturales y Desarrollo Rural
Con orientación en Manejo y Conservación de Recursos Naturales

Por

Andrea Jimena Aguilar Andrade

2021

El Colegio de la Frontera Sur

Las personas abajo firmantes, miembros del jurado examinador de:

---

hacemos constar que hemos revisado y aprobado la tesis titulada

Reclutamiento de peces arrecifales en el Parque Nacional Arrecifes de Xcalak, análisis comparativo de métodos de muestreo.

Para obtener el grado de **Maestra en Ciencias en Recursos Naturales y Desarrollo Rural**

	Nombre	Firma
Director	Dr. Felipe Eloy Sosa Cordero	
Asesora	Dra. Laura Carrillo Bibriezca	
Asesora	Dra. Martha Elena Moreno Valdez	
Asesora	M. en C. Lourdes Vásquez-Yeomans	
Sinodal adicional	Dr. Miguel Ángel Ruiz Zárate	
Sinodal adicional	Dra. Mariana E. Callejas Jiménez	
Sinodal suplente	Dra. Rebeca Adriana Gasca Serrano	

Dedicatoria

A mi Familia!

A Kamila, por ser un gran motivo que me impulsa siempre a hacer el mejor esfuerzo.

A mis padres, Rebeca y Emilio, mi hermano Damián por su cariño y su incondicional apoyo aún a la distancia.

A Cata, por todo su amor y cuidados.

Agradecimientos.

A mis padres por todo su apoyo y a Kamila por su paciencia y acompañamiento.

Al Dr. Eloy Sosa Cordero por aceptarme como tesista y por el apoyo brindado durante toda la maestría.

A mi comité tutelar, la Dra. Laura Carrillo Bibriezca, la Dra. Martha Elena Valdéz Moreno y en especial a la M. en C. Lourdes Vásquez Yeomans por sus comentarios y correcciones realizadas al trabajo de tesis y artículo que hicieron de este trabajo algo mejor.

A José Ángel Cohuo Collí por su apoyo constante en campo y laboratorio, por sus comentarios a los escritos y por los ánimos brindados durante la etapa final de este proceso.

A los miembros del sínodo, Dr. Miguel Ángel Ruiz Zárate, Dr. Mariana Callejas Jiménez y la Dra. Rebeca Adriana Gasca Serrano

A El Colegio de la Frontera Sur, ECOSUR, unidad Chetumal, por abrirme sus puertas, por todos los nuevos conocimientos y experiencias adquiridas y permitirme llegar hasta donde estoy en el ámbito académico.

A mis compañeros y amigos de la maestría que de una u otra manera siempre nos apoyamos, sobretodo a Leslie y Alicia.

Al M. en C. Holger Weissenberger por su apoyo en la realización del mapa presentado.

A los Sres. Oscar Salazar Aguilar, Nemesio Salazar y la Sra. Constantina Olvera de Xcalak.

Al Consejo Nacional de Ciencia y Tecnología por la beca otorgada para la realización de la Maestría en Ciencias en Manejo de Recursos Naturales y Desarrollo Rural.

A las autoridades del Parque Nacional Arrecifes de Xcalak (PNAX-CONANP), por el apoyo y las facilidades para el uso de sus instalaciones.

A MAR Fund-FMCN por los fondos aportados al proyecto “Monitoreo participativo del reclutamiento de peces de arrecife: Indicador de conectividad en el Arrecife Mesoamericano” [A1804007-MEX10019]

Tabla de contenido.

Resumen

El proceso de reclutamiento es fundamental para mantener las poblaciones de peces de arrecife; por lo tanto, su monitoreo es fundamental para explicar variaciones en la abundancia de estos organismos. Con el propósito de obtener datos de reclutamiento, utilizamos tres métodos de muestreo en una laguna arrecifal: a) colectores de columna de agua (CCA), un arte simple y de bajo costo, b) grabación en video "in situ" de peces que ocupan parches de arrecifes, y c) una red de arrastre utilizada en fondos de pastos marinos.

Los tres métodos se aplicaron de tal manera que permitieran evaluar la similitud de los resultados obtenidos con cada uno, en cuanto al número de especies, índices de abundancia y patrón temporal del asentamiento de postlarvas, para así permitir el análisis y discusión de las ventajas y desventajas de cada método; además, de la elaboración de listas de especies capturadas con cada uno de los artes.

Con los tres métodos utilizados, en el mes de marzo se registraron 68 especies y 51 especies en el muestreo de agosto-septiembre. Cada método permitió la captura de modo exclusivo de un determinado número de especies. En marzo, en los CCA se capturó de manera exclusiva una especie, en la red de arrastre 17 especies y 37 especies con videofilmaciones. En agosto-septiembre, los CCA capturaron 14 especies y las videofilmaciones 32 especies. Nuestros resultados permitieron encontrar diferencias significativas entre las colectas obtenidas con cada arte de muestreo.

Cada uno de los métodos de muestreo presentó ventajas y desventajas, por lo que su uso dependerá de los objetivos de trabajo. Cuando el objetivo de investigación consista en describir la composición y abundancia de la comunidad de peces juveniles (reclutas), se recomienda emplear más de un método de muestreo, cuyos resultados sean complementarios entre sí.

Palabras clave. Laguna arrecifal, postlarvas, colectores, reclutamiento, Sistema Arrecifal Mesoamericano, Xcalak

INTRODUCCIÓN

Los arrecifes de coral son ecosistemas de elevada complejidad, capaces de albergar de cientos a miles de especies de organismos, además de brindar múltiples servicios ambientales (Reyes-Bonilla et.al., 2014). Hoy en día, estos ecosistemas valiosos soportan fuertes presiones a distintas escalas de espacio y tiempo. A escala local sufren los impactos del desarrollo costero, turismo, sobrepesca, contaminación (Lang et al., 1988; Betancourt y González-Sansón, 2011; Alvarez-Filip et al., 2019); a escala regional, están los efectos de especies invasoras (pez león) (Albins y Hixon, 2008), la llegada masiva de sargazo (Rodríguez-Martínez et al., 2016); a escala global, operan el cambio climático principalmente el incremento en la temperatura y en la acidificación del océano (Andersson et al., 2019).

Los arrecifes de coral poseen una elevada biodiversidad, con hábitats para numerosas especies de invertebrados y vertebrados, destacando los peces arrecifales como componente clave en la estructura y función del ecosistema (Jackson et al., 2001; Morales-Aranda, 2011). Históricamente la pesca ha sido una actividad humana dirigida sobre grupos selectos de peces, que genera efectos directos e indirectos sobre el ecosistema arrecifal. Un caso particularmente relevante en la región del Arrecife Mesoamericano (MAR) es la explotación no regulada de agregaciones de peces reproductores en áreas de arrecifes, excepto Belice (Sosa-Cordero et al., 2009; Kobara et al., 2013; Sadovy y Colin 2014).

Un gran número de especies de peces arrecifales tienen una historia de vida compleja que comprende cuatro etapas: huevo, larva, juvenil y adulto (Leis, 1991; Kritzer y Sale 2006). Los dos primeros estadios, huevos y larvas, conforman lo que se conoce como ictioplancton; mientras que los juveniles se establecen generalmente en hábitats bénticos donde permanecen como adultos. Por tanto, los peces utilizan múltiples hábitats a lo largo de su desarrollo ontogénico (Eggleston, 1995; Research Plannig Inc., 2003; White et al., 2019).

La vida planctónica de las larvas de peces tiene fuertes consecuencias en el reclutamiento de los peces de arrecife, con el reclutamiento referido como el proceso aditivo por el cual las poblaciones son renovadas anualmente a través de la incorporación de nuevos individuos jóvenes (reclutas) que son resultado del proceso reproductivo (Levin, 1994; Caley et al., 1996; Carr y Sims, 2006).

En trabajos recientes se reporta que las larvas de peces exhiben características de comportamiento que les confiere capacidad natatoria en una dirección determinada (Rojas, 2014), por ejemplo, pueden desarrollar migración vertical en la columna de agua, capacidad natatoria direccional, y de navegación hacia hábitats apropiados para su asentamiento. Leis (2015) menciona que las larvas de peces arrecifales están notoriamente dotadas para nadar y orientarse en mar abierto, además de buenas capacidades sensoriales (audición, olfato, visión). Por todo ello, la dispersión de las larvas de peces de arrecife se considera un proceso biofísico, con fuerte influencia de las corrientes marinas y el comportamiento de las larvas (Paris et al., 2005, 2007; Leis, 2015, White et al., 2019).

A través de la dispersión hacia fuera de la zona arrecifal principalmente por medio de las corrientes, las larvas minimizan el riesgo de depredación ocasionada por especies que habitan el arrecife, incrementando la probabilidad de sobrevivencia y el flujo genético entre las poblaciones (Richards y Lindeman, 1987; Ortega y García, 2002; Ishihara y Tachihara, 2011). Sin embargo, en esta etapa, los peces sufren mortalidades muy altas (Houde, 2008), lo que repercute en el reclutamiento.

La investigación sobre el reclutamiento de peces constituye una rama de la ciencia pesquera amplia y muy activa (Hjort, 1914; Browman, 2014) y de la ecología marina (Sale, 2004). Es un componente central en la evaluación de la dinámica de las poblaciones de peces, su estructura, estabilidad y, en consecuencia, su manejo sostenible (Haddon 2011). El reclutamiento depende de la existencia de adultos y de la supervivencia de los juveniles y viceversa (Fig.1) (Williams, 1991; Planes et al., 1993; Pile et al., 1996, Trujillo-Millán 2004, Villegas-Sánchez et al., 2015; White et al. al., 2019). Este último punto es relevante porque, en la actualidad, las poblaciones de peces están sujetas a altos niveles de explotación y varias presiones ambientales aceleradas (Sadovy, 2016).

El Sistema Arrecifal Mesoamericano (SAM) es la segunda barrera arrecifal más extensa del mundo con ~1000 km de longitud, y que comprende las costas de México, Belice, Guatemala y Honduras (Almada-Villela et al., 2002). Contiene arrecifes de barrera, de borde, plataforma de extensión variable e islas, con un gradiente de hábitats que incluye estuarios tropicales de manglar, humedales costeros, praderas pastos marinos y aguas oceánicas (RPI, 2003). En este mosaico de hábitats ocurren procesos de conectividad a través del sistema de corrientes, y un corredor de áreas marinas y costeras que albergan una amplia diversidad de peces de importancia ecológica e interés comercial como son varias especies de las familias Serranidae, Lutjanidae, Labridae, Scaridae, Acanthuridae, Coryphaenidae, Istiophoridae y Scombridae (Muhling et al., 2013; Vásquez-Yeomans et al., 2017; Martínez et al., 2019).

Existen numerosos estudios sobre el proceso de reclutamiento en peces de arrecife alrededor del mundo. Por ejemplo en Australia se ha trabajado varios tópicos como son la ontogenia, dispersión larval, variación anual en reclutamiento (Eckert 1984; Leis 1986; Milicich y Doherty, 1994). Se han realizado experimentos en larvas de peces en fase de asentamiento utilizando trampas de luz, con sonido y sin sonido, llegando a la conclusión de que las larvas llegan al arrecife guiadas por el sonido (Simpson et al., 2004). En Barbados se estimó la duración del período larval y los patrones de reclutamiento; encontrando que el reclutamiento ocurre en distintas fases lunares y la duración larval varió entre 23 y 34 días en especies del género *Coryphopterus* mientras que la larva de *Gnatholepis thompsoni* tuvo una duración de 46 a 112 días (Sponaugle y Cowen, 1994). En Florida se comparó el suministro larval de peces arrecifales en áreas protegidas y no protegidas encontrando que los sitios con el mismo nivel de protección tenían patrones significativamente diferentes de suministro de larvas, así como la diversidad de larvas y reclutas, pero la magnitud del reclutamiento difería solo por el nivel de protección, donde las densidades eran mayores en las reservas (Grorud-Colvert y Sponaugle, 2009). En Belice, Nolan y

Danilowicz (2008) realizaron muestreos con redes de canal y redes de cresta obteniendo una captura de 53,579 larvas de peces que representaron 33 familias e identificaron 59 especies.

En la región del SAM se han desarrollado previamente numerosos trabajos relacionados con el ictioplancton en hábitats costeros y oceánicos. En aguas oceánicas, se realizaron cruceros para cuantificar la abundancia de larvas de peces y características oceanográficas relacionadas, lo que resultó en una gran abundancia de taxones costeros y estuarinos (Eleotridae, Priacanthidae) en el sur del SAM, mientras que, en el norte de SAM, una mezcla de taxones mesopelágicos asociados a arrecifes (Myctophidae, Sparidae) (Muhling et al., 2013). Asimismo, se ha analizado el reclutamiento de estadios larvales del macabí *Albula spp*, especie valiosa en la pesca deportiva (Vásquez-Yeomans et al., 2009). Se ha reportado reclutamiento en hábitats costeros del SAM: en Guatemala y Honduras (Arrivillaga & Baltz, 1999; Gudiel-Corona, 2016). Así como en el Caribe mexicano. Álvarez-Cadena et al., 2007 utilizando una red neuston en la laguna Nichupté, registró 5,577 larvas distribuidas en 55 familias y 115 especies. Gonzáles-Salas et al. (2003) utilizó en el caribe mexicano, incluyendo Xcalak, censos visuales para evaluar los patrones espaciales de los reclutas de peces arrecifales encontrando 6320 peces pertenecientes a 58 especies, 30 géneros y 18 familias. Entre los estudios de reclutamiento costeros cercanos a Xcalak se encuentran Vásquez-Yeomans et al. (1998; 1999, 2011). En Mahahual, 60 km al norte de Xcalak, con arrastres superficiales de una red de plancton estándar, Vásquez-Yeomans et al. (1998) recolectaron 2,082 larvas con 30 especies y 54 géneros; las densidades más altas se encontraron en la laguna arrecifal. Utilizando un método similar, en Bahía de la Ascensión, a 260 km al norte de Xcalak, Vásquez- Yeomans y Richards (1999) capturaron 10,198 larvas correspondientes a 57 familias, 84 géneros y 74 especies. En Bacalar Chico, en la frontera entre México y Belice, utilizando tres artes de muestreo distintos, Vásquez-Yeomans et al. (2011) recolectaron 7,460 larvas de 118 especies pertenecientes a 53 familias. Solís-Mena (2018), utilizando una red de canal amarrada en el canal principal frente a Xcalak, capturó un total de 3983 larvas de peces, identificando 45 familias, 62 géneros y 56 especies. Encontró siete taxa dominantes: *Ctenogobius* *saepepallens* (47%), *Gnatholepis thompsoni* (24,39%), *Callionymus bairdi* (7,86%), familia Dactyloscopidae (7,81%), *Acyrtops amplicirrus* (6,68%), *Sparisoma spp*. (6,28%) y *Cryptotomus roseus* (5,16%). Dos estudios previos estrechamente relacionados con el presente trabajo reportaron índices de reclutamiento de peces marinos, que correspondían a la abundancia relativa de postlarvas capturadas con colectores de columna de agua (CCA) diseñados por Steele et al. (2002). Primero, en Xcalak y Punta Allen, México (Yam Poot, 2013), y después en Guatemala (Gudiel-Corona 2016). Desde 2013, en la región MAR, hay esfuerzos realizados por una red de conectividad regional con el objetivo de monitorear el reclutamiento de peces de arrecife, basado en la abundancia relativa de postlarvas de peces utilizando CCA en una red de Áreas Marinas Protegidas (AMP) (Malca et al., 2015; Vásquez-Yeomans et al.2017, 2020). También existen estudios de reclutamiento en otros sitios como Xcaret (Ayala-Campos, 2014) y Banco Chinchorro (Villegas-Sánchez et al., 2015).

Estas contribuciones previas pueden verse como las bases del conocimiento en materia de reclutamiento de peces de arrecife; pero se requiere mayor estudio para un mejor entendimiento del proceso de reclutamiento en peces arrecifales. De igual manera, las metodologías para la estimación del reclutamiento de peces de arrecife necesitan de afinamiento y análisis comparativos.

OBJETIVOS DE LA TESIS

Objetivo general:

Evaluar del uso simultáneo de métodos de muestreo alternativos, Colectores de columna de agua (CCA), red de arrastre y videofilamaciones *in situ* dentro de la laguna arrecifal para medir el reclutamiento de peces, y estimar el ingreso de postlarvas y juveniles (reclutas) a las áreas costeras.

Objetivos particulares:

i) Comparar las listas de especies obtenidas por cada uno de los métodos.

ii) Estimar la abundancia relativa de las postlarvas y peces juveniles colectados con el empleo de cada método.

iii) Determinar las ventajas y desventajas del uso de cada método.

ARTÍCULO

Application of alternative sampling methods to evaluate reef fish recruitment (February 2021)

Sometido a Peer J

Evaluation of reef fish recruitment through the application of alternative sampling methods in the reef lagoon habitats.

Andrea J. Aguilar Andrade[1], Lourdes Vásquez-Yeomans[1], Felipe Eloy Sosa-Cordero[1*], José Ángel Cohuo Colli[1], Laura Carrillo[2], Martha Elena Valdez Moreno[1]

[1]Department of Systematics and Aquatic Ecology, El Colegio de la Frontera Sur; Chetumal, Quintana Roo, México

[2]Department of Observation and Study of the Earth, Atmosphere and Ocean, El Colegio de la Frontera Sur; Chetumal, Quintana Roo, México

Corresponding Author:

Felipe Eloy Sosa Cordero*

Av. Centenario Km 5.5, Chetumal, Quintana Roo, Col Pacto Obrero Campesino, 77014, México

Email address: esosa@ecosur.mx

Abstract

The recruitment process is paramount for replenishing reef fish populations; hence, its monitoring conveys information to explain reef fish abundance variation. To obtain recruitment data, we used three methods to quantify the abundance of postlarvae and early juveniles in the reef lagoon: a) water column collectors (WCC), a low cost and simple sampling gear, b) "in situ" videorecording of fish occupying patch reefs, and c) a trawl net operated on seagrass bottoms. For each method, we calculated postlarvae and juvenile fish abundance indexes and prepared lists of fish species, stages, and sizes. We discuss each method's advantages and disadvantages, giving further consideration for their use in a participative program for reef fish recruitment monitoring in the Mesoamerican Reef region. We concluded that the selected method depends on the research objectives and the resources available; however, we highly recommended employing more than one method periodically to obtain a fuller picture of the fish recruitment.

Method. We simultaneously used three sampling gears in the reef lagoon of the Arrecifes de

Xcalak National Park (PNAX) and quantified the abundance of reef fish postlarvae and juveniles. We evaluate the results in terms of the number and composition of species, abundance indexes, and their variation corresponding to fish settlement pulses around the new moon. We deployed WCC's in the proximity of coral heads and reef patches and daily checked for seven days. We carried out video filming on randomly selected reef patches. Sampling with the trawling net was carried out mostly on seagrass beds near the mangrove-bordered coastline and the back reef sites, close to the reef crest.

Results. In March, when using all three gears, a total of 68 fish species were recorded; in August-September, using two gears, 51 species were collected in total. Each gear allowed to capture a certain number of fish species exclusively. Our results showed apparent differences due to the method used, considering the number of species and their abundance registered. Thus, for two methods: video filming and WCC's, Shannon's index of diversity reached values >2 in both sampling periods. The Simpson's index attained values ≈1 for each sampling method, which indicates a greater possibility of the dominance of one or some species in the sampled habitat. During March, the Jaccard's index of similarity showed substantial similarity among the fish species obtained from video recording and the trawl net. Overall, each sampling method presented advantages and disadvantages, and the chosen method will depend on the research objectives and the available resources. For monitoring reef fish recruitment, the WCC's seem appropriate, being the most selective method, with the lowest costs, reduced time, and resources needed for the sampling task. Due to the three methods complemented each other, we recommend apply, on a periodical basis, more than one sampling method.

Keywords. Reef lagoon, postlarvae, collectors, Mesoamerican Barrier Reef System, Xcalak

Introduction

Coral reefs are highly complex ecosystems capable of harboring hundreds to thousands of marine species besides supplying multiple environmental services (Reyes-Bonilla et al. 2014). Coral reefs have high biodiversity, providing habitats for numerous invertebrates and vertebrates species, especially reef fishes, critical components in the ecosystem's structure and function. Currently, these valuable ecosystems face intense pressures at different spatial and temporal scales. Locally, they suffer the impacts of coastal development, tourism, overfishing, and pollution (Lang et al. 1988; Betancourt y González-Sansón, 2011; Alvarez-Filip, 2019); on a regional scale, the effects of invasive species (i.e., lionfish) (Albins and Hixon, 2008; Cobian Rojas et al. 2018), and the massive arrival of sargassum (Rodríguez-Martínez et al. 2016). On a global scale, they are under the effects of climate change and ocean acidification (Andersson et al. 2019).

Coral reefs possess high biodiversity, with reef fish being a prominent component in the ecosystem's structure and function. Historically, fishing has been a human activity targeting selected fishes groups, which generates direct and indirect effects on the reef ecosystem. A case particularly relevant in the Mesoamerican Reef (MAR) region is the unregulated exploitation of spawning fish aggregations in reef areas –excepting Belize (Sadovy and Colin 2014, Sosa-Cordero et al. 2009; Kobara et al. 2013).

Most reef fish species have a complex life history comprising four stages: egg, larvae, juvenile, and adult (Leis, 1991; Kritzer and Sale 2004). The first two, egg and larvae, are free-living stages being a part of the plankton known as ichthyoplankton, while juveniles settle in benthic habitats where they remain adults. Therefore, fish use multiple habitats throughout their ontogenetic development (Eggleston, 1995; RPI, 2003; White et al. 2019). The eggs and early larvae are among the most challenging fish life stages for taxonomic identification based on morphological features (Leis, 1991; Richards, 2006); even though recently developed genetical tools (Barcoding) are proving to be helpful in this task (Valdez-Moreno et al. 2010, Leyva-Cruz et al. 2016).

The recruitment process is paramount for reef fish populations' replenishment and persistence, in which the early life stages are particularly critical. The survival of fish larvae has severe consequences for the recruitment of reef fish, with recruitment referred to as the additive process by which populations are replenished annually through the incorporation of new young individuals (recruits) that are the result of the reproductive process (Levin, 1994; Caley et al. 1996; Carr and Sims, 2006). Here, we focused on the influx of postlarvae and early juveniles of reef fish associated with the new moon, as evidenced by pulses on the abundance of those life stages.

Old and recent works report that fish larvae exhibit behavioral characteristics that give them swimming capacity in a determined direction (Rojas, 2014, Leis, 1986); for example, they can perform vertical migration in the water column and navigate suitable habitats for settlement. Leis (2015) highlighted that reef fish larvae are remarkably endowed to swim and orient themselves in the open sea, in addition to having good sensorial (hearing, smell, and vision) capabilities. Thus, the dispersal of reef fish larvae is a biophysical process, strongly influenced by marine currents and larval behavior (Paris et al. 2005, 2007; Leis, 2015, White et al. 2019). By dispersing out of the reef zone mainly through currents, larvae minimize the risk of mortality due to predation caused by species that inhabit the reef, increasing the probability of survival and gene flow between populations (Richards and Lindeman, 1987; Ortega and García, 2002; Ishihara, T. and Tachihara, K. 2011). Nevertheless, during the larval stage, the fish suffer very high mortalities (Houde, 2008), consequently decreasing the number of individuals in the population.

Research on fish recruitment constitutes a broad, very active fisheries science branch (Hjort, 1914; Browman, 2014) and marine ecology (Sale, 2004). It is a central component in evaluating the dynamics of fish populations, their structure, stability, and, consequently, their sustainable management (Haddon 2011). Recruitment depends on adults' existence and juveniles' survival and vice versa (Fig. 1) (Williams, 1991; Planes et al. 1993; Pile et al. 1996, Trujillo-Millán 2004, Villegas-Sánchez et al. 2015; White et al. 2019). The latter point is relevant because, currently, fish populations are subject to high exploitation levels and several hastening environmental pressures (Sadovy, 2016).

The Mesoamerican Barrier Reef System is the second largest reef barrier in the world, with ~1000 km in length, comprising Mexico, Belize, Guatemala, and Honduras, which defines the Mesoamerican Reef (MAR) region (Almada-Villela et al. 2002). It contains barrier and margin reefs, a variable extension of continental shelf and islands with a habitat gradient that includes tropical mangrove estuaries, coastal wetlands, seagrass meadows, and ocean waters (RPI, 2003). In this mosaic of habitats, connectivity processes occur through the current system and a corridor network of marine and coastal areas that harbor a high diversity of fish of ecological importance and commercial value, such as various species of the families Serranidae, Lutjanidae, Labridae, Scaridae, Acanthuridae, Coryphaenidae, Istiophoridae, and Scombridae (Muhling et al. 2013; Vásquez-Yeomans et al. 2017; Martínez et al. 2019).

Numerous works dealing with the ichthyoplankton in coastal and oceanic habitats have been previously developed in the MAR region. In ocean waters, cruises were conducted to quantify the abundance of fish larvae and related oceanographic features, which resulted in a high abundance of coastal and estuarine taxa (Eleotridae, Priacanthidae), and at northern MAR, a mixture of reef-associated mesopelagic taxa (Myctophidae, Sparidae) were found (Muhling et al. 2013). Likewise, the recruitment of larval stages of the bonefish *Albula* spp –a valuable species in sport fishing, has been analyzed (Vásquez-Yeomans et al. 2009). Recruitment in coastal habitats has been reported in Guatemala and Honduras (Arrivillaga & Baltz, 1999; Gudiel-Corona, 2016). In the Mexican Caribbean, there are recruitment studies in Xcaret (Ayala-Campos, 2014) and Banco Chinchorro (Villegas-Sánchez, 2015). Alvarez-Cadena et al. 2007 using a neuston net in the Nichupté lagoon, alongside Cancun, recorded 5,577 larvae distributed in 55 families and 115 species. Among the coastal recruitment studies close to Xcalak are Vásquez-Yeomans et al. (1998; 1999, 2011). In Mahahual, 60 km north of Xcalak, with surface tows of standard plankton net, Vásquez-Yeomans et al. (1998) collected 2,082 larvae with 30 species and 54 genera; the higher densities were found in the reef lagoon. Using a similar method, in Bahía de la Ascensión, 260 km northern of Xcalak, Vásquez-Yeomans and Richards (1999) captured 10,198 larvae corresponding to 57 families, 84 genera and 74 species. In Bacalar Chico -on the Mexico-Belize border, using three distinct sampling gears, Vásquez-Yeomans et al. (2011) collected 7,460 larvae of 118 species belonging to 53 families. Solís-Mena (2018), using a channel net moored on the main channel off Xcalak, caught a total of 3,983 fish larvae, identifying 45 families, 62 genera, and 56 species. He found seven dominant taxa: *Ctenogobius saepepallens* (47%), *Gnatholepis thompsoni* (24.39%), *Callionymus bairdi* (7.86%), Dactyloscopidae family (7.81%), *Acyrtops amplicirrus* (6.68%), *Sparisoma* spp. (6.28%) and *Cryptotomus roseus* (5.16%). Two previous studies closely related to the present work reported marine fish recruitment indexes, which corresponded to the relative abundance of postlarvae caught with water column collectors (WCC) designed by Steele et al. (2002). First, in Xcalak and Punta Allen, Mexico (Yam Poot, 2013), and second in Guatemala (Gudiel-Corona 2016). Since 2013, in the MAR region, there are efforts conducted by a regional connectivity network aimed to monitor the reef fish recruitment, based on the relative abundance of fish postlarvae using WCC in a network of Marine Protected Areas (MPAs) (Malca et al. 2015; Vásquez- Yeomans et al. 2017, 2020).

The objective of the present work was to obtain fishery-independent data on fish recruitment by quantifying the abundance of fish postlarvae and juveniles (recruits) during their influx to coastal areas associated with the new moon, using simultaneously three alternative sampling methods in the reef lagoon. Our results will improve the knowledge basis required for the consolidation of the regional fish recruitment monitoring program in a network of MPAs along the Mesoamerican Reef region.

Materials & Methods

Study area

Arrecifes de Xcalak National Park (PNAX) (Fig. 2) is a marine protected area (MPA) created in 2000 (DOF 27/11/2000), which covers a total area of 17949 Ha, with 13935 Ha (77.6%) corresponding to marine ecosystems (López- Jiménez, 2016). This MPA is located alongside the town of Xcalak (Fig. 2), on the southern coast of the Mexican Caribbean, and the central portion of the Mesoamerican Reef region (MAR). PNAX and adjacent areas include terrestrial and marine ecosystems in a good state of conservation.

Our study was developed in the reef lagoon off the town of Xcalak (Fig. 2). The reef lagoon, delimited from the coastline to the reef ridge, consists mainly of sandy bottoms covered by beds of two seagrass species *Syringodium filiforme* and *Thalassia testudinum,* with reef patches formed mostly by *Montastrea annularis*. Vegetation submerged in the reef lagoon presents a good state of preservation, with meadows that extend to the reef, where 98 reef fish species have been reported (López-Jiménez, 2016).

Oceanic circulation is a primary factor in connectivity processes throughout the MAR region (Nichols and Williams, 2009). The surface circulation in the MAR region was described by Carrillo et al. (2015). In general, the circulation pattern is part of the Caribbean Sea's main circulation system that consists of a primary westward flow, the Caribbean Current with numerous eddies and turns (Andrade and Barton, 2000; Badan et al. 2005; Carrillo et al. 2015). The Caribbean current is called the Cayman Current when it passes over this basin and impinges on the Yucatan peninsula. Afterward, it produces a circulation pattern in the MAR with two major branches, one coastal and intense current (speeds of up to 2 m / s) known as the Yucatan Current, and a southern portion of the MAR with variable speeds in direction and with lower magnitude, highlighting a mesoscale gyre in the region of the Gulf of Honduras (Badan et al. 2005; Carrillo et al. 2015). This circulation pattern produces two sub-areas in terms of potential dispersion, a northern region where the plankton is rapidly dispersed northwards, and a southern region where the plankton is potentially subject to more extensive retention (Carrillo et al. 2015; Martínez et al. 2019). This regional circulation largely determines the oceanographic conditions affecting the coral reefs, such as the thermohaline structure (Carrillo et al. 2016) and the connectivity between the AMPs of the MAR region (Martínez et al. 2019). The latter, since the waters can be transported from the oceanic zone to the reef either by the effect of the tide, wind, waves, or other mechanisms capable of penetrating the coastal zone on the platform, it is expected that it influences the dynamics of the interacting benthic and pelagic communities with the reef ecosystem (D'Alessandro et al. 2007).

Field Work

Water column collectors (WCC). These are collectors developed by Steele et al. (2002), being simple in design, low cost, easy to manipulate, and yielding a selective capture. Each WCC consists of a 3mm plastic mosquito net mesh that is wrinkled and then inserted into a 25 mm opening plastic mesh cylinder bag (Steele et al. 2002; Vásquez-Yeomans & Malca, 2013). To keep each WCC vertical and in a fixed position, every WCC was tied to a surface buoy and a dead weight at the bottom, and a small weight ~ 0.5 kg was pocketed inside the cylinder bag (Fig. 3).

Sampling fish postlarvae with WCC was performed during two new moons (NM) periods: i) March 1 to 10, 2019, NM: March 6; and ii) August 28 to September 3, 2019, NM: August 31. Twenty WCC collectors (Table I) were deployed in ten stations placed in the reef lagoon of the PNAX. Some of the stations have been used since 2013 when the first regional monitoring effort called Mesoamerican Reef Connectivity Exercises (ECOME) was conducted (Malca et al. 2013; Vásquez Yeomans et al. 2017). The criteria for the site selection of stations considered the bottom type and the relative protection from the flow of tidal currents.

Collector placement and inspection procedure

Ten stations were installed on the first day in the afternoon, around 6:00 p.m. (local time, GMT-5) on March 2, 2019 and on August 29, 2019, respectively. Each station consisted of two WCC separated from each other by ~ 6-10 m, and deployment depth varied between 1.5 and 3 m. Their positions were georeferenced by using a GPS Garmin, model e-Trex10. The data recorded in each station included: station number, GPS coordinates, date and time of WCC deployment, depth and bottom type, as well as information on the weather: wind (approximate direction), cloud cover, and waves.

WCC collectors were inspected daily by free diving, every morning at 07:00 a.m., from March 3 in the first sampling period and August 30 onwards for the second period. Each WCC was carefully covered with a bag and then lifted for a diver. The captured specimens were counted and photographed; some fish were also preserved in 96% alcohol in labeled containers. Once checked, the WCC was returned and fixed back to its same placement spot.

“In situ” videorecording of the natural habitat in the reef lagoon

During March 3 to 9, 2019, n=14 distinct patch reef or small coral heads in the reef lagoon of the PNAX (Table II) were reviewed through video recording helped by SCUBA diving (Table II). These patches were randomly selected from a larger set, all of them located along six transects perpendicular to the coastline (Fig. 4); three transects were within the area (polygon) delimited by WCCs stations, and the remaining three were outside of that polygon. In each transect, two to three sites with patch reefs or small coral heads were considered potential sampling units, and a fraction of them was randomly chosen to complete fourteen units.

In August 2019, ten out of the fourteen previously selected sampling units were reviewed through video recording and SCUBA diving (Table III); these n=10 sites had high abundance and diversity values in March. In each sampling period, the sampling units' review comprised the entire patch reef /coral head or a section of it, depending on their total size. The field records in each sampling unit were completed afterward with data obtained by a thorough visual inspection of the respective video footage. There was no fish collection, so the counting and identification were based on careful examination of the recorded images.

Trawling Net

During March 4, 5, and 9, 2019, were sampled n= 7 stations (Table IV) for early juveniles of fish with a hand-operated trawling net, 7 m long, 2 m drop, and a 0.5 cm mesh size. We carried out trawls on seagrass beds near the mangrove-bordered coastline and the back reef, close to the reef ridge. The haul length was variable, between 5 and 12 m, so that the swept area of the individual trawls varied between 35 and 105 m^2. Collected fish were preserved in 96% alcohol in labeled containers.

Sample processing and data analysis

Laboratory work consisted of identifying specimens collected with WCC and the trawling netand the revision of video recorded images on high-resolution screens. A stereoscopic microscope, Zeiss model Stemi SV6, was used, and various identification keys of reef fish postlarvae and juveniles were consulted (Humann 2014, Richards 2006, Vásquez-Yeomans et al. 2014). The BOLDSYSTEMS library (www.boldsystems.org) and the FishBase database contain photographic images of specimens captured in reef environments, and the website http://www.coralreeffish.com, were also consulted. Identification was accomplished to the lowest possible taxonomic level. The information drawn from all the biological material, such as the taxonomic composition and the corresponding abundance by taxa, was compiled in a database, allowing to prepare a list of species for the reef fish postlarvae and juveniles resulting from each sampling method. The analysis does not include any adults or late juveniles captured with the trawl net or detected in the video recordings in this work. We avoid the overestimation of the number of species by adopting the following criteria: i) counting all the species to which the gender and species were determined, on a reliable basis; ii) include only as a single distinct species when only the genus was determined, without assigned species; and iii) counting as a single distinct species for those fish identified solely at the family level (only applied once).

Taxonomic composition analysis

Based on the captures obtained with each method, their respective lists of species composition and abundance by taxa were constructed (Tables V and VIII). Two indexes of diversity, the Shannon-Wiener and Simpson (Table VI and X), were estimated based on data gathered for each sampling method. Likewise, to contrast the results among sampling methods, qualitative techniques based on presence-absence and observations were applied. Using the Jaccard's index, a dendrogram of similarity was constructed (Table VII y IX) to evaluate the degree of similarity between different sets of species; in this case, among the species' lists from distinct sampling methods (Albatineh & Niewiadomska-Bugaj, 2011). The 95% confidence intervals of these indexes were estimated by the bootstrap resampling method using the R software (R Core Team, 2019).

Results

The results of the two sampling periods (March 2019 and August-September 2019) are presented separately. Thus, our purpose was to emphasize the noticeable differences we found in the number of postlarvae and juvenile fish caught during each period, emulating the seasonal/interannual variation characterized by contrasting abundance and diversity values. The latter also allowed us to evaluate the performance of the sampling methods used under different levels of abundance and diversity.

Sampling period: March 2 to 10th, 2019

Water column collectors (WCC). Only eight individuals resulted from the retrieval of 20 collectors lifted in eight nights (Fig. 5A). This total catch, achieved with a sampling effort of 160 checked collectors, yielded a total average abundance index of 0.05 individuals per lifted collector ($ind \cdot collector^{-1}$). The daily values of this index had an interval of 0 to 2, and an average of ($\bar{y} \pm de$) of 1.00 ± 0.925 $ind \cdot collector^{-1}$.!"; the daily average had higher values on March 3, 5, and 9, 2019 (Fig. 9A), three and one days before new moon NM, respectively; and three days after NM. The taxonomic examination of the fish caught allowed to identify four species belonging to three genera of three families: *Monacanthus tuckeri* with 4 individuals (50%), followed by *Caranx* sp. with two individuals (25%), one tetraodontid *Canthigaster rostrata*, and one monacanthid, *Monacanthus ciliatus*, these last two species each represented by an individual (12.5%) (Table V).

Videorecordings. The examination of video recordings from n=14 patch reefs or small coral heads, taken in six days, allowed to quantify a total of 1,836 postlarvae and juvenile fish (Fig. 6A). This total, derived from 57 sites inspected, gave a total average index of 32.21 individuals per site surveyed ($ind \cdot site^{-1}$). This index's daily values varied between 0 and 485 $ind \cdot site^{-1}$ with an average $(y \pm de)$ of 20.00 ± 24.99 $ind \cdot site^{-1}$ (Fig. 10A); the daily average maximum, 40.41 ± 31.06 $ind \cdot site^{-1}$, was recorded on March 8, two days after NM (Fig. 10A). A number of 29 species belonging to 12 genera of 8 families were identified (Table V).

Of the total captured, 84.8% was identified at the species level and 15.2% at the genus level. Labridae was the most abundant family, with 986 individuals (53.70%) distributed as *Halichoeres bivittatus* (542 ind; 29.52%), *Thalassoma bifasciatum* (206 ind; 11.22%), and *Halichoeres garnoti* (202 ind; 11.02%). The Scaridae family was second in abundance with 386 individuals (21.02%); *Scarus iseri* (225 ind; 12.25%) was the most abundant species in this family. The third family was the Pomacentridae with 267 individuals (14.54%); *Abudefduf saxatilis* (167 ind; 9.11%) was the species with more individuals in this family; followed by the Haemulidae family with 155 individuals (6.42%) (Table V). These four families represented 95% of the individuals detected in video films. The following families represented the other 5%: Acanthuridae, Lutjanidae, Monacanthidae, Pomacanthidae y Tetraodontidae. Overestimation of the number of species was avoided by applying the criteria already specified in the methods section.

Trawling net. Due to the large number of individuals caught with this net, it was used only in March 2019. In seven trawls, with a total surface of 630 m^2, 436 postlarvae and juvenile fish were captured; that is, 0.692 individuals per m^2 ($ind \cdot m^{-2}$). Catch per trawl ranged from 0 to 3.871 $ind \cdot m^{-2}$. Examination of collected fishes allowed to identify 22 species belonging to 13 genera of 10 families (Tabla V). With this net, the Haemulidae family was the most abundant with seven *Haemulon* genus species; *Haemulon sciurus* had the most presence with 148 individuals (33.94%), *Haemulon spp*. (120 ind; 27.52%) and *Haemulon flavolineatum* (33 ind; 7.56%). The Lutjanidae family was the second in abundance, with 25 specimens of the *Lutjanus griseus* (5.73%). The Scaridae family was third in number, represented by *Sparisoma chrysopterum* (23 ind; 5.27%). The remaining 20% was represented by species from other families (Table V).

With the three sampling methods: WCC, video recording, and trawling net, a total of 2,280 fish postlarvae and juveniles belonging to 68 species were recorded. Each method allowed to capture a given number of species exclusively; thus, a single species *Caranx sp*. (1.4%) was captured only with WCCs; while 37 species (54.40%) were detected exclusively in video recordings, and 17 (25%) were collected solely with the trawl net. On the other hand, the number of species collected by two methods (video recording and trawl net) was 10 (14.70%) species; the only species recorded by all the three methods used was *Canthigaster rostrata* (1.40%) (Fig. 7).

To evaluate indexes of a) diversity that a community composed of equally common species would have, and b) similarity between the results from each of the sampling methods we used, the Shannon-Wiener, Simpson (Table VI), and Jaccard indexes were estimated. (Table VII; Fig. 8). The results were as follows: Shannon's diversity index was higher 2.67 with the video recording method, followed by 2.25 for the trawling net, and 1.21 for collectors WCC. Regarding the Simpson's diversity index, the larger value, 0.90, was achieved for video recording, 0.81 for the trawling net, and 0.65 for collectors WCC. Jaccard index attained values of 0.20 (trawling net *vs*. video recording), 0.02 (videorecording *vs*. collectors WCC), and 0.1 (trawling net *vs*. collectors WCC).

Sampling period: August 29 – September 4, 2019.

Water column collector (WCC**).** A total catch of 89 individuals was obtained from 20 collectors lifted every morning over six days (Fig. 5B); thus, a total effort of 120 lifted collectors yielded an average total index of 0.741 ($ind \cdot collector^{-1}$). The daily values of this index ranged from 0 to 46, with an average of 14.83 ± 15.992 $ind \cdot collector^{-1}$ (Fig. 9B); the maximum daily average, 5.1 ± 3.296 $ind \cdot collector^{-1}$, was recorded on August 31, 2019 (Fig. 9B), one day after NM. The taxonomic examination of the 89 specimens captured allowed identifying 14 species belonging to 13 genera from 9 families (Table VIII). In this period, the Scaridae family was the most abundant in the WCC with 42 individuals (47.2%), allocated into three dominant species: *Scarus sp* (18 ind; 20.22%), *Sparisoma sp* (15 ind; 16.85%), and *Sparisoma rubripinne* (9 ind; 10.11%). Labridae was the second most abundant family with 20 specimens (22.47%), distributed in *Doratonotus megalepis* (15 ind; 16.85%), and *Halichoeres bivittatus* (5 ind; 5.61%). *Cantigaster rostrata,* of the Tetraodontidae family was the fifth in abundance with 6 individuals (6.74%). These species amounted to 76.38% of all the fish caught with collectors WCC in the second period.

Videorecordings. The examination of video recordings at n=10 sites, distinct patch reefs, allowed quantifying a total of 2,685 postlarvae and juvenile fish for three days of sampling (Fig. 6B). This total from 30 inspected sites produced a total average index of 89.5 individuals per surveyed site ($ind \cdot site^{-1}$). The daily values of this index varied between 27 and 308 $ind \cdot site^{-1}$ with an average of 89.5 ± 72.488 $ind \cdot site^{-1}$ (Fig. 10B); the maximum daily average, 105.4 ± 77.375 $ind \cdot site^{-1}$, was recorded on August 30, one day before the NM (Fig.10B). Based on the collected fishes' taxonomic analysis, 39 species belonging to 18 genera of 12 families were identified (Table VIII).

The prominent families observed were Labridae with 1395 individuals (51.9%), represented by the taxa *Halichoeres bivittatus* (622 ind; 23.1%), *Halichoeres garnoti* (410 ind; 15.2%), *Thalassoma bifasciatum* (236 ind; 8.7%), and *Halichoeres pictus* (127 ind; 4.7%). The Scaridae family was second in abundance, with 742 individuals (27.63%), and *Scarus iseri* (534 ind; 19.9%) being the species with the larger number of individuals. The third family in abundance, the Haemulidae, had 277 individuals (10.31%) represented mostly by *Haemulon flavolineatum* (246 ind; 9.1%) and followed the Pomacentridae family with 199 individuals (7.22%), the species *Abudefdus saxatilis* (124 ind; 4.6%) achieved the highest abundance. These four families represented 97% of the specimens collected, and the remaining 3% were made up of species from families: Acanthuridae, Chaetodontidae, Gobiidae, Lutjanidae, Mullidae, Sciaenidae, Serranidae, and Tetraodontidae (Table VIII).

The leading families observed were Labridae with 1,395 individuals (51.9%), distributed in *Halichoeres bivittatus* (622 ind; 23.1%), *Halichoeres garnoti* (410 ind; 15.2%), *Thalassoma bifasciatum* (236 ind; 8.7%), and *Halichoeres pictus* (127 ind; 4.7%). The Scaridae family was second most abundant with 742 individuals (27.63%), with *Scarus iseri* (534 ind; 19.8%) as the most abundant species in this family, followed by the Haemulidae family with 277 individuals (10.31%) represented by *Haemulon flavolineatum* (246 ind; 9.1%) and the Pomacentridae family with 199 individuals (7.22%) being *Abudefdus saxatilis* (124 ind; 4.6%) the species with the highest abundance in this family. These four families represented 97% of the specimens detected in the video films. The remaining 3% were species from other families (Acanthuridae, Chaetodontidae, Gobiidae, Lutjanidae, Mullidae, Sciaenidae, Serranidae y Tetraodontidae).

Trawling net. In the second period, this sampling gear/method was not used. In March, sampling with this net yielded a large catch, but the captured specimens' size indicated that they came from previous recruitment events, one to two new moons before. As it did not correspond to the pulse of recruits of the current new moon, we decided that no longer to use this gear in our study.

With the two sampling methods used in August-September, WCC, and video recording, a total of 2774 larvae and juveniles of 51 species were recorded. From this total, 14 (27.4 %) species were captured only with WCC, and 32 (62.7 %) were detected uniquely in video recordings, while 5 (9.8 %) species were recorded in both sampling methods (Fig. 11).

To evaluate the results obtained with each sampling method, based on August-September's data, we computed the Shannon-Wiener's and Simpson's diversity indexes and the Jaccard's index of similarity (Table IX). The following results were obtained: Shannon index: 2.33 (videorecording) and 2.41 (WCC); Simpson index: 0.86 (videorecording) and 0.87 (collectors WCC) (Table X); and Jaccard index: 0.11 (videorecording *vs*. collectors WCC).

Despite the small number of data corresponding to the abundance index were obtained with two distinct methods, collectors WCC *versus* video recording, for the same species in the same site or station, and the same new moon (August 31); the intensity of the relationship between both measurements was analyzed by applying the correlation analysis. Figure 12 displays the five pairs of observed index values coming with each used method, and there was no defined pattern or trend. A correlation analysis based on observed values of abundance indexes produced an estimate of the Pearson coefficient, $\hat{r}$= -0.57 with p= 0.32, which was non-significant statistically.

Discussion

Choosing the appropriate sampling method is an essential step in the research design, moreover, in the context of medium to long-term programs for monitoring and conservation purposes. Overall, based on our study, we contend that the choice of a sampling method to quantify the abundance of postlarvae and juvenile fish in coral reef habitats requires taking into account multiple factors such as selectivity of the gear, seasonality in abundance, the behavior of the species and their early stages, as well the available resources, e.g., personnel, equipment, and materials. According to our results, the three methods we used proven to be useful to obtain data on the abundance and diversity of postlarvae and juveniles in the reef lagoon. However, our results exhibited remarkable differences between the two sampling periods (March 2019 and August-September 2019) regarding both the number and size/stage of postlarvae and juvenile fish caught, and the assemblage of fish species and families collected. The latter allowed us to evaluate how varied the outcomes and performance of the distinct sampling methods we used at different levels of abundance and diversity. As a first point, it must be noted that the trawling net was an effective method for sampling late juveniles of fish, which settled to benthic habitats during previous new moon events, two or three months before the current new moon. For this reason, and due to their higher catches, we halted the use of this sampling method for the second sampling period. This gear is suitable for studies needing additional analysis on the captured specimens, such as measuring the size and weight of individuals, condition factor, stomach contents, otolith reading to determine age (Peñailillo et al. 1996; Marín et al. 2010; Pardo, 2017) and its isotopic chemical composition for connectivity studies (Herzka, 2005; Medina and Herranz, 2014).

Unsurprisingly, we found that each sampling method had different outcomes in terms of quantity and quality. The number of individuals caught varied notably between WCC collectors and video recording or the trawl net (Figs. 5, 6, 9, 10). We observed the same in the values of diversity indexes. However, when we considered together the two sampling periods, it can be noted that the daily abundance indexes with both methods, WCC, and video recording, followed a similar pattern around the new moon, with their maximum value achieved -1 to 1 or 2 days after the new moon.

The simultaneous use of the three sampling methods provided a broader picture of the number of postlarvae and juvenile fish species at the local scale within days around the new moon. The same widened view resulted when several gears were used in a survey conducted in the nearby area of Bacalar Chico (Vásquez-Yeomans et al., 2011). Similarly, several authors reported better catches of fish larvae and postlarvae during new moon periods (Hernández y Shaw, 2003; Yam Poot, 2013; Solís-Mena, 2018).

If only the WCC collectors were used, several species could be excluded from the recorded list; for example, the March sample would have excluded the 50 species registered with the remaining two methods combined. Likewise, using only the trawl net or video recording would have meant reductions of 29 and 12 species, respectively, from the total registered (Fig. 7). Such differences were more noticeable in the sampling conducted in August-September when there was a generalized increase in abundance; in that case, if using only WCC, we would have omitted the recording of 29 fish species that were detected solely in video recording (Fig. 11).

Alternatively, these exclusions of species due to using a single sampling method instead of a combination of methods should be evaluated against the monitoring objectives. Reduction in the number of recorded species considerably affects biodiversity studies, but its effect diminishes when the sampling is focused on a select group of species captured with the chosen method.

Another issue linked to using a single method is the omission of selected fish species of commercial value, such as fish from the families Lutjanidae (*Ocyurus chrysurus, Lutjanus synagris*) and Serranidae. Moreover, species of ecological importance such as fish from the Scaridae family (*Scarus taeniopterus, S. coeruleus, S. iseri, Sparisoma aurofrenatum, S. viride, S. atomarium*, and *S. frondosum*) and lionfish (*Pterois* spp) could also be excluded.

Our survey found that different ranges of sizes and stages were collected among the methods. Thus, the trawling net captured specimens originated from previous recruitment during earlier new moon events, two or three months before the current new moon phase. Therefore, it is inappropriate to compare the trawl net and WCC data since the latter gear captures reflect mostly recruitment events during the current moon. Videorecording detected postlarvae and juveniles from the most recent recruitment events, including the current new moon (sampling period) and also previous new moon events and adult fish. In this work, adults or late juveniles captured with the trawl net or detected in the video recording were not included in the list of species nor subsequent analyses. It is worth mentioning that there were differences in the stages of specimens of the same species captured among the different methods. For instance, *Canthigaster rostrata* was registered in all gears during March. Specimens collected with WCC measured between 13 and 17 mm of standard length (SL), while those caught with the trawling net measured between 40 to 45 mm SL and those detected on video recording were adults with an average size of ~ 55 mm SL. In March, a species of commercial value *Lutjanus analis* collected with the trawling net had sizes from 90 to 100 mm SL and was also detected in video with an average of 150 mm SL. In August, *Thalassoma bifasciatum* was captured with WCCs with 28 mm SL, and specimens ranging from 100 to 120 mm SL were seen on video recording. In March and August-September, *Monacanthus tuckeri* appeared in WCCs with sizes between 16 to 22 mm SL, while the specimen captured with the trawling net measured 34 mm SL. Overall, the collectors WCC tended to capture the smaller fish and earlier stages, corresponding to the current new moon's settlement.

The "in situ" review of the natural habitat through video recording with SCUBA diving, which does not capture any fish, was the method that registered the largest number of fish and distinct species. This method also yielded the broadest size range, from newly settled individuals of recent entry during the current new moon to juveniles and adults from previous new moon events, one or two months before. This method was relatively similar to that used by Morales-Aranda et al. (2011) in Mahahual, Xahuaychol, and the Arrecifes de Xcalak National Park (PNAX) during samplings in 2010 to characterize the reef fish structure (including all the life stages); obtaining for Xcalak a total of 4,704 individuals of reef fish belonging to 78 species in 28 families and 42 genera. The most abundant species were: *Cleptius parrae* (755 ind, 16%), *Thalassoma bifasciatum* (687 ind, 15%), *Acanthurus coeruleus* (289 ind, 6%), *Haemulon carbonarium* (256 ind, 5%), and *Stegastes partitus* (237org, 5%).

This method presented complications related to species identification and the counting of fish that could affect the abundance estimation. These issues were also mentioned by Sabido-Itzá et al. (2019). However, we were able to register cryptic species of the Gobiidae and Labrisomidae families since the examination of numerous videos allowed us to observe their movement in the sandy and coral substrate, as they usually occupy the complex structure of the natural habitat. Considering the multiple aspects of efficiency of capture, size of catches, sampling effort, gear selectivity, sample processing, weather dependency, general costs, we could evaluate which of the three methods would be more convenient to apply according to particular research objectives. In Table XI, we present an account of the advantages and disadvantages of each sampling method. Indeed, the sampling method's selection depends also on the available budget, i.e., the resources needed to cover the expenses due to personnel, equipment, and materials. Finally, based on our results, we consider it highly recommended to use an additional sampling method periodically to obtain a fuller picture of the entire assemblage of fish species and their early stages inhabiting our study area.

Even though we conducted sampling in the same area (reef lagoon), each method's results exhibited different total abundance values, species composition –with a small overlap in recorded species, and the size range of the same species. It should be noted that the two sampling periods corresponded to contrasting scenarios in the abundance level of fish postlarvae and juvenile. In March, when we used three sampling methods, it was a period of low abundance, which coincides with the seasonal variation of larval abundance reported by Vásquez-Yeomans and Richards (1999); in contrast, August-September represented a period of moderate to high abundance, with only two sampling methods used. We could expect that each sampling method would have a different response in terms of its capture capacity or efficiency under such conditions.
Between the two periods, there were visible differences in the total catch, abundance index, and composition (diversity) of registered species with the WCC collectors. In March, WCC stations had a total catch of eight individuals, an abundance index of 0.05 $ind \cdot collector^{-1}$ and four species, the lowest values in the historical series of abundance indices started in 2004-2005 (Yam Poot, 2013), an effort that continued until 2019 (Figs. 5 and 9). The low catch observed at WCC stations deployed in Xcalak in March 2019 also occurred in Bacalar Chico Marine Reserve (Belize), a relatively close MPA (Lourdes Vásquez-Yeomans pers. Comm., 2019). Comparing the results of March 2019 to those of the previous sampling in March 2014, we found that the total catch of 63

individuals in 2014 was higher than the total catch of 8 in 2019. From the species present in 2014, only three species (*Monacanthus tuckeri*, *M*. *ciliatus*, and *Canthigaster rostrata*) were also caught in March 2019. In the historical series of samples with WCC in the MAR region, only in 2014, there was sampling in March, since the regional monitoring is conducted regularly in August-September (Yam-Poot, 2013 and Vásquez-Yeomans et al. 2020). During August-September, we captured 89 individuals of 19 species in the same WCC stations, with an abundance index of 0.7410.05 $ind \cdot collector^{-1}$; hence the abundance increased 14.8 times, toward similar levels we found in previous records.

With video recording, in March 2019, a greater diversity (36 species), a lesser total catch of 1,836 individuals, and an abundance index of 32.21 $ind \cdot site^{-1}$ were observed, compared to August-September 2019 when the diversity was lower (33 species), but total catch increased to 2,685 individuals as did the abundance index, 89.5 $ind \cdot site^{-1}$. Likely, this three-fold difference in abundance was partially due to the prevailing environmental conditions during each sampling period. In March 2019, there was a higher arrival of sargassum in the reef lagoon, whose accumulation and decomposition releases leachates modifying the water's physical-chemical properties. Furthermore, the intense SE winds and rain in March 2019 led to cancel the sampling for two days. In contrast, during August-September-2019, the arrival of sargassum decreased. In the satellite images, the amount of sargassum in March 2019 was higher than in August-September (Espinosa et al. 2020); this coincided with our observations (no rain) during the sampling period and further information provided by the PNAX personnel. Another factor that could be influential in the magnitude of the catch is the variation (direction and intensity) of the marine currents near the study area, which can favor or restrain the entry of postlarvae to the reef lagoon.

Regarding the relationship between the abundance indices from distinct sampling methods, we did not have sufficient data to fit a quantitative model (Fig. 12). The total average values of two sampling methods, WCC and video recording, followed the same increasing trend between sampling periods, with the WCC collectors achieving an abundance index 14.8 times, and with video recording a value 2.8 times greater in August-September 2019 than in March 2019. Thus, two distinct methods produced the same signal of change in abundance of fish postlarvae and juvenile in the lagoon reef.

Conclusions

Since each sampling method has advantages and disadvantages, their use will depend on the research objectives and the monitoring program's purpose and scope. Based on our results, we concluded that using the three sampling methods simultaneously allows achieving a fuller picture of the fish community in terms of species and sizes of early stages of fish present in the study area (reef lagoon). The latter is critical to the monitoring of fish recruitment and to evaluate the functioning of nursery areas. However, it is practically difficult to implement a program based on multiple methods due to the budget limitation and the human effort needed to develop this research in the medium or long term. As a pragmatic guide, it is imperative to evaluate the costs in resources, time, and labor that each method requires, together with inherent properties of the sampling gear: species and stage selectivity; as well as the statistical aspects of the variability of the data and sample size –the latter not addressed here.

The present work provides elements for evaluating three sampling methods of postlarvae and juvenile fish with potential application for a monitoring program in reef areas. In the MAR region, since 2013, the WCC collectors have been used to estimate recruitment indices by family and selected species of fish in a network of Marine Protected Areas (MPAs) (Yam Poot, 2013; Malca et al. 2015; Vásquez-Yeomans et al. 2017, 2020). This work presented the advantages and disadvantages of the WCC collectors and two other methods in terms of the number of species, with a reduced range of sizes corresponding to the early stages of recently recruited fish. The WCC captures specimens that enter during the new moon period. The use of WCC spends a reduced time for sampling operations and sample processing in the laboratory. These characteristics of WCC make them a preferred option to be selected as a sampling method for a medium and long-term monitoring program; due to its low cost and ease of implementing to a network of stations of AMPs. However, due to their high selectivity, it is recommended periodically to complement WCC with another sampling method, i.e., video recording. The trawling net is a useful method when it is required to collect specimens for additional analysis such as age determination (otoliths), trophic webs (stomach content), and condition factor.

The temporal variability in the recruitment of fish was evident in the present work. During August-September 2019, the number of postlarvae and juveniles of fish increased notably in both WCC and video recording on reef patches. The difference was notable when the average values of the indexes registered in March-2019 were compared with the values of August-September-2019. Additional research efforts are required to determine the causal factors for the observed differences.

Regarding the diversity measurements, it is noted that the Shannon index reached values > 2 for both sampling periods and both methods: video recording and WCC; this would be indicative of a species diversity that tends to be moderate to high. The Simpson index represents the probability that two randomly selected individuals in a given habitat were the same species had values ≈ 1 for each of the sampling methods. This value indicated a greater possibility of the dominance of one or some species in the habitat. The consequence above mentioned needs to be corroborated by examining dominant families in each sampling period and gear. The families Hemulidae and Lutjanidae dominated in the trawling net, and the families Labridae, Scaridae, and Hemulidae were more abundant in video recording and WCC stations. According to the Jaccard similarity index, the methods exhibiting the most remarkable similarity were the trawling net and video recording since they shared 10 species in common during March sampling. For the August-September sampling, even though the similarity value between the two methods used was higher than the value during March, it was still lower than the similarity value between video recording and the trawl net, which allowed us to define that the sampling methods that shared the most species in common were video recording and trawling net.

Acknowledgments

To the personnel of PNAX, CONANP, Lic. Orozco Ojeda, Biol. C. Ruiz Lozano and the student Y. Gómez. Also the Biol. M. Sabido /IBANQROO-SEMA. To Mrs. O. Salazar Aguilar, N. Salazar Young and Ms. C. Olvera from Xcalak town. To H. Weissenberger from ECOSUR. MAR Fund-FMCN funded the project "Participatory monitoring of reef fish recruitment: Connectivity indicator in the Mesoamerican Reef" [A1804007-MEX10019]. To CONACyT for the scholarship number 001283. FID-784, ECOSUR internal research program also provided funding.

References

Albatineh, A. N., & Niewiadomska-Bugaj, M., 2011. Correcting Jaccard and other similarity indices for chance agreement in cluster analysis. Advances in Data Analysis and Classification, 5(3), 179-200.

Albins, M. A., & Hixon, M. A., 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology Progress Series*, 367, 233-238.

Almada-Villela, P., Mcfield, M., Kramer, P., Kramer, P. R., & Arias-Gonzalez, E., 2002. Status of coral reefs of Mesoamerica-Mexico, Belize, Guatemala, Honduras, Nicaragua and El Salvador. Status of coral reefs of the world, 303-324.

Álvarez-Cadena, J. N., Ordóñez-López, U., Almaral-Mendivil, A. R., Ornelas-Roa, M., & Uicab-Sabido, A., 2007. Larvas de peces del litoral arrecifal del norte de Quintana Roo, Mar Caribe de México. *Hidrobiológica*, 17(2), 139-150.

Alvarez-Filip, L., Estrada-Saldívar, N., Pérez-Cervantes, E., Molina-Hernández, A., & González-Barrios, F. J., 2019. A rapid spread of the stony coral tissue loss disease outbreak in the Mexican Caribbean. *PeerJ*, 7, e8069.

Andrade, C.A., & Barton, E.D., 2000. Eddy development and motion in the Caribbean Sea. J. *Geophys. Res*. 105 (C11), 26191–26201.

Andersson, A.J., Venn, A.A., Pendleton, L., Brathwaite, A., Camp, E.F., Cooley, S., Gledhill, D., Koch, M., Maliki, S., & Manfrino, C., 2019. Ecological and socioeconomic strategies to sustain Caribbean coral reefs in world. *Regional Studies in Marine Science*, 29, 100677.

Arrivillaga, A., & Baltz, D., 1999. Comparison of fishes and macroinvertebrates on seagrass and bare-sand sites on Guatemala's Atlantic coast. *Bulletin of Marine Science*, 65(2): 301–31

Ayala-Campos M.Y., 2014. Riqueza y abundancia en el reclutamiento de post-larvas de peces arrecifales del Caribe Mexicano en zonas aledañas al Parque Ecológico Xcaret, Quintana Roo, México. Tesis de Maestría en Ciencias. Universidad Nacional Autónoma de México.

Badan, A., Candela, J., Sheinbaum, J., & Ochoa, J., 2005. Upper-layer circulation in the approaches to Yucatan Channel. Circulation in the Gulf of Mexico: Observations and Models (*Geophysical Monograph series*), AGU, vol. 161, pp. 57–69.

Betancourt, C. A., & González-Sansón, G., 2011. Composición de la ictiofauna costera de Ciudad de la Habana y evaluación preliminar de los factores que la determinan. *Revista de Investigaciones Marinas,* 28(1), 43-56.

Browman, H. I., 2014. Commemorating 100 years since Hjort's 1914 treatise on fluctuations in the great fisheries of northern Europe: where we have been, where we are, and where we are going. – ICES *Journal of Marine Science*, 71: 1989–1992.

Caley, M. J., Carr, M. H., Hixon, M. A., Hughes, T. P., Jones, G. P., & Menge, B. A.,1996. Recruitment and the local dynamics of open marine populations. Annual Review of Ecology and Systematics, 27(1), 477-500.

Carr, M. & C. Sims., 2006. Recruitment. In: The ecology marine fishes: California and Adjacent Waters. LG Allen, DJ Pondella, and MH Horn, eds. University of California Press, p. 411-427.

Carrillo, L., Johns, E.M., Smith, R.H., Lamkin, J.T., & Largier, J.L. 2015., Pathways and hydrography in the Mesoamerican Barrier Reef System. Part 1: Circulation. Cont. Shelf Res. 109, 164– 176. http://dx.doi.org/10.1016/j.csr.2015.09.014.

Carrillo, L., Johns, E.M., Smith, R.H., Lamkin, J.T., & Largier, J.L., 2016. Pathways and hydrography in the Mesoamerican Barrier Reef System. System Part 2: Water masses and thermohaline structure

Cobián Rojas, D., Schmitter-Soto, J. J., Aguilar-Perera, A., Aguilar Betancourt, C. M., Ruiz-Zárate, M. Á., González Sansón, G., & Caballero Aragón, H., 2018. Diversidad de las comunidades de peces en dos áreas marinas protegidas del Caribe y su relación con el pez león. *Revista de Biología Tropical*, 66(1), 189-203.

D'Alessandro, E., Sponaugle, S., & Lee, T., 2007. Patterns and processes of larval fish supply to the coral reefs of the upper Florida Keys. *Marine Ecology Progress Series*, *331*, 85-100.

Diario Oficial de la Federación, SEGOB, 27 de noviembre de 2000. Recuperado de: http://www.dof.gob.mx/nota_detalle.php?codigo=2064038&fecha=27/11/2000#:~:text= DOF%3A%2027%2F11%2F2000,17%2C949%2D45%2D62.025%20hect%C3%A1reas.

Eggleston, D.B., 1995. Recruitment of Nassau grouper, *Epinephelus striatus*: post-settlement abundance, microhabitat features, and ontogenetic diet shifts. *Marine Ecology Progress* Series 124: 9-22.

Espinosa, L. A., & Ng, J. J. L., 2020. El riesgo del sargazo para la economía y turismo de Quintana Roo y México. Documento de trabajo, *20*(02), 2.

Gudiel-Corona, V. M., 2016. Diversidad de poslarvas de peces en arrecifes coralinos y pastos marinos del Refugio de Vida Silvestre Punta de Manabique, Caribe de Guatemala. Tesis de licenciatura. Universidad de San Carlos de Guatemala. Facultad de Ciencias Quìmicas y Farmacia. Guatemala 69 pp.

Haddon, M., 2011. Modelling and quantitative methods in fisheries. CRC Press. Boca Raton, Fla.
USA. 2nd ed. 465 pp.

Hernandez, F. J., & Shaw, R. F., 2003. Comparison of plankton net and light trap methodologies for sampling larval and juvenile fishes at offshore petroleum platforms and a coastal jetty off Louisiana. In American Fisheries Society Symposium (pp. 15-38). American Fisheries Society

Herzka, S., 2005. Assessing connectivity of estuarine fishes based on stable isotope ratio analysis. *Estuarine, Coastal and Shelf Science* 64(1): 58-69

Hjort, J., 1914. Fluctuations in the great fisheries of the northern Europe viewed in the light of biological research. RAPP. P. V. Reun. Cons. Perm. Int. Explor.Mer. 20:

Houde, E. D., 2008. Emerging from Hjort's shadow. J. Northw. Atl. Fish. Sci., 41: 53–70. doi:10.2960/J.v41.m634

Humann P., & Deloach N., 2014. Reef Fish Identification: Florida, Caribbean, Bahamas. 3rd New World Pub. 239 p

Ishihara, T., & Tachihara, K., 2011. Pelagic Larval Duration and Settlement Size of Apogonidae, Labridae, Scaridae, and Tripterygiidae Species in a Coral Lagoon of Okinawa Island, Southern Japan1. *Pacific Science*, 65(1), 87-93.

Kobara S., Heyman W. D., Pittman S.J. & Nemeth R. S., 2013. Biogeography of transient reef-fish spawning aggregations in the Caribbean: A synthesis for future research and management. Oceanography and Marine Biology. 51 281-326

Kritzer J.P., & Sale P.F., 2006. Marine Metapopulations. *Elsevier Academic Press*. USA 544pp

Lang, J., Alcolado P, Carricart-Ganivet JP, Chiappone M, Curran A, Dustan P, Gaudian G, Geraldes F, Gittings S, Smith R, Tunnell W, Wiener J. 1998. Status of coral reefs in the northern areas of the wider Caribbean, 123-134 pp. In: Wilkinson C (ed) Status of coral reefs of the world. Australian Institute of Marine Science.

Leis, J.M., 1986. Vertical and horizontal distribution of fish larvae near coral reefs at Lizard Island.
Great Barrier Reef. *Marine Biology*. 90:505-516

Leis, J. M., 1991. The pelagic stage of reef fishes: the larval biology of coral reef fishes. In: The Ecology of Fishes of Coral Reefs. Academic Press, San Diego. p. 183-227.

Leis, J.M., 2015. Is dispersal of larval reef fishes passive? In: Ecology of Fishes on Coral Reefs. Cambridge, pp. 223–226. https://doi.org/10.1017/CBO9781316105412.025.

Levin, P. S., 1994. Fine-scale temporal variation in recruitment of a temperature demersal fish: importance of settlement versus post-settlement loss. *Oecología* 97: 124-133.

Leyva-Cruz, E., Vásquez-Yeomans, L., Carrillo, L., & Valdez-Moreno, M., 2016. Identifying pelagic fish eggs in the southeast Yucatan Peninsula using DNA barcodes. *Genome*, *59*(12), 1117-1129.

López-Jiménez, L., 2016. Conservación en el Parque Nacional Arrecifes de Xcalak. En: Teoría y Praxis 21: 9-30

Malca, E., Vásquez-Yeomans, L., González, C., Gudiel-Corona, V., Sosa-Cordero, F. E., Carrillo, L., & González, M. J., 2015. Capacity building in marine protected areas and connectivity in the Mesoamerican Barrier Reef System: Larval fish recruitment. In *Proceedings of the Gulf and Caribbean Fisheries Institute* (Vol. 67, pp. 277-283).

Marín, B., Allen, T., Balza, M., Tavares, R., & Barrios, A., 2010 Determinación del crecimiento post-larvario del Tinícalo *Xenomelaniris brasiliensis* (Quoy y Gaimard) (Pisces: Atherinidae) utilizando el análisis de sus otolitos. Instituto Oceanográfico de Venezuela. 49 (1): 17-22

Martínez, S., Carrillo, L., & Marinone, S. G., 2019. Potential connectivity between marine protected areas in the Mesoamerican Reef for two species of virtual fish larvae: *Lutjanus analis* and *Epinephelus striatus*. *Ecological Indicators*, *102*, 10-20.

Medina, N.F., & Herranz, V.M., 2014. Uso de isótopos estables en investigaciones en ecología. Ambiociencias, 11: 25-33.

Morales Aranda, A. A., Soto, S., & Ganivet, C., 2011. Variación espacio-temporal de los peces arrecifales de la costa sur de Quintana Roo. Tesis de Maestría. El Colegio de la Frontera Sur, unidad Chetumal, Quintana Roo, 162 pp

Muhling, B. A., Smith, R. H., Vásquez–Yeomans, L., Lamkin, J. T., Johns, E. M., Carrillo, L., ... & Malca, E., 2013. Larval fish assemblages and mesoscale oceanographic structure along the Mesoamerican Barrier Reef System. *Fisheries Oceanography*, 22(5), 409-428.

Nichols, C.R., & Williams, R.G., 2009. Encyclopedia of Marine Science. Facts on File, USA, p. 626.

Ortega, J. R., & García, J. R., 2002. Caracterización del ictioplancton a través del Canal de la Mona, con énfasis en familias arrecifales. Tesis Doctoral, Universidad de Puerto Rico, Recinto Universitario de Mayagüez.

Pardo, A., Dos Santos, A., Laaz, E., Preciado, M., Ramos, E., Panchana, R., & Jarrín, J. M., 2017. Estudio para evaluar el uso de anillos anuales de otolitos para estimar la edad de Merluza (*Merluccius gayi*) capturadas en pesquerías Ecuatorianas. *Revista Tecnológica-ESPOL*, 30(2).

Paris, C., Chérubin, L., & Cowen, R., 2007. Surfing, spinning, or diving from reef to reef: effects on population connectivity. *Marine Ecology Progress Series*. 347, 285–300. https://doi. org/10.3354/meps06985.

Paris, C. B., Cowen, R. K., Claro, R., & Lindeman, K. C., 2005. Larval transport pathways from *Cuban snapper* (Lutjanidae) spawning aggregations based on biophysical modeling. *Marine Ecology Progress Series*. *296*, 93-106

Peñailillo P., Jessica, & Araya C., Miguel., 1996. Momento de formación y periodicidad de los microincrementos de crecimiento en otolitos de larvas de pejerrey (*Austromenidia regia*) mantenidas en laboratorio. Investigaciones marinas. 24, 31- 38

Pile, A. J., Lipcius, R. N., Van Montfrans, J., & Orth, R. J., 1996. Density-dependent settler-recruit- juvenile relationships in blue crabs. *Oceanographic Literature Review*, 5(44), 496.

Planes, S., Levefre, A., Legendre, P., & Galzin, R., 1993. Spatio-temporal variability in fish recruitment to a coral reef (Moorea, French Polynesia). *Coral Reefs*, *12*(2), 105-113.

R Core Team., 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: https://www.R-project.org/.

Reyes-Bonilla, H., Álvarez del Castillo-Cárdenas, P. A., Calderón-Aguilera, L. E., Erosa-Ricárdez, C. E., Fernández-Rivera Melo, F.J., Frausto, T.C., Luna-Salguero, B. M. ., Moreno-Sánchez, X. G., Mozqueda-Torres, M. C., Norzagaray-López ,C. O., & Petatán-Ramírez, D., 2014.
Servicios ambientales de arrecifes coralinos: El caso del Parque Nacional Cabo Pulmo, B.
C. S. In: Urciaga-García, J. I. (ed.). Desarrollo Regional en Baja California Sur: Una perspectiva de los Servicios Ecosistémicos. Universidad Autónoma de Baja California Sur, La Paz. pp. 49- 78.

Richards, W.J. (Ed.)., 2006. Early stages of Atlantic fishes. An identification guide for the Western Central North Atlantic. CRC Taylor y Francis, Boca Ratón, Florida (l-ll): 1-2581 p.

Rodríguez-Martínez, R.E., van Tussenbroek, B.I., Jordán-Dahlgren, E., 2016. Afluencia masiva de sargazo pelágico a la costa del Caribe mexicano (2014–2015). In: García-Mendoza, E., Quijano-Scheggia, S.I., Olivos-Ortiz, A., Núñez-Vázquez, E.J. (Eds.), Florecimientos Algales nocivos en México. CICESE, Ensenada, México (ISBN: 352–365.978-607-95688-5-6).

Rojas, P.M., 2014. Diel variation in the vertical distribution of fish larvae forced by upwelling filaments off Punta Angamos (northern Chile). *Latin American Journal of Aquatic Research*.142: 401-417

Research Planning, Inc., (RPI), 2003. Informe Final de la Consultoría Internacional SAM Análisis crítico sobre las agregaciones reproductivas Contrato #TF-027739.

Sabido-Itzá, M. M., Castro-Pérez, J. M., Nava-Martínez, G., Medina-Quej, A., & Hernández-Millán, M. B., 2019. Los censos visuales en transectos de banda subestiman la abundancia del pez león Pterois spp. en arrecifes coralinos del Caribe. *Revista de biología marina y oceanografía*, 54(3), 329-335

Sadovy de Mitcheson, Y., 2016. Mainstreaming fish spawning aggregations into fishery management calls for a precautionary approach. *BioScience, 66*(4), 295-306

Sadovy de Mitcheson, Y., & Colin, P.L. (Eds.)., 2014. Reef Fish Spawning Aggregations: Biology, Research and Management. In: Fish and fisheries series, vol. 35, *Springer Verlag*, Berlin. Sale P.F., 2004. Connectivity, Recruitment Variation, and the Structure of Reef Fish Communities. Integr. *Comp. Biol.* 44:390-399

Solís-Mena, J.del C., 2018. Abundancia y diversidad de larvas de peces en el Parque Nacional Arrecifes de Xcalak (PNAX) usando un arte de muestreo alternativo. Tesis de licenciatura. Tecnológico Nacional de México. Instituto Tecnológico de Chetumal. 116pp

Sosa-Cordero, E., Ramírez-González, A., Olivares-Escobedo, J., Cohuó-Collí, J. A., Mercadillo-Elguero, I., & Quintal-Lizama, C., 2009. Programa de ordenamiento pesquero del Estado de Quintana Roo. 1. Pesquería de meros y especies afines. Informe Final presentado a CONAPESCA-SAGARPA. Chetumal, Quintana Roo, Mexico: El Colegio de la Frontera Sur, 110.

Steele, M. A., Malone, J. C., Findlay, A. M., Carr, M. H., & Forrester, G. E., 2002. A simple method for estimating larval supply in reef fishes and a preliminary test of population limitation by larval delivery in the kelp bass *Paralabrax clathratus*. *Marine Ecology Progress Series*, 235, 195-203.

Trujillo Millán, Ó., 2004. Reclutamiento de peces de arrecife en Isla Cerralvo y Punta Perico, BCS México. Tesis Doctoral. Instituto Politécnico Nacional. Centro Interdisciplinario de Ciencias Marinas.

Valdez-Moreno, M., Vásquez-Yeomans, L., Elías-Gutiérrez, M., Ivanova, N. V., & Hebert, P. D., 2010. Using DNA barcodes to connect adults and early life stages of marine fishes from the Yucatan Peninsula, Mexico: potential in fisheries management. *Marine and Freshwater Research*, 61(6), 655-671.

Vásquez-Yeomans, L., Ordóñez-López, U., & Sosa-Cordero, E., 1998. Fish larvae adjacent to a coral reef in the western Caribbean Sea off Mahahual, Mexico. *Bulletin of Marine Science*, 62(1), 229-245

Vásquez-Yeomans, L., & Richards, W. J., 1999. Variación estacional del ictioplancton de la Bahía de la Ascensión, Reserva de la Biosfera de Sian Ka'an (1990-1994). *Revista de biología tropical*, 197-207

Vásquez-Yeomans, L., Vega-Cendejas, M. E., Montero, J. L., & Sosa-Cordero, E., 2011. High species richness of early stages of fish in a locality of the Mesoamerican Barrier Reef System: a small-scale survey using different sampling gears. *Biodiversity and Conservation*, 20(11), 2379-2392

Vásquez-Yeomans, L., Leyva-Cruz E. & Valdez-Moreno, M., 2017. Huevos y Larvas en el ciclo de vida de los peces. *Ecofrontera*s 59: 17-18.

Vásquez Yeomans L., & Malca E., 2013. Protocolo de captura de postlarvas de peces arrecifales. Ejercicio de conectividad. http://www.marfund.org/documentosreddeconectividad/2%202013%20Jul-30%20PROTOCOLO%20LARVAS%20ECOME.pd

Vásquez-Yeomans, L., Sosa-Cordero, E., Lara, M. R., Adams, A. J., & Cohuo, J. A., 2009. Patterns of distribution and abundance of bonefish larvae *Albula spp*. (Albulidae) in the western Caribbean and adjacent areas. *Ichthyological research*, *56*(3), 266-275.

Vásquez-Yeomans, L., Malca, E., Sosa-Cordero, E., Carrillo, L., González, C., & González, M. J., 2017. Fomento de Capacidades en AMP y Conectividad en el Arrecife Mesoamericano. Ejercicios de Conectividad (ECOME) en el SAM 2013-2016. Informe final. ECOSUR. Chetumal, Quintana Roo., México. 50 pp.

Vásquez-Yeomans, L., Malca, E., Morales, S., Cohúo J.A & Yam, G., 2014. Catálogo de postlarvas y juveniles de peces del SAM. Ejercicios de Conectividad en el Mesoamericano (ECOME 1 y ECOME 2). 9 p.

Vásquez-Yeomans, L., Sosa-Cordero, E., Carrillo, L., Malca, E., & González, C., 2020. Fomento de Capacidades en AMP y Conectividad en el Arrecife Mesoamericano. Ejercicios de Conectividad (ECOME) en el SAM 2013-2020. Informe final. ECOSUR. Chetumal, Quintana Roo., México. 57 pp.

Victor, B.C., 2006. A photographic guide to the larvae of coral reef fishes. http://www.coralreeffish.com/larvae.html.

Villegas-Sánchez, C.A., Lara-Arenas, J.H., Castro-Pérez, J.M. & Arias-González, J.E., 2015. Patrones de reclutamiento de cuatro especies ícticas en hábitats de parche y cordillera del arrecife Banco Chinchorro (Caribe mexicano). *Revista Mexicana de Biodiversidad* 86: 396–405

White, J.W., Carr, M.H., Caselle, J.E., Washburn, L., Woodson, C.B., Palumbi, S.R., Carlson, P.M., Warner, R.R., Menge, B.A., Barth, J.A., & Blanchette, C.A., 2019. Connectivity, dispersal, and recruitment: Connecting benthic communities and the coastal ocean. *Oceanography* 32(3):50–59.

Williams, D. McB., 1983. Daily, Monthly and yearly variability in recruitment of a guild of coral reef fishes. *Mar. Ecol. Prog. Ser*. 10: 231-237.

Williams, D.M.C.B., 1991. Patterns and processes in the distribution of coral reef fishes. The ecology of fishes on coral reefs. *Academic Press*, San Diego. 437-474

Yam Poot, G.M., 2013. Evaluación de trampas de asentamiento de postlarvas para desarrollar índices de reclutamiento de peces marinos de importancia comercial. Tesis de Licenciatura de Biología. Instituto Tecnológico de Chetumal. Chetumal, Quintana Roo, 96 pp.

Figures 1- 12

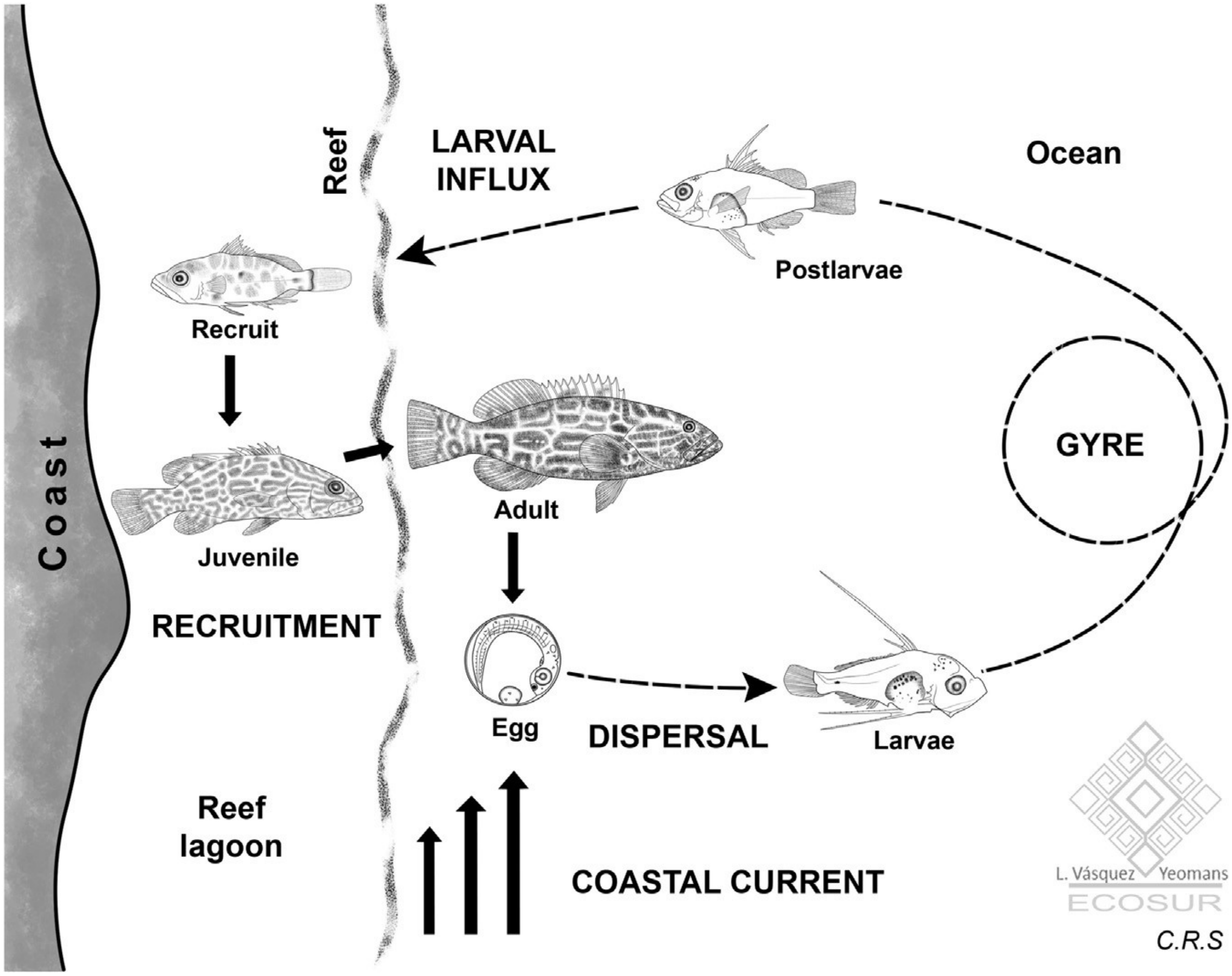

Figure.1 Example of the life cycle of *Mycteroperca bonaci*, includes reproductive adults, juveniles, and early life stages: eggs, larvae, and postlarvae, with the physical processes that influence their dispersal and subsequent return to coastal habitats where recruitment occurs. Diagram from Carrillo et al. (2017).

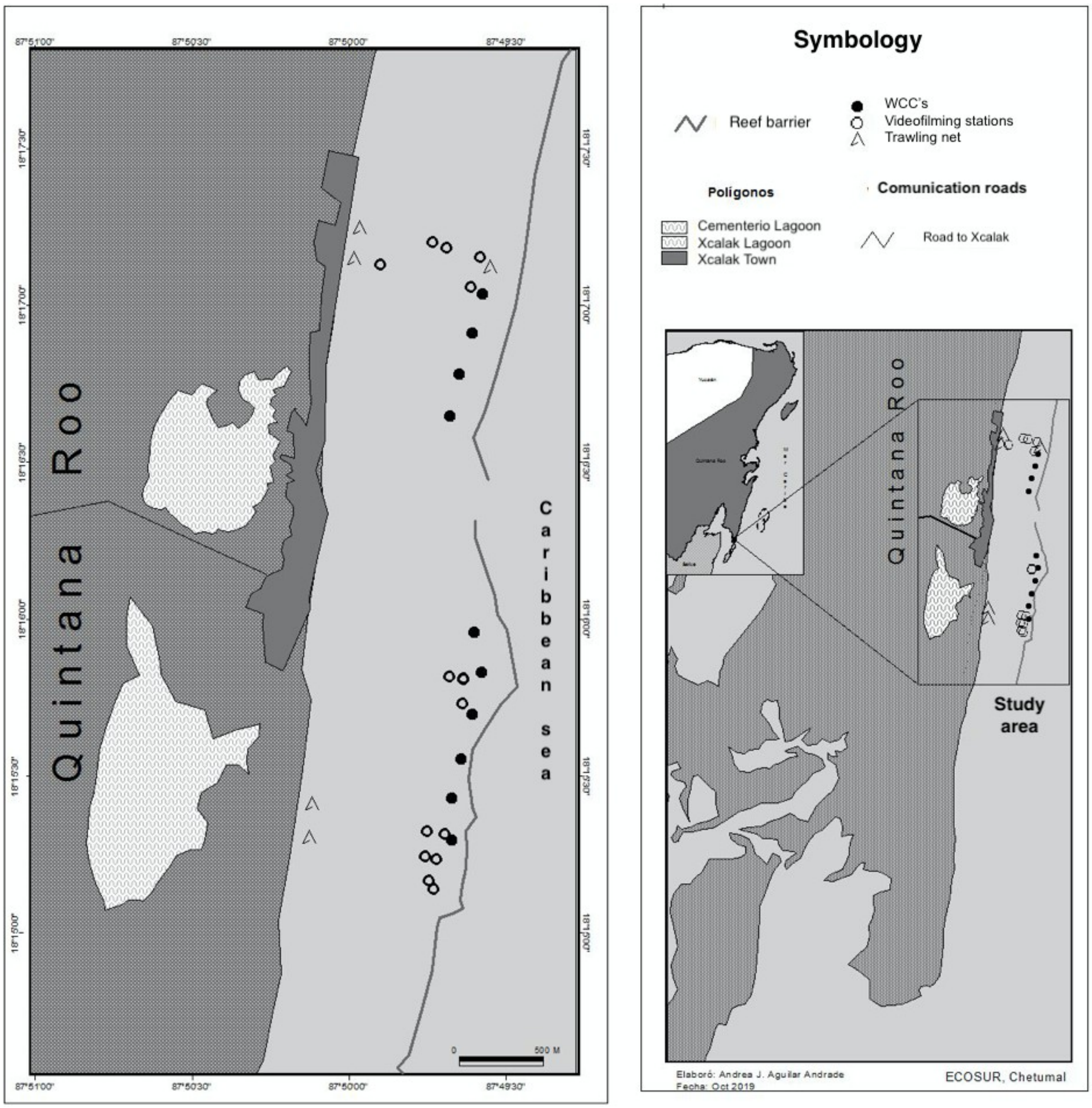

Figure 2. The study area map includes the Arrecifes de Xcalak National Park (PNAX) and the town of Xcalak.

Figure 3. Water column collector (WCC) (Vásquez-Yeomans y Malca 2012)

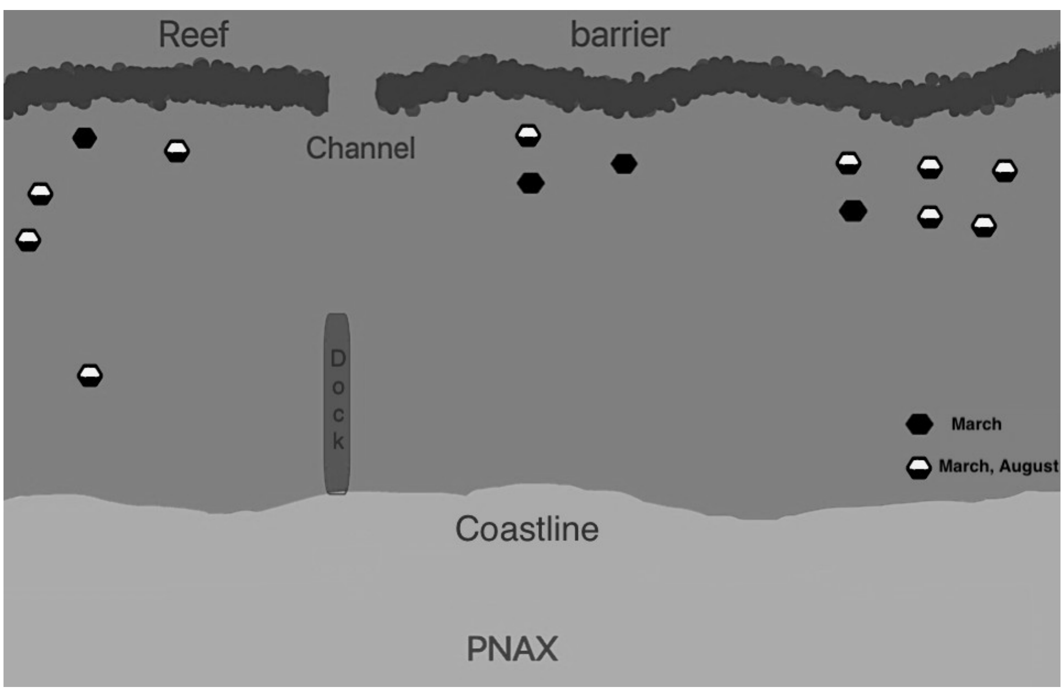

Figure 4. Schematic spatial representation of the reef lagoon showing the video-transects' location taken in March and August-September 2019. Total sampling units n=14

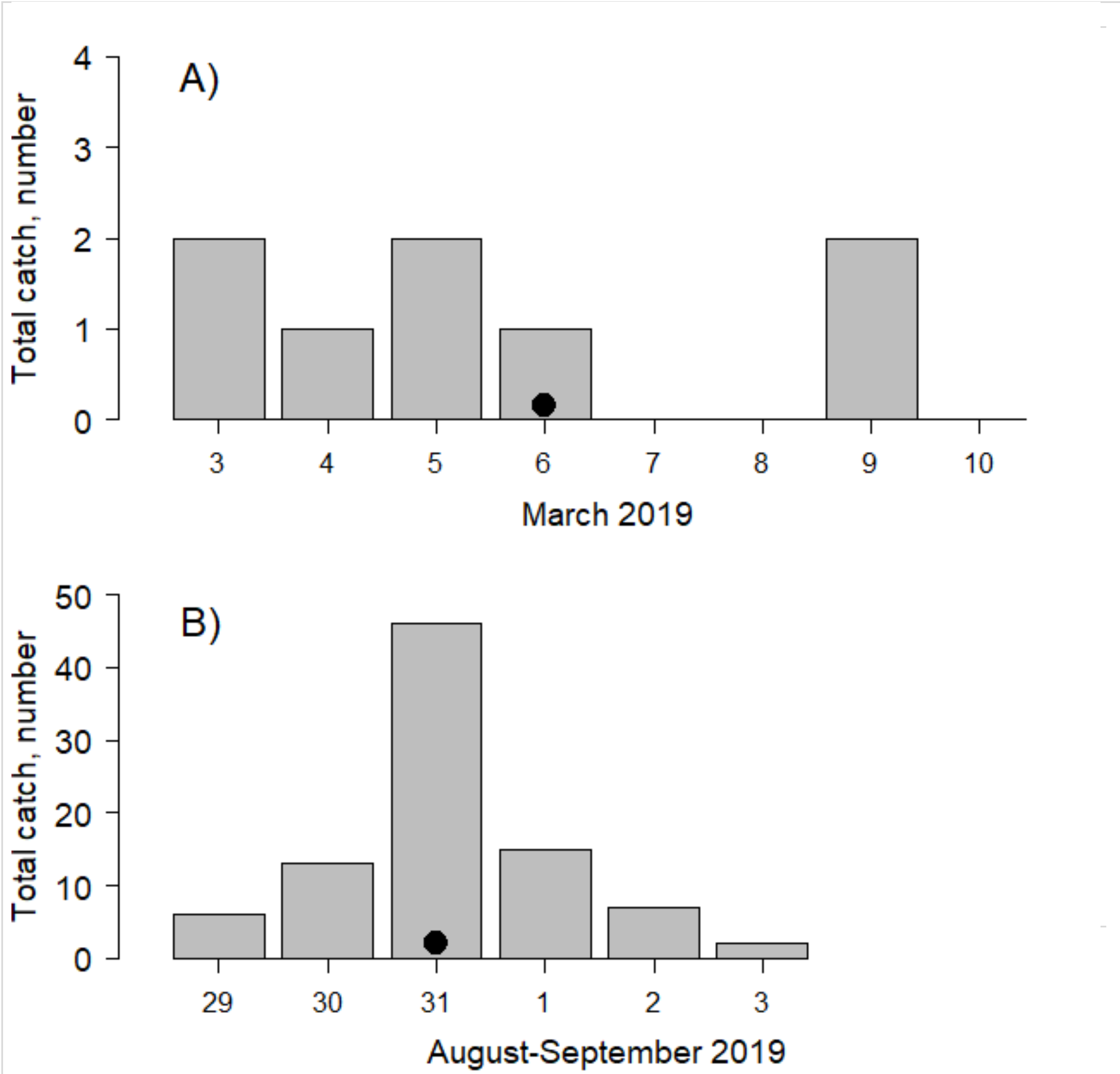

Figure 5. The total daily catch of fish postlarvae and juveniles, in the number of individuals, obtained in WCC collector stations in both sampling periods: A) March and B) August-September 2020 in Arrecifes de Xcalak National Park. The dark circle indicates the date of the new moon.

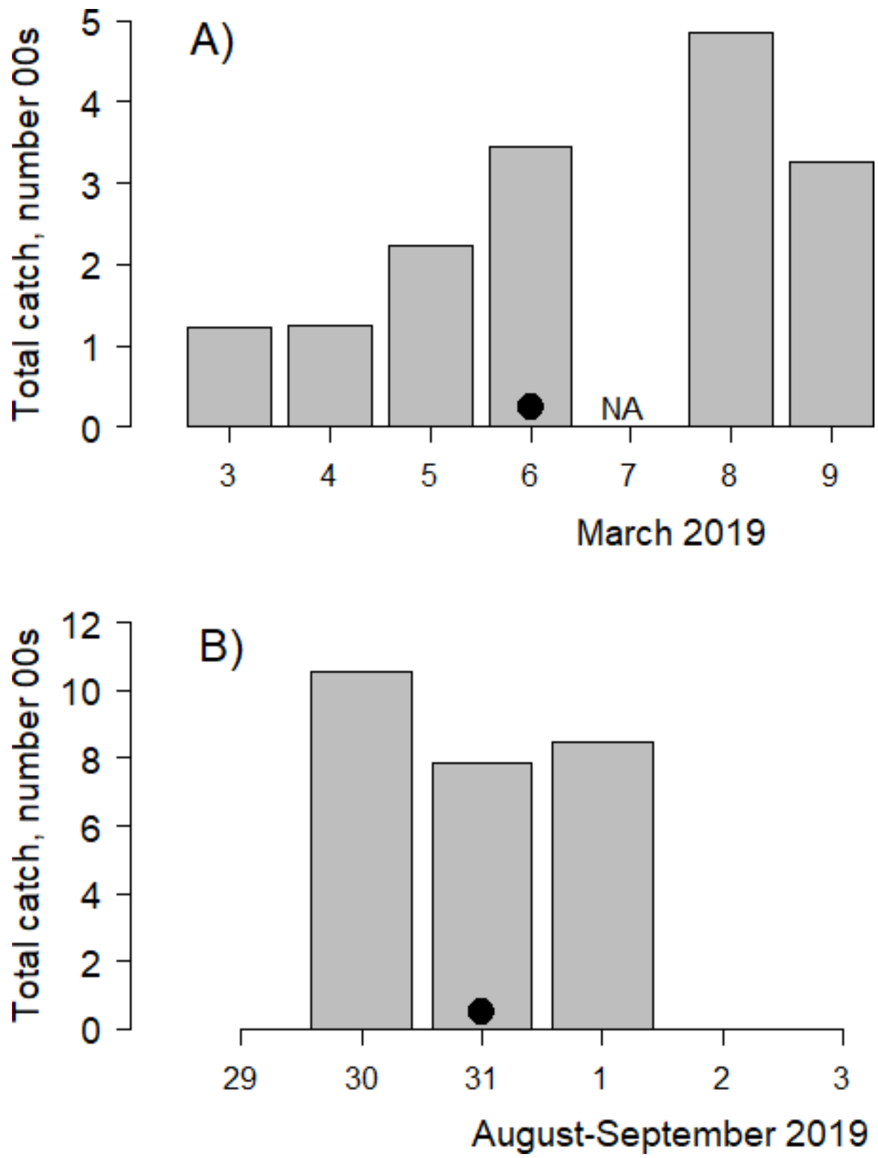

Figure 6. Daily total counts of fish postlarvae and juveniles, in the number of individuals detected by video recording made at the reef patches and coral heads of the Arrecifes de Xcalak National Park, during both periods: A) March, and B) August -September 2020. The new moon (dark circle) and the cancellation of the sampling on March 7 (NA) are indicated.

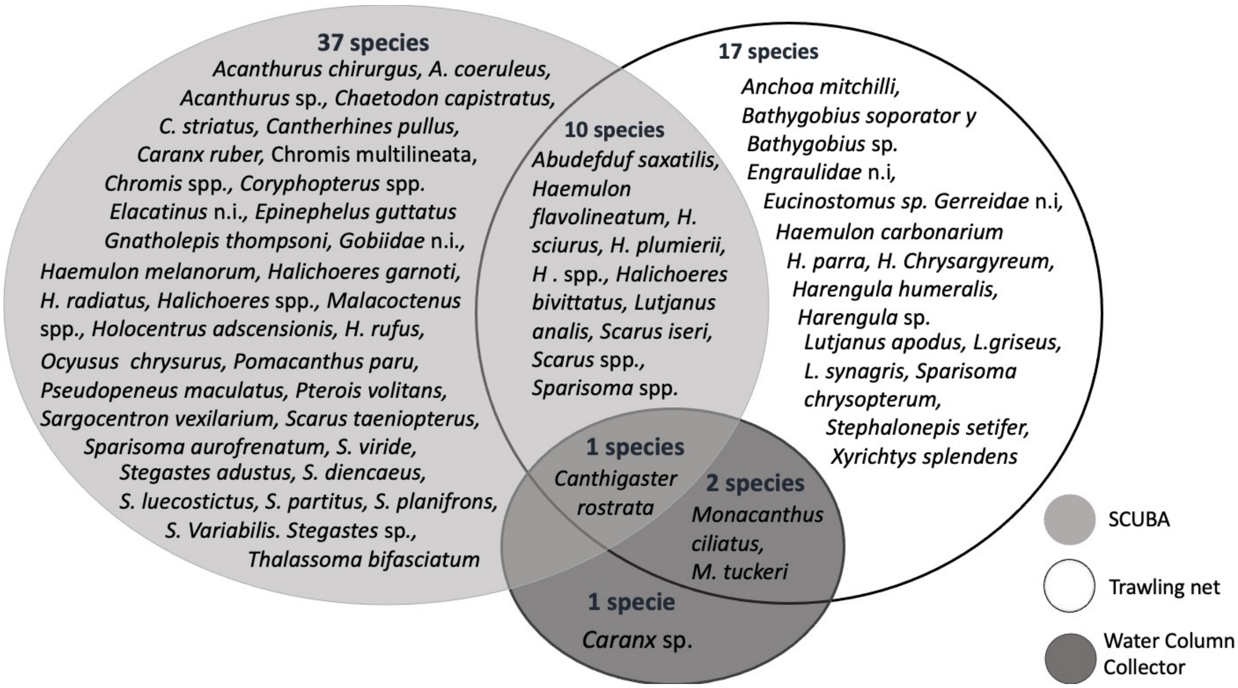

Figure 7. Venn diagrams of fish species that were recorded with each sampling method during March 2019. Total numbers by each method are indicated. N.i. = unidentified.

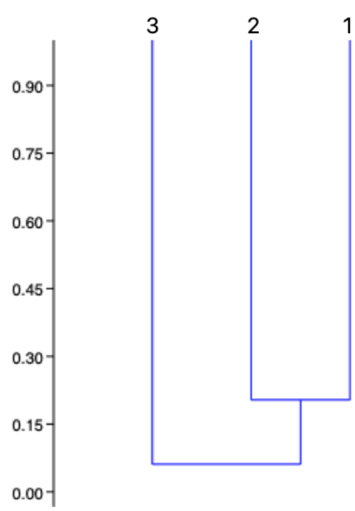

Figure 8. Dendrogram of Jaccard index values calculated with species composition data from the sampling methods used in March 2019 in Arrecifes de Xcalak National Park. The numbers represent three sampling methods: videorecording (1), trawl (2), and WCC collectors (3).

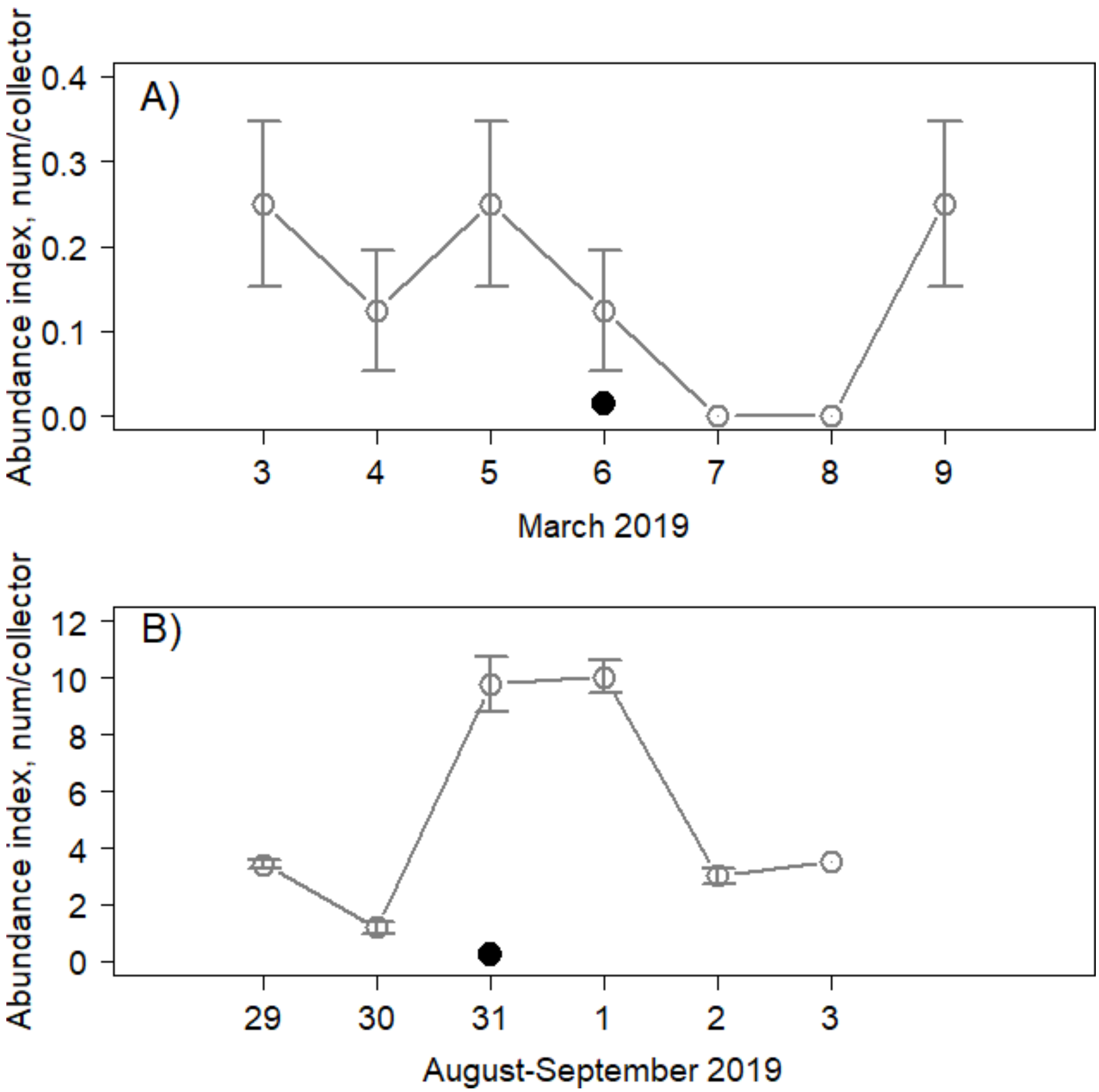

Figure 9. Daily abundance index of postlarvae and juveniles, in the number of individuals per collector, average and standard error, obtained with WCC during both periods: A) March, and B) August-September 2020. The dark circle indicates the date of the new moon.

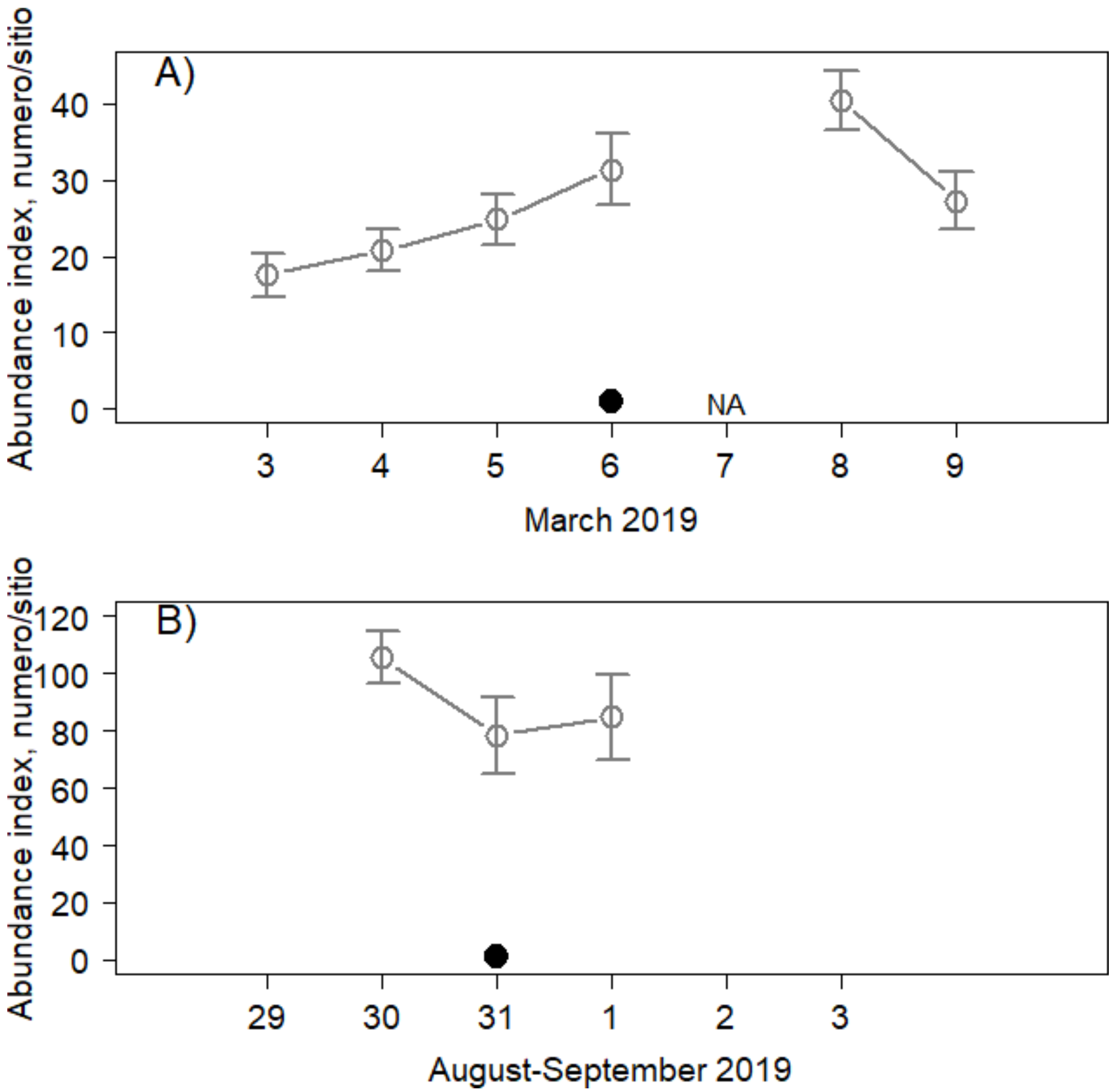

Figure 10. Daily abundance index of postlarvae and juveniles, in the number of individuals per site reviewed, average and standard error, detected by video recording during both periods: A) March, and B) August-September 2020. The new moon (dark circle) and the cancellation of the sampling on March 7 (NA) are indicated.

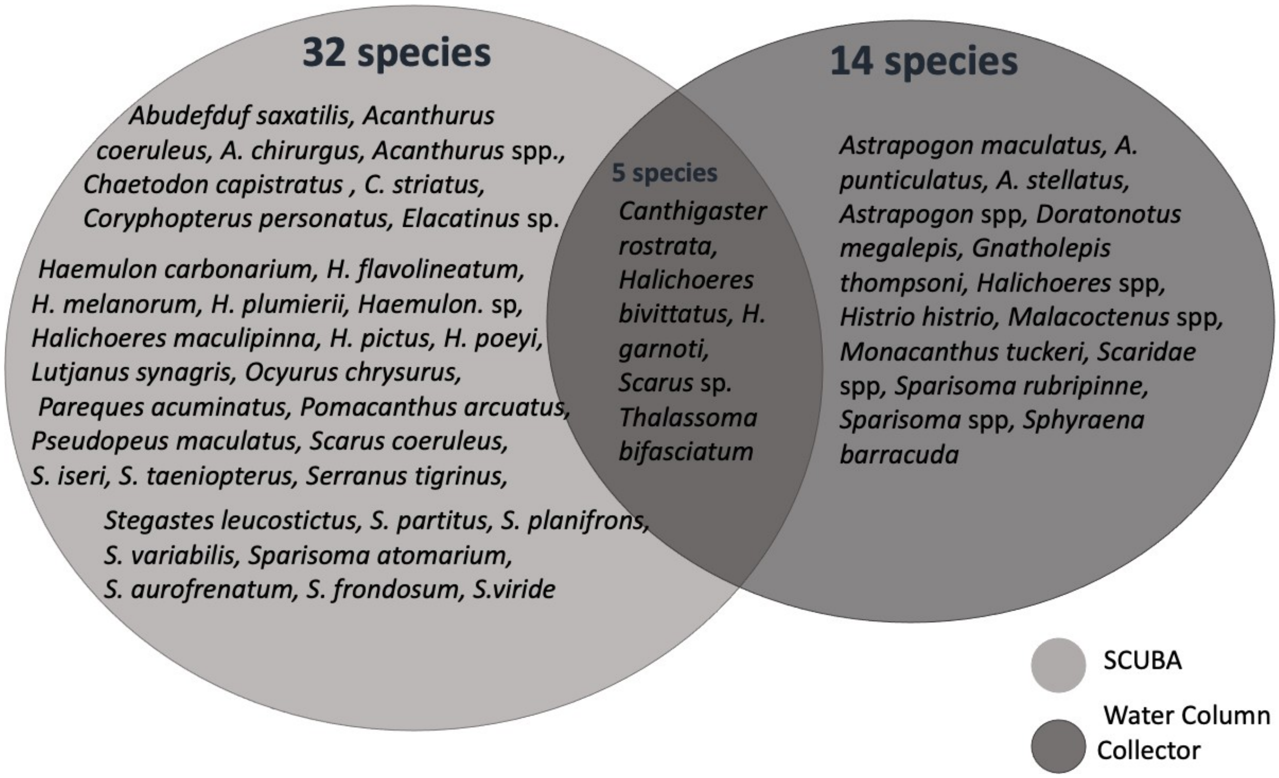

Figure 11. Venn diagrams of fish species recorded with each sampling method in August-September 2019 in Arrecifes de Xcalak National Park. The total number of species collected by each method is indicated. Neither. = unidentified.

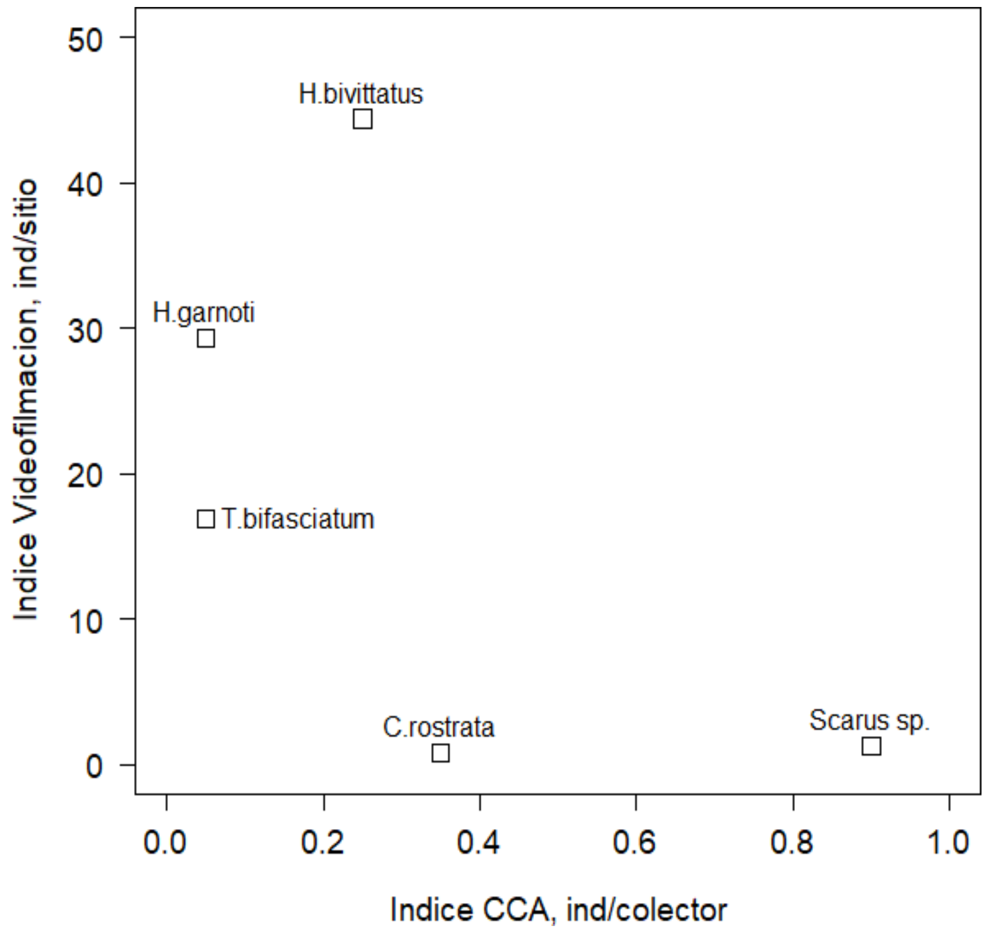

Fig 12. The relation between the values of abundance indexes of fish species caught in common using WCC collectors, $ind \cdot collector^{-1}$, and video recording in patch reefs, $ind \cdot site^{-1}$ during March 2019, and August-September 2019 the Arrecifes de Xcalak National Park (PNAX).

Tables I - XI

Table I. Location of the ten stations of WCC collectors in the reef lagoon of the Arrecifes de Xcalak National Park (PNAX).

Station	CCA	Geographical coordinates	
1	1 y 2	18°17'2.30" N	87°49'34.60" W
2	3 y 4	18°16'54.80" N	87°49'36.60" W
3	5 y 6	18°16'46.90" N	87°49'39.00" W
4	7 y 8	18°16'38.87" N	87°49'40.87" W
5	9 y 10	18°15'57.60" N	87°49'36.10" W
6	11 y 12	18°15'49.80" N	87°49'34.70" W
7	13 y 14	18°15'33.40" N	87°49'38.60" W
8	15 y 16	18°15'33.40" N	87°49'38.60" W
9	17 y 18	18°15'25.80" N	87°49'40.40" W
10	19 y 20	18°15'17.75" N	87°49'40.40" W

Table II. Location of the reef patches, sites, or sampling units (n = 14), where video recording was taken (SCUBA) in Arrecifes de Xcalak National Park. Sampling period: March 2019.

Station I	Geographical coordinates		Station II	Geographical coordinates	
Spot 1	18°17'9.00"N	87°49'34.90"W	Spot 1	18°17'3.05"N	87°49'36.90"W
Spot 2	18°17'11.08"N	87°49'41.00"W	Spot 2	18°17'7.80"N	87°49'54.10"W
Spot 3	18°17'12.03"N	87°49'44.03"W			
Station III			**Station IV**		
Spot 1	18°15'48.50"N	87°49'38.20"W	Spot 1	18°15'18.90"N	87°49'41.70"W
Spot 2	18°15'48.70"N	87°49'38.20"W			
Spot 3	18°15'49.10"N	87°49'38.90"W	Spot 3	18°15'19.40"N	87°49'45.10"W
Station V			**Station VI**		
Spot 1	18°15'14.10"N	87°49'43.40"W	Spot 1	18°15'8.40"N	87°49'43.90"W
Spot 3	18°15'14.60"N	87°49'45.50"W	Spot 3	18°15'9.90"N	87°49'44.70"W

Table III. Location of the reef patches, sampling units (n = 10), where video where video recording was taken in Arrecifes de Xcalak National Park. Sampling: August 2019.

Station	Geographical coordinates		Station	Geographical coordinates	
T1E3	18°17'12.03"N	87°49'44.03"W	T5E1	18°15'14.10"N	87°49'43.40"W
T2E1	18°17'3.50"N	87°49'36.64"W	T6E3	18°15'9.90"N	87°49'44.70"W
T5E3	18°15'14.60"N	87°49'45.50"W	T4E1	18°15'18.90"N	87°49'41.70"W
T2E2	18°17'7.80"N	87°49'54.10"W	T6E1	18°15'8.40"N	87°49'43.90"W
T1E2	18°17'10.98"N	87°49'41.33"W	T3E1	18°15'48.50"N	87°49'38.20"W

Table IV. Location of the sampling stations, n = 5, with a trawling net on the seabed in Arrecifes de Xcalak National Park. Sampling: March 2019.

Trawl	Geographical coordinates	
Station 1a	18°17' 07.47"N	87º 49' 32.58''W
Station 1p	18°17' 14.84"N	87º 49' 57.87''W
Station 2 p	18°17' 09.09"N	87º 49' 59.05''W
Station 4p	18°15' 24.79"N	87º 50' 07.02''W
Station 5p	18°15' 18.3"N	87º 50' 07.50''W

Table V. List of fish species collected in Arrecifes de Xcalak National Park during the new moon period. March 2019

Family	Gender	Species	WCC	Video	Trawl net
Acanthuridae	*Acanthurus*	*chirurgus*		20	
Acanthuridae	*Acanthurus*	*coeruleus*		2	
Acanthuridae	*Acanthurus*	spp.		2	
Carangidae	*Caranx*	spp.	2		
Clupeidae	*Harengula*	sp			1
Gerreidae	*Eucinostomus*	spp.			11
Gerreidae	n.i.	n.i.			3
Gobiidae	*Bathygobius*	*soporator*			4
Gobiidae	*Bathygobius*	spp.			2
Haemulidae	*Haemulon*	*carbonarium*			9

Haemulidae	*Haemulon*	*chrysargyreum*			1
Haemulidae	*Haemulon*	*flavolineatum*		5	33
Haemulidae	*Haemulon*	*melanorum*		1	
Haemulidae	*Haemulon*	*parra*			2
Haemulidae	*Haemulon*	*plumierii*		29	1
Haemulidae	*Haemulon*	*sciurus*		2	148
Haemulidae	*Haemulon*	spp.		118	120
Labridae	*Halichoeres*	*bivittatus*		542	2
Labridae	*Halichoeres*	*garnoti*		202	
Labridae	*Halichoeres*	*radiatus*		1	
Labridae	*Halichoeres*	spp.		35	
Labridae	*Thalassoma*	*bifasciatum*		206	
Labridae	*Xyrichtys*	*splendens*			1
Lutjanidae	*Lutjanus*	*analis*		1	5
Lutjanidae	*Lutjanus*	*apodus*			6
Lutjanidae	*Lutjanus*	*griseus*			25
Lutjanidae	*Lutjanus*	*synagris*			2
Lutjanidae	*Ocyurus*	*chrysurus*		13	
Monacanthidae	*Cantherhines*	*pullus*		2	
Manacanthidae	*Monacanthus*	*ciliatus*	1		3
Monacanthidae	*Monacanthus*	*tuckeri*	4		1
Monacanthidae	*Stephanolepis*	*setifer*			17
Pomacanthidae	*Pomacanthus*	*paru*		2	
Pomacentridae	*Abudefduf*	*saxatilis*		167	3
Pomacentridae	*Stegastes*	*adustus*		1	
Pomacentridae	*Stegastes*	*diencaeus*		7	
Pomacentridae	*Stegastes*	*leucostictus*		35	
Pomacentridae	*Stegastes*	*partitus*		27	
Pomacentridae	*Stegastes*	*planifrons*		27	
Pomacentridae	*Stegastes*	sp.		1	
Pomacentridae	*Stegastes*	*variabilis*			
Scaridae	*Scarus*	*iseri*		225	5
Scaridae	*Scarus*	spp.		15	7
Scaridae	*Scarus*	*taeniopterus*		1	
Scaridae	*Sparisoma*	*aurofrenatum*		3	
Scaridae	*Sparisoma*	*chrysopterum*			23
Scaridae	*Sparisoma*	spp.		109	1
Scaridae	*Sparisoma*	*viride*		33	
Tetraodontidae	*Canthigaster*	*rostrata*	1	2	2
		Totals	**8**	**1836**	**438**

Table VI. The estimated diversity index of species composition with each sampling method used in Arrecifes de Xcalak National Park. Period sampling: March 2019.

Index	**Sampling method**					
	Videorecording		Trawl net		WCC collectors	
Simpson	0.900		0.819		0.656	
Shannon	2.67		2.25		1.21	
	Min	Máx	Min	Máx	Min	Máx
Simpson	0.894	0.905	0.819	0.852	0.562	0.750
Shannon	2.625	2.712	2.168	2.361	1.074	1.386

Table VII. The Jaccard index values showing the degree of similarity between the collection of fish postlarvae and juveniles with three sampling methods in March 2019.

	Videorecording	Trawl net	CCA colectors
Videorecording	1	0.2034	0.022
Trawl net	0.2034	1	0.1
CCA colectors	0.0222	0.1	1

Table VIII. List of fish species collected in Arrecifes de Xcalak National Park during the new moon sampling period. August-September 2019.

Family	**Gender**	**Specie**	**WCC**	**Videorecording**
Acanthuridae	*Acanthurus*	*chirurgus*		12
Acanthuridae	*Acanthurus*	*coeruleus*		16
Acanthuridae	*Acanthurus*	spp.		2
Antenariidae	*Histrio*	*histrio*	3	
Apogonidae	*Apogon*	*maculatus*	1	
Apogonidae	*Apogon*	sp.	1	
Apogonidae	*Astrapogon*	*punticulatus*	2	
Apogonidae	*Astrapogon*	*stellatus*	1	
Chaetodontidae	*Chaetodon*	*capistratus*		3
Chaetodontidae	*Chaetodon*	*striatus*		8
Gobiidae	*Coryphopterus*	*personatus*		10
Gobiidae	*Elacatinus*	spp.		3
Gobiidae	*Gnatholepis*	*thompsoni*	2	
Haemulidae	*Haemulon*	*carbonarium*		1

Haemulidae	*Haemulon*	*flavolineatum*		246
Haemulidae	*Haemulon*	*melanorum*		23
Haemulidae	*Haemulon*	*plumierii*		4
Haemulidae	*Haemulon*	spp.		3
Labridae	*Doratonotus*	*megalepis*	15	
Labridae	*Halichoeres*	*bivittatus*	5	622
Labridae	*Halichoeres*	*garnoti*	1	410
Labridae	*Halichoeres*	*maculipinna*		1
Labridae	*Halichoeres*	*pictus*		127
Labridae	*Halichoeres*	*poeyi*		7
Labridae	*Halichoeres*	sp.	1	
Labridae	*Thalassoma*	*bifasciatum*	1	236
Labrisomidae	*Malacoctenus*	sp.	1	
Lutjanidae	*Lutjanus*	*synagris*		1
Lutjanidae	*Ocyurus*	*chrysurus*		1
Monacanthidae	*Monacanthus*	*tuckeri*	4	
Mullidae	*Pseudopeneus*	*maculatus*		1
Pomacanthidae	*Pomacanthus*	*arcuatus*		1
Pomacentridae	*Abudefduf*	*saxatilis*		124
Pomacentridae	*Stegastes*	*leucostictus*		50
Pomacentridae	*Stegastes*	*partitus*		5
Pomacentridae	*Stegastes*	*planifrons*		12
Pomacentridae	*Stegastes*	*variabilis*		3
Scaridae	*Scarus*	*iseri*		534
Scaridae	*Scarus*	spp.	18	18
Scaridae	*Sparisoma*	*aurofrenatum*		58
Scaridae	*Sparisoma*	*atomarium*		4
Scaridae	*Sparisoma*	*coeruleus*		79
Scaridae	*Sparisoma*	*frondosum*		1
Scaridae	*Sparisoma*	*rubripinne*	9	
Scaridae	*Sparisoma*	spp.	15	16
Scaridae	*Sparisoma*	*taeniopterus*		1
Scaridae	*Sparisoma*	*viride*		31
Scaridae	n.i.	n.i.		
Sciaenidae	*Pareques*	*acuminatus*		1
Serranidae	*Serranus*	*tigrinus*		1
Sphyraenidae	*Sphyraena*	*barracuda*	2	
Tetraodontidae	*Canthigaster*	*rostrata*	6	9
		Total	**89**	**2685**

Table IX. The Jaccard index values showing the degree of similarity between the collection of fish postlarvae and juveniles with two sampling methods during August-September 2019.

	Videorecording	WCC collectors
Videorecording	1	0.11538
CCA Collectors	0.11538	1

Table X. Estimated diversity indexes of the composition by species with each method used in Arrecifes de Xcalak National Park during August-September 2019.

	Videorecording		WCC collectors	
Simpson	0.860		0.878	
Shannon	2.331		2.41	
	Min	Max	Min	Max
Simpson	0.855	0.867	0.844	0.900
Shannon	2.293	2.377	2.193	2.558

Table XI. Qualitative comparison of the three sampling methods used in this work, with respect to various aspects.

Videorecording	WCC Collectors	Trawl net
a) Detection or capture of fish recruited during the current new moon		
Detect fish from the current and previous moon	Catch fish that entered coastal areas on the current moon	Catch fish from previous moons, two to three moons ago
b) Fish mortality associated with the size of the catches		
No mortality, no catch	Low mortality, feasible to release live fish, low catches	High mortality, high catches
c) Stress level on fish sampled		
Low stress, no handling or catching fish	Moderate to high stress, it is feasible to release live fish	High stress from catching and handling fish
d) Provision of samples of individuals for further studies		
No. The information is only recorded in videos	Yes. It allows collecting fish for other types of studies	Yes. It allows collecting fish for other types of studies
e) Relative cost in human labor, time, sampling effort		
High cost, requires equipment, staff and time; high sampling effort	Low cost, requires little sampling time and effort	Regular cost, with moderate sampling effort
f) Sample processing, time and human labor		
Moderate-high review time (videos), difficult to measure and identify	Short review time, easy to identify, take pictures	Moderate review time, easy to measure and identify
g) Method dependence on weather conditions		
Requires good weather conditions, without turbidity	Low to regular dependence on weather conditions	Little effect of weather conditions
h) Sample permit		
It doesn’t require. Only permission for underwater filming	It’s required a collection permit	It is essential to have a sample permit

i) Selectivity of the method		
Low selectivity. Very diverse and abundant samples	High selectivity. Samples of less diversity and abundance	Low selectivity. Very diverse samples, with moderate abundance

CONCLUSIONES

El presente trabajo provee elementos para la valoración de tres métodos de muestreo para la estimación de postlarvas y juveniles de peces, en cuanto a su potencial aplicación para un programa de monitoreo de postlarvas y juveniles de peces en una región determinada; por ejemplo, en la región del SAM.

Dado que cada método de muestreo tiene ventajas y desventajas, su uso dependerá de los objetivos de investigación, el propósito y el alcance del programa de monitoreo. Con base en nuestros resultados, concluimos que el uso de los tres métodos de muestreo simultáneamente permite lograr una imagen más completa de la comunidad de peces en términos de especies y tamaños de las primeras etapas de los peces presentes en el área de estudio (laguna de arrecife). Esto último es fundamental para el seguimiento del reclutamiento de peces y para evaluar el funcionamiento de las áreas de crianza. Sin embargo, es difícil implementar un programa basado en múltiples métodos debido a la limitación presupuestaria y al esfuerzo físico necesario para desarrollar esta investigación en el mediano o largo plazo. Es imperativo evaluar los costos en recursos, tiempo y mano de obra que requiere cada método, junto con las propiedades inherentes del equipo de muestreo: selectividad de especies y estadios; así como los aspectos estadísticos de la variabilidad de los datos y el tamaño de la muestra, estos últimos no abordados aquí.

El presente trabajo proporciona elementos para evaluar tres métodos de muestreo de postlarvas y peces juveniles con potencial aplicación para un programa de monitoreo en áreas de arrecifes. En la región SAM, desde 2013, los colectores de columna de agua se han utilizado para estimar índices de reclutamiento por familia y especies de peces seleccionadas en una red de Áreas Marinas Protegidas (AMP) (Yam Poot, 2013; Malca et al., 2015; Vásquez-Yeomans et al., 2017, 2020). Este trabajo presentó las ventajas y desventajas de los Colectores de Columba de Agua (CCA) y otros dos métodos en términos del número de especies, con una gama reducida de tamaños correspondiente a las primeras etapas de los peces recién reclutados. Los CCA capturan especímenes que ingresan durante el período de luna nueva. El uso de CCA requiere un tiempo reducido para el muestreo y el procesamiento de muestras en el laboratorio. Estas características lo convierten en una apropiada opción para ser seleccionado como método de muestreo para un programa de monitoreo a mediano y largo plazo; debido a su bajo costo y facilidad de implementación a una red de estaciones de AMPs. Sin embargo, debido a su alta selectividad, se recomienda complementar periódicamente los CCA con otro método de muestreo, como la grabación de video. La red de arrastre es un método útil cuando se requiere recolectar especímenes para análisis adicionales tales como determinación de edad (otolitos), redes tróficas (contenido de estómago) y factor de condición.

La variabilidad temporal en el reclutamiento de peces fue evidente en el presente trabajo. Durante agosto-septiembre de 2019, el número de postlarvas y juveniles de peces aumentó notablemente tanto en los CCA como en grabaciones de video en parches de arrecifes. La diferencia fue notable cuando se compararon los valores promedio de los índices registrados en marzo-2019 con los valores de agosto-septiembre-2019. Se requieren esfuerzos de investigación adicionales para determinar los factores causales de las diferencias observadas.

En cuanto a las medidas de diversidad, se observa que el índice de Shannon alcanzó valores > 2 tanto para los períodos de muestreo como para ambos métodos: la grabación de video y CCA; esto sería indicativo de una diversidad de especies que tiende a ser de moderada a alta. El índice de Simpson representa la probabilidad de que dos individuos seleccionados al azar en un hábitat dado fueran de la misma especie y tuvieran valores ≈ 1 para cada uno de los métodos de muestreo. Este valor indicó una mayor posibilidad de predominio de una o algunas especies en el hábitat. La consecuencia antes mencionada debe ser corroborada examinando las familias dominantes en cada período de muestreo y arte. Las familias Hemulidae y Lutjanidae dominaron en la red de arrastre, y las familias Labridae, Scaridae y Hemulidae fueron más abundantes en grabaciones de video y estaciones CCA. Según el índice de similitud de Jaccard, los métodos que exhibieron la similitud más notable fueron la red de arrastre y la grabación de video, ya que compartieron 10 especies en común durante el muestreo de marzo. Para el muestreo de agosto-septiembre, aunque el valor de similitud entre los dos métodos utilizados fue mayor que el valor durante marzo, fue aún menor que el valor de similitud entre la grabación de video y la red de arrastre, lo que permitió definir que los métodos de muestreo que compartieron la mayoría de las especies en común fueron la grabación de video y la red de arrastre.

LITERATURA CITADA

Albins, M. A., y Hixon, M. A., 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. Marine Ecology Progress Series, 367, 233-238.

Almada-Villela, P., Mcfield, M., Kramer, P., Kramer, P. R. y Arias-Gonzalez, E., 2002. Status of coral reefs of Mesoamerica-Mexico, Belize, Guatemala, Honduras, Nicaragua and El Salvador. Status of coral reefs of the world, 303-324.

Álvarez-Cadena, J. N., Ordóñez-López, U., Almaral-Mendivil, A. R., Ornelas-Roa, M. y Uicab-Sabido, A., 2007. Larvas de peces del litoral arrecifal del norte de Quintana Roo, Mar Caribe de México. Hidrobiológica, 17(2), 139-150.

Alvarez-Filip, L., Estrada-Saldívar, N., Pérez-Cervantes, E., Molina-Hernández, A. y González-Barrios, F. J., 2019. A rapid spread of the stony coral tissue loss disease outbreak in the Mexican Caribbean. PeerJ, 7, e8069.

Andersson, A.J., Venn, A.A., Pendleton, L., Brathwaite, A., Camp, E.F., Cooley, S., Gledhill, D., Koch, M., Maliki, S. y Manfrino, C., 2019. Ecological and socioeconomic strategies to sustain Caribbean coral reefs in world. Regional Studies in Marine Science, 29, 100677.

Arrivillaga, A. y Baltz, D., 1999. Comparison of fishes and macroinvertebrates on seagrass and bare-sand sites on Guatemala's Atlantic coast. Bulletin of Marine Science, 65(2): 301–31

Ayala-Campos M.Y., 2014. Riqueza y abundancia en el reclutamiento de post-larvas de peces arrecifales del Caribe Mexicano en zonas aledañas al Parque Ecológico Xcaret, Quintana Roo, México. Tesis de Maestría en Ciencias. Universidad Nacional Autónoma de México.

Betancourt, C. A. y González-Sansón, G., 2011. Composición de la ictiofauna costera de Ciudad de la Habana y evaluación preliminar de los factores que la determinan. Revista de Investigaciones Marinas, 28(1), 43-56.

Browman, H. I., 2014. Commemorating 100 years since Hjort's 1914 treatise on fluctuations in the great fisheries of northern Europe: where we have been, where we are, and where weare going. – ICES Journal of Marine Science, 71: 1989–1992.

Caley, M. J., Carr, M. H., Hixon, M. A., Hughes, T. P., Jones, G. P. y Menge, B. A., 1996. Recruitment and the local dynamics of open marine populations. Annual Review of Ecology and Systematics, 27(1), 477-500.

Carr, M. y Sims, C., 2006. Recruitment. In: The ecology marine fishes: California and Adjacent Waters. LG Allen, DJ Pondella, and MH Horn, eds. University of California Press, p. 411-427.

Eckert, G.J. 1984. Annual and spatial variation in recruitment of labroid fishes among seven reefs in the Capricorn/Bunker Group, Great Barrier Reef. Marine Biology 78: 123-127.

Eggleston, D.B., 1995. Recruitment of Nassau grouper, *Epinephelus striatus*: post-settlement abundance, microhabitat features, and ontogenetic diet shifts. Marine Ecology Progress Series 124: 9-22.

González-Salas, C., Nuñez-Lara, E., Ruiz-Zarate, M.A., Hernández-Landa, R.C., and Arias-González, J. E. 2003. Condition of coral reef ecosystems in the central and southern Mexican Caribbean (Part 3: juvenile reef fishes) Atoll Res. Bull. N°496, pp. 598-610.

Grorud-Colvert, K. y Sponaugle. S., 2009. Larval supply and juvenile recruitment of coral reef fishes to marine reserves and non-reserves of the upper Florida Keys, USA. Mar Biol. 156: 277-288.

Gudiel-Corona, V. M., 2016. Diversidad de poslarvas de peces en arrecifes coralinos y pastos marinos del Refugio de Vida Silvestre Punta de Manabique, Caribe de Guatemala. Tesis de licenciatura. Universidad de San Carlos de Guatemala. Facultad de Ciencias Quìmicas y Farmacia. Guatemala 69 pp.

Haddon, M., 2011. Modelling and quantitative methods in fisheries. CRC Press. Boca Raton, Fla. USA. 2nd ed. 465 pp

Hjort, J., 1914. Fluctuations in the great fisheries of the northern Europe viewed in the light of biological research. RAPP. P. V. Reun. Cons. Perm. Int. Explor.Mer. 20:

Houde, E. D., 2008. Emerging from Hjort's shadow. J. Northw. Atl. Fish. Sci., 41: 53–70. doi:10.2960/J.v41.m634

Ishihara, T. y Tachihara, K., 2011. Pelagic Larval Duration and Settlement Size of Apogonidae, Labridae, Scaridae, and Tripterygiidae Species in a Coral Lagoon of Okinawa Island, Southern Japan1. *Pacific Science*, *65*(1), 87-93.

Jackson JBC, Kirby Berger MX, Botsford KA, Bourque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science. 293:629–638

Kritzer J.P. y Sale P.F., 2006. Marine Metapopulations. Elsevier Academic Press. USA 544pp

Kobara S., Heyman W. D., Pittman S.J. y Nemeth R. S., 2013. Biogeography of transient reef-fish spawning aggregations in the Caribbean: A synthesis for future research and managment. Oceanography and Marine Biology. 51 281-326

Lang, J., Alcolado P, Carricart-Ganivet JP, Chiappone M, Curran A, Dustan P, Gaudian G, Geraldes F, Gittings S, Smith R, Tunnell W, Wiener J. 1998. Status of coral reefs in the northern areas of the wider Caribbean, 123-134 pp. In: Wilkinson C (ed) Status of coral reefs of the world.

Leis, J.M., 1986. Vertical and horizontal distribution of fish larvae near coral reefs at Lizard Island. Great Barrier Reef.Marine Biology. 90:505-516

Leis, J. M., 1991. The pelagic stage of reef fishes: the larval biology of coral reef fishes. In: The Ecology of Fishes of Coral Reefs. Academic Press, San Diego. p. 183-227.

Leis, J.M., 2015. Is dispersal of larval reef fishes passive? In: Ecology of Fishes on Coral Reefs. Cambridge, pp. 223–226. https://doi.org/10.1017/CBO9781316105412.025.

Levin, P. S., 1994. Fine-scale temporal variation in recruitment of a temperature demersal fish: importance of settlement versus post-settlement loss. Oecología 97: 124-133.

Malca, E., Vásquez-Yeomans, L., González, C., Gudiel-Corona, V., Sosa-Cordero, F. E., Carrillo, L., y González, M. J., 2015. Capacity building in marine protected areas and connectivity in the Mesoamerican Barrier Reef System: Larval fish recruitment. In Proceedings of the Gulf and Caribbean Fisheries Institute (Vol. 67, pp. 277-283).

Martínez, S., Carrillo, L., y Marinone, S. G., 2019. Potential connectivity between marine protected areas in the Mesoamerican Reef for two species of virtual fish larvae: *Lutjanus analis* and *Epinephelus striatus*. Ecological Indicators, *102*, 10-20.

Milicich, M.L. y Doherty. P., 1994. Larval supply of coral reef fish populations: magnitude and synchrony of replenishment to Lizard, Great Barrier Reef. Mar. Ecol. Prog. Ser. 110:121-134.

Morales Aranda, A. A., Soto, S., & Ganivet, C., 2011. Variación espacio-temporal de los peces arrecifales de la costa sur de Quintana Roo. Tesis de Maestría. El Colegio de la Frontera Sur, unidad Chetumal, Quintana Roo, 162 pp

Muhling, B. A., Smith, R. H., Vásquez-Yeomans, L., Lamkin, J. T., Johns, E. M., Carrillo, L., ... y Malca, E., 2013. Larval fish assemblages and mesoscale oceanographic structure along the Mesoamerican Barrier Reef System. Fisheries Oceanography, 22(5), 409-428.

Nolan, C.J. y Danilowicz, B.S., 2008. Advantages of using crest nets to sample presettlement larvae of reef fishes in the Caribbean Sea. Fish Bull 106:213–221

Ortega, J. R. y García, J. R., 2002. Caracterización del ictioplancton a través del Canal de la Mona, con énfasis en familias arrecifales. Tesis Doctoral, Universidad de Puerto Rico, Recinto Universitario de Mayagüez.

Paris, C. B., Cowen, R. K., Claro, R., & Lindeman, K. C., 2005. Larval transport pathways from *Cuban snapper* (Lutjanidae) spawning aggregations based on biophysical modeling. *Marine Ecology Progress Series*. *296*, 93-106

Paris, C., Chérubin, L. y Cowen, R., 2007. Surfing, spinning, or diving from reef to reef: effects on population connectivity. Marine Ecology Progress Series. 347, 285–300. https://doi. org/10.3354/meps06985

Pile, A. J., Lipcius, R. N., Van Montfrans, J. y Orth, R. J., 1996. Density-dependent settler-recruit- juvenile relationships in blue crabs. Oceanographic Literature Review, 5(44), 496.

Planes, S., Levefre, A., Legendre, P. y Galzin, R., 1993. Spatio-temporal variability in fish recruitment to a coral reef (Moorea, French Polynesia). Coral Reefs, 12(2), 105-113.

Richards, W. J., y Lindeman, K. C., 1987. Recruitment dynamics of reef fishes: planktonic processes, settlement and demersal ecologies, and fishery analysis. Bulletin of Marine Science, 41(2), 392-410.

Richards, W.J. (Ed.). 2006. Early stages of Atlantic fishes. An identification guide for the Western Central North Atlantic. CRC Taylor y Francis, Boca Ratón, Florida (I-II): 1-2581 p.

Reyes-Bonilla, H., Álvarez del Castillo-Cárdenas, P. A., Calderón-Aguilera, L. E., Erosa-Ricárdez, C. E., Fernández-Rivera Melo, F.J., Frausto, T.C., Luna-Salguero, B. M. ., Moreno-Sánchez, X. G., Mozqueda-Torres, M. C., Norzagaray-López ,C. O. y Petatán-Ramírez, D., 2014.
Servicios ambientales de arrecifes coralinos: El caso del Parque Nacional Cabo Pulmo, B.
C. S. In: Urciaga-García, J. I. (ed.). Desarrollo Regional en Baja California Sur: Una perspectiva de los Servicios Ecosistémicos. Universidad Autónoma de Baja California Sur, La Paz. pp. 49- 78.

Rodríguez-Martínez, R. E., Van Tussenbroek, B. y Jordán-Dahlgren, E., 2016. Afluencia masiva de sargazo pelágico a la costa del Caribe mexicano (2014-2015). Florecimientos Algales Nocivos en México. Ensenada: CICESE, 2016, 352-365.

Rojas, P.M., 2014.Diel variation in the vertical distribution of fish larvae forced by upwelling filaments off Punta Angamos (northern Chile). Latin American Journal of Aquatic Research, 142: 401-417

Research Planning Inc., (RPI), 2003. Informe Final de la Consultoría Internacional SAM Análisis crítico sobre las agregaciones reproductivas Contrato #TF-027739.

Sadovy de Mitcheson, Y., 2016. Mainstreaming fish spawning aggregations into fishery management calls for a precautionary approach. *BioScience, 66*(4), 295-306

Sadovy de Mitcheson, Y. y Colin, P.L. (Eds.). 2014. Reef Fish Spawning Aggregations: Biology, Research and Management. In: Fish and fisheries series, vol. 35, Springer Verlag, Berlin.

Sale P.F. 2004. Connectivity, Recruitment Variation, and the Structure of Reef Fish Communities. Integr. Comp. Biol. 44:390-399

Simpson, S.D., Meekan, M.G., McCauley R.D. y Jeffs. A., 2004. Attraction of settlement-stage coral reef fishes to reef noise. Mar. Ecol. Prog. Ser. 276:263- 268.

Solís-Mena, J.del C., 2018. Abundancia y diversidad de larvas de peces en el Parque Nacional Arrecifes de Xcalak (PNAX) usando un arte de muestreo alternativo. Tesis de licenciatura. Tecnológico Nacional de México. Instituto Tecnológico de Chetumal. 116pp

Sosa-Cordero, E., Ramírez-González, A., Olivares-Escobedo, J., Cohuó-Collí, J. A., Mercadillo-Elguero, I., y Quintal-Lizama, C., 2009. Programa de ordenamiento pesquero del Estado de Quintana Roo. 1. Pesquería de meros y especies afines. Informe Final presentado a CONAPESCA-SAGARPA.. Chetumal, Quintana Roo, Mexico: El Colegio de la Frontera Sur, 110.

Sponaugle, S. y Cowen, R.K., 1994. Larval durations and recruitment patterns of two Caribbean gobies (Gobiidae): contrasting early life histories in demersal pawners. Mar Biol. 120:133-143.

Steele, M. A., Malone, J. C., Findlay, A. M., Carr, M. H. y Forrester, G. E., 2002. A simple method for estimating larval supply in reef fishes and a preliminary test of population limitation by larval delivery in the kelp bass *Paralabrax clathratus*. Marine Ecology Progress Series, 235, 195-203.

Trujillo-Millán, Ó., 2004. Reclutamiento de peces de arrecife en Isla Cerralvo y Punta Perico, BCS México. Tesis Doctoral. Instituto Politécnico Nacional. Centro Interdisciplinario de Ciencias Marinas.

Vásquez-Yeomans, L., Ordóñez-López, U., & Sosa-Cordero, E., 1998. Fish larvae adjacent to a coral reef in the western Caribbean Sea off Mahahual, Mexico. Bulletin of Marine Science, 62(1), 229-245

Vásquez-Yeomans, L., y Richards, W. J., 1999. Variación estacional del ictioplancton de la Bahía de la Ascensión, Reserva de la Biosfera de Sian Ka'an (1990-1994). Revista de biología tropical, 197-207

Vásquez-Yeomans, L., Sosa-Cordero, E., Lara, M. R., Adams, A. J., & Cohuo, J. A., 2009. Patterns of distribution and abundance of bonefish larvae *Albula spp*. (Albulidae) in the western Caribbean and adjacent areas. *Ichthyological research*, *56*(3), 266-275.

Vásquez-Yeomans, L., Vega-Cendejas, M. E., Montero, J. L. y Sosa-Cordero, E., 2011. High species richness of early stages of fish in a locality of the Mesoamerican Barrier Reef System: a small-scale survey using different sampling gears. Biodiversity and Conservation, 20(11), 2379-2392

Vásquez-Yeomans, L., Malca, E., Sosa-Cordero, E., Carrillo, L., González, C., & González, M. J., 2017. Fomento de Capacidades en AMP y Conectividad en el Arrecife Mesoamericano. Ejercicios de Conectividad (ECOME) en el SAM 2013-2016. Informe final. ECOSUR. Chetumal, Quintana Roo., México. 50 pp.

Vásquez-Yeomans, L., Sosa-Cordero, E., Carrillo, L., Malca, E., & González, C., 2020. Fomento de Capacidades en AMP y Conectividad en el Arrecife Mesoamericano. Ejercicios de Conectividad (ECOME) en el SAM 2013-2020. Informe final. ECOSUR. Chetumal, Quintana Roo., México. 57 pp.

Villegas-Sánchez, C.A., Lara-Arenas, J.H., Castro-Pérez, J.M. y Arias-González, J.E., 2015. Patrones de reclutamiento de cuatro especies ícticas en hábitats de parche y cordillera del arrecifeBanco Chinchorro (Caribe mexicano). Revista Mexicana de Biodiversidad 86: 396–405

White, J.W., Carr, M.H., Caselle, J.E., Washburn, L., Woodson, C.B., Palumbi, S.R., Carlson, P.M.,Warner, R.R., Menge, B.A., Barth, J.A. y Blanchette, C.A., 2019. Connectivity, dispersal, and recruitment: Connecting benthic communities and the coastal ocean. Oceanography 32(3):50–59.

Williams, D., 1991. Patterns and processes in the distribution of coral reef fishes. En: Sale, P.F. (Ed.). The ecology of fishes on coral reefs. Academic Press, San Diego. 437-474.

Yam Poot, G.M. 2013. Evaluación de trampas de asentamiento de postlarvas para desarrollar índices de reclutamiento de peces marinos de importancia comercial. Tesis de Licenciatura de Biología. Instituto Tecnológico de Chetumal. Chetumal, Quintana Roo, 96 pp.