Conceptual Framework for Estimating Annual Quotas in Mexican Queen Conch (*Strombus gigas*) Fisheries

ERNESTO A. CHÁVEZ[1] and SILVIA CONSTANZA-MORA[2]

[1]*Centro Interdisciplinario de Ciencias Marinas, I. P. N.*
Av. Instituto Politécnico Nacional s/n, Col. Sta Rita, Playa El Conchalito La Paz, B.C.S., 23096 México
[2]*Universidad Autónoma Metropolitana, U. Xochimilco, Esc. de Ciencias Biológicas y de la Salud*
Calzada del Hueso 1100, Del. Coyoacán 04960, México

ABSTRACT

Catch records of the queen conch (*Strombus gigas* L) caught at three areas of south eastern Mexico (Alacran Reef, Cozumel and Chinchorro Bank) were examined under the context of pseudo-cohort analysis and an age structured simulation model. The goal of the study was to assess the queen conch stock in each exploitation zone. Queen conch densities, and population parameter values were compiled from published sources in order to apply the analytical methods mentioned above. Estimations of the stock biomass, current fishing mortality (F) and F at the maximum sustainable yield (F_{MSY}) as extreme reference point, were made; this allowed to test the F and age of first catch required for the maximum biological yield, the maximum economic yield and the maximum social benefit as optimum harvesting strategies. Recommendations for the queen conch recovery and sustainable explotation are provided.

KEY WORDS: Queen conch, stock assessment, bio-economic simulation, south eastern Mexico

Marco Conceptual para la Estimacion de Cuotas de Captura en las Pesquerías Mexicanas de Caracol Rosado (*Strombus gigas*)

Se analizaron datos de captura de caracol rosado (*Strombus gigas* L) de tres zonas del sureste de México (Arrecife Alacranes Reef, Cozumel y Banco Chinchorro); el análisis se basó en el contexto del rendimiento por recluta, análisis de pseudo-cohortes y con un modelo de simulación basado en la estructura por edades. El objetivo del estudio fue el de evaluar los rendimientos de caracol rosado en cada zona donde es explotado. Los datos de densidad y los parámetros de la población del caracol rosado fueron compilados de la literatura y con ellos se aplicaron los métodos analíticos antes mencionados. Se estimó la biomasa de las existencias, la mortalidad por pesca (F) y la F en el nivel de rendimiento máximo sostenible (F_{MSY}) como punto de referencia extremo; esto permitió probar la F y la edad de primera captura requeridas para obtener el rendimiento máximo en biomasa, el rendimiento económico máximo y máximo beneficio social como posibles estrategias de explotación. Se hacen recomendaciones para la recuperación del recurso y para lograr su explotación en el marco de la conservación del recurso.

PALABRAS CLAVES: Caracol rosado, evaluación del recurso, simulación bio-económica, sureste de México

Le Cadre Conceptuel pour Estimer des Quotas Annuels dans les Pêcheries de Lambi Mexicain (*Strombus gigas*)

Les records de prise de lambis (*Strombus gigas* L) dans trois régions du sud-est du Mexique (Alacran Reef, Cozumel et Chinchorro Bank) ont été examinés sous le contexte de production excédentaire, l'analyse de production par recrue, l'analyse de pseudo-cohorte et un modèle de simulation structuré par l'âge. Le but de l'étude était d'évaluer le stock de lambis dans chaque zone d'exploitation. Les densités de lambis et les valeurs de paramètre démographiques ont été compilées à partir de sources publiées pour appliquer les méthodes analytiques mentionnées ci-dessus. Des estimations de la biomasse de stock, la mortalité de pêche actuelle (F) et F à la production durable maximum (FMSY) comme le point de référence extrême, ont été fournies avec chaque méthode; cela a permis d'évaluer le F et l'âge de première prise exigée pour la production biologique maximum, la production économique maximum et l'avantage social maximum comme les stratégies de récoltes optimales dans chaque région. Les recommandations pour la récupération de lambis et l'exploitation durable sont fournies.

MOTS CLÉS: Lambi, évaluation de stock, simulation bio-économique, sud-ouest Mexique,

INTRODUCTION

Queen conch stock is one of the most valuable fisheries resources of the Caribbean coral reefs. Unfortunately, it has been overfished throughout most of its distribution range and the stocks have usually been severely overexploited and in some cases the fishery has been pushed to local extinction as economic activity. Therefore, the goal of this paper is to analyze existing information available and to propose maximum allowable yields to restore or to avoid stock collapse of Mexican fisheries.

BACKGROUND

A workshop was held at Isla San Andrés, Colombia in November 2005, sponsored by the GCFI, was addressed to building a scientific consensus on regional queen conch management strategies; the main tasks assigned correspond to:

i) Compile queen conch morphometric relationships,
ii) Propose regional indices to follow-up possible trends in conch abundance, and
iii) To expand conceptual frameworks to estimate

annual quotas based upon standing stock estimations, dynamic production models, age structured assessment, or use of FAO's precautionary approach when no data are available.

Some of these accomplished tasks include information which is basic to carry on further stock assessments:

Population parameters — Information contained in the queen conch book edited by Appeldoorn and Rodriguez (1994) was compiled. Mean parameter values of the weight-length relationship and the operculum length-shell length (in cm and g) are the following:

Weight (W) - Length (L)
$W = a*L^b$, a = 0.0167; b = 2.93
(Modified after Appeldoorn, 1994)

Operculum Length (OL) - Shell length (SL)
OL = a+b*SL, a = -7.4; b = 0.37
(Herrera *et al*. 1994)

Operculum Width (OW) – Shell length (SL)
OW = a+b*SL, a = -1.0 b = 0.09
(Herrera *et al.* 1994)

Mean values of the growth parameter values and natural mortality (M) recorded by several authors (Chávez and Arreguín-Sánchez 1994, Rathier, and Battaglia 1994, Jensen 1996, 1997) were used to obtain a mean value, which was used to analyze the stock dynamics. Total length and meat weight are the variables used for reference; length ranges from 20.7 to 38.9 cm and meat weight from 119 to 724 g. Mean natural mortality value M = 0.605, W_{meat} = 356 g and growth parameter K = 0.4146. These values were used to reconstruct age structure on fitting the FISMO simulation model (Chávez 2005).

TRENDS IN CONCH ABUNDANCE

Records of conch density from various sources and localities around the Caribbean were compiled from several sources, and graphically shown in Figure 1. There, is evident that in ten out of the sixteen countries exploiting queen conch, densities are so low that are not enough to replace the stocks, where densities with 56 conchs per hectare are indicated by a horizontal line, showing the no-mating minimum densities found by Stoner and Ray-Culp (2000). Therefore, careful management practices should be applied there in order to allow restoration of the stocks and the fisheries in Bahamas, Virgin Islands, St. John, St. Thomas, Puerto Rico, St. Croix, Bermuda, Chinchorro Bank (Mexico), and Florida. Surveys recording queen conch densities have been made elsewhere in recent years; however, data included in Figure 1 give a general idea of the regional situation in the Caribbean. It is important to bear in mind that the over exploitation may change the picture, some times in very short time, as evidenced by Cozumel, which in Figure 1 appears as the most healthy stock; however, the intensity of exploitation lead to Mexican authorities to establish a ban to its capture, which has been applied for several years now.

According to the findings by Lugo-Fernández *et al*. 2001, Sale (2004), Delgado *et al.* (2005), and Thorrold SR (2006), there is diffuse drift of larval stages from the western Caribbean supplying the north western Caribbean, the Gulf of Mexico and the coasts of Florida (Chávez-Hidalgo *et al*. 2009); by analogy, it is expected that the east Caribbean stocks may play a similar role supplying the western Caribbean reef areas, otherwise dramatic extinctions in some low-density areas would have already occurred, but it is not the case.

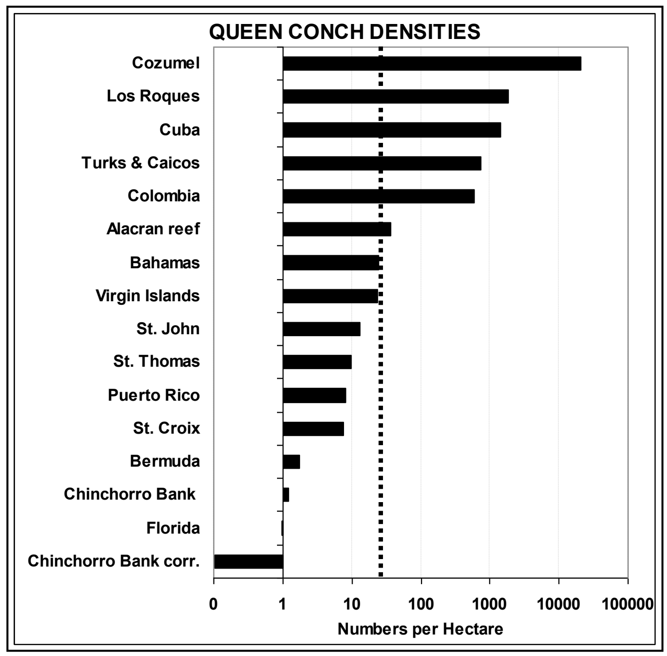

Figure 1. Queen conch stock densities recorded at several localities of the Caribbean, showing densities ranked in order of abundance. The dotted line indicates the no-mating minimum density (56/hec.) recorded by Stoner and Ray-Culp (2000). Based on data compiled directly or from other authors (Alcolado 1976, Berg 1976, Weil and Laughlin 1984, Botero 1984, Ferrer and Hernández 1989, Chávez and Arreguín-Sánchez 1994, Friedlander *et al*. 1994, Glazer and Berg 1994, Rodríguez-Gil 1994, and Basurto *et al*. 2005), with modifications.

THE QUEEN CONCH IN MEXICO

In three areas in south eastern Mexico the queen conch fisheries have been established for long time, but over exploitation has forced the government to ban two of them. This paper examines the case of the stocks of Alacran reef (Figure 2a), Cozumel (Figure 2b) and Chinchorro Bank (Figure 2c), Mexico, with the purpose of assessing the biomass in each of the three places where there is a fishery or there was one before its closeness, in order to provide recommendations to advise on the optimum harvesting strategies to apply in each place; the first one Alacran reef, is on the northern Campeche Bank, and the other two, Cozumel and Chinchorro Bank, are on the Caribbean coast of Mexico.

Alacran Reef

Here, the catch was as high as 306 tons in 1979, decreasing to 10 tons in 1987 with a slight increase to 51 tons in 1990. The fishery was closed in 1994 (Rodríguez-Gil 1994) and it has been banned until present time. There are opinions stating that the stock is recovered, but unfortunately, poaching has been taking place in recent times and density surveys are too few to determine the stock biomass and the possibility of assigning allowable quotas.

A reconstruction of the fishery was made by applying a simulation model where a reference was made to the exploitation rate E at the MSY level ($E_{MSY}= F_{MSY}/Z$) or limit reference point, as shown in Figure 3; in this figure, it is evident that in the last three years of catch records, the over exploitation exceeds the E_{MSY} leading to an exhausted stock.

In the queen conch exploited at Alacran reef, catch records available (Figure 3) range from 1970 to 1986 with 50 and 51 tons respectively; catch reached a maximum of 306 tones in 1979 declining abruptly with a few temporary recoveries between 1979 and 1982 (Rodíguez-Gil 1994). Local authorities closed the fishery permanently since 1986.

According to our own evidence, the apparent recovery of the stock over time lead to the increase of an illegal fishery that has becoming a social problem and the fishing authorities have been coping with pressure by the fishermen claiming to open the fishery again as a mean to control poaching.

The use of the pseudo cohort analysis seems to be quite convenient when fishing effort data are absent, and estimations of conch density are a suitable option instead. Hence, a pseudo cohort analysis (Gulland 1983) was carried on and it was applied to the years when there are catch data available (1976 to 1990); the same method was applied to the conch stock of Martinique by Rathier and Battaglya (1994) and as they mention, it is based on the same two equations as cohort analysis, but different from these authors, age was used here instead lengths. Time units are years and the age of first catch used in these analyses is three years, corresponding to a total length of 21 cm. The catch number per age group in a given year is estimated using the age-length key, the growth parameters and the length-weight relationship. Thereafter, population abundance at each age is estimated using the catch equation. This method was applied to each year of catch data and results were integrated in Figure 4, showing that

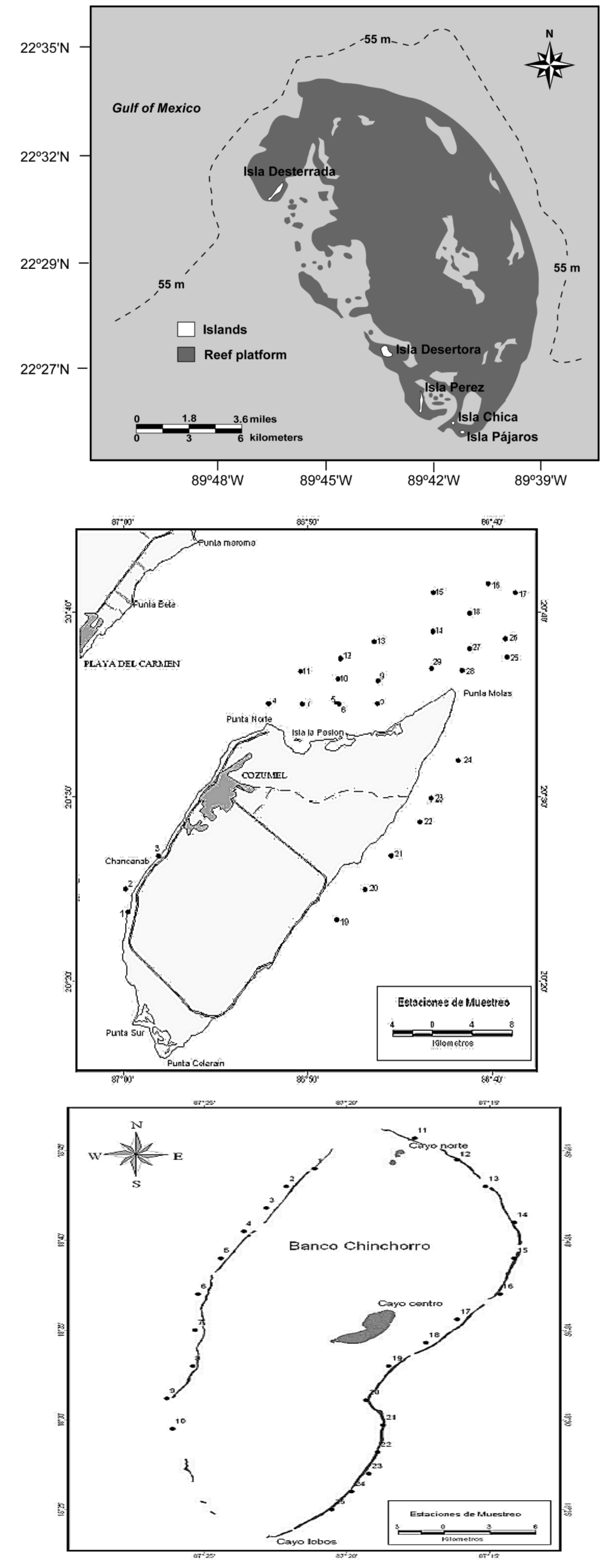

Figure 2a. (top) Alacran reef on ther northern shelf of Yucatan (after Tunnell, 2007). **b.** Cozumel (center), and **c.** Chinchorro Bank (bottom), both on the Mexican Caribbean coast, showing sampling stations by the Fisheries Institute in 2005 (b and c after Basurto *et al*. 2005).

the MSY corresponds to the catch of 1981 and in 1987 the stock was fully collapsed. An extension of the use of the pseudo-cohort analysis, where estimates of the MSY expressed as fresh weight as well as meat weight under a wide series of conch densities is shown in Figure 6. It is hoped that this approach may serve as a basis for its application in other grounds where the queen conch is exploited. Here the MSY is not intended to be adopted as a target for the fishery; in an effort to ensure that many fisheries may be depleted as consequence of over exploitation; in recent literature, recommendations to adopt the criterion of $0.75F_{MSY}$, are more frequently seen.

Cozumel

In this island, the fishery took place on the northern shelf of the bank, where it has an extension big enough to hold a significant amount of conch to sustain the fishery (Figures 2b, 5a). Samplings carried-on by the Fisheries Institute of Mexico display a declining tendency, ranging from 0.0822 (conchs/m^2) in 1995 to 0.0051 in 2005. Despite the high variability shown by the data, it is evident that a control of the access was required to avoid a collapse of the stock, which apparently occurred after 2005, leading to a closure of the fishery. Unfortunately, no catch data were available of this fishery and therefore it was not possible to carry-on an updated assessment of the stock to derive specific recommendations for its queen conch fishery management.

Chinchorro Bank

Catch data show a decline in densities, from 0.157 (conchs/m^2) in 1989 to near zero ten years later and an apparent recovery in the last five years of the series (Figure 5b); however, the report by Basurto *et al*. (2005) does not explain why samplings made in the nineties covered all the lagoon reef in an area bigger than 300 km^2 and during the last five years they have been constrained the surveys to the reef edge in an area of only 25.1 km^2. This omission implies huge differences in stock size, being nearly tenfold larger in the nineties as compared to the current decade, where the over exploitation collapsed the population in the lagoon, limiting its distribution to the reef edge only, where a small stock persists in depths where free divers are not able to reach.

STOCK ABUNDANCE

On the basis of the reef areas of Alacran (Figure 2a), Cozumel (Figure 2b) and Chinchorro Bank (Figure 2c), stock sizes were inferred. Stock assessment was conducted based on historical catch records, population parameters, and the reef area, and the application of the psudo-cohort analysis and with a simulation model (Chávez 2005). The latter reconstructs the age structure (for a detailed description of the method the reader should refer to the paper cited above and also in the paper by Chávez and Ley-Cooper (this volume). The F_{MSY} value at an age of first catch of tc = 0.2 found was F = 0.2, the year when the maximum catch was recorded at the reef.

Parameter values are indicated above. The expression Maximum Sustainable Yield (MSY) is used here as the extreme reference point, not as a target of the fishery. References to stock density were used at each reef by considering that the reef size is constant, so catch records, when available, can be considered a good indication of stock density; as an example of the potential yield expressed as fresh and as meat volumes, Figure 6 was prepared, showing the relationship of maximum yield as a function of conch density. It is hoped that it can be used as a quick reference to other queen conch stocks along the Caribbean.

ASSESSMENTS USING AGE STRUCTURE

Records of Alacran reef include 17 years of catch data; no effort data are available. Therefore, application of the FISMO simulation model (Chávez 2005) suggests that the MSY level is 225 tons and obtained with the fishing effort applied in 1979 (Figure 3). A full knowledge of queen conch stock dynamics and other important processes ruling its dynamics may still be far from being reached. However, on the basis of data compiled from the literature, enough information is known nowadays to be able to assess the queen conch stocks to a level where it can be much more accurate than just a rough approach (Figure 7a, b). When costs and benefits of the activity are available, another optional target for managing the stock can be the maximum

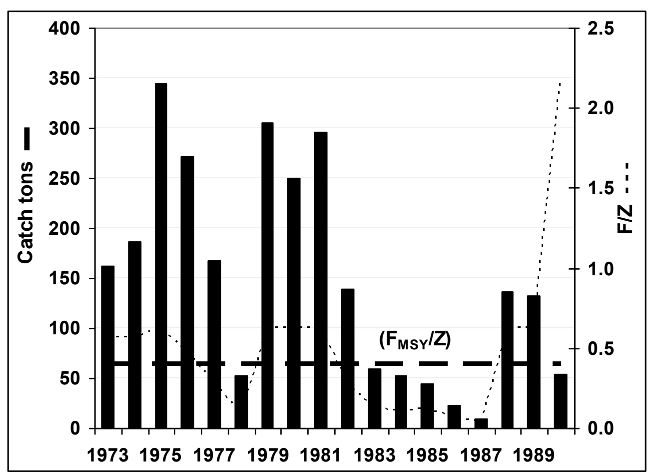

Figure 3. Catch records of queen conch of Alacran reef. Maximum potential yield evaluated with the aid of the FISMO simulation model (Chávez, 2005), corresponds to a catch of 225 tons. Horizontal dotted line indicates the exploitation rate (F/Z) at the maximum yield (F_{MSY}/Z), or threshold of over exploitation. The thinner dotted line shows the exploitation rate estimated each year; therefore, each time this line is above the value defined by the F_{MSY}/Z, is interpreted as a condition of an over exploited stock (after Beaver and Chávez 2007).

economic yield (F_{MEY}), because implies the convenient option of exploiting the stocks below the limit attained at the F_{MSY} and ensuring this way that fisheries being sustainable. In this regard, it may be considered that management regulation should impose quotas based on minimum densities as a reference, rather than quotas based on yields.

However, on the basis of the widespread areas occupied by the conch, many of them not accessible to fishers, there are many places beyond the fishing grounds, where the queen conch may find suitable conditions for reproduction, and this way the connectivity plays its role spreading offspring and replacing the stock in areas where conchs have been overexploited by fishermen. In order to protect the adult stock and to ensure that breeding zones remain inaccessible to fishers, conch exploitation in all the Caribbean should be made only by free diving.

By making reference to the Chinchorro Bank fishery, it is worth mentioning that the queen conch stock occupied all the lagoon area years ago, which is nearly eight times larger than the current edge of the Bank, where the samplings have been recently made. If the stock is allowed to be restored, then all the variables represented in Figure 7 A, B, could be multiplied by 12 and then is easy to perceive that in theory, the stock could allow the exploitation of nearly 60 tones, and the socio-economic benefits could sustain a much larger number of fishers that would significantly improve their living standards.

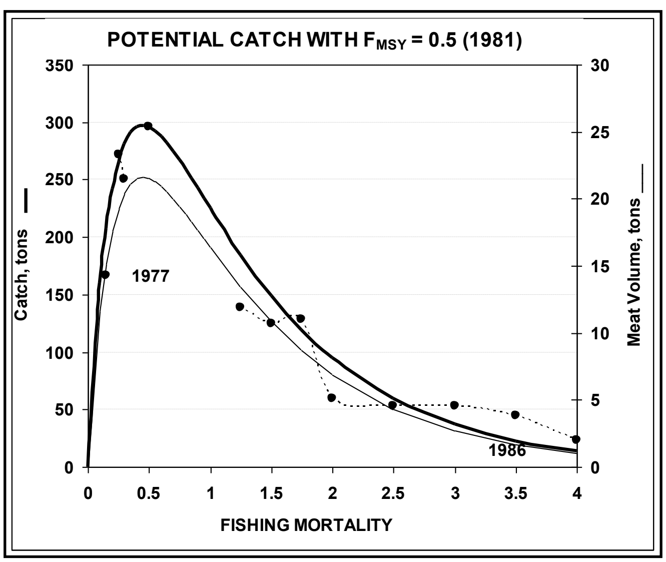

Figure 4. Application of the pseudo-cohort analysis to the queen conch stock of Alacran reef, Yucatan. Results are integrated over time. Maximum yield corresponds to the year 1981 when the catch attained its maximum volume (296 tons) and the F was at the F_{MSY}.

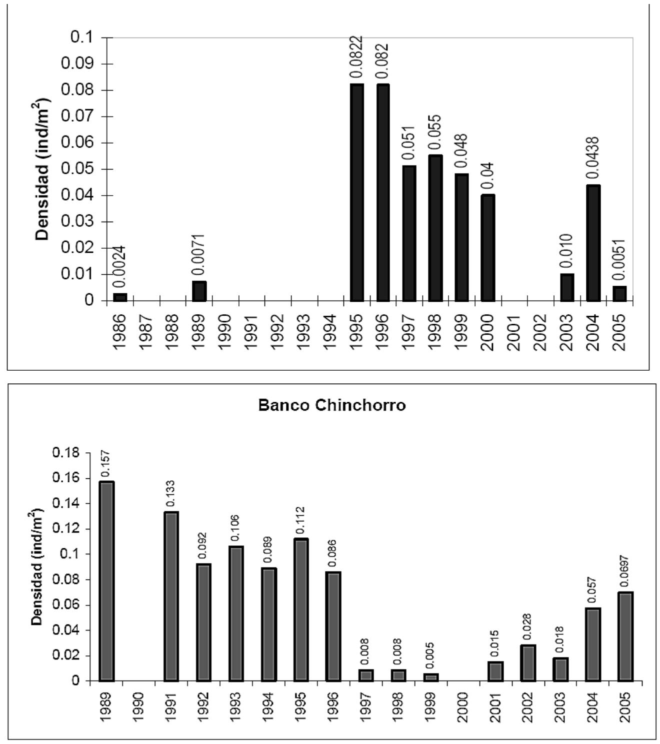

Figure 5a. Trends of the queen conch stock density (Number/m^2) recorded at Cozumel (top), and **b.** Chinchorro Bank (bottom) over time (after Basurto *et al*. 2005). It is important to consider that samplings in Chinchorro Bank used to cover the entire reef lagoon (>300 km^2), whilst in recent years densities are referred only to its edge in an area of only 25.1 km^2 (INP 2005); therefore, before 1997, stock size must have been nearly tenfold larger than in current times.

CONCLUDING REMARKS

Three conditions must be fulfilled in order to avoid further stock depletions, one, is not to lose control on the catch; banning has been an inconvenient at Alacran reef because it has stimulated illegal catch (Rodríguez-Gil Pers. comm.), especially through the last few years, when the stock apparently reached exploitable densities; the same process may ocurr in Cozumel. The second condition is to assess the stocks every year and to provide advice to fishing authorities before opening each fishing season so applying the principles of adaptive management. Finally, the third requirement is to carry-on capacity building; the San Andrés workshop gave a clear example in the sense that some scientific authorities are capable to do quite accurate assessments of the queen conch stocks, but the fishermen and some representatives of the fishing industry clearly showed that the fishing authorities lack of good advice so they may not be applying their management procedures on an informed basis and an evident misinformation on several avenues avoids the application of good management procedures, such that stocks do not fulfill the warranty of being exploited in a sustainable way.

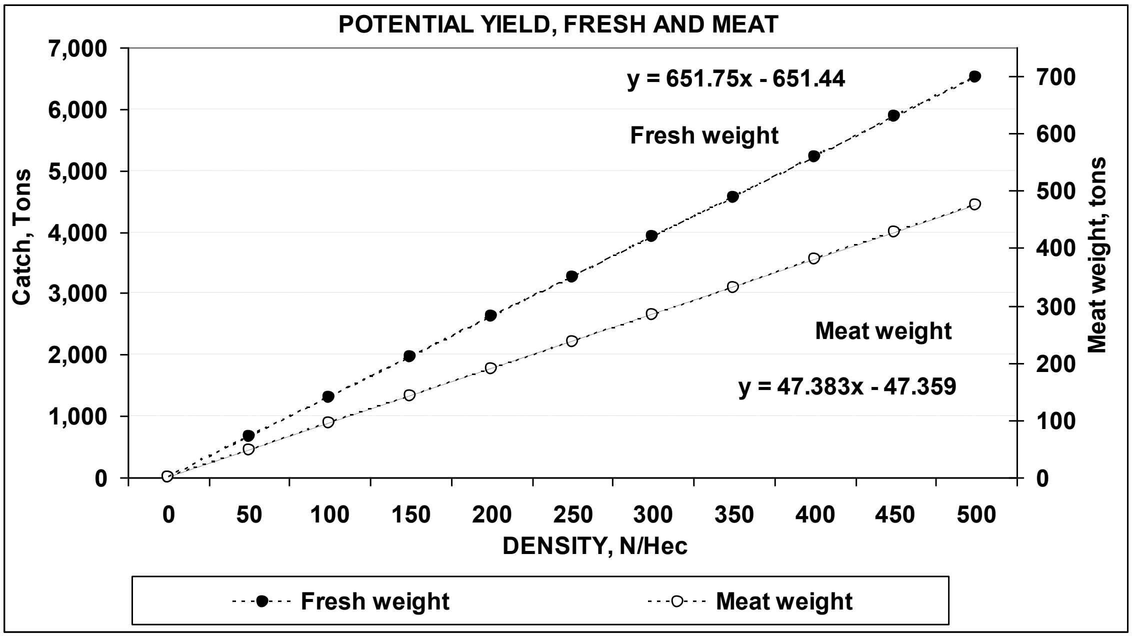

Figure 6. Estimations of the queen conch potential yield based on the use of the pseudo-cohort analysis using as reference different densities. Yield is estimated in relation to the area of Alacran reef, with 26,400 Hectares, but it can be easily inferred to other areas by making reference to the reef area occupied by each stock.

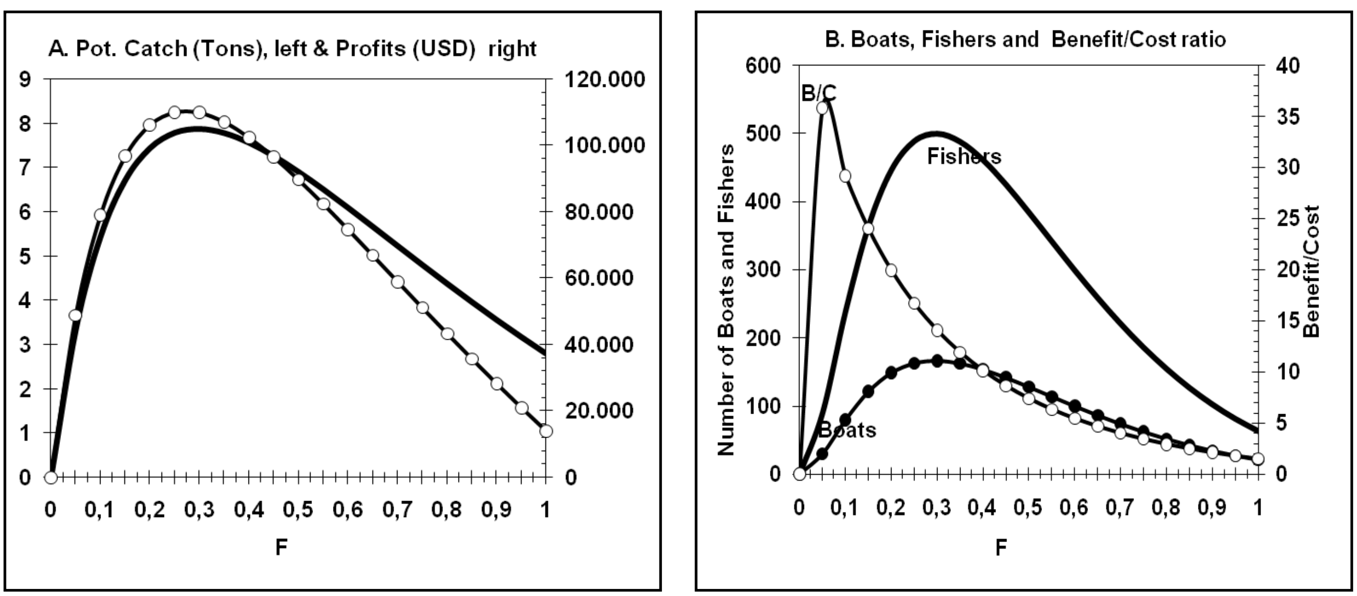

Figure 7a. (left) Potential maximum biological yield (Y_{MSY}), as a function of the age of first catch and the fishing mortality at Chinchorro Bank. According to the last fifteen years of simulation, the Maximum Yield (7.5 tons) can be obtained at a fishing pressure of F = 0.3 and tc = 3 years old. This scenario would provide profits in a maximum of $110,000 USD. However, the MEY would be obtained by reducing F at F_{MEY} = 0.25 with nearly the same profits; here, the yield would also be the same as the one obtained under Y_{MSY}. **Figure 7b.** (right) Potential maximum economic indicators (B/C, number of fishers and number of boats) as a function of the age of first catch (tc = 3 years old) and the fishing mortality, which is different for each variable.

AKNOWLEDGEMENTS

The senior author holds a research fellowship from EDI and COFAA, IPN.

LITERATURE CITED

Alcolado, P. 1976. Crecimiento, variaciones morfológicas de la concha y algunos datos biológicos del cobo *Strombus gigas* L. (Mollusca Mesogastropoda). Instituto de Oceanología, *Academia de Ciencias de Cuba, Serie Oceanológica* **34**:1-36.

Appeldoorn, R. 1994. Spatial variability in the morphology of queen conch and its implications for management regulations. Pages 145-157 in: R.S. Appeldoorn and B. Rodríguez (Eds.) *Queen conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Basurto, M., P. Cadena, G. Escobedo, F. Fernández, y F. Figueroa. 2005. Evaluación de la población de *Strombus gigas* en los bancos de Cozumel y Chinchorro y recomendaciones para su aprovechamiento sostenible. Centro Regional de Investigación Pesquera de Puerto Morelos, Quintana Roo. Informe de Investigación, 21 pp.

Beaver, C. and E.A. Chávez. 2007. Reef Fisheries. Pages 112-118 in: J. W. Tunnell, Jr., E.A. Chávez, and K, Withers (Eds.) *Coral Reefs of the Southern Gulf of Mexico*. Texas A&M University Press, College Station, Texas USA.

Berg, C.J. 1976. Growth of the queen conch *Strombus gigas*, with a discussion of the practicality of its culture. *Marine Biol*ogy **34**:191-199.

Botero, L. 1984. Observaciones sobre una población del cobo *Strombus gigas* L. en la Ensenada de Neguange, Caribe colombiano. *An. Inst. Inv. Mar. Punta de Betín* **14**:47-66.

Chávez, E.A. 2005. FISMO: A Generalized Fisheries Simulation Model. Pages 659-681 in: G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, and D. Woodby (Eds.). *Fisheries Assessment and Management in Data-limited Situations*. Alaska Sea Grant College Program, University of Alaska, Fairbanks, Alaska USA.

Chávez, E.A. and F. Arreguín-Sánchez. 1994. Simulation Modelling for conch fishery management. Pages 125-13 in: R.S. Appeldoorn and B. Rodríguez (Eds.) *Queen Conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Chávez, E.A. and K. Ley-Cooper. 2010. Bioeconomic assessment of a spiny lobster fishery of the Northwestern Caribbean. *Proceedings of the Gulf and Caribbean Institute* [In press].

Chávez-Hidalgo, A., G. De la Cruz-Agüero, and E.A. Chávez. 2009. Evidences on the connectivity of coral reefs of the Gulf of Mexico and the Mexican Caribbean. *Proceedings of the 11th International Coral Reef Symposium* Fort Lauderdale, Florida USA.

Delgado, G.A., R.A. Glazer, D. Aldana-Aranda, A. De Jesús-Navarrete, and L. Rodríguez-Gil. 2005. Identifying larval sources and sinks in the Florida Keys and Mexico using drift vials. *Proceedings of the Gulf and Caribbean Fisheries Institute* **58**:496-497.

Ferrer, L.T. and H. Hernández. 1989. Cuantificación de las poblaciones de Cobo *Strombus gigas* de las lagunas arrecifales del norte de Camagüey (Sector Punta Maternillo-Cayo Romano). Paginas 23-42. en: *Monografía Estudio de los Grupos Insulares y Zonas Litorales del Archipiélago Cubano con Fines Turísticos*. Suplemento.

INP (Fisheries Institute, Mexico).2006.Caracol del Caribe. Instituto Nacional de la Pesca, México. Paginas 127-744 en: *Carta Nacional Pesquera*. Diario Oficial de la Federación, México.

Friedlander, A., R.S. Apeldoorn, and J. Beets. 1994. Spatial and temporal variations in stock abundance of queen conch *Strombus gigas*, in the U.S. Virgin Islands. Pages 51-60 in: R.S. Appeldoorn and B. Rodríguez (Eds.) *Queen Conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Friedlander, A., R.S. Appeldoorn, and J. Beets. 1994. Spatial and temporal variations in stock abundance of queen conch, *Strombus gigas*, in the U. S. Virgin Islands. Pages 51-60 in: R.S. Appeldoorn and B. Rodriguez (Eds.).*Queen conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Glazer, R.A. and C.J. Berg. 1994. Queen conch research in Florida: An overview. Pages 79- 95 in: R.S. Appeldoorn and B. Rodríguez (Eds.) *Queen Conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Gulland, J.A. 1983. *Fish Stock Assessment: A Manual of Basic Methods*. Wiley-Interscience, FAO/Wiley series on Food and Agriculture, Volume 1. Chichester, United Kingdom. 223 pp.

Grau, P. and P. Alcolado. 1978. Caracterización de las poblaciones de cobo *Strombus gigas* en la plataforma cubana. I Congr. Ciencias del Mar junio 1987, La Habana. Resumen. 43 pp.

Herrera, A., J. Espinoza, D. Ibarzábal, R. Brito, G. González, G. Gotera, y E. Díaz. 1994. Datos sobre el cobo *Strombus gigas* (Mollusca Gastropoda) en la dieta de la langosta espinosa (*Panulirus argus*) Crustacea: Decapoda del borde de la plataforma suroccidental de Cuba. Paginas 159-167: R.S. Appeldoorn and B. Rodríguez (Eds.) *Queen conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Hesse, K.O. *1979*. Movement and migration of the queen conch, *Strombus gigas*, in the Turks and Caicos Islands. *Bulletin Marine Sci*ence **29**:303-311.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Science* **53**:820–822.

Jensen, A.L. 1997. Origin of the relation between K and L_{inf} and synthesis of relations among life history parameters. *Canadian Journal of Fisheries and Aquatic Science*. 54: 987-989.

Lugo-Fernández A., K.J.P. Deslarzes J.M. Price, G.S. Boland, and M.V. Morin. 2001. Inferring probable dispersal of Flower Garden Banks Coral Larvae (Gulf of Mexico) using observed and simulated drifter trajectories. *Continental Shelf Research* 21:47-67.

Rathier, I. & B. Battaglia. 1994. Assessment of the Martinique queen conch fishery and management perspectives. Pp: 29-49. *In*: R. S. Apeldoorn and B. Rodríguez (eds.) *Queen conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques, Caracas, Venezuela.

Rathier, I., & A. Battaglya. 1994. Assessment of the Martinique queen conch fishery and management perspectives. pp: 29-50. *In*: Appeldoorn, R and B. Rodríguez (Eds). *Queen conch, Biology, Fisheries and Mariculture*. Fundación Científica Los Roques. Venezuela.

Rodríguez-Gil, L. 1994. Análisis de la evolución de la pesquería de caracol en dos estados de la Península de Yucatán, México y en una cooperativa de pescadores. Pages 113-124 in: R.S. Appeldoorn and B. Rodríguez (Eds.) *Queen Conch Biology, Fisheries and Mariculture*. Fundación Científica Los Roques. Caracas, Venezuela.

Sale P.F. 2004. Connectivity, Recruitment Variation, and the Structure of Reef Fish Communities. *Integrated Comparative Biology* **44**:390-399.

Schaefer, M. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Bulletin I-ATTC/Bol. CIAT* **1**(2): 27-56.

Stoner, A.W. and M. Ray-Culp. 2000. Evidence of allele effects in an over -harvested marine gastropod: density-dependent mating and egg production. *Marine Ecology Progress Ser*ies **202**:297-302.

Strasdine, S. 1984. The ecology and biology of the queen conch *Strombus gigas*. Belize Fisheries Department, Belize and IDRC, Canada (File No. 3-P-70-0097). 87 pp.

Thorrold, S.R. 2006. Ocean ecology; don´t fence me in. New research that combines ocean circulation and genetic models to predict population structure of coral will help conservation efforts in tropical reef ecosystems. *Current Biology* **16**(16):638-640.

Tunnell, J.W. 2007 Reef distribution. Pages 14-22 in: J.W. Tunnell, Jr., E.A. Chávez, and K. Withers (Eds.). *Coral Reefs of the Southern Gulf of Mexico*. Texas A&M University Press, College Station, Texas USA.

Weill, E. and R. Laughlin. 1984. The biology, population dynamics and reproduction of the queen conch, *Strombus gigas* L. in the Archipiélago Los Roques National Park. *Journal of Shellfish Res*earch **4**:45-62.