PANAMJAS
Pan-American Journal of Aquatic Sciences

Historical exploitation and evaluation of the brown shrimp fishery *Farfantepenaeus californiensis* (Decapoda, Dendrobranchiata) in the Gulf of Tehuantepec, Oaxaca, Mexico.

PEDRO CERVANTES-HERNÁNDEZ[1,*], ANDREA FLORES GÓMEZ[1], SAUL JAÍME SERRANO GUZMÁN[1], SEBASTIÁN RAMOS CRUZ[2] & MARIA ISABEL GALLARDO BERUMEN[1]

[1]*Universidad del Mar, campus Puerto Ángel, Instituto de Recursos e Industrias, Carretera a Zipolite Ciudad Universitaria s/n, C.P. 70902, A.P. 47, Distrito de San Pedro Pochutla, Puerto Ángel, Oaxaca, México.* [*]*Email: pch@angel.umar.mx*
[2]*Programa Camarón, Instituto Nacional de la Pesca, Centro Regional de Investigación Pesquera - Salina Cruz. C.P. 70680, Salina Cruz, Oaxaca, México*

Abstract. Shrimp marine fishery in the Gulf of Tehuantepec was evaluated between 1960 and 2002. In this first evaluation brown, white, crystal and blue shrimp catches were analyzed together as a single population, but the authors used the same level of fishing effort to all shrimp species (151 ships); for this reason, we do not know which or which shrimp species were mainly exploited. A special evaluation to the *Farfantepenaeus californiensis* marine fishery was made from 1991 to 1998 by using Schaefer's biomass dynamic model with the observation error. Two units of the fishing effort were used (the number of trips and the number of ships). The brown shrimp fishery was not over-fished in the analyzed period, but during the 1996-97 fishing season, it recorded a level high of explotation. These results were used as a historical point of reference to evaluate the biomass changes between 1999 and 2005. During this last period, the brown shrimp fishery was over-fished. Annual commercial catch data of this period were obtained without the fishing effort record. For this reason, these data were not used in the biomass dynamic models.

Keywords: Dynamic models, exploitation, biomass, Gulf of Tehuantepec, shrimp fleet.

Resumen. Explotación histórica y evaluación de la pesquería de camarón café *Farfantepenaeus californiensis* (Holmes) (Decapoda, Dendrobranchiata) del Golfo de Tehuantepec, Oaxaca, México. La pesquería marina de camarón en el Golfo de Tehuantepec fue evaluada entre 1960 y 2002. En esta primera evaluación, las capturas de camarón café, blanco, cristal y azul fueron analizadas juntas como una población única, pero los autores usaron el mismo nivel de esfuerzo de pesca para todas las especies de camarón (151 barcos); por esta razón, no sé conoce cuál o cuáles especies de camarón fueron principalmente explotadas. Una evaluación especial para la pesquería de *Farfantepenaeus californiensis* fue realizada, de 1991 a 1998, usando el modelo dinámico de biomasa de Schaefer con el error de observación. Dos unidades de esfuerzo de pesca fueron usados (el número de barcos y el número de viajes). La pesquería de camarón café no fue sobre-explotada durante el periodo analizado, pero durante la temporada de pesca 1996-97, ésta registró un nivel alto de explotación. Estos resultados fueron usados como puntos de refencia para evaluar los cambios anuales de biomasa entre 1999 y 2005. Durante este último periodo, la pesquería de camarón café fue sobre-explotada. Los datos anuales de la captura comercial de éste periodo, fueron obtenidos sin el registro del esfuerzo de pesca. Por esta razón, estos datos no fueron utilizados en los modelos de biomasa dinámica.

Palabras clave: modelos dinámicos, explotación, biomasa, Golfo de Tehuantepec, flota camaronera.

Introduction

In the Gulf of Tehuantepec, the brown shrimp is captured in fishing zone 90, which is located between Punta Chipehua near Salina Cruz, Oaxaca (16º01´31.39´´ North and 95º22´24.56´´ West) and Puerto Chiapas, Chiapas (14º40´55.81´´ North and 92º23´44.13´´ West) (Fig.1). Fishing zone 90 is composed of five subsectors, with an approximate distance of 143 km between them and a total area of 5,988 km^2 of continental platform (Sepulveda & Soto 1991). In this fishing zone, the ships operate from five to 40 fathoms (i.e., 9.1 to 72.8 m) using trawl nets with light mesh of 57.15 mm (Anonimo 2004). A great number of salt marshes and coastal lagoons are located along the coastline, of which the most important are "El Sistema Lagunar Huave" in Oaxaca and "La Laguna del Mar Muerto", shared by the states of Oaxaca and Chiapas (Reyna-Cabrera & Ramos-Cruz 1998) (Fig. 1).

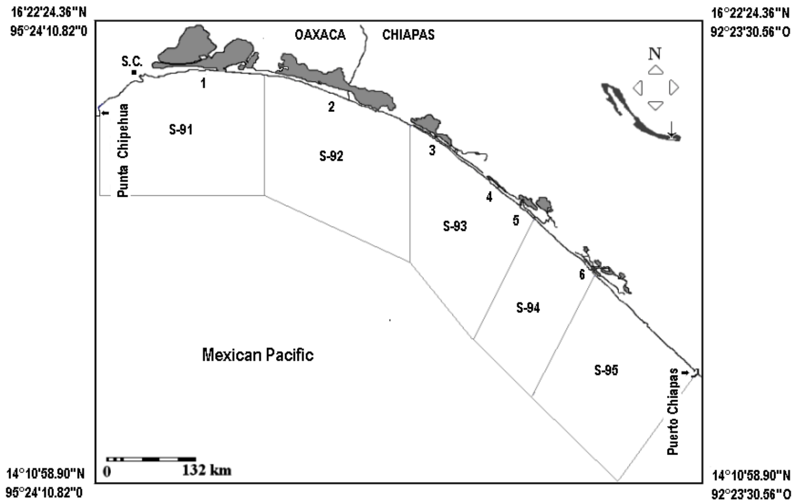

Figure 1. Geographic location of marine fishing zone 90 in the Gulf of Tehuantepec; sub-sectors (from S-91 to S-95). The coastal lagoon systems are: Huave (1); Mar Muerto (2); Cabeza de Toro-La Joya-Buenavista (3); Patos-Solo Dios (4); Carretas-Pereyra (5); Chantuto-Panzacola (6). Salina Cruz (S.C.).

Marine shrimp fishery in the Gulf of Tehuantepec was evaluated by Cervantes-Hernández *et al.* (2006) from 1960 to 2002. Brown shrimp, white shrimp, crystal shrimp and blue shrimp catches were analyzed together as a single population. The authors used Schaefer's model (1954) in order to estimate the maximum sustainable yield value (MSY=2,342 tons) and the level of fishing effort at which the maximum sustainable yield is achieved (f_{MSY}=151 ships) ($r=0.723$, $p<0.05$). Based on this model, the authors observed that the fishing effort had two periods of change. In the first period, from 1960 to 1980, the fishing effort was observed relatively constantly between 150 and 200 ships. During the first period, the maximum sustainable yield value was reached and surpassed at the end of the 70´s and at beginning of the 80´s. In the second period, an increase from 220 to 350 ships was recorded from 1981 to 2002, and over-fishing of shrimp was observed. Additionaly, within the second period, from 1983 and 2000, the authors reported an inversely proportional relationship between the marine and artisanal catches that, in combination with the increase of the fishing effort, caused the over-explotation of marine shrimp fishery in the Gulf of Tehuantepec.

A similar level of fishing effort was used by Cervantes-Hernández *et al.* (2006) to all shrimp species from the Gulf of Tehuantepec. The results obtained by these authors did not show which species were more affected by the historical changes of the fishing effort. For this reason, in this work the brown shrimp fishery was evaluated from 1991 to 1998. Such an analysis for the brown shrimp in the Gulf of Tehuantepec had not been done before. The results obtained were used as a historical point of reference to describe the recent biomass changes of *Farfantepenaeus californiensis* (Holmes 1900) in the Gulf of Tehuantepec, from 1999 to 2005.

The Schaefer (1954) and Fox (1970)

biomass dynamic models (with the observation error) were used in order to evaluate the exploitation (over-fished or non-over-fished) and to estimate the annual biomass changes between 1991 and 1998. According to Punt & Hilborn (1996), both objectives were developed based on the description of the following parameters: MSY; f_{MSY}; the maximum population size (k); the intrinsic growth rate (r); the catchability coefficient (q).

Materials and Methods

Annual commercial catch data of *F. californiensis* were used to estimated the catch per unit of effort (CPUE, tons per number of trips and ships). This information was obtained from fishing zone 90 in the Gulf of Tehuantepec during seven fishing seasons (from September to May) between 1991 and 1998. Annual commercial catch data between 1999 and 2005 were obtained without the fishing effort record and, for this reason, these data were not used in the biomass dynamic models. Annual commercial catch data were provided to the Universidad del Mar in Puerto Ángel, Oaxaca, México by the Centro Regional de Investigación Pesquera of Salina Cruz, Oaxaca (Project 2IR043). The particular characteristics of the comercial ships were not available.

According to Punt & Hilborn (1996), the Schaefer and Fox models are respectively: $B_{t+1}=[B_t+r\cdot B_t\cdot(1-(B_t/k)-C_t]\cdot V_t$ and $B_{t+1}=[B_t+r\cdot B_t\cdot(1-(\ln B_t/\ln k)-C_{t.}]\cdot V_t$. ($B_{t+1}$=predicted biomass; B_t=present biomass; k=maximum population size; r=intrinsic growth rate; C_t=present catch; $V_{t=}$ observation error). $V_t=[\ln I_t-\ln U_t]$ (I_t=present catch per unit of effort; U_t= predicted catch per unit of effort).

The likelihood function of logarithmic normal distribution was used to obtain the estimation error (ε) between I_t and U_t. According to Ludwin & Walters (1989), the likelihood function is: $-\ln\ell(k, r/I_t)=\sum_{t=1}^{n}[\ln SD_{Vt}+(1/2)\cdot\ln 2\pi+V_t^2/2\cdot SD_{V\,t}^2]$. ($-\ln\ell$ =minimum likelihood of the parameters k and r). $SD_V=\sqrt{[(1/n)\cdot\sum_{t=1}^{n}(V_t^2)]}$ (SD_{Vt}=standard deviation of V_t; n=total number of fishing seasons analyzed). The catchability coefficient was estimated with: $q=EXP[(1/n)\cdot\sum_{t=1}^{n}\ln(I_t/B_t)]$.

The SD_{Vt} values obtained were used to evaluate the statistic fit between the I_t and U_t in the Schaefer and Fox models. Acording to Ludwin & Walters (1989), SD_{Vt} take values between zero and one. A SD_{Vt} value near zero guarantees a good statistic fit between I_t and U_t values; this means that the observation error was not present in all the analyzed fishing seasons or was present only in some of these. Therefore, the predicted annual biomass changes of *F. californiensis* in the Gulf of Tehuantepec are statisticly reliable. A SD_{Vt} value near one suggests a bad statistic fit between I_t and U_t values; this means that the observation error was present in all or almost all the analyzed fishing seasons. Therefore, the predicted annual biomass changes of *F. californiensis* in the Gulf of Tehuantepec are not statisticly reliable.

According to Polacheck *et al.* (1993), the confidence intervals for the parameters k and r were estimated only to the model that resulted in the best statistic fit between the I_t and U_t.

The maximum sustainable yield value and the level of fishing effort at which the maximum sustainable yield is achieved were estimated with: $MSY=r\cdot k/4$; $f_{MSY}= r/2\cdot q$.

According to Chien-Hsiung (2004), the relationships between equilibrium and non-equilibrium in a fishery were considered in order to describe the exploitation and the annual biomass changes of *F. californiensis*. The relationships are:

a) When the biomass changes oscillate below MSY value, the fishery was not over-fished because the level of fishing effort is relatively low. This relationship allows an increase in the net production without affecting the equilibrium between the birth and death rates (the biomass is at equilibrium). Both rates were considered in parameter r.

b) When the biomass changes have reached or surpassed the MSY value, the fishery is generally over-fished by an increase of the fishing effort. This relationship will break the equilibrium between the birth and death rates (the biomass is not at equilibrium).

c) The MSY value can not be greater or equal than the k parameter value.

Results

Table I shows the parameter of *F. californiensis* obtained with the Schaefer and Fox models.

Table I. Parameter of *Farfantepenaeus californiensis*, between 1999 and 2005; the maximum sustainable yield (MSY), the level of fishing effort at which the maximum sustainable yield is achieved (f_{MSY}), the catchability coefficient (q), the maximum population size (k), the intrinsic growth rate (r), the standard deviation of the observation error (SD_{Vt}).

Models	MSY tons	f_{MSY}	q	k tons	r annual	
Schaefer	118	136 trips	0.01210	143	3.31	SD_{Vt}=0.178
Schaefer	113	78 ships	0.23570	123	3.66	SD_{Vt}= 0.123
Fox	148,210	1,787 trips	0.00769	21,534	27.53	SD_{Vt}=0.212
Fox	11,753,442	332,022,098 ships	0.00009	1,581,815	29.72	SD_{Vt}=0.643

Schaefer's models estimated similar values for MSY, k and r (Table I). The parameter q and the f_{MSY} value were not consistent, because the units of the fishing effort used are physically different (trips and ships) (Table I). Both models generated a good statistic fit between the I_t and U_t (Figures 2 and 3). The standard deviation values were estimated with the number of trips in 0.178 and with the number of ships in 0.123 (Table I).

Based on Schaefer's model with the number of trips, the I_t and U_t values resulted in a good statistic fit in the 1991-92, 1993-94, 1996-97 and 1997-98 fishing seasons (57 % without record errors) (Fig. 2). Only the 1992-93, 1994-95 and 1995-96 fishing seasons showed a bad statistic fit (43 % with record errors) (Fig. 2).

Based on Schaefer's model with the number of ships, the I_t and U_t values resulted in a good statistic fit in the1991-92, 1992-93, 1993-94, 1996-97 and 1997-98 fishing seasons (71 % without record errors) (Fig. 3). Only the 1994-95 and 1995-96 fishing seasons showed a bad statistic fit (29 % with record errors) (Fig. 3).

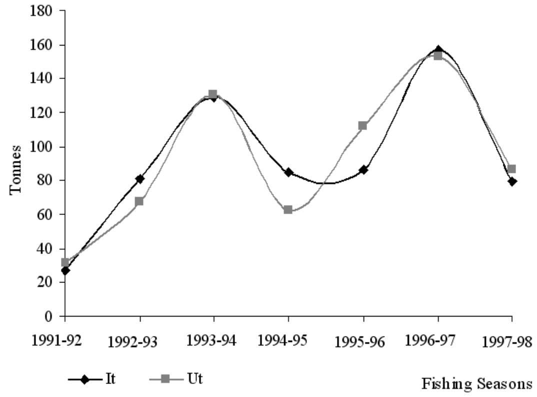

Figure 2. Schaefer's model with the number of trips and statistic fit between observed catch per unit of effort (I_t) and predicted catch per unit of effort (U_t).

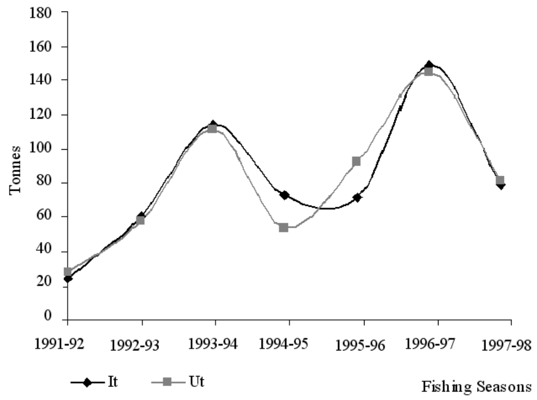

Figure 3. Schaefer's deterministic model with the number of ships and statistic fit between observed catch per unit of effort (I_t) and predicted catch per unit of effort (U_t).

Fox's model with the number of trips generated a standard deviation value of 0.212 (Table I). This model did not generate a good statistic fit between the I_t and U_t and only the 1991-92 and 1992-93 fishing seasons showed a good statistic fit (29 % without record errors) (Fig. 4). Fox's model with the number of ships generated a standard deviation value of 0.643 (Table I). This model did not generate a good statistic fit between the I_t and U_t (100 % of data set with record errors). As a result, all Fox's models were discarded for this analysis.

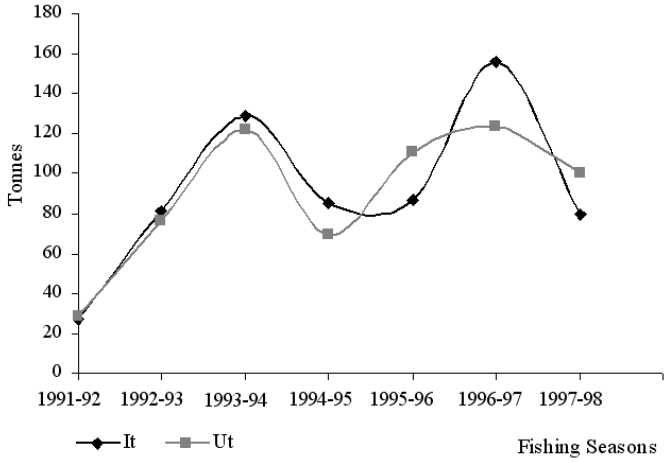

Figure 4. Fox's model with the number of trips and statistic fit between observed catch per unit of effort (I_t) and predicted catch per unit of effort (U_t).

Based on the results shown in Table I and figures 1 and 2, we suggest that Schaefer's models are statisticly reliable and could be used in order to evaluate the exploitation and to estimate the annual biomass changes of *F. californiensis* in the Gulf of Tehuantepec between 1991 and 1998. Both objectives were described with: $B_{t+1}=[B_t+3.31\cdot B_t\cdot(1-(B_t/143)-C_t]\cdot V_t$ for the number of trips (Table I and Fig. 5) and $B_{t+1}=[B_t+3.66\cdot B_t\cdot(1-(B_t/123)-C_t]\cdot V_t$ for the number of ships (Table I and Fig. 6).

With the number of trips, the predicted annual biomass changes were observed below MSY value in the 1991-92, 1992-93, 1993-94, 1994-95, 1995-96, 1997-98 fishing seasons (Fig. 5). In the 1996-97 fishing season and between 1999 and 2005 the predicted annual biomass changes were observed above MSY value (Fig. 5).

The results indicated that the fishery of *F. californiensis* in the Gulf of Tehuantepec was not over-fished between 1991 and 1998 because 99 % of the predicted annual biomass changes were observed at equilibrium (Fig. 5). This fishery from 1999 to 2005 was over-fished because 100 % of the predicted annual biomass changes were observed at non-quilibrium. In this last period the predicted annual biomass changes were observed between 133 and 154 tons, close to k value (Fig. 5).

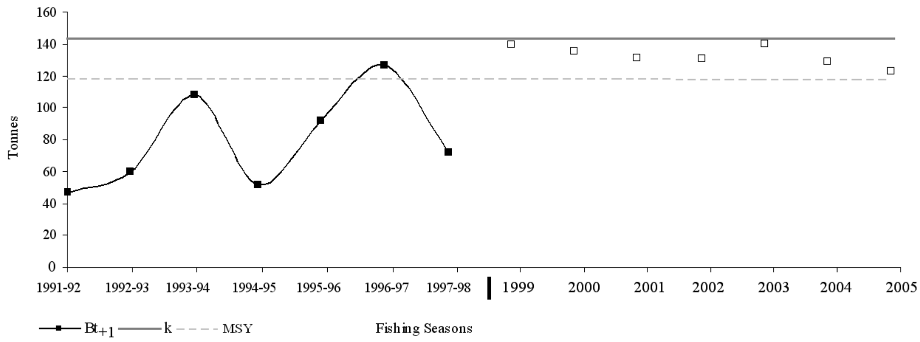

Figure 5. Schaefer's model with the number of trips and evaluation of the fishery of *Farfantepenaeus californiensis* in the Gulf of Tehuantepec; the black circles with a continuous line are predicted biomass (B_{t+1}); the white circles are present biomass (B_t); the continuous line is the maximum population size (k); the discontinuous line is the maximum sustainable yield (MSY).

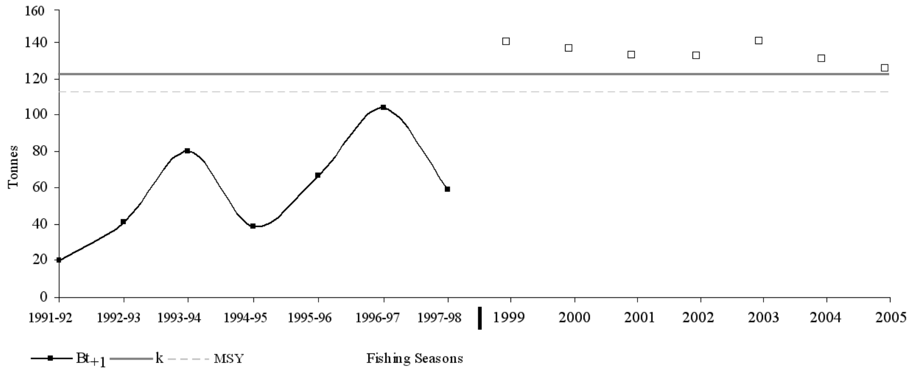

Figure 6. Schaefer's model with the number of ships and evaluation of the fishery of *Farfantepenaeus californiensis* in the Gulf of Tehuantepec; the black circles with a continuous line are predicted biomass (B_{t+1}); the white circles are present biomass (B_t); the continuous line is the maximum population size (k); the discontinuous line is the maximum sustainable yield (MSY).

With the number of ships, the predicted annual biomass changes were obseved below MSY value in all fishing seasons. The predicted annual biomass changes were observed above MSY value between 1999 and 2005 (Fig. 6).

The results indicated that the fishery of *F. californiensis* in the Gulf of Tehuantepec was not over-fished between 1991 and 1998 because 100 % of the predicted annual biomass changes were observed at equilibrium (Fig. 6). The fishery from 1999 to 2005 was over-fished because 100 % of the the predicted annual biomass changes were observed at non-equilibrium. In this last period the predicted annual biomass changes were observed between 133 and 154 tons, above k value (Fig. 6).

Table II shows the confidence intervals for the parameters k and r in both Schaefer's models.

Table II. Confidence intervals for the maximum population size (k) and for the intrinsic growth rate (r); the lower confidence interval (LCI), the upper confidence interval (UCI).

Schaefer's Models	k	LCI	UCI	r	LCI	UCI
number of trips	143	140	150	3.31	13.11	3.41
number of ships	123	122	124	3.66	3.62	3.75

Discussion

The observation error was used in order to evaluate record errors in annual commercial catch data (Punt 1988) and to generate a reliable statistic fit between the I_t and U_t (Ludwin & Walters 1989). The analysis of these errors resulted in an important strategy because the commercial catch-at-age data was not available for the fishery of *F. californiensis* in the Gulf of Tehuantepec.

Considering the number of ships and Fox's model with the process error, Morales-Bojorquez *et al.* (2001) evaluated the fishery of *F. californiensis* in the Gulf of California between 1976 and 1997. With this error, the statistic fit between observed and predicted catch per unit of effort generated a SD_{Wt} value of 0.209. The authors indicated that the number of ships was the best unit of fishing effort to evaluate this fishery; however, Schaefer's model and the number of trips were not used in this work.

With Schaefer's model and the observation error, we obtained a reliable statistic fit between the I_t and U_t (Fig. 3 and 4). The standard deviation value reported by Morales-Bojorquez *et al.* (2001) with the process error, was greater than standard deviation values obtained with the number of trips (SD_{Vt}=0.178) and with the number of ships (SD_{Vt}=0.123) (Table I). This suggests that the predicted annual biomass changes of *F. californiensis* in the Gulf of Tehuantepec were statisticly more reliable than the predicted annual biomass changes reported by Morales-Bojorquez *et al.* (2001).

Morales-Bojorquez *et al.* (2001) indicated that analyzed commercial catch data did not have record errors and additionally, these authors did not relate the observed catch per unit of effort between fishing seasons. Based on this, these authors concluded that the predicted biomass of *F. californiensis* in the Gulf of California had a "stochastic" behavior between 1976 and 1997. The predicted annual biomass changes could not be explained with Fox's model and, according to these authors, the predicted annual biomass changes were produced by others factors not considered in Fox's model (environmental, population or both).

Catch per unit of effort records were considered as independent from one fishing season to the other by Morales-Bojorquez *et al.* (2001); however, according to Hilborn & Walters (1992) this is not necessarily the best assumption because the catch recorded in a fishing season will be related to the catch recorded in the next fishing season. For this reason, we estimated the observation errors (or record errors) in each fishing season to relate catch per unit of effort records between analyzed fishing seasons. Based on this, we obtained a "deterministic" behavior of the predicted biomass of *F. californiensis* in the Gulf of Tehuantepec from 1991 to 1998. In this case, the predicted annual biomass changes were generated by the observation errors in Schaefer's models.

In the north Mexican Pacific the oceanographic conditions are more stable than in the south Mexican Pacific (Cervantes-Hernández *et al.* 2008 b). For this reason, the net production of shrimp in the fishing zones from the north Mexican Pacific (Zone10: El Sauzal-Baja California Norte, 50: La Paz-Baja California Sur, 20: Guaymas, Sonora, 30: Mazatlán, 40: Sinaloa y 60: Bahía de Banderas, Nayarit) has always been greater than the net production of shrimp reported from fishing zone 90 in the Gulf of Tehuantepec (Cervantes-Hernández *et al.* 2008 a).

In the Gulf of California the annual biomass changes of *F. californiensis* were reported between 25,000 and 40,000 tons from 1976 to 1997 (Morales-Bojorquez *et al.* 2001). In the Gulf of Tehuantepec it was observed between 20 and 105 tons from 1991 to 1998. In this same gulf an average of 143 tons were observed from 1999 to 2005 (Figures 5 and 6).

In this study the maximum population size resulted at 143 tons with the number of trips and at 123 tons with the number of ships (Tables I, II). In the Gulf of California the parameter k has been reported at 31,912 tons (Morales-Bojorquez *et al.* 2001). With these k values, we concluded that the annual biomass changes (the net production) of shrimp in temperate zones (Gulf of California) are greater than the annual biomass changes of shrimp in tropical zones (Gulf of Tehuantepec).

The parameter k reported by Morales-Bojorquez *et al.* (2001) was consistent with Sierra-Rodríguez *et al.* (2000). The authors reported a k value at 10,000 tons for the blue shrimp population and at 9,400 tons for the white shrimp population in the north Mexican Pacific between 1983 to 1999.

In this study the parameter q resulted at 0.01210 with the number of trips and at 0.23570 with the number of ships (Table I). In the Gulf of California the parameter q has been reported at 0.00023 (Morales-Bojorquez *et al.* 2001). With these q values, we concluded that the brown shrimp catches in temperate zones (Gulf of California) are less available than the brown shrimp catches in tropical zones (Gulf of Tehuantepec).

The parameter q reported by Morales-Bojorquez *et al.* (2001) was consistent with Sierra-Rodríguez *et al.* (2000). The authors reported a q value at 0.001 in the blue shrimp population from the Gulf of California. Considering a sweep area, the q value was estimated by using Schaefer's model and the observation error.

Comparing the k and q values between temperate and tropical climatic zones, we observed an inverse relationship between the annual biomass changes (the net production) and the brown shrimp catches. i. e. the Gulf of California had greater net production with a lower level of brown shrimp catches (between 2 and 10 tons of catch per unit of effort). The Gulf of Tehuantepec had lower net production with a greater level of brown shrimp catches (between 50 and 160 tons of catch per unit of effort). The results obtained from 1999 to 2005 in the Gulf of Tehuantepec were consistent with the aforementioned conclusions.

The results obtained indicated that, in the Gulf of Tehuantepec, large fluctuations in the annual biomass changes of *F. californiensis* are more likely than small fluctuations. According to Morales-Bojorquez *et al.* (2001) in the Gulf of California, large fluctuations in the annual biomass changes of *F. californiensis* are less likely than small fluctuations. This comparison between the annual biomass changes is consistent with the oceanographic conditions reported to the north (Morales-Bojorquez *et al.* 2001) and south (Cervantes-Hernández *et al.* 2008 b) from the Mexican Pacific.

In the Gulf of Tehuantepec f_{MSY} value has been estimated at 151 ships by Cervantes-Hernández *et al.* (2006) between 1960 and 2002 (for all shrimp). For the fishery of *F. californiensis* we estimated a f_{MSY} value at 78 trips, from 1991 to 1998. This suggests an increase of 73 ships on marine shrimp fishery explotation (in three years). 241 ships were reported in fishing zone 90 during 2003 (Anonimo 2005).

The results obtained with the number of trips (Fig. 5 and Table I) was not compared with others bibliographical results because studies with this type of fishing effort have not been done in the Mexican Pacific.

The net production shrimp from 1999 to 2005 was recorded between 133 and 154 tons, close to k (with the number of trips) (Fig. 5) and above k (with the number of trips) (Fig. 6). The fishery of *F. californiensis* in the Gulf of Tehuantepec was over-fished between 1999 and 2005 (Figures 5 and 6). In this period, high levels of net production were observed, with an inverse relationship between net production and the brown shrimp catches. This report was consistent with Anonimo (2005), where the authors reported a reduction of 50 % in the brown shrimp catches in the Gulf of Tehuantepec (668 tons) during the 2002-03 fishing season.

The Gulf of Tehuantepec had lower net production with a greater level of brown shrimp catches. This conclusion suggests that, a good evaluation for any fishery should consider a simultaneous analysis of the net production and catches. The evaluation of a fishery should never be done by analyzing only one of these data sets, because the evaluation will be incorrect. We must consider the real differences between the weight of the net production and the catches.

Acknowledgments

Thanks to the CRIP of Salina Cruz, Oaxaca, México for providing the data set used in this research, and to the Universidad del Mar (UMAR) for economic resources. Sincere thanks to D. Brockett, S. Abels, E. Robles Zavala and anonymous reviewers for their valuable time and comments regarding this article.

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Received June 2009
Accepted June 2010
Published online August 2011