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An Assessment and Management of Green Tiger Shrimp (*Penaeus semisulcatus*) Fishery in the Jazan Area (Red Sea, Saudi Arabia)

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Abstract. The maximum sustainable yield (MSY) and the corresponding values of fishing effort (number of fishing days) were estimated for the green tiger shrimp, *Penaeus semisulcatus* fishery in the Jazan area of the Red Sea. The equilibrium as well as the non-equilibrium approach was used to fit the surplus-production model on the statistical data of catch and fishing effort. The study area extends from Lat 17º40' N southwards to the Yemeni border which supports the activity of more than 90% of the bottom trawlers exploiting the shrimp fishery in the Saudi Red Sea coast .

Results from both treatments indicated that the current fishery for the tiger shrimp is under the level of maximum sustainable exploitation. The maximum sustainable yield (MSY) was estimated at 945.3 and 829.8 tonnes by the equilibrium and non-equilibrium model, respectively. The corresponding levels of fishing effort required to generate the maximum sustainable yield (MSY) were estimated by the two models, respectively at 21.620 and 17.370 fishing days per fishing season.

Keywords: Red Sea, Tiger shrimp, *Penaeus semisulcatus*, Maximum Sustainable yield, Surplus-production modeling, Fisheries.

Introduction

Shrimp resources in the Jazan area are (Fig. 1) exploited by an industrial fleet of bottom trawlers ranging in size from 20 to 31 meters in length. The green tiger shrimp *Peneaus semisulcatus* dominates the commercial catches from trawlers operated in this area and constituted 82.5% to 90.5% of the total shrimp catch during the study period (Fig. 2).

Fig. 1. A map showing the study area off the Saudi coast which extends from Lat. 17º40'N southwards to the Yemeni border covering an estimated total area of about 10,000 square kilometers.

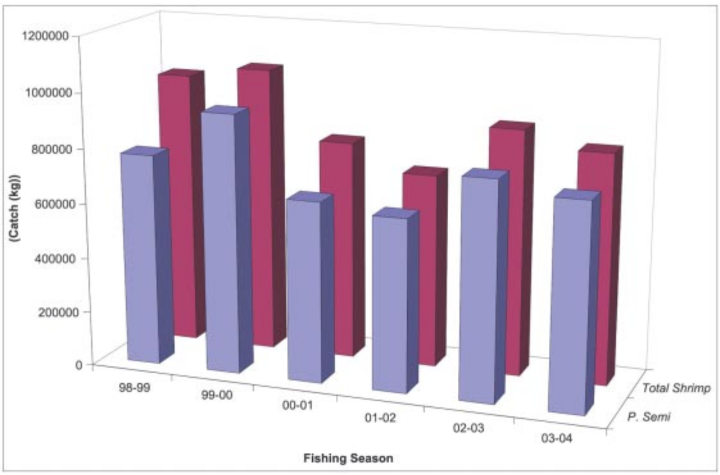

Fig. 2. Catch (kg) of tiger shrimp and total shrimp taken by bottom trawlers from Jazan area during the fishing seasons 98/99-03/04.

Its catch has showed a sharp decline over the last six (95/96-00/01) fishing seasons (Abdallah and Abushusha, 2003). The increase in the fishing effort in the Jazan area has raised concerns relating to the resource management implications.

A set of precautionary management measures are being accordingly applied by the Saudi government to approach sustainable exploitation of shrimp fishery. In this context, the objectives of this study were to monitor the status of the shrimp fishery and provide information required for its management.

Materials and Methods

Data Sources

Statistical data on catch (yield in biomass) and corresponding fishing effort (No. fishing days) for the period 1998/1999-2003/2004 have been compiled from the Jazan Fisheries Service Station (JFSS).

Data Analysis

Production Models

Two methods were used to fit the surplus-production model to the data on catch and fishing effort (No. of fishing days) of tiger shrimp in The Jazan area (Fig. 1).

The first treatment considered the equilibrium approach of surplus production model (Schaefer, 1954). The Schaefer model expresses the yield per unit of fishing effort as a function of fishing effort:

$$Y(i) / f(i) = a + b f(i) \quad (1)$$

Where $f(i)$ = effort in year, i = 1, 2, ..., n

$Y(i) / f(i)$ = yield in weight per unit of effort in year, i = 1, 2, ..., n

The slope, *b*, must be negative if the yield per effort decreases for increasing *f*. The intercept, *a*, is the yield per effort value obtained just after the first boat fishes on the stock for the first time.

To derive an estimate of Maximum Sustainable Yield (MSY) the following derivative of formula (1) was used:

$$Y(i) = a f(i) + b f(i)^2 \quad (2)$$

The graph of equation (2) is a parabola and it takes its maximum value for:

$$f_{(MSY)} = -0.5\, a / b \quad (3)$$

The corresponding maximum sustainable yield (MSY) becomes:

$$MSY = -0.25\, a^2 / b \quad (4)$$

The second treatment followed the non-equilibrium approach of the surplus production model as described by Prager (1994). This model was applied using ASPIC computer program (Prager 1995) that fits a non-equilibrium logistic (Schaefer) production model to catch and effort data. This model uses a fitting procedure similar to that developed by Pella (1967), later used by Pella and Tomlinson (1969) in their GENPROD computer program, and termed the "time-series method" by Hilborn and Walters (1992). The basic model is derived by postulating that the time rate of surplus biomass production (the excess of growth and recruitment over natural mortality) can be represented by the differential equation:

$$dB_t / dt - (r - F_t) - r / K\, B_t^2 \qquad (5)$$

Where B_t is the population biomass at time t, F_t is the corresponding rate of fishing mortality, r is a constant model parameter often considered the population's intrinsic rate of increase, and K is a constant model parameter often considered the carrying capacity of the environment (maximum population size). Details of the model development are described in Prager (1994 and 1995).

The estimation process results in direct estimates of B_1, r, K, and q, which define unique estimates of the stock biomass levels B_2, B_3, ..., B_T and the stock's production during each period of time. The corresponding estimates were derived from the model:

$$\text{MSY} = Kr/4,\ B_{\text{MSY}} = K/2,\ F_{\text{MSY}} = r/2 \text{ and } f_{\text{MSY}} = r/2q \qquad (6)$$

Where B_{MSY} is the stock biomass at MSY; F_{MSY} is the fishing mortality at MSY; f_{MSY} is the rate of fishing effort at MSY. Estimates are given by substituting r and q (the catchability coefficient) for the unknown true values in the mentioned expressions (Prager 1994). The model was applied to the time series data (1998/1999-2002/2003) on catch (tonne) and effort (No. fishing days). The model was used to predict the shrimp yield during the season 2003/2004 to detect its fitness in describing the dynamics of shrimp population under study.

Bootstrapping (BOT mode) was used for bias correction and construction of approximate nonparametric confidence intervals. In BOT mode, ASPIC used bootstrapping to estimate the variability of several predicted quantities and to adjust for estimation bias. Yields and residuals were predicted from the original fit, and then the residuals were increased by an adjustment factor (Stine, 1990). A bootstrapped data set was constructed by combining predicted yield $\hat{Y}_{ij}$ with a randomly-chosen adjusted residual to arrive at a pseudo-yield value Y^*_{ii}. The model was then refitted using the pseudo-yields in place of the original observed yields. This process was repeated up to 600 times.

Following the bootstrap run, ASPIC-P in ASPIC program was used to run projection for the period 2004/2005-2009/2010.

Results

Catch, Fishing Effort and Catch per Unit Fishing Effort

The catch of tiger shrimp increased (Table 1) from 773.27 tone during the fishing season 98/99 to its peak (944.11 t) in the season 99/00. This followed by a decrease to reach its minimum value (628.12 t) during 01/02. Another increase (792.27 t) was observed in the season 20/23 which was followed by a slight decrease (747.27 t) during the season 03/04 (Fig. 2).

Fishing effort expressed in number of fishing days, showed the same trend of catch fluctuation with a maximum (17328 day) and a minimum (9366 day) during the fishing seasons 99/00 and 01/02, respectively (Fig. 3).

Table 1. Maximum sustainable yield (MSY) of tiger shrimp in Jazan area and the corresponding level of fishing effort (fMSY) estimated by equilibrium approach of surplus production model (Schaefer, 1954).

Year I	Yield (kg) Y(i)	Effort (no. fishing days) f(i) x	Schaefer Y(i) f(i) y
1998-1999	773271	13626	56.74
1999-2000	944109	17328	54.48
2000-2001	658661	11727	56.16
2001-2002	628139	9366	67.06
2002-2003	792415	11698	67.73
2003-2004	747269	10262	72.81
Mean	757311	12335	62.50
Intercept a Slope b MSY f_{MSY}			87.45027512 –0.00202247 945323 21620

Catch per unit fishing effort (kg/fishing day) assumed to be proportional to abundance showed a slightly decrease from 56.74 to 54.48 during the seasons 98/99 and 99/00, respectively. This was followed by a contentious increase to reach its maximum value (72.81 kg/fishing day) during the season 03/04 (Fig. 4).

Equilibrium Surplus Production Model

The equilibrium logistic (Schaefer 1954) production model was applied to catch and catch per fishing effort data (Table 1) of tiger shrimp in the area of study. The estimated maximum sustainable yield (MSY) and the corresponding level of fishing effort (f_{MSY}) are given in Table (1) and graphically represented

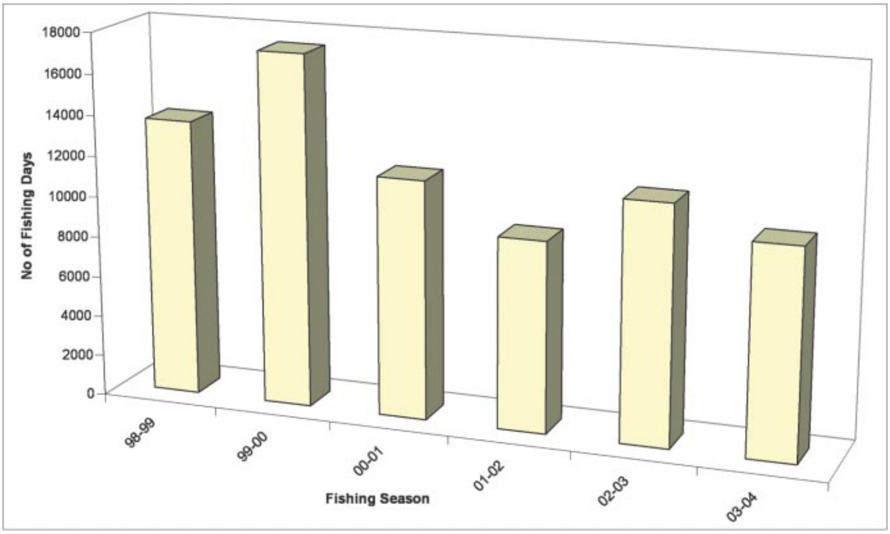

Fig. 3. Fishing effort (no. of fishing days) exerted by bottom trawlers in Jazan area during the fishing seasons 98/99-03/04.

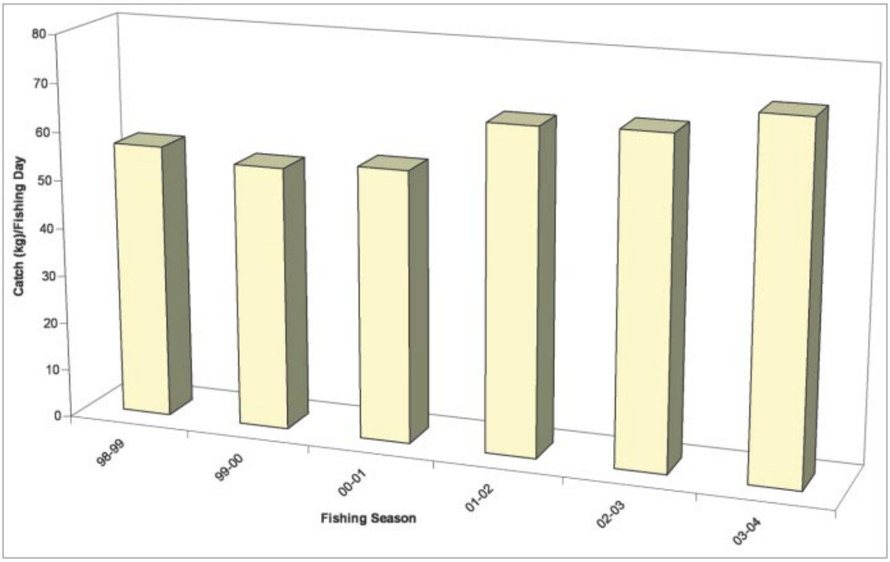

Fig. 4. Catch (kg) of tiger shrimp per unit of fishing effort (fishing day) exerted by bottom trawlers in Jazan area during the fishing seasons 98/99-03/04.

in Fig. (5). This model indicates that a maximum sustainable yield of 945.323 tones could be achieved by fishing effort of 21620 fishing days per fishing season. This means that an increase of the existing fishing effort (10262 days) by a percent of 111% is required to increase the existing yield (747.269 t) by a 26%.

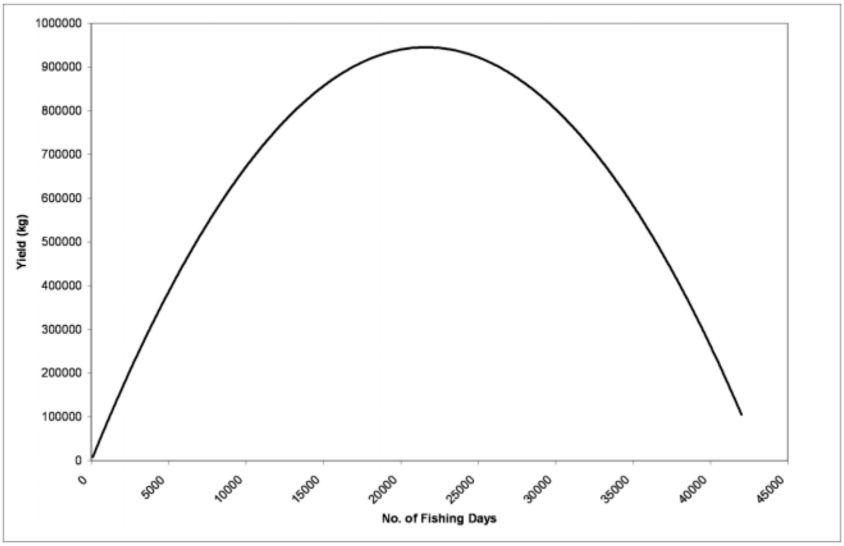

Fig. 5. Maximum sustainable yield (MSY) of tiger shrimp in Jazan area and the corresponding level of fishing effort (f_{MSY}) estimated by equilibrium surplus production model (Schaefer, 1954).

Non-Equilibrium Surplus Production Model

A stock-production model incorporating covariates (ASPIC) program (Prager, 1994) was used to fit a non-equilibrium logistic production model to the same data series on catch and fishing effort of the tiger shrimp. A maximum sustainable yield of 829.8 t was estimated to be produced by a biomass (f_{MSY}) of 468.5 t at a fishing mortality (f_{MSY}) of 1.771. The number of fishing days required to generate the maximum sustainable yield was estimated at 17370 day which exceeds the current fishing level by a portion of 69.3%.

The estimated population trajectory (Table 2 and Fig. 5) indicate that the yield of the tiger shrimp was below the estimated surplus production during the seasons 98/99, 00/01 and 01/02 while it exceeded the surplus productions during the seasons 97/98, 99/00 and 02/03.

The estimated ratio of fishing mortality F to f_{MSY} was below that providing the MSY level during the detected period except in the fishing season 99/00 when it reached its maximum (1.03) value.

Table 2. Estimated population trajectory (no-bootstrapped) for tiger shrimp catch and fishing effort data from the Jazan area.

Fishing season	Estimated total fishing mortality (F)	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mortality to Fmsy	Ratio of biomass to Bmsy
97/98	1.334	775.3	1034.0	1034.0	375.9	0.753	2.731
98/99	1.269	609.0	773.0	773.0	755.0	0.7166	1.326
99/00	1.825	517.4	944.0	944.0	816.2	1.030	1.288
00/01	1.172	561.6	658.0	658.0	791.5	0.615	1.015
01/02	0.958	655.4	628.0	628.0	696.3	0.541	1.300
02/03	1.252	632.4	792.0	792.0	727.0	0.707	1.446
03/04							1.307

Stock biomass showed a declining trend from 775.3 t during 97/98 to 517.4 t during 99/00, then it slightly increased (561.6 t) during 00/01 and (655.4) 01/02, declined (632.4 t) during 02/03.

The model estimated the yield of tiger shrimp during the season 03/04 at 751.6 t which is very close to the actual observed yield (747.3 t).

Bootstrap results are given in Table (3) and Fig. (6). These indicate that fmsy, F/Fmsy and B/Bmsy were estimated with relatively high precision where the relative interquartile IQ range = 0.248, 0.185 and 0.093, respectively. Low values of relative bias indicate that all parameters were predicted with acceptable precisions.

Table 3. Results of bootstrapped analysis for tiger shrimp catch and fishing effort data from the Jazan area using BOT mode of ASPIC.

Parameter		Point estimate	Relative bias	Relative inter-quartile (IQ) range
MSY	Maximum sustainable yield (t.)	829.8	6.29%	0.88
K	Maximum stock biomass (t.)	937.0	29.00%	0.514
R	Populationís intrinsic rate of increase	3.542	9.66%	0.692
Q	Catchability coefficient	0.000102	9.68%	0.479
Bmsy	Stock biomass (t.) at MSY	468.5	29.00%	0.514
Fmsy	Fishing effort (fishing days) at MSY	17370	4.83	0.248
Fmsy	Fishing mortality at MSY	1.771	9.66	0.692
F/Fmsy	Ratio of F to Fmsy	0.707	4.11%	0.185
B/Bmsy	Ratio of B to Bmsy	1.307	–2.41%	0.093

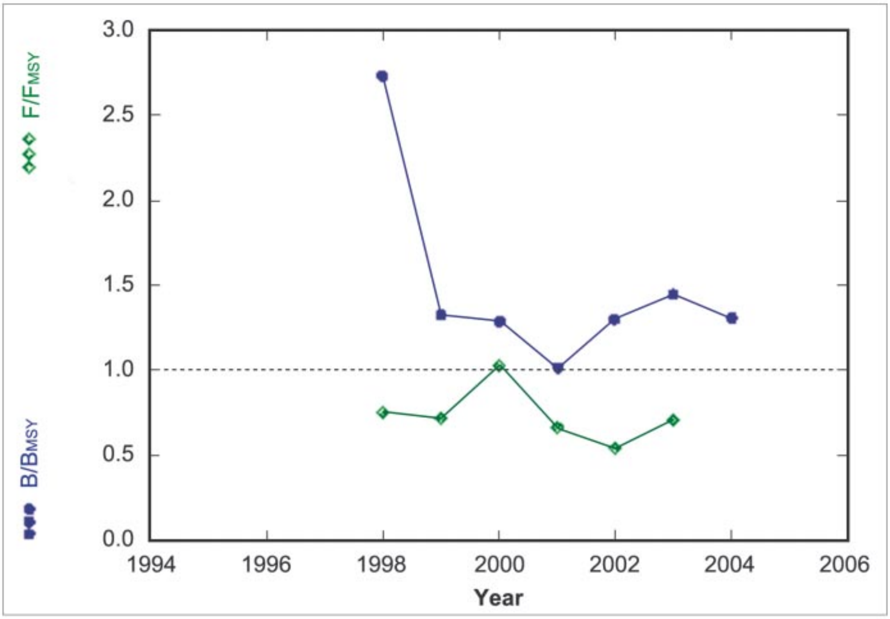

Fig. 6. Trajectory of relative fishing mortality rate (F/Fmsy) and relative Biomass (B/Bmsy) during the period 1998/1999-2002/2003 that was used to predict the yield of 03/04 season (non-bootstrap results).

Using the bootstrap results, the yield of 03/04 as a feed value and assuming that a 30% of the current fishing effort (fishing days) would be increased seasonally, ASPIC-P was used to project the shrimp yields during the period 2004/2005-2009/2010. Relative bias ranged from –0.77% to 1.39% and Relative IQ ranged from 0.025 to 0.07 indicating the highly precision of predicted values (Table 4, and Fig. 7- 9).

Table 4. Project Tiger shrimp yield using ASPIC-P.

Fishing season	Estimated yield (t.)	Relative bias	Relative interquartile (IQ) range
2005/2006	895.1	1.39%	0.025
2006/2007	833.9	0.88%	0.47
2007/2008	825.8	0.08%	0.62
2008/2009	824.6	–0.45%	0.67
2009/2010	824.4	–0.77%	0.070

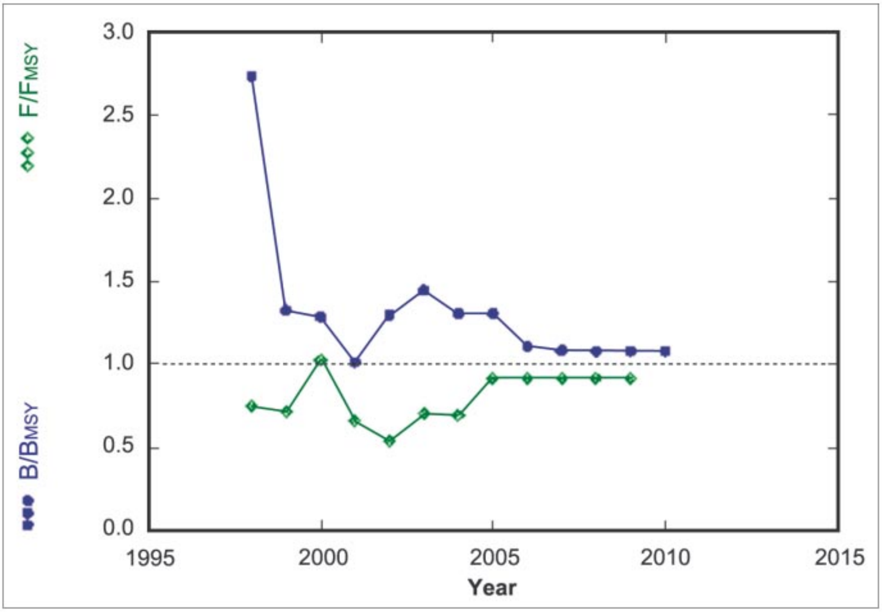

Fig. 7. Trajectory of relative fishing mortality rate (F/Fmsy) and relative Biomass (B/Bmsy) of tiger shrimp during the period 1998/1999-2009/2010 (Bootstrap results).

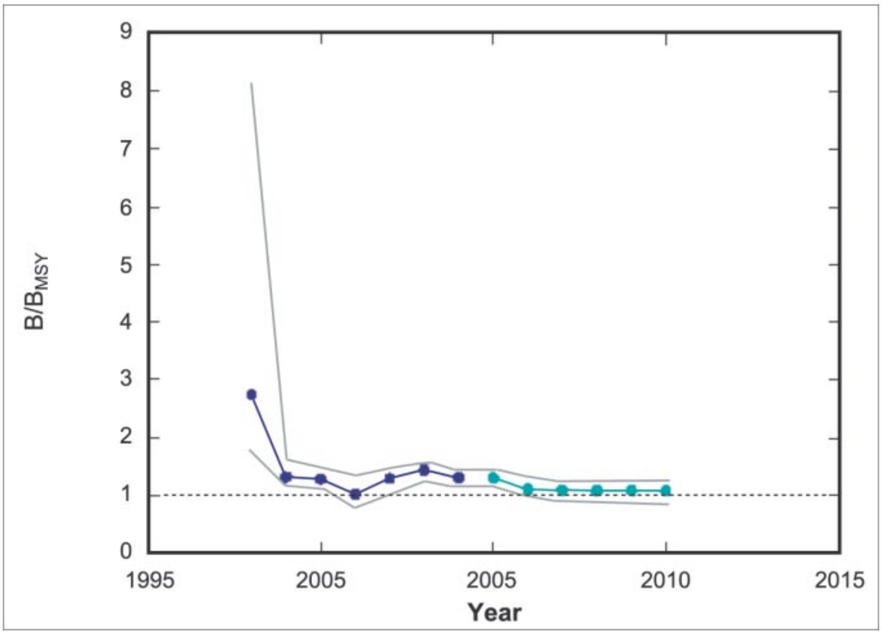

Fig. 8. Time plot of B/Bmsy of tiger shrimp with 80% Bias-Corrected (BC) Confidence Interval.

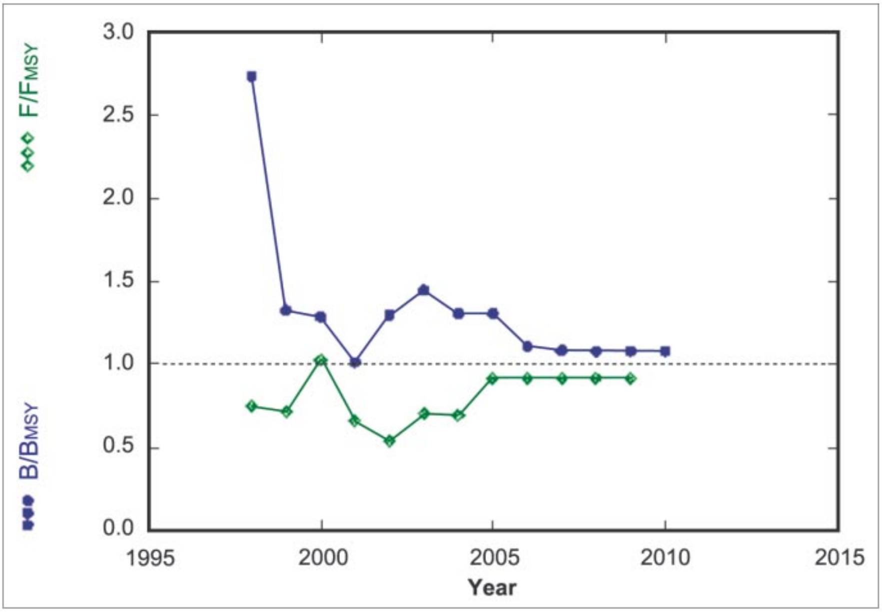

Fig. 9. Time plot of F/Fmsy of tiger shrimp with 80% Bias-Corrected (BC) Confidence Interval.

Discussion

The surplus-production model has a long history in science (Schaefer 1954, 1957; Pella 1967; Fox 1970; Prager 1994; El-Ganainy 1992) and has proven useful in management of fish stocks. It is characterized by its simplicity compared to such models as tuned cohort analyses. Surplus production models use data on removals from the stock and relative abundance through time to obtain estimates of maximum sustainable yield (MSY) and related benchmarks (Vaughan, *et al*., 2000).

Several treatments of surplus-production models (Schaefer 1954 and 1957) have assumed that the yield taken each year could be considered the equilibrium yield. Pella (1967), Pella and Tomlinson (1969), and Prager (1994) did not use the equilibrium assumption.

Both non-equilibrium and equilibrium suggested that the yield of tiger shrimp in the area of study is under exploited. Different estimates of the MSY were obtained from the two models. This can be attributed to the finding of Prager (1994) on that equilibrium models can overestimate MSY when used to assess a declining stock.

The ratio of fishing mortality F to Fmsy estimated by the non-equilibrium model showed a close agreement with the Abdallah and Abushusha (2003) who pointed out that the tiger shrimp stock was overexploited in the same area of study during the year, 2000. The close agreements of the estimated yield for the season 03/04 with that actually observed yield is an additional indicator that the non-equilibrium model describes the tiger shrimp stock more precisely.

Although the projected yield values recommend seasonally 30% increase of the current fishing days, an economical evaluation for the revenue should be conducted before implementing such increase on the fishing effort.

Acknowledgements

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تقييم وإدارة مصايد الروبيان أم نعيره (بينيوس سميسلكيتس) في منطقة جيزان (البحر الأحمر، المملكة العربية السعودية)

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المستخلص. يتم استغلال مصائد الروبيان في منطقة جيزان بالمملكة العربية السعودية باستخدام أسطول صيد تجارى يتكونَ منْ سفن الجر القاعى التى يَتراوحُ طولها منْ ٢٠-٣١َ متراً. يحتل روبيانُ أم نعيَرة – النمرِ الأخضر *Peneaus semisulcatus* المركَز الأول من حيث الكم فى محصَول أسطول الصيد التجاري الذى يعمل في منطقة الدراسة ؛ حيث يُشكّلُ من ٥, ٨٢٪ إلى ٥, ٩٠٪ منْ صيدِ الروبيانِ الكليِّ الذى تَم رصده أثناء فترةِ الدراسةَ.

أظهر محصول روبيان أم نعيره هبوطا حاداً خلال الستّة سنوات الماضية (١٩٩٥/ ١٩٩٦م – ٢٠٠٠/ ٢٠٠١م) . وقد أحدثت الزيادة في جُهد الصيدَ المبذول في منطقة جيزان المخاوفَ التي تَتعلّقُ بالإدارة المستدَامة للموارد البحرية الحية بمنَطقة الدراسة، مما دفع الحكومة السعودية إلى اتخاذ إجراءات احترازية لتحقيق الاستغلال المستدام لمصائد الروبيان. وفي هذا السياق،تستهدفَ هذه الدراسة مراقَبة الوضَع الراهن لمصائدَ الروبيانِ وتقديم المعلومات التى تَتطلّبها الإَدارة المستدامة لتلك المصائد.

تم تعيين المحصول الأقصى المُستدام (MSY) والقيَم المناظرة لجُهد الصيد (عدد أيامَ الصيد لكل موسم) لمصائد الروبيانِ أبَو نعيرهِ في منطقةَ جيزانَ بالبحر الأحمر – المملكة العربية السعودية.

تم تطبيق نموذج الإنتاج الفائض باستخدام افتراض التوازن، بالإضافة إلى افتراض عدم التوازن لملاءمة نموذجِ الإنتاج الفائض لتحليل المعطيات

الإحصائيةِ للإنتاج و جُهد الصيدَ.

تمتدُ منطقةُ الدراسةَ منْ خط عرض ١٧ درجة و ٤٠ دقيقة جنوباً إلى الحدود اليمنية ؛ حيث تدَعم نشاطَ أكثر منْ ٩٠ ٪ من سفن الصيد العاملة بطريقةَ الجر القَاعى التى تستهدف الروَبيانَ في ساحلِ اَلبحر الأحمرِ السعودي.

النَتائج منْ كلتا المعالجتين أشارتْ بأنّ الاستغلالَ الحالي لروبيان النمر الأخضرَ -َ أم نعيرة، تحت مستوى الاستغلال الأقصى. تم استَنتاج المحصول الأقصى المستدام عند مستوى ٣٢٣َ, ٩٤٥ و ٨٢٩,٨ طنًا بافتراض نموذج التوازن ونموذجِ عدم التوازن، على التوالي.

أثبتت الدراسة باستخدام النموذجين أن تحقيق الإنتاج الأقصى المستدام يتطلب زيادة جهد الصيد المبذول، إلى المستوى ٢١٦٢٠ و١٧٣٧٠ يومِ صيدِ على التوالي لكلّ موسم صيدِ فى العام.