Review [Revisión]

MULTIDISCIPLINARY APPROACH TO ASSESS COMMERCIALLY IMPORTANT MARINE STOCKS IN THE COASTAL WATERS OF THE YUCATAN PENINSULA – CONTRIBUTION BY CCBA-UADY †

[ENFOQUE MULTIDISCIPLINARIO PARA EVALUAR LAS POBLACIONES MARINAS DE IMPORTANCIA COMERCIAL EN LAS AGUAS COSTERAS DE LA PENÍNSULA DE YUCATÁN – CONTRIBUCIONES DEL CCBA-UADY]

Harold Villegas-Hernández, Carlos González-Salas, Sergio Guillén-Hernández*, Gaspar Poot-López, Raúl Díaz-Gamboa and Dawrin Pech-Puch

Departamento de Biología Marina, Campus de Ciencias Biológicas y Agropecuarias, Universidad Autónoma de Yucatán, Km. 15.5, carretera Mérida-Xmatkuil, A.P. 4-116 Itzimná, C.P. 97100, Mérida, Yucatán, México. Email. ghernand@correo.uady.mx
** Corresponding author*

SUMMARY

Background. Since the formation of the research group in marine biology at the CCBA, different aspects of this discipline have been developed. One of them is the identification of populations and possible stocks of fish of commercial importance, using different techniques. The stock delineation (or population structure) are central considerations for fishery assessment and strategic management of marine natural resources and have to be addressed from a meta-population perspective where complementary technical approaches meet to enable the best picture to delineate complex stock structures. **Objective.** To review the current knowledge on the stock concept and the use of a multidisciplinary approach to properly assess commercially important marine stocks in the coastal waters of the Yucatan peninsula. **Methodology.** We present the research explored so far by the marine biology laboratory (LABIOMA by its acronym in Spanish) of the Autonomous University of Yucatán regarding the marine resources off the coast of the Yucatan peninsula, and the future lines of investigation pursued by our personnel, from fishing gear selectivity, abundances and catchability estimates, traditional morphometrics, parasitological and life history traits as biological tags, to more precise analyses such as fish otolith shape or even stable isotope analysis, genotypic markers, and marine natural products chemistry. **Main findings.** Single technical approaches are insufficient to delineate complex stock structures, especially in wide marine open access ecosystems, and there is a need to harness the full power of complementary and synergistic multidisciplinary approaches to improve fishery assessment and management efficiency in marine natural resources from the coastal areas of the Yucatan peninsula. **Implications.** Most stock assessment models are based on a single unit stock assumption, however the full impact of management actions, including identifying the complexity of the stock of any marine species subject to fishing, could affect the perpetuity of its abundances if the population subunits are not properly located. **Conclusion.** Identification of stocks is necessary for several reasons including allocation of catches, recognition and protection of nursery and spawning areas, and for development of optimal harvest and monitoring strategies. To this end, the LABIOMA are strengthening the assessments of commercially important marine stocks by using multidisciplinary approaches, whose lines of research represent basic aspects to be known and would be of great help to decision makers at the time of establishing more precisely, catch quotas, fishing areas, closed seasons, and therefore make more efficient the management strategies.

Keywords: marine resources; stock identification; population structure; fishery assessment; coastal waters; Yucatan peninsula.

RESUMEN

Antecedentes. Desde la formación del grupo de investigación en biología marina del CCBA se han desarrollado diferentes aspectos de esta área. Uno de ellos es la identificación de poblaciones y posibles stocks de peces de

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importancia comercial, utilizando diferentes técnicas. La delimitación del stock (o estructura de la población) son consideraciones centrales para la evaluación de la pesca y la gestión estratégica de los recursos naturales marinos y deben abordarse desde una perspectiva de meta-población, donde los enfoques técnicos complementarios se encuentran para permitir la mejor imagen para delinear estructuras de poblaciones complejas. **Objetivo.** Revisar el conocimiento actual sobre el concepto de stock y el uso de un enfoque multidisciplinario para evaluar adecuadamente los stocks marinos de importancia comercial en las aguas costeras de la península de Yucatán. **Metodología.** Presentamos la investigación explorada hasta el momento por el laboratorio de biología marina (LABIOMA) de la Universidad Autónoma de Yucatán sobre los recursos marinos frente a las costas de la península de Yucatán, y las líneas futuras de investigación que persigue nuestro personal, desde estimaciones de la selectividad, abundancias y capturabilidad de los artes de pesca, morfometría tradicional, rasgos parasitológicos y del ciclo de vida como marcas biológicas, hasta análisis más precisos como la forma del otolito de peces o incluso el análisis de isótopos estables, marcadores genotípicos y química de productos naturales marinos. **Hallazgos principales.** Los enfoques técnicos únicos son insuficientes para delinear estructuras de poblaciones complejas, especialmente en ecosistemas marinos de acceso abierto amplios, y es necesario aprovechar todo el poder de los enfoques multidisciplinarios complementarios y sinérgicos para mejorar la evaluación de la pesca y la eficiencia de la gestión en los recursos naturales marinos de las zonas costeras de la península de Yucatán. **Implicaciones.** La mayoría de los modelos de evaluación de stock se basan en un supuesto de stock de una sola unidad, sin embargo, el impacto total de las acciones de manejo, incluida la identificación de la complejidad del stock de cualquier especie marina sujeta a la pesca, podría repercutir en la perpetuidad de sus abundancias sino se ubican las subunidades poblacionales adecuadamente. **Conclusión.** La identificación de las poblaciones es necesaria por varias razones, incluida la asignación de capturas, el reconocimiento y protección de las zonas de cría y desove, y para el desarrollo de estrategias óptimas de captura y seguimiento. Para ello, el LABIOMA está fortaleciendo las evaluaciones de stocks marinos de importancia comercial mediante enfoques multidisciplinares, cuyas líneas de investigación representan aspectos básicos por conocer y que serían de gran ayuda para los tomadores de decisiones a la hora de establecer con mayor precisión, cuotas de captura, zonas de pesca, vedas, y por tanto hacer más eficientes las estrategias de gestión.

Palabras clave: recursos marinos; identificación de stock; estructura poblacional; evaluación de pesquerías; aguas costeras; Península de Yucatán.

INTRODUCTION

Since the formation of the Degree in Marine Biology in 2006, the Campus of Biological and Agricultural Sciences of the Autonomous University of Yucatán (CCBA-UADY) created the Marine Biology Laboratory (LABIOMA by its acronym in Spanish). The projects carried out by department of marine biology have dealt with several aspects related to the use of marine natural resources, such as reproductive biology, parasitology, histopathology, population genetics, invasive species, phycology, trophic biology of marine mammals, and production of aquatic organisms. One of the main objectives of the research group at LABIOMA has been the management of marine fisheries resources. At the beginning, this research group was made up of four researchers, two from a degree in biology and with previous work in the marine area, and two more that were specifically hired with this profile. Research topics were marine algae, helminth diversity, ichthyology, and marine protected areas. Later, with the hiring of more personal, these areas were expanded and integrated to form interdisciplinary groups. Results of this interaction is what is presented in this paper.

Fisheries management is moving towards a precautionary approach to ensure sustainable utilization of our marine resources (Flores-Nava *et al.*, 2016; Fernández *et al.*, 2011; FAO, 2016). One requirement of the precautionary approach is to consider the full impact of management actions, including explicit consideration of stock complexity, thus there is a growing interest in the importance and recognition of individual spawning components within historically established management units (Garcia and Grainger, 1997). Stock identification studies are carried out with the objective of obtaining management units that are significant biological entities and thus reduce the uncertainty in the evaluation models and/or improve the management of the resource.

Stock concept in fisheries assessment

A population has been defined a group of individuals of the same species that live together in an area of sufficient size to permit normal dispersal and/or migration behavior and in which numerical changes are largely determined by birth and death processes (Berryman, 2002). Meanwhile the stock concept essentially describes characteristics of a population unit assumed homogeneous for particular management purposes (Begg *et al.*, 1999b; a). In this regard, the stock structure has been acknowledged as essential to infer potential evolution and extinction risk derived from over exploitation and the inappropriate management of this marine resource (Ihssen *et al.*, 1981; Cadrin, 2020; Cadrin *et al.*, 2014). Consequently, the stock concept in its current working form defines semi-discrete units of fish with some definable attributes of interest to managers, since to manage any given fishery effectively and implement worthwhile stock rebuilding programs.

The knowledge of the stock structure and degree of mixing among populations is important for the rational management of marine resources, especially when dealing with important commercial species. Thus, it is important to know the identity of the stock structure of the species on a regional basis, and how fishing effort and mortality is distributed amongst the various components, in which case each identified stock must be managed separately to optimize their yield, if not a failure to recognize the stock structure of an exploited species can lead to overfishing and depletion of less productive stocks (Cadrin, 2020). Therefore, the definition of stock requires spatial limits to be defined, which in practice it exceedingly difficult to delimit the borders between populations or stocks.

Different techniques have been used in the stock identification in fisheries, including the use of parasites (Baldwin *et al.*, 2012; Lester and MacKenzie, 2009; MacKenzie *et al.*, 2008; Vasconcelos *et al.*, 2017), the comparison of patterns of morphometric variation in fish (Turan *et al.*, 2006; Murta, 2000); differences in the morphology (Stransky *et al.*, 2008a; Tracey *et al.*, 2006; Stransky *et al.*, 2008b) and chemical composition of otoliths (Campana, 1999; Bergenius *et al.*, 2005; Jónsdóttir *et al.*, 2006) and molecular analysis such as mitochondrial DNA or microsatellite DNA sequencing (Shaklee and Currens, 2003; Beacham *et al.*, 2000; Corander *et al.*, 2006; Beacham *et al.*, 1999).

Despite progress in the different methodologies applicable to stocks identification, the most successful way to approach the problem of defining stock limits is through a holistic approach (Begg and Waldman, 1999), which involves a wide spectrum of complementary techniques and thus obtain the best possible image in response to the requirements whether ecological, productive, evolutionary or operational that the definition of stock may imply. Thus, a recommended protocol is the complementary application of genotypic, ecological and/or phenotypic-based approaches in a holistic manner to maximize the probability of defining the stock structure (Pita *et al.*, 2016; Abaunza *et al.*, 2008; Begg and Waldman, 1999).

Research approaches for marine resources off the coast of the Yucatan peninsula

Parasites as an ecological approach

Parasites have been widely used as indicators of various aspects of fish biology (Williams *et al.*, 1992), however one of their most important applications is in stock identification of their hosts (MacKenzie and Abaunza, 1998; Lester and MacKenzie, 2009). The advantages and limitations of using parasites as biological tags have been recognized and reported by many works (MacKenzie and Abaunza, 1998, 2014; Williams *et al.*, 1992; Lester and MacKenzie, 2009). In this regard, LABIOMA have carried out researches regarding the helminths that parasitize some of the main marine resources in the region of the Yucatan peninsula, such as the grey snapper *Lutjanus griseus* (Argáez-García *et al.*, 2010), the black grouper *Mycteroperca bonaci* (Espínola-Novelo *et al.*, 2013, 2015), the French grunt *Haemulon flavolineatum* (Guillén-Hernández et al. *in press*) and the red octopus *Octopus maya* (Guillén-Hernández *et al.*, 2018b; a). At LABIOMA we continue to investigate and provide the necessary tools for the analysis of parasite communities and populations and the identification of the characteristics of the species that can be used as biological tags for stock identification in any given fish or invertebrate species exploited by regional fisheries, such as the lane snapper *Lutjanus synagris.*

Otolith shape as a phenotypic approach

Otoliths are crystalline structures and part of the hearing and balance system in fish that mainly consist of calcium carbonate and are ideal structures for use in fish stock identification, containing a range of measurable characteristics including linear and shape morphometrics, optical density, and microstructural zonation and growth patterns, and elemental constituents (Ihssen *et al.*, 1981; Campana and Thorrold, 2001; Campana and Casselman, 1993). Otoliths grow throughout the life of fish, are metabolically inert, and are typically available as a historical time series because of routine age and growth assessments (Campana and Thorrold, 2001; Popper *et al.*, 2005; Campana *et al.*, 1997; Begg *et al.*, 2005). It is known that otolith shape differences greatly depend on both differential growth rates and the consistency of the environment integrated over the life history of fish in each stock, which provides a phenotypic basis for stock separation that is useful for fisheries management (Campana and Thorrold, 2001; Thorrold *et al.*, 1997; Begg and Waldman, 1999). At LABIOMA the otoliths shape (based on Fourier contour analyses) have successfully been used to differentiate subunits in species such as the bicolour damselfish *Stegastes partitus* (Villegas-Hernández *et al.*, 2008), the white grunt *Haemulon plumierii* (Treinen-Crespo *et al.*, 2012; Villegas-Hernández *et al.*, 2014), or the bastard grunt *Pomadasys ncises* (Villegas-Hernández *et al.*, 2018a). Moreover, age determination and growth model studies have also been explored in *S. partitus* (Villegas-Hernández *et al.*, 2008) and the white grunt *H. plumierii* (Oribe-Pérez *et al.*, 2020). Currently, we are focusing on the use of hierarchical neuronal networks based on deep learning machines by gathering information of the Fourier descriptors from the otolith shape of fishes from the coasts off the Yucatan peninsula, and creating a big data set that would allow us to identify fish species or populations.

DNA molecular markers as genotypic approach

Molecular genetics has made some remarkable contributions to our understanding of populations, providing novel insights into previously inaccessible aspects of the natural history of marine organisms. Whether mitochondrial or nuclear DNA, both have proven to be invaluable tools in species and stock identification as a population-genetic, phylogeographic, and phylogenetic markers (Wirgin and Waldman, 2005; Antoniou and Magoulas, 2013; Carvalho and Hauser, 1994). A variety of molecular markers have been used to carry out the delineation of stocks, such as microsatellite loci (Ruzzante, 1998; Cadrin *et al.*, 2014; Sabatini *et al.*, 2018; Wirgin and Waldman, 2005; O' Conell and Wright, 1997; Antoniou and Magoulas, 2013). In this regard, DNA microsatellites have been used at LABIOMA as biological markers to determine the structure of stocks of the white grunt *Haemulon plumierii* (Villegas-Hernández *et al.*, 2014), the black grouper *Mycteroperca bonaci* (González-Salas *et al.*, 2020), and the French grunt *Haemulon flavolineatum* (González-Salas *et al.*, 2021). The interest in use of mitochondrial markers, specifically the use of mitochondrial gene cytochrome c oxidase I (commonly known as COI-I) in support of the taxonomic identification of fish has increased in recent years. The use of the COI-I gene as a barcode has been found to be effective in classifying and identifying vertebrates and invertebrates and the COI-I gene has been used extensively in various biological groups (Bingpeng *et al.*, 2018). The next step in LABIOMA is the use of the COI-I in support of traditional morphological classification methods. This technology has certain advantages with respect to traditional methods, among which are, the ability to discern with great reliability the species morphologically very similar externally between them, therefore, it is difficult to distinguish them from each other simply by their morphological characteristics, something that with the barcode it is possible to accurately distinguish such species. Another advantage can be reflected when analyzing the different stages of development of the species, where morphological differences can vary even more considerably during the various stages of development, but DNA barcode technology can identify individuals at different stages of development without difficulty; the last and no less important advantage is the possibility of discovering cryptic species, revealing even the evolutionary distances between species, and therefore revealing cryptic species that had previously been classified as the same.

Reproductive biology of fishes

It is known that information about population dynamics and reproduction in target species by fishing is fundamental to outline sustainable management measures, such as closed seasons and minimum catch sizes, that would guarantee its continuity in the area before they reach overexploitation levels and threaten its abundance and fisheries (Domeier *et al.*, 2002; Villacorta and Saint, 1999). In this sense, LABIOMA has also explored the reproductive biology of fish species with an alternative potential for commercial exploitation, such as the southern pufferfish *Sphoeroides nephelus* (Peniche-Perez *et al.*, 2019), and the major sergeant *Abufdefduf saxatilis* (Villegas-Hernández *et al. in press*), as well as the traditional exploited species such as the white grunt *Haemulon plumierii* (Solís-flores *et al.*, 2021). Nowadays, the LABIOMA have centered its attention on using the reproductive biology of marine species and its potential use in aquaculture for human consumption. In this sense, it is intended to obtain a breeding population (sexually mature specimens) that would be the basis for producing fingerlings to be raised for a few weeks or months before harvest in fish farms, instead of collecting individuals from the wild. Another ongoing research line at LABIOMA is the climate change-related reproductive biology features, the physiological adaptations of marine organisms (such as changes in maturity size, fecundity, spawning phenology and condition) to the increase in sea temperature could in fact be playing an important role in the establishment of this thermophilic fauna in areas that they did not previously occupy.

Fisheries resource assessment

Regional fisheries have also been studied at LABIOMA. Research has been developing in collaboration with other institutions as UNAM and

CINVESTAV, which involved the studies of crustaceans, molluscs, echinoderms, and fishes. In the artisanal shrimp fishery, the main contribution has been the growth modelling of juveniles and sub-adults of two species of genus *Farfantepenaeus* determining the months of highest recruitment in coastal lagoons (Monsreal-Vela *et al.*, 2016). The seasonal abundance of crustaceans associated with the blue crab (*Callinectes sapidus*) fishery, and the abundance and population size of *C. sapidus*, have been estimated with marking-recapture techniques (Celis-Sánchez *et al.*, 2014; Villegas-Hernández *et al.*, 2018b).

LABIOMA´s personnel have participated in the preparation of technical reports that have served as a basis to guide public policies in the areas of fishing and aquaculture. In 2016, the final report of the Diagnosis of the Fishing and Aquaculture Sectors in the State of Yucatán and the Master Plan for the Development of Sustainable Fishing and Aquaculture in Yucatán were presented, which established the bases to meet the needs of both sectors. In this regard, LABIOMA has orientated its research in applying sampling and modelling tools to determine the size of the stock of a population both in number and biomass.

In fisheries research, the basic hypothesis is that the total catch (C) divided by the effort (f), over a period, is proportional to the average abundance of the population (N): $CPUE = q \cdot N$, where q is the catchability coefficient (Ricker, 1975). Therefore, the study of the space-time variation of catchability is a key element in the stock assessment. The previous one has been used to analyze the spatio-temporal variations of the abundance and catchability of the octopus *O. maya* on the continental shelf of the Yucatan Peninsula (Gamboa-Álvarez *et al.*, 2015). In addition, the density, selectivity, and vulnerability of the Atlantic blue crab (*Callinectes sapidus*) were determined using catch data and catchability estimations (Poot-López *et al.*, 2019). The sea cucumber fishery in the Campeche Bank has been reviewed including the problems associated with its fishing, and the alternatives for sustainable use and its restoration (Gamboa-Álvarez *et al.*, 2020). In addition, the survival and growth of both wild-translocated individuals and released-cultured juveniles have been examined in the four-sided sea cucumber (*Isostichopus badionotus*) off the northern coast of the Yucatan Peninsula (Gamboa-Álvarez *et al.*, 2021).

Since recreational fishing is not fully regulated or even understood in Mexico, nowadays at LABIOMA we are increasing our attention on the practice of recreational fishing in order to generate information about biological-fishery issues on the species caught by recreational fishermen, which would allow more appropriate management strategies. For instance, it has been described the catch composition, the catch per unit effort (CPUE), size at first capture (L_{50}) and the length-weight relationship (LWR) of the fish species caught by the recreational fishing (Poot-López *et al.*, 2018, 2017). Recently, we carried out a study in which the composition of the catch, the coefficient of catchability, vulnerability and selectivity were compared between two fishing gear size for three fish species commonly caught by recreational fishing such as the white grunt *Haemulon plumierii*, the yellow-tail snapper *Ocyurus chrysurus* and the lane snapper *Lutjanus synagris* (Gómez-Torres *et al. in press*). And the research continues with the socio-economics characterization of this fishery as a first step to establish more reasonable regulatory measures.

Stable isotope analysis for the identification of stocks

Stable isotope abundances are useful for the understanding of feeding relationships and trophic positions in aquatic ecosystems (Díaz-Gamboa *et al.*, 2018). The consumer's body composition signal reflects the food ingested, assimilated, and integrated over time, but varies depending on the tissue used and its respective metabolic and turnover rate (Tieszen *et al.*, 1983; Hobson *et al.*, 1994). Due to the fact that there is a selective retention of heavier isotopes and an excretion of the lighter ones, animals have higher $\delta^{13}C$ and $\delta^{15}N$ values than their diet (Peterson and Fry, 1987; Das *et al.*, 2000). Therefore, stable isotopes are used to describe trophic positions and relationships, as well as understand the relative dietary contributions from various primary sources exploited by consumers, allowing us to distinguish between terrestrial vs. aquatic, inshore vs. offshore or pelagic vs. benthic prey, or stocks.

Trophic ecology of marine animals has been studied in LABIOMA since 2013, exploring the dietary preferences of coastal bottlenose dolphins in Yucatan and suggesting those animals feed on fishes and octopus very appreciated for the commercial fisheries (Olivares-Rodríguez, 2015, 2017). These studies have set the tone for the exploration of contaminants present in marine mammals as top predators, as they reflect the health status of the lower trophic links. It has now been discovered that the route of entry of several urban and industrial pollutants present in dolphins is through the diet, which in turn is contaminated from the base of the food chain by the runoff of water into the sea (Misra *et al.*, 2019). Upcoming studies of trophic ecology in LABIOMA focus on the entire food web from producers, primary links to top predators in order to establish the relationship between them and be able to give rise to the identification of stocks.

Marine Natural Products Chemistry

Marine Natural Products Chemistry (MNPC) is a new research line at the Autonomous University of Yucatán, being the CCBA-UADY one of the few places in Mexico that have this new research line. The great variety of secondary metabolites that are produced by a species (micro or macro-organism) are of great interest, since these can function as markers that allow to identify and be able to differentiate one species from another (chemotaxonomy), as well as to understand the trophic niche of each organism in the environment (chemical ecology), in addition these metabolites can help to understand more questions complex such as the behaviour and evolution of an individual. One of the fields in which MNPC is best known is biotechnology, due to the wide variety of applications that these metabolites may have, either in areas such as biomedicine (obtaining drugs), agriculture (fertilizers), industry (antifouling, biomaterials), etc. One of the novel areas in which the MNPC have importance is in marine conservation, the search for new compounds with human utility helps to give a monetary value for the marine organisms, in addition to the value from the point of view of existence.

Until 2019 only 66 compounds of 18 species of marine organisms in the Yucatan Peninsula had been isolated, however, these metabolites showed a wide variety of pharmacological activities, including antiviral, antibacterial, cytotoxic, anti-predatory and interesting activities as the modulatory behaviour in animal models, some of these compounds was proposed as potential alternatives against brain diseases (schizophrenia, epilepsy, and Alzheimer's) (Pech-Puch *et al.*, 2020c). It is for this reason that LABIOMA has seen with great potential the incursion of the MNPC among its lines of research, thanks to which it has been able to isolate more than 30 natural products of marine organisms of the Yucatan Peninsula, being more than 10 of these new compounds reported and that showed a variety of pharmacological activities (antibacterial, anticancer, antiviral, anti-inflammatory, etc.) (Pech-Puch *et al.*, 2019, 2020a;b;d, 2021).

We are currently proposing to use the methodologies and specific tools of the MNPC (HPLC, Nuclear Magnetic Resonance, Mass Spectrometry, etc.) to complement the research focused on the evaluation of marine stocks, among the main approaches the use of marine natural products produced by parasites of fishes as potential markers of stocks.

CONCLUSIONS

For effective management of any given marine resource, innovative marine stewardship policies are required to address how fishing opportunities need to be allocated in space and time. This later, would help to monitor and obtain accurate estimates of abundances, catches and fishing effort and to assess and implement alternate exploitation strategies. To this end, we are at LABIOMA strengthening the assessments of commercially important marine stocks by using multidisciplinary approaches, such as population genetics, growth modelling, mark-recapture experiments, reproductive biology, trophic ecology, marine chemistry, and the parasitic communities of marine organisms on the coasts of the Yucatan Peninsula. These lines of research represent basic aspects to be known at the beginning of a fishing operation and would be of great help to decision makers at the time of establishing more precisely, catch quotas, fishing areas, closed seasons, and therefore make more efficient the repopulation strategies of these species that at present are probably in danger of overexploitation. Although fisheries are an important research area in the laboratory, as the publications cited in this review have shown, this is not our only research topic. Works on the biology of marine mammals, marine invertebrates as intermediate hosts in the life cycles of parasites, taxonomy of algae and marine invasive species, are also important research subjects in our research group.

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