

STOCK ASSESSMENT OF THE OFFSHORE MAURITIAN BANKS USING DYNAMIC BIOMASS MODELS AND ANALYSIS OF LENGTH FREQUENCY OF THE SKY EMPEROR (*Lethrinus mahsena*)

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ABSTRACT

The main objective of this study was to determine MSY reference points for the Saya de Malha and the Nazareth banks north of Mauritius. As no catch at age data is available to perform analytical age structured stock assessment, catch and effort data from 1989 to 2004 were analysed. Surplus production/dynamic biomass models were used to determine stock status through estimation of MSY, f_{MSY} , absolute biomass, relative biomass and relative fishing mortality. Bootstrapping for bias correction on estimates, setting of confidence limits and projection with set catch levels were conducted. Lower limits (95%) of the MSY using the Logistic model were estimated at 2,531 and 1,623 t, and the f_{MSY} was estimated at 40,390 and 32,280 fishermandays for the Saya de Malha and Nazareth banks, respectively. Hind casting trials suggest that the model was relatively stable when more than 12 years were included in the analysis. Results should be interpreted carefully given the assumptions of the dynamic biomass models and potential limitations of the input data. Length frequency data of *Lethrinus mahsena* from Saya de Malha bank were also analysed to estimate growth parameters and mortality rates. As expected, *L. mahsena* was found to be a slow growing and long-lived species. The main recommendations from this study are that TAC should be re-introduced for the banks fishery and fishery-independent stock indices should be used in future analysis. The basis for the application of age structured models should be laid immediately, not as a substitute but as a complement to dynamic biomass models.

Keywords: MSY, f_{MSY} , dynamic biomass models, bootstrap, hind-casting trials, Saya de Malha, Nazareth, *Lethrinus mahsena*, TAC, banks fishery, Mauritius.

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ACRONYMS

AFRC	Albion Fisheries Research Centre
ASPIC	A Stock Production Model Incorporating Covariates
B_{MSY}	Biomass at MSY
B/B_{MSY}	Relative Biomass
CI	Confidence Intervals
CPUE	Catch Per Unit Effort
ELEFAN	Electronic Length Frequency Analysis
F_{MSY}	Fishing mortality at MSY
F/F_{MSY}	Relative Fishing Mortality
f_{MSY}	Optimum effort at MSY
fdays	Fishermandays: Number of fisherman x number of fishing days
LFDA	Length Frequency Distribution Analysis
LOA	Length Over All
MSY	Maximum Sustainable Yield
SLCA	Shepherd Length Composition Analysis
VBGF	Von Bertalanffy Growth Function
VPA	Virtual Population Analysis

INTRODUCTION

The Republic of Mauritius is an important maritime state in the Indian Ocean with an Exclusive Economic Zone of 1.9 million km². The most important supply of fish is catch from the Saya de Malha and Nazareth banks located in the north of Mauritius. Of a population of 1.2 million, about 700 fishermen are employed in the banks fishery and 10,000 people are indirectly engaged in the fisheries sector, which contributes nearly 2% of the GDP. The total landed annual catch from the banks is around 3,200 t of gutted fish. In 1992, a licensing system was introduced for the banks fishery and to further consolidate that measure; in 1994 a catch quota system was implemented based on historical catch. No stock assessment has been conducted since 1992 and as of 2001 no quotas have been set for the banks fishery.

The vessels engaged in the inter-island trade in the early period (1930s) of the banks fishery caught fish mainly for salting, which was brought to Mauritius (Ardil 1969, Samboo 1987). Trawling was attempted in 1931, but proved unsuccessful due to the potential damage on the substrate (FAO 1979). Systematic exploitation of the banks fish stocks began in 1949, after a survey of the fishery resources of the Mauritius-Seychelles ridge (Wheeler and Ommanney 1953). Frozen fish were produced in the 1960s but marketing was difficult due to the relatively high abundance of fresh fish on the local market (Ardil 1969). With the gradual acceptance of frozen fish by the population, more vessels joined in the banks fishery (Samboo 1983). The fishery grew up in fleet size during the 1970s when Mauritian vessels and chartered Korean vessels started to exploit the bank fish stocks (Samboo 1987). Price of fish, formerly controlled by decree was liberalised in 1981 and import duty on vessels acquired by local companies was waived in 1982 (Samboo 1987). These measures led to increased investment in the fishing industry and from 1983 to 1995, the fleet grew from nine to 17 vessels (Figure 1).

During the last ten years, almost half of the fishing vessels ceased operation, as they were not seaworthy due to mechanical problems while others were too old. The number of fishing vessels in the banks fishery is presently eight and their size (LOA) ranges from 30 to 45 m.

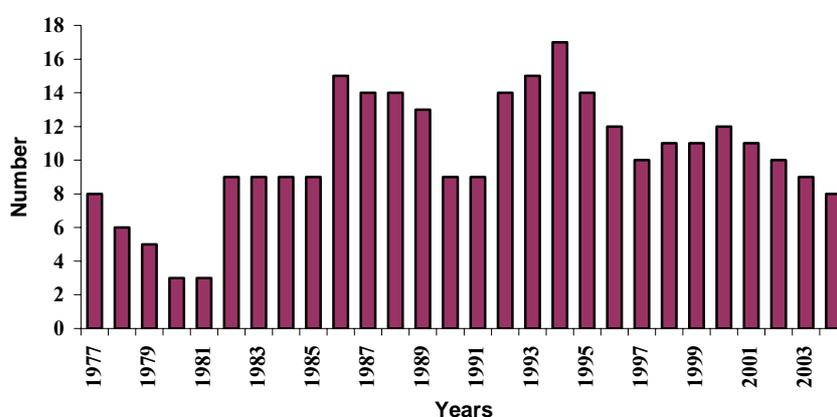


Figure 1: Number of fishing vessels operating in the Saya de Malha and Nazareth banks from 1977 to 2004 (Samboo 1987, AFRC 2004).

Fishing on the banks is practiced using hand lines in a “mothership-dory” system. A “mother” fishing vessel takes between 45 and 60 days for a fishing campaign, and performs four to five trips per year. The mother vessel carries 15 to 20 glass fibre dories, which are launched at sea once the vessel reaches the fishing grounds. They fish at a depth of about 20-50 m within a range of 6 km from the mother vessel. The dories return to the mother vessel either at mid-day or evening with the day’s catch. The catch is gutted and gilled at sea on the way back to the mother vessel. Upon arrival, the catch for the day is weighed, rinsed with seawater, blast frozen at -20°C and the next day, placed in bags or in bulk kept in the fish hold on board the vessel.

The fishing effort exerted on the Nazareth bank and the Saya de Malha bank has undergone substantial changes from 1977 to 2004. The reported annual effort has fluctuated from 7,000 to 25,000 fishermandays for the Nazareth bank and from 3,000 to 47,000 fishermandays for the Saya de Malha bank. The reported catch also has varied from 500 to 1,500 t for the Nazareth bank and from 500 to 3,300 t for the Saya de Malha bank (Samboo 1987, AFRC 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004).

About 90% of the banks fishery catch consists of the sky emperor *Lethrinus mahsena*, locally known as “dame-berri”. The rest mainly comprises other lethrinids and serranids (Bertrand 1986, Samboo 1989).

1.1 Rationale and objectives of the project

A time series of 25 years of catch and effort data is available for the Mauritian banks fishery. On the other hand, there is no catch at age data available for a suitable time series to perform analytical age structured stock assessment (e.g. VPA/cohort analysis or statistical catch-at-age analysis). *L. mahsena* is a slow growing and long-lived species, which makes age based modelling application difficult and costly. The lack of technical knowledge and qualified human resources for ageing fish are also major drawbacks for age-structured analysis.

These factors contribute to the justification of applying surplus production models/biomass dynamic models to the available catch and effort data. Moreover, no stock assessment studies have been undertaken since 1994, when the quota system was implemented.

The main objectives of this project are to estimate the maximum sustainable yield (MSY) and the fishing effort at MSY (f_{MSY}) of the Saya de Malha bank and the Nazareth bank, by analysing the catch and effort data using dynamic biomass models. Length frequency data analysis for *L. mahsena* from the Saya de Malha bank will also be conducted for estimation of growth parameters, mortality rates and exploitation rates. Ultimately, the outcome of this project will provide advice for the banks fishery management. Moreover, the aim is to identify the major drawbacks of the present Mauritian monitoring system and attempt to come forward with recommendations for its improvement, in view of enhanced stock assessment methodology for the sustainable exploitation of the Mauritian banks fishery resources.

2 FISH SPECIES AND STOCK ASSESSMENT OF THE BANKS FISHERY

L. mahsena, the main species of the catch, is a demersal species found in sandy and seagrass reef areas at a depth of 2-100 m. It feeds mainly on echinoderms (sea urchins), crustaceans and fishes, while eating molluscs, tunicates, sponges, and polychaetes in lesser quantities (Sato and Walker 1984). It is a protogynous hermaphrodite and generally a non-migratory species (Carpenter and Allen 1989). Aldonov and Druzhinin (1979) recorded a growth rate (k) at 0.32 for *L. mahsena* from Yemen, which was more than twice the growth rate found in the Mauritian banks. Grandcourt (2002) estimated the growth rate of *L. mahsena* in the nearby Seychelles waters as 0.194.

Bautil and Samboo (1988) carried out a preliminary assessment for *L. mahsena* on the Nazareth bank using length frequency data collected from the commercial catch. The growth rate (k) was estimated at 0.1, length at infinity (L_{∞}) at 61.7 cm, total mortality (Z) at 0.45, length at first capture (L_c) at 29.5 cm, fishing mortality (F) was estimated at 0.23 and natural mortality (M) at 0.22. Sexually mature *L. mahsena* on the Saya de Malha bank were found during the periods December-January and May-June (Soondron *et al.* 1999). They also reported the length at first maturity at 19 cm and the length at first capture at 26.7 cm, the estimated k at 0.12 and L_{∞} at 60.5 cm. Pilling and Mees (2000) estimated the growth parameters k at 0.08 and L_{∞} at 66.5 cm, using length frequency of *L. mahsena* from the Chagos waters.

In a study on otoliths of *L. mahsena* and their validation for growth parameter estimation, some evidence for the annual nature of the increments was observed (Pilling *et al.* 2000). This evidence was confirmed by the unimodal distribution resulting from the edge analysis of otoliths, indicating that opaque band formation was initiated once a year, from May to August. From this observation, it was concluded that increments seen in the otoliths of *L. mahsena* from Mauritius are annual deposits (Pilling *et al.* 2000).

Sanders (1989) determined the MSY (gutted fish) for the Saya de Malha bank as 2 887 t and 1,280 t for the Nazareth bank using an equilibrium surplus production model. Potential yields of the two banks have also been calculated from catch per unit area data (Mees 1992). He estimated the productivity of demersal hand line caught species in the shallow waters around Seychelles (north of Saya de Malha) at 168 kg km⁻² yr⁻¹. Assuming the fishable area for Saya de Malha bank to be 12,500 km² and the productivity to be similar to that of the Seychelles, he estimated the potential yield for Saya de Malha as 2,100 t and that for the Nazareth bank as 1,680 t (Mees 1992).

Age structure and growth rates of a fish population are essential components in the assessment of exploited population dynamics (Rowling and Reid 1992). Von Bertalanffy growth parameters (L_{∞} , k and t_0) are inputs into many assessment methods, which estimate biological and fishery parameters (*e.g.* mortality, yield-per-recruit). Clearly, growth parameters have the potential to influence the outcome of particular stock assessments and are important in the derivation of reference points for fisheries management (Gulland 1973).

Where no or little information on age or length structure exists, surplus production/dynamic biomass dynamic models can be applied (Sullivan *et al.* 1990,

Sullivan 1992, Chen and Andrew 1998, Quinn and Deriso 1999). Production models are among the simplest stock assessment models commonly used in fisheries and input data are a time series of catch and effort from commercial fisheries (Hilborn and Walters 1992). Biomass is modelled simply with a function that combines life processes and does not consider population age or size structures. The biomass model is linked to the exploitation history of the fishery by an abundance index that is assumed to be proportional to the biomass (Hilborn 1997).

Simulation studies have suggested that management advice based on surplus production methods may be as robust as population estimates based on age structured analyses (Ludwig and Walters 1985, Punt 1994). Earlier, the index of abundance in dynamic biomass models was CPUE data, but the use of the results from fishery-independent research surveys are now preferred as an index of abundance (Cooke and Beddington 1984, Quinn and Deriso 1999)

Three classical models have been widely used: the Schaefer (1957) model, the Fox (1970) model and the Pella and Tomlinson (1969) model. These models differ in their parabolic relationship between equilibrium yield and equilibrium biomass. In the Schaefer model maximum productivity occurs at half biomass levels. Pella and Tomlinson (1969) provide a model with an additional parameter to allow the maximum biomass level to be shifted to the left or right. In the Fox model, the maximum productivity is skewed to the left i.e. less than 50% of the biomass (Quinn and Deriso 1999).

The production models have changed from assuming equilibrium, to those that do not make an equilibrium assumption i.e. dynamic biomass models (Hilborn and Walters 1992). Equilibrium production models often perform poorly (Boerema and Gulland 1973, Larkin 1977, Saila *et al.* 1979, Punt 1994). They tend to overestimate the sustainable yield and the optimum effort. Their use in the past may even have contributed to a number of fishery stock collapses (Boerema and Gulland 1973, Larkin 1977). For equilibrium assumptions to hold, a fishery must very rapidly move to a stable state whenever there is change in fishing effort. This is unrealistic and leads to significant bias. Time-series fitting using maximum likelihood or non-linear least square minimisation is now the recommended approach (Hilborn and Walters 1992, Haddon 2001).

Simplicity is both a strength and weakness of dynamic biomass models (Prager 1994). They require few data time series of catch and abundance index, are straightforward to implement and extend, and few assumptions render them relatively transparent. However their simplicity precludes insight to biological processes (growth, stock recruitment relationship and natural mortality) and takes no account of age or size structure (Gonzalez and Restrepo 2001).

The time series of catch and effort data available for the Mauritian offshore banks fishery is presently the most reliable data for stock assessment purposes. Therefore, dynamic biomass models can be used for analysing the stock dynamics and determine reference points such as MSY and f_{MSY} for the Mauritian banks fishery.

3 MATERIAL AND METHODS

3.1 Study area

Saya de Malha and Nazareth banks are located to the north of Mauritius along the Mascaregne Ridge (Figure 2 and Table 1). These banks are regions with sandy bottoms with depths varying from 50 to 60 m, surrounded by a shallower coralline rim sloping to around 150 m. The Nazareth bank is inside the EEZ of Mauritius, while Saya de Malha bank is located outside the EEZ limits (Figure 2). However, Mauritius has traditional fishing rights on part of Saya de Malha.

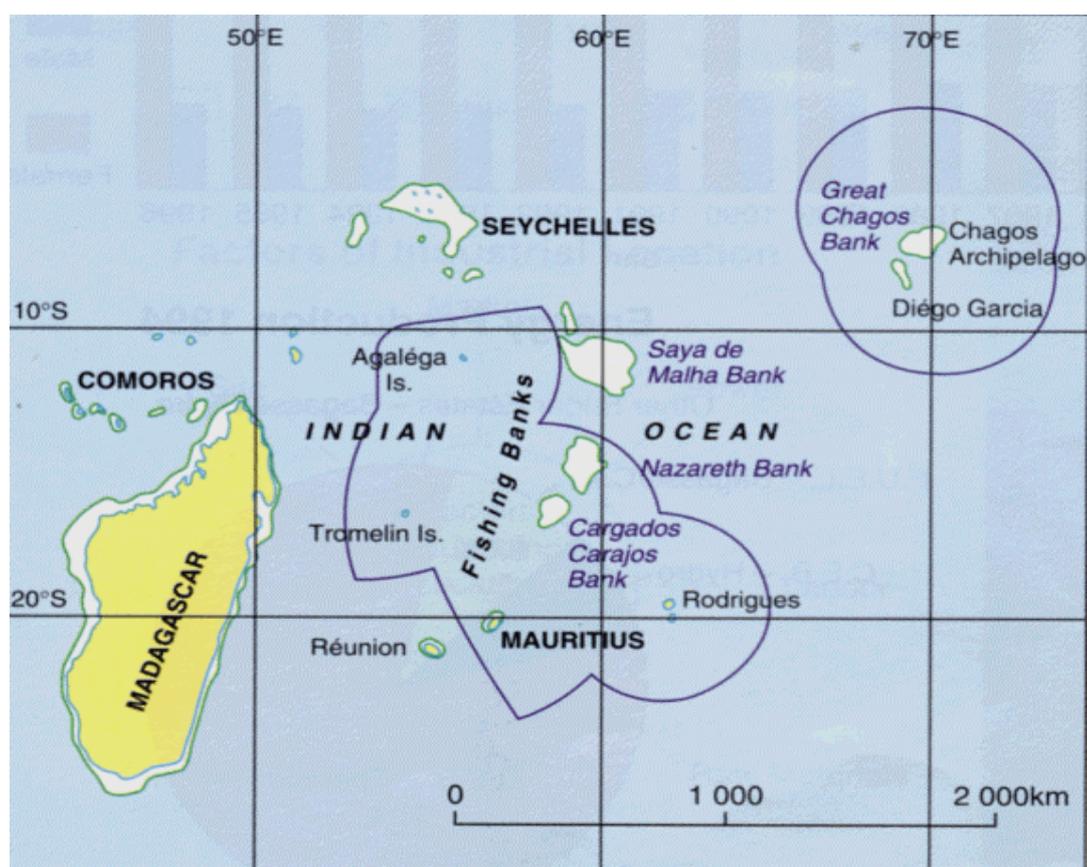


Figure 2: Exclusive Economic Zone of Mauritius, the Saya de Malha and the Nazareth banks (Dulymamode *et al.* 2002).

Table 1: Distance from Mauritius, total area and fishable areas (< 60 m depth) of the Saya de Malha bank and Nazareth bank (Sanders 1989).

Fishing banks	Distance (km)	Total area (km ²)	Fishable area (km ²)
Saya de Malha	1,050	42,116	12,500
Nazareth	650	22,814	10,000

3.2 Data collection

Series of catch and effort data from 1977 to 2004 are available for the Nazareth bank and the Saya de Malha bank. The years considered for analysis were from 1989 to 2004, as reliable data collection has been reported since October 1988 (Samboo 1989). Earlier years were omitted from the analysis mainly because of the incompleteness of the catch/effort data series and the involvement of chartered Korean vessels and vessels from the Reunion Island (Samboo 1989).

Data on the banks fishery have been collected by the statistical unit of the research division of the Ministry of Fisheries and Natural Resources. Upon arrival of banks fishing vessels at the fish landing port at Port-Louis, logbooks are verified for discrepancies on board and collected. The logbooks for each vessel provide daily information on the number of fishermen, catch and effort at specific fishing locations, amongst others. These are processed for catch (tonnes), which is gutted and gilled, and effort data (fishermandays-fdays: number of fishermen multiplied by the number of fishing days). The catch per unit effort (CPUE) is calculated by dividing the catch in kg by the number of fdays. The landing and logbook figures are counter verified by data from the Mauritius Marine Authority, which provide figures of total landed amount by vessel.

The catch of all banks fishing vessels is sampled for length frequency data of *L. mahsena*, by fishery officers of the Albion Fisheries Research Centre. During unloading, length frequency sampling sessions are conducted on board from random portions of frozen fish. Total length to the nearest mm is recorded. An average of 350 fish specimens are sampled per fishing vessel.

3.3 Catch and effort data analysis using surplus production models

3.3.1 Equilibrium assumption method

The Schaefer and the Fox models using equilibrium assumptions were used to calculate the maximum sustainable yield (MSY) and the fishing effort needed to obtain the maximum sustainable yield (f_{MSY}) for the Nazareth bank and the Saya de Malha bank.

The Schaefer model assumes that yield is related to fishing effort by a symmetrical parabola. The effort (f) and catch per unit effort (CPUE) were plotted and the intercept (a) and the slope (b) of the regression line drawn through the points were determined.

$$(1) \quad CPUE = a + bf$$

$$(2) \quad Y = af + bf^2$$

where Y is the yield

$$(3) \quad MSY = -a^2 / 4b$$

$$(4) \quad f_{MSY} = -a / 2b$$

In the Fox model an asymmetrical curve is described for the relationship of the effort with the yield. The relationship is as follows:

$$(5) \quad \ln(\text{CPUE}) = a + bf$$

The yield, MSY and f_{MSY} is expressed as:

$$(6) \quad Y = f e^{a + bf}$$

$$(7) \quad \text{MSY} = (-1/b) e^{(a-1)}$$

$$(8) \quad f_{\text{MSY}} = -1/b$$

For the Fox model, the values of the intercept (a) and the slope (b) are obtained by plotting the regression line through the plots of effort against the $\ln(\text{CPUE})$ (Sparre and Venema 1998). This analysis was done using the program R.

3.3.2 Time series fitting using dynamic biomass model in R

Conceptually, surplus production models/biomass dynamic models are based on the idea that the biomass in a given year (B_{t+1}) depends on the biomass of the previous year (B_t) plus recruitment and growth, minus catch and natural mortality. The changes in a population's biomass can be written as:

$$\text{next biomass} = \text{last biomass} + \text{recruitment} + \text{growth} - \text{catch} - \text{mortality}$$

The dynamic biomass model was used to fit the catch and effort time series data from the Nazareth and Saya de Malha banks. The fitting was based on the Logistic population growth model as follows:

$$(9) \quad B_{t+1} = B_t + rB_t (1 - B_t / K)$$

When catch is included in the above equation, we obtain the Schaefer surplus production model:

$$(10) \quad B_{t+1} = B_t + rB_t (1 - B_t / K) - C_t$$

Where $C_t = qfB_t$ and,

C_t = catch,

B_t = biomass at time t,

K = carrying capacity of the system or maximum population size,

r = intrinsic rate of production or rate of increase of the population,

q = catchability coefficient,

f = effort

In the equation above, the middle term: $rB_t (1 - B_t / K)$ is the surplus production. If surplus production is greater than the catch, the population size increases and if catch equals or is close to the surplus production, a fishery operating in the system gives the MSY and the population size is expected to remain constant.

In dynamic biomass models, time series fitting using maximum likelihood or non-linear least squares minimisation is the principle. Estimates of the initial biomass and model parameters are generated, catch data are incorporated in the production model to predict the whole biomass series, a measure of difference between observed and predicted values is identified and then the differences are minimised to fit the models (Hilborn and Walters 1992, Prager 1994, Punt and Hilborn 1996, Quinn and Deriso 1999, Haddon 2001).

The stock abundance can be constructed by effort data corresponding to the time series of catches and at the same time assuming that CPUE is linearly related to abundance. Using the production model, each point in the entire time series of data was predicted. The initial guess parameter values were iteratively adjusted to minimise the difference ($\hat{\epsilon}$) between the observed CPUE and the predicted CPUE by the model, where:

$$(11) \quad \hat{\epsilon} = (CPUE_{pred} - CPUE_{obs})^2$$

and where

$$(12) \quad CPUE_{pred} = qB_{pred}$$

So, if observed $CPUE = Ct / f$, then predicted $CPUE = qB_{(t)}$. The estimation procedure is separated into a few steps, namely: initialisation of parameters, projection based on those parameters, evaluation of the fit to observed data, and search for parameters which give the best fit to the data (Stefansson 2005).

The primary unknown parameters of the model are $B_{(t)}$, K , r and q . The first three were taken as starting guesses, with q fixed. Then r and q were estimated. After successive estimations and subsequent optimisations, all the parameters, K , B_t , r and q were estimated at the same time. These were used to estimate MSY , f_{MSY} , B_{MSY} and F_{MSY} . During initialisation of parameters, K was taken as three times the maximum yield, B_t was taken as twice the maximum yield, r was guessed as 1 and q was taken as the mean of the CPUE divided by B_t (Appendix 1).

Using non-linear estimation procedures, the best parameter values of K , $B_{(t)}$, r and q were found, while at the same time minimising the difference between observed and predicted CPUEs. The management parameters of importance from this dynamic biomass production model are given by:

$$(13) \quad MSY = rK / 4$$

$$(14) \quad B_{MSY} = K / 2$$

$$(15) \quad F_{MSY} = r / 2$$

$$(16) \quad f_{MSY} = r / 2q$$

3.3.3 Stock-production model incorporating covariates

A non-equilibrium dynamic biomass model incorporating covariates [ASPIC 5.10.1] (Prager 2005) was applied to catch and effort data from the Saya de Malha and the Nazareth banks. Three model shapes, namely: Logistic, Fox and the Generalized Estimate Exponent were used.

In addition to data on catch and effort, ASPIC requires starting guesses and ranges for the parameters to be estimated by the model: K , MSY , B_1/K (the ratio of the biomass at the beginning of the first year to the carrying capacity) and q (Table 2).

Table 2: ASPIC input parameters of the FIT mode for Saya de Malha and Nazareth banks.

Bank	Starting guess					
	B_1/K	MSY	Range of MSY	K	Range of K	q
Saya de Malha	0.5	3000	500-5000	6500	1000-10000	mean (CPUE) / 2*max(Y)
Nazareth	0.5	2000	500-3500	5000	1000-10000	mean (CPUE) / 2*max(Y)

After fitting the values for the above parameters, the FIT mode is run. At this point ASPIC computes estimates of parameters, including time trajectories of fishing intensity and stock biomass. The results of the fit were used to compute bias-corrected approximate confidence limits (95% CL) through bootstrap analysis. The model fittings are under the assumption that yield in each year is known more precisely than fishing effort or relative abundance. In other words, all model fittings were conditioned on yield, rather than on effort or relative CPUE (Prager 2005).

If there is normal convergence, the point estimates of the FIT mode were loaded in the BOT mode for bootstrapping. In this mode the programme computes bootstrap confidence intervals on estimated quantities. This approach resamples the residuals from the optimum fit to generate new bootstrap samples of the observed time series. The residuals between the observed and predicted catch rates (CPUE), are used for bootstrap analysis. Bootstrap data sets are constructed by combining predicted CPUE with a randomly chosen residual to compute a pseudo-CPUE value. The model is then refit, using the pseudo-CPUE, which is assumed to relate back to stock biomass via the catchability coefficient ($CPUE = qB_t$). The process is repeated at least 1000 times (bootstrap trials) for each different fit. At each trial the objective function used is the sum of squared errors (Haddon 2001, Prager 2005).

The BOT mode outputs are used to create trajectories of absolute biomass (B), relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}). Estimated bootstrapped parameters were loaded in the PROJECTION mode to determine bias corrected trajectories 2005-2009. Only the Logistic model was used for projection scenarios. For each bank, projections were made assuming three fishing scenarios: yield at the estimated MSY , average yield of the period 1995-2004 and yield above the MSY level.

Hind-casting trials (Haddon 2001, Prager 2005) were conducted to compare the assessment results (MSY and f_{MSY}) and insight into the stability of the model for different series of data for Saya de Malha bank and Nazareth bank. First, data from the years 1989-1995 to 1989-2004 were fitted with successive reduction in number of years and then data series from 1990-2004 to 1999-2004 with successive reduction in

years were analysed. Convergence, a criterion to data fitting by the Logistic model, was the reference point to obtain unconstrained parameter estimates.

3.4 Length frequency distribution analysis

3.4.1 Growth parameter estimation

Analysis and processing of length frequency data (2002-2005) from the Saya de Malha bank was conducted using the Length Frequency Distribution Analysis software (LFDA Version 5.0, Kirkwood *et al.* 2001). This package incorporates two non-parametric length-based methods of growth assessment: SLCA (Shepherd *et al.* 1987) and ELEFAN (Pauly 1980, Pauly 1987, Brey *et al.* 1988).

Length frequency data from Saya de Malha bank were available only for the period 2002-2005. For the Nazareth bank length data were available only for a limited number of months for the period 2002-2005, rendering them unsuitable for analysis.

It was assumed that the growth of *L. mahsena* conforms to the von Bertalanffy growth model. The basic concept for estimation of growth parameters is that given a set of length frequency distributions we seek the set of von Bertalanffy parameters that leads to the best description of the distributions. A score function is defined that measures the goodness of fit achieved to the length frequency data for each combination of von Bertalanffy parameters. The method used in LFDA is a non-linear estimation for finding the best parameters within the observed data (Kirkwood *et al.* 2001).

The three parameters to be estimated were: the asymptotic maximum length of the fish (L_{∞}), the rate of growth (k) and the nominal age at which the length of the fish is zero (t_0), under the assumption that the growth curve describes growth accurately right down to zero length. The von Bertalanffy equation takes the form:

$$(17) \quad L(t) = L_{\infty} [1 - \exp(-k(t-t_0))]$$

The SLCA method estimates the best-fitting L_{∞} and k parameter set by maximising a goodness of fit function. This is based on a sine wave, which is positive at predicted modal lengths and negative at predicted inter-modal lengths. To score the fit, a correlation coefficient between the data and test function is calculated. Test function values for each length class are weighted by the square root of the number of individuals present in that length class, and summed across all examined length classes. Growth parameters which best describe the length distribution maximise the resulting score function (Shepherd *et al.* 1987).

To assess the fit of growth parameters, the ELEFAN method first restructures the length distribution. This restructuring, using a 'moving average frequency', denotes peaks (above the moving average) and troughs (below the moving average) in the distribution (Pauly 1987). A growth curve is then derived, based on a selected set of L_{∞} and k values, and compared to the restructured length distribution. That growth curve is then scored by summing the restructured values for each length class the growth curve passes through ('explained sum of peaks'; ESP). Hence, it is a function of the proportion of available peaks hit and troughs avoided by that curve. The

‘available sum of peaks’ (ASP) for the distribution represents the maximum score, which could be obtained by a single growth curve, being the sum of maximum restructured values for each peak. The ratio ESP/ASP is then maximised by varying the growth parameter set, to identify the best fitting growth parameters (Pauly 1987).

When several pairs of L_{∞} and k were identified by each method after trial and iteration, the pair with the value of L_{∞} and k that gave the maximum score per defined grid was chosen.

3.4.2 Growth performance index, mortality rates and exploitation rates

Growth performance index- \dot{O} (Pauly and Munro 1984) was determined for *L. mahsena* from the Saya de Malha bank as follows:

$$(18) \quad \dot{O} = \log(k) + 2 \log(L_{\infty})$$

The total mortality coefficient Z , was estimated using the linear length-converted catch curve (LCCC) method and the Beverton-Holt method as incorporated in LFDA, using the final estimates of L_{∞} and k and the length distribution data (Gayanilo and Pauly 1997). The natural mortality M was estimated using (Pauly’s 1980) empirical equation relating M , L_{∞} , k and T .

$$(19) \quad \ln(M) = -0.0152 - 0.279 \ln(L_{\infty}) + 0.654 \ln(k) + 0.463 \ln(T)$$

Where, T is the annual sea surface temperature of $\sim 27^{\circ}$ C for the Mauritian banks Nautical Almanac for the Indian Ocean 2000. Fishing mortality rate was calculated as:

$$(20) \quad F = Z - M.$$

The exploitation rate, E , was computed by dividing F by Z .

4 RESULTS

4.1 Catch and effort data

Catch, effort and (CPUE) fluctuated considerably from 1989 to 2004 on both the Saya de Malha bank and the Nazareth bank. A striking trend is observed in the CPUE values on both banks. These were relatively low for the years when the effort was high, and were relatively high when effort was low. The yield from Saya de Malha bank has been more than double that from the Nazareth bank, except in 1997 and 2001 (Table 3 and Figure 3). The mean CPUE for the period 1989 to 2004 has been about 76 kg fday⁻¹ for both banks.

During the period 1989-2004, the mean catch from the Saya de Malha bank was around 2,200 t, with a maximum of 3,173 t in 1993 and a minimum of 1,283 t in 2001 (Table 3 and Figure 3a). The mean effort exerted was about 30,000 fdays, with a maximum of 45,944 fdays in 1994 and a minimum of 10,304 fdays in 2001. The effort was relatively low from 1989 to 1991, but increased considerably for the next five years with a corresponding increase in catch. Consequently the fishing effort and catch decreased and were relatively stable from 1997 to 2004, except in 2001 when the effort and catch were significantly reduced. This resulted in an increase in CPUE. The CPUE was highest in 2001 at 124.1 kg fday⁻¹ and lowest at 57.8 kg fday⁻¹ in 1996.

On the Nazareth bank, the mean catch from 1989 to 2004 was 1,100 t, with a maximum of 1,720 t in 1997 and a minimum of 468 t in 2003. The mean effort was 15,000 fdays. The period 1993 to 1997 experienced the highest effort (~ 24,000 fdays) and from 1998 to 2004, the fishing effort decreased to almost half that value. The CPUE was highest at 99.2 kg fday⁻¹ in 2001 and lowest at 52.5 kg fday⁻¹ in 1996.

Table 3: Catch (tonnes of gutted fish), effort (fishermandays) and CPUE (kg fday⁻¹) from the Saya de Malha and Nazareth banks for the period 1989-2004.

Year	Saya de Malha			Nazareth		
	Effort	Catch	CPUE	Effort	Catch	CPUE
1989	29,288	2,177	74.3	11,059	837	75.7
1990	19,316	1,410	73.0	11,649	914	78.5
1991	20,257	1,782	88.0	9,757	793	81.3
1992	41,715	2,825	67.7	12,168	952	78.2
1993	45,944	3,173	69.1	20,543	1,358	66.1
1994	47,148	3,142	66.6	22,464	1,494	66.5
1995	44,163	2,957	67.0	23,847	1,533	64.3
1996	39,504	2,283	57.8	23,850	1,253	52.5
1997	25,042	1,798	71.8	26,005	1,720	66.1
1998	27,059	2,054	75.9	13,337	1,086	81.4
1999	30,073	2,107	70.1	14,712	1,121	76.2
2000	26,988	2,099	77.8	11,938	1,080	90.5
2001	10,340	1,283	124.1	13,773	1,366	99.2
2002	25,083	2,090	83.3	9,837	918	93.3
2003	29,371	2,354	80.1	6,426	468	72.8
2004	23,729	1,689	71.2	10,154	855	84.2
Mean	30,314	2,201	76.1	15,095	1,109	76.7

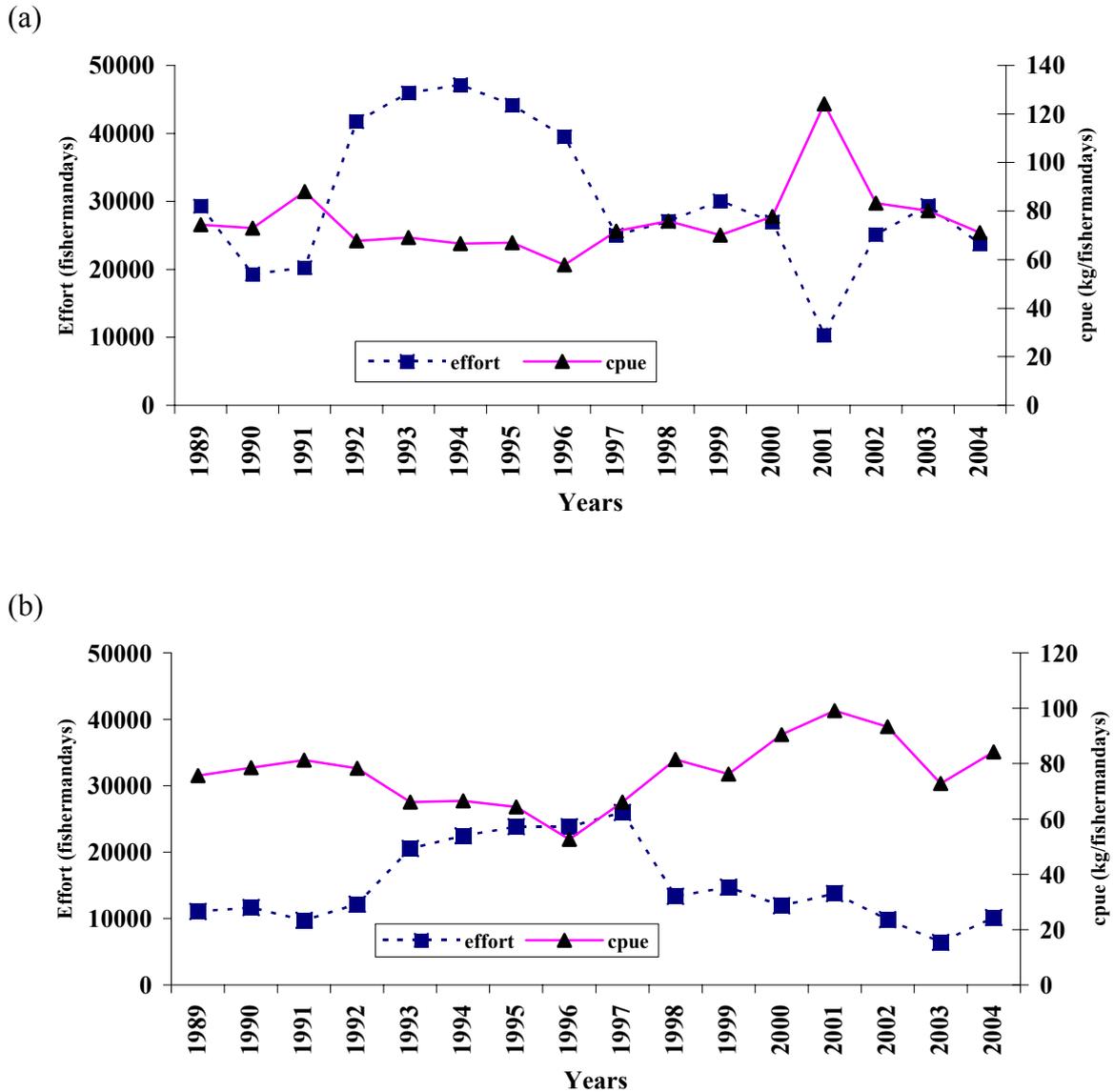


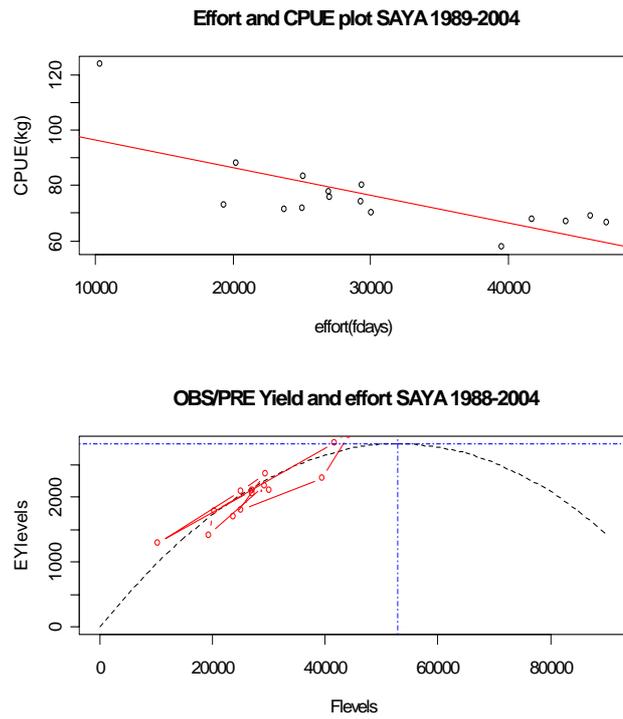
Figure 3: Effort and CPUE trends on Saya de Malha bank (a) and Nazareth bank (b) for the period 1989-2004.

4.2 Equilibrium assumption fit to catch and effort data

Plots were made using effort and CPUE data, the relation between effort levels and yields at equilibrium levels were also determined by the Schaefer and Fox models (Figures 4 and 5).

With respect to both banks, the MSY and the f_{MSY} were higher using the Fox model compared to the Schaefer model (Table 4).

(a)



(b)

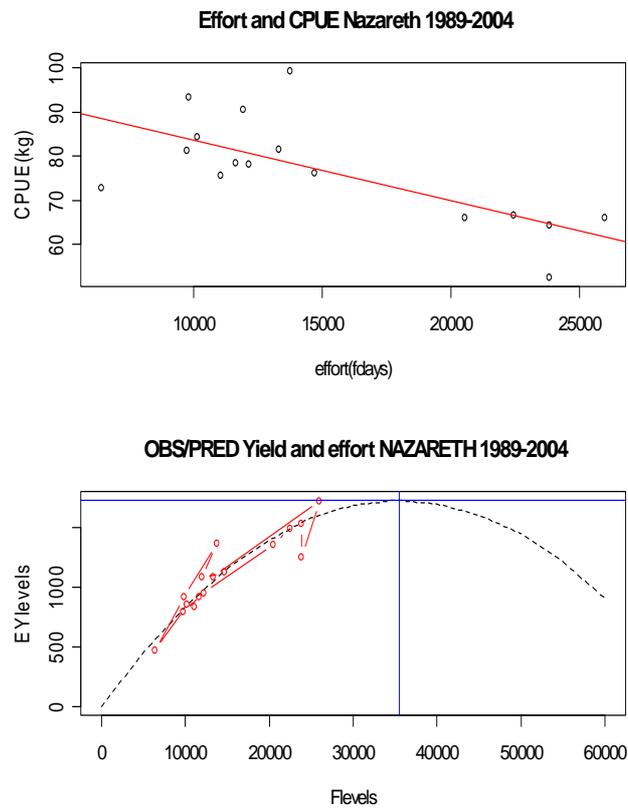
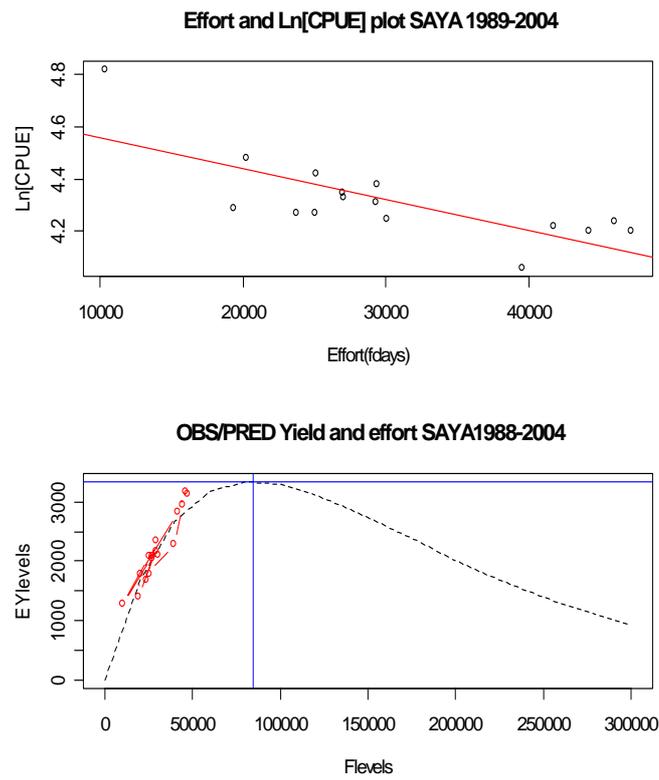


Figure 4: Effort, CPUE observed and predicted yield on Saya de Malha bank (a) and Nazareth bank (b) using the Schaefer equilibrium assumption model.

(a)



(b)

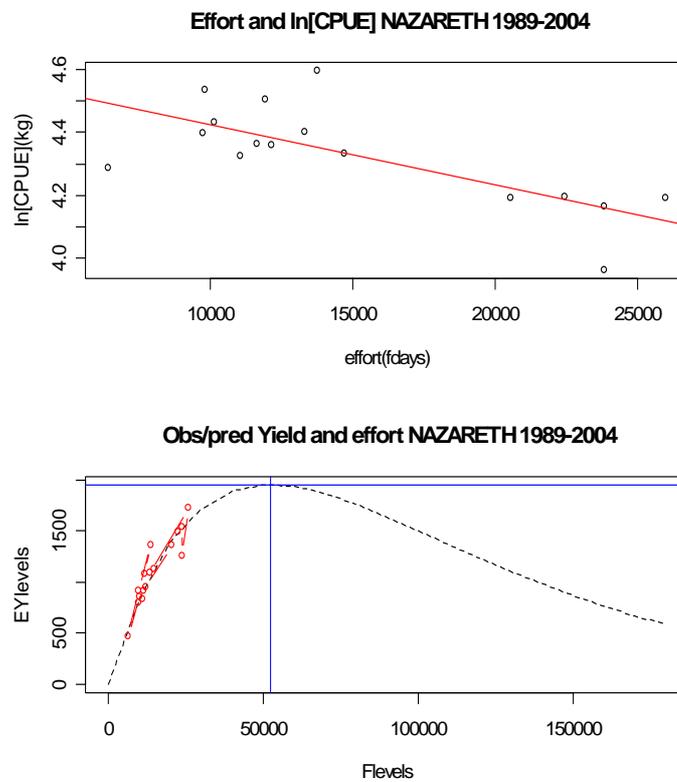


Figure 5: Effort, CPUE, observed and predicted yield on Saya de Malha bank (a) and Nazareth bank (b) using the FOX equilibrium assumption model.

Table 4: Estimates of MSY (tonnes) and f_{MSY} (fishermandays) using the Schaefer and Fox equilibrium assumption models on Saya de Malha and Nazareth banks.

Banks	Schaefer model		Fox model	
	MSY	f_{MSY}	MSY	f_{MSY}
Saya de Malha	2,821	52,874	3,341	84,602
Nazareth	1,729	35,528	1,950	52,493

4.3 Time-series fitting using dynamic biomass model in R

The correlation between the predicted CPUE and the observed CPUE was positive at 0.479 for Saya de Malha bank and 0.324 for Nazareth bank (Figure 6 and Figure 8). The yield trajectories in relation to the predicted biomass from 1989 to 2004 were on the right descending portion of the predicted biomass levels i.e. at biomass greater than B_{MSY} (Figure 7 and Figure 9). The biomass/yield curves for Saya de Malha and Nazareth banks show that different maximum yields are sustained at different biomass levels. On the Saya de Malha bank MSY of 3,176 t is obtained at a B_{MSY} level of 4,862 t, while for the Nazareth bank the MSY of 2,281 t is obtained at B_{MSY} of 3,761 t. The f_{MSY} for the Saya de Malha bank and the Nazareth bank were 63,319 and 50,668 fdays, respectively.

The yield trajectory as compared to the respective predicted biomass levels for the Saya de Malha bank show that the yields for the years 1992 to 1995 were close to the estimated MSY level. From 1989 to 1991 and from 1996 to 2004, the yield was well below the MSY level (Figure 7). On the Nazareth bank the yield has been well below the predicted MSY (Figure 9). Estimated values for the parameters r , K , B_t and q are given in Table 5.

Table 5: Estimated parameters on the Saya de Malha and Nazareth banks, using the non-equilibrium dynamic biomass production model in R.

Parameters	MSY	f_{MSY}	B_{MSY}	F_{MSY}	K	B_t	r	q
Saya de Malha	3,176	63,319	4,862	0.653	9,724	7,078	1.31	0.010
Nazareth	2,281	50,668	3,761	0.606	7,523	6,299	1.21	0.012

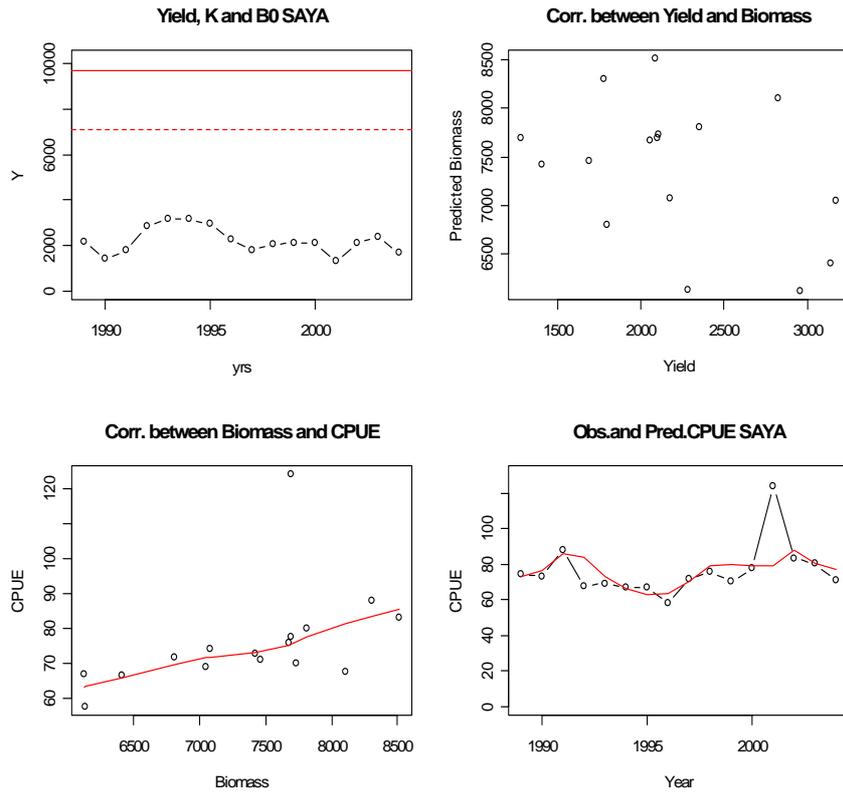


Figure 6: Correlation of yield, K , B_t , CPUE, observed and predicted CPUE for Saya de Malha bank using the non-equilibrium dynamic biomass model.

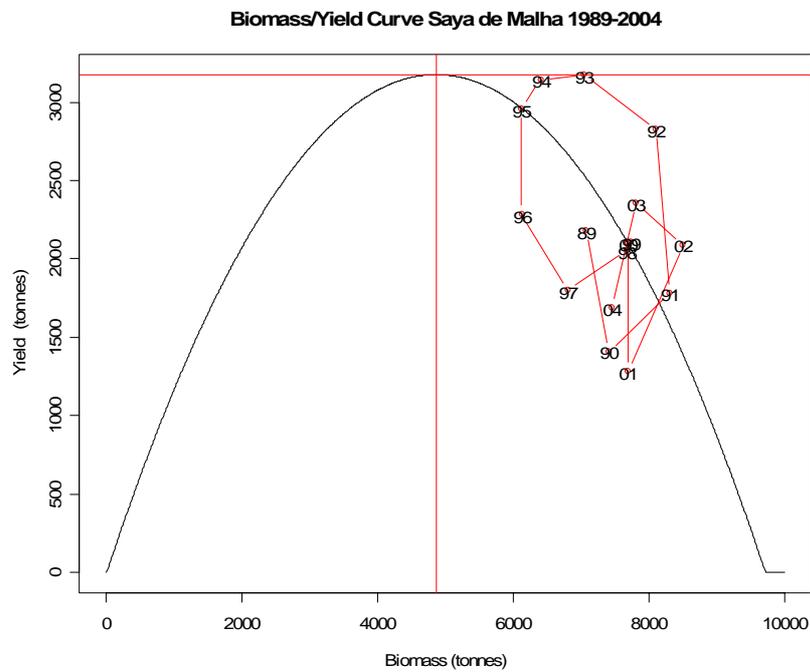


Figure 7: Biomass and yield curve showing observed and predicted yield trajectory on Saya de Malha bank for the period 1989-2004.

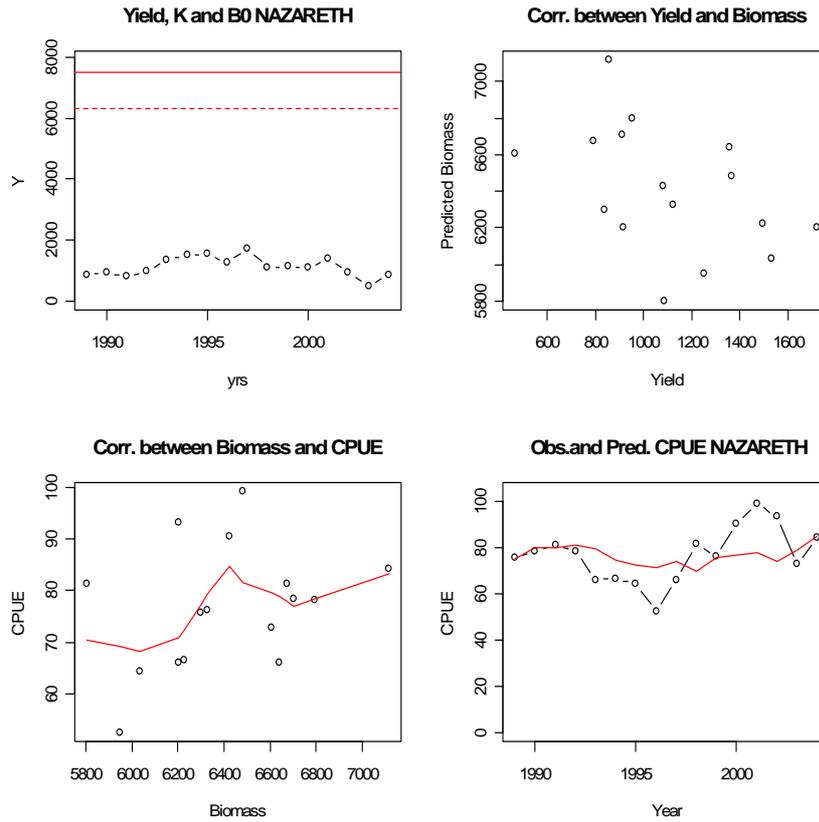


Figure 8: Correlation of yield, K , B_t , CPUE, observed and predicted CPUE for Nazareth bank using the non-equilibrium dynamic biomass model.

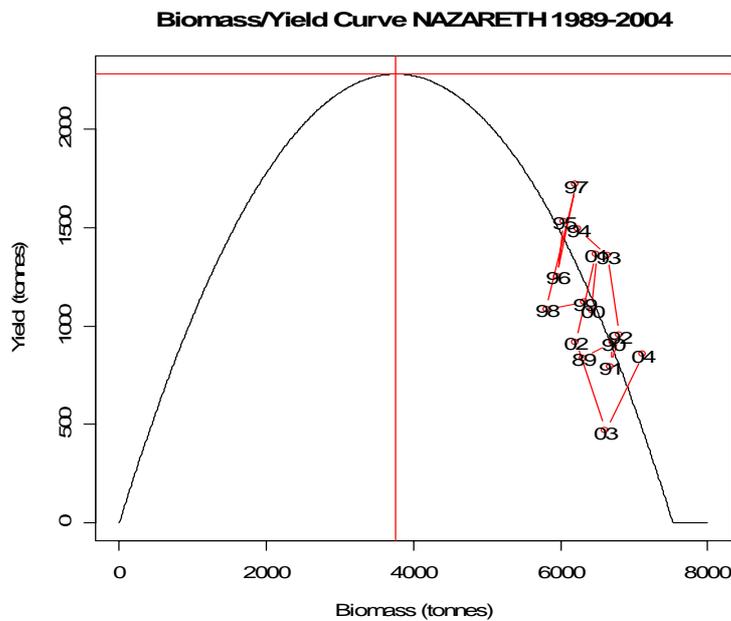


Figure 9: Biomass and yield curve showing the observed and predicted yield trajectory on Nazareth bank for the period 1989-2004.

4.4 Time-series fitting incorporating covariates (ASPIC)

4.4.1 *Saya de Malha bank*

Initial runs in the ASPIC FIT mode for all the three models gave normal convergence. The observed CPUE and predicted CPUE indexes are shown in Figure 10. The estimated biomass fluctuated from 4,500 to 6,350 t (Figure 11). It was estimated to be lowest during 1993-1997 and highest in 2002-2003. The estimated surplus production was close to the yield for the period 1989-2004. However, from 1992 to 1995 and in 2002-2003 the yield was slightly higher than the estimated surplus production according to the Logistic model. The estimated surplus production shows a decreasing trend for the last nine years (Figure 11).

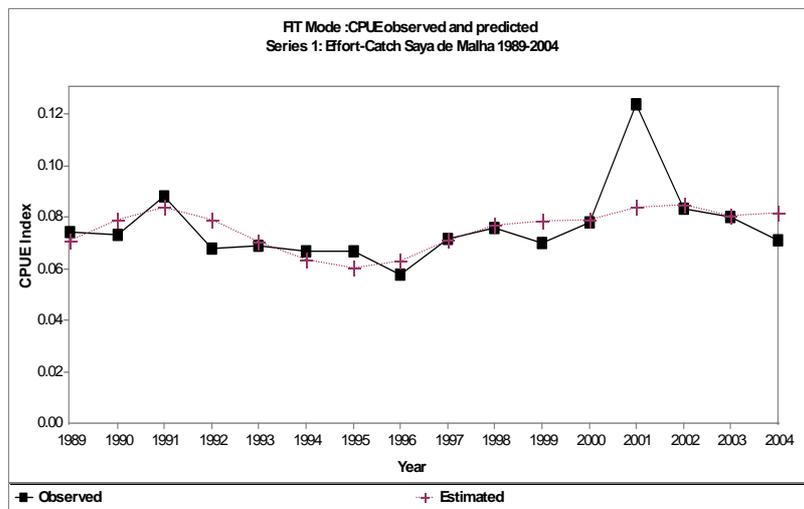


Figure 10: Observed and predicted values of CPUE on Saya de Malha bank using the dynamic non-equilibrium Logistic model in ASPIC for the period 1989-2004.

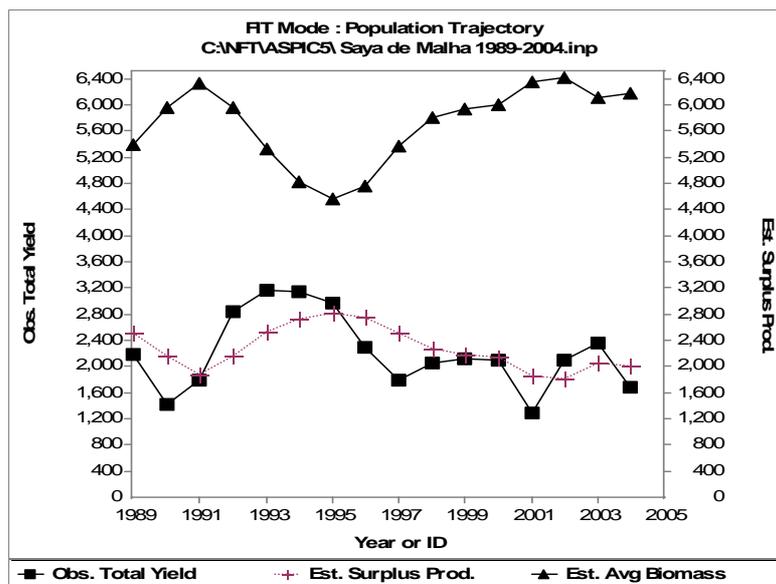


Figure 11: Observed yield, estimated average biomass and surplus production on Saya de Malha bank using the Logistic model in ASPIC for the period 1989-2004.

The estimated MSY from the models varied as from 2,689 to 3,170 t and the f_{MSY} varied from 42,460 to 76,860 fdays. The estimated B_{MSY} fluctuated from 3,048 to 5,135 t. Point estimates for all parameters are given in Table 6.

The estimates of MSY, f_{MSY} and the interquartile ranges after bootstrapping using approximate 95% upper and lower confidence limits are shown in Table 7 and Appendix 2.

Table 6: Estimated parameters on the Saya de Malha bank using the ASPIC FIT mode.

MODEL	MSY	f_{MSY}	B_1/K	K	B_{MSY}	F_{MSY}	q
Logistic	2,866	54,390	0.653	7,968	3,984	0.72	0.013
Fox	3,170	76,860	0.615	8,286	3,048	1.04	0.014
Generalized, Estimate Exponent	2,689	42,460	0.710	7,815	5,135	0.52	0.012

Table 7: Estimates of MSY and f_{MSY} from bootstrapped analysis in ASPIC with bias corrected confidence limits for the Saya de Malha bank.

MODELS	Bias-corrected approximate confidence limits					
	MSY			f_{MSY}		
	95 % <i>lower</i>	95 % <i>upper</i>	<i>IQ</i> <i>range</i>	95 % <i>lower</i>	95 % <i>upper</i>	<i>IQ</i> <i>range</i>
Logistic	2,531	3,925	289.4	40,390	86,780	10,640
Fox	2,632	4,530	514.1	49,820	125,600	21,270
Generalized, Estimate Exponent	2,473	2,947	153.6	20,360	53,380	6,197

IQ- Inter quartile

According to the Logistic model, the absolute biomass predicted would decrease slightly and average to about 5,000 t when fished at the MSY level (2,866 t) for the next five years (Figure 12a). For an annual yield of 2,070 t, the average yield in 1995-2004, the biomass is predicted to stabilise at about 6,000 t (Figure 12b). If the yield was set at 3,200 t or near to the maximum catch observed in 1989-2004, the model predicts quite a rapid decrease in biomass to levels as low as 4,000 t in 2009 (Figure 12c). The confidence level values of these estimates are relatively narrow; however, the lower confidence limits at 80% are closer to the average than the upper confidence limits (Figure 12a, 12b and 12c).

The relative biomass (B/B_{MSY}) is predicted to fluctuate between 1.30 and 1.75, within 80% lower and upper confidence intervals, for the estimated MSY level (Figure 13a) and the average catch (Figure 13b) scenarios. For yield set at above the MSY, the ratio tends towards or below 1 for the next five years (Figure 13c). The confidence limits of the relative biomass are close to the average, except for the case, if yield was to be set at higher than the MSY level. The parameters and confidence intervals in the case of removing the last ten years average catch (2,070 t) from the stock are more stable in the projection of relative biomass (Figure 13b).

The relative fishing mortality (F/F_{MSY}), for the catch set at MSY and catch set at 2,070 t ranged from 0.5 to 0.85 (Figures 14a and 14b). The lower and upper confidence limits are stable over the projection years. However, if catches were to be set at levels higher than the estimated MSY, the F/F_{MSY} ratio would increase from 0.8 to 1.2 in just five years (Figure 14c). The 80% confidence interval limits are also wide and diverge to larger ranges for the next five years (Figure 14c).

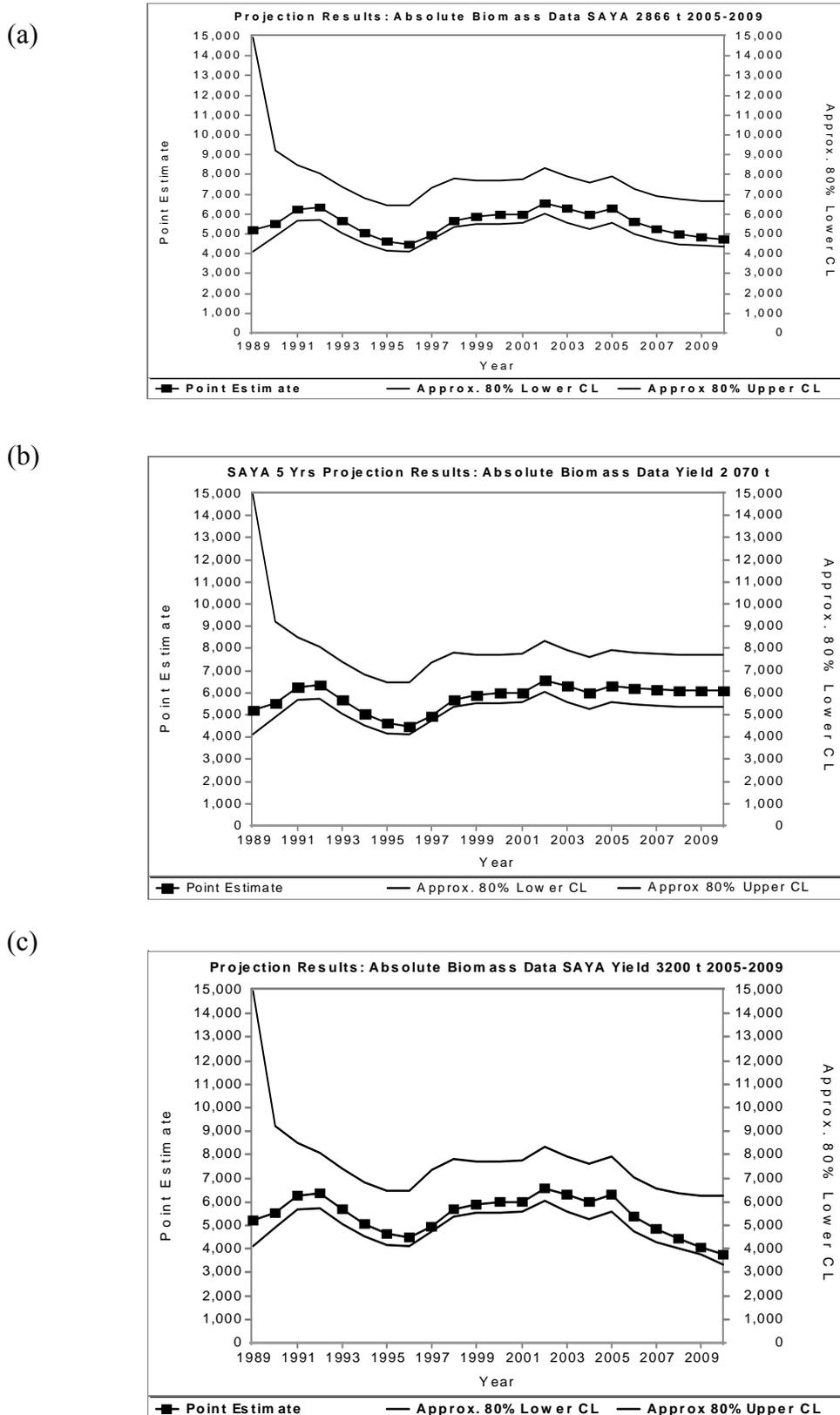


Figure 12 : Five years projection (2005 to 2009) trajectories of absolute biomass with annual catch at the MSY level of 2,886 t (a), annual catch at 2,070 t (b) and annual catch at 3,200 t (c) on Saya de Malha bank.

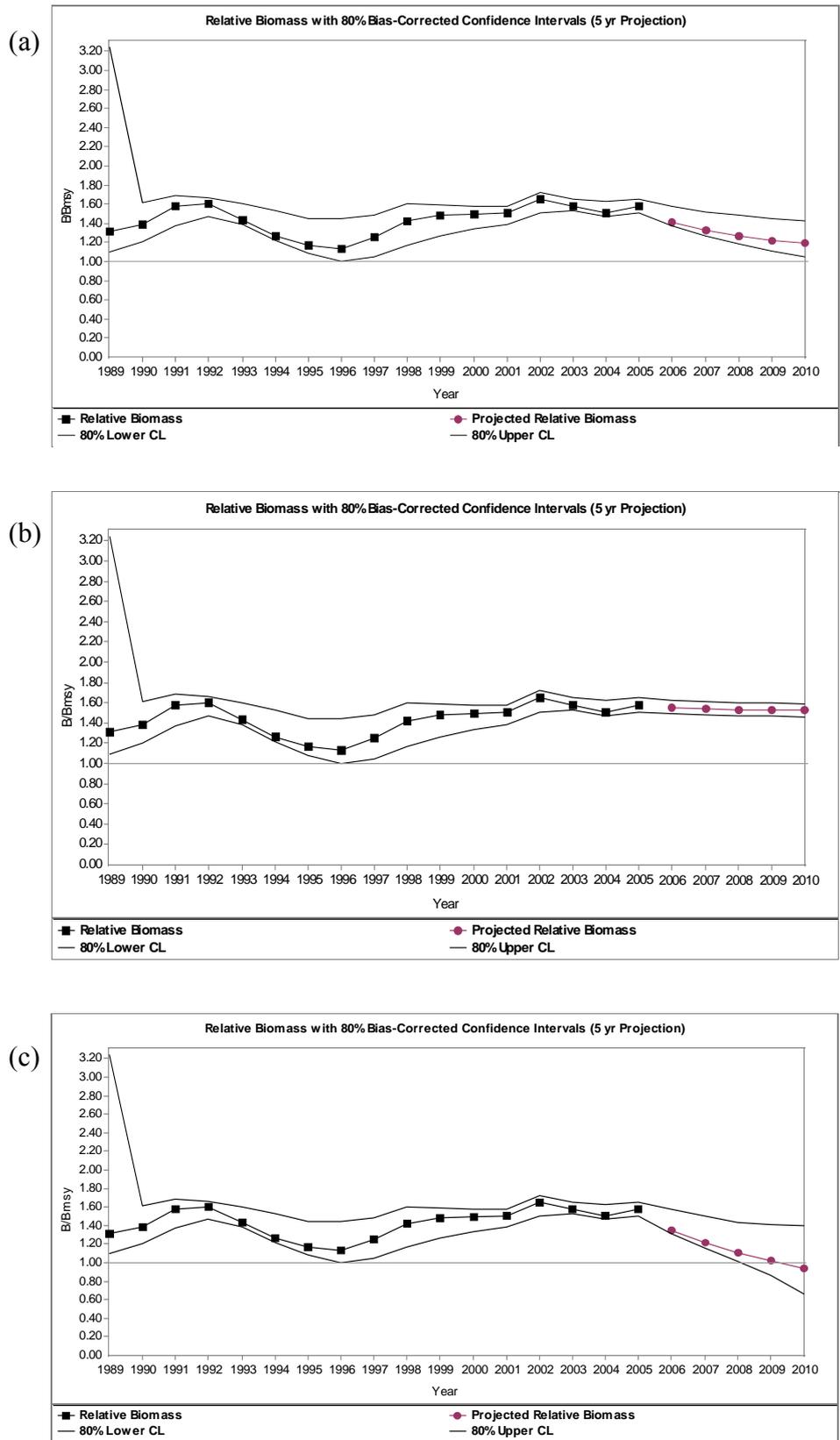
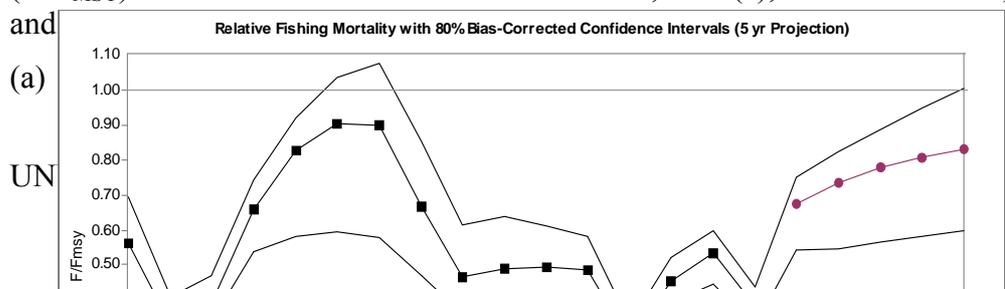


Figure 13: Five year projection (2005 to 2009) trajectories of relative biomass (B/B_{MSY}) with annual catch at the MSY level of 2,886 t (a), annual catch at 2,070 t (b) and



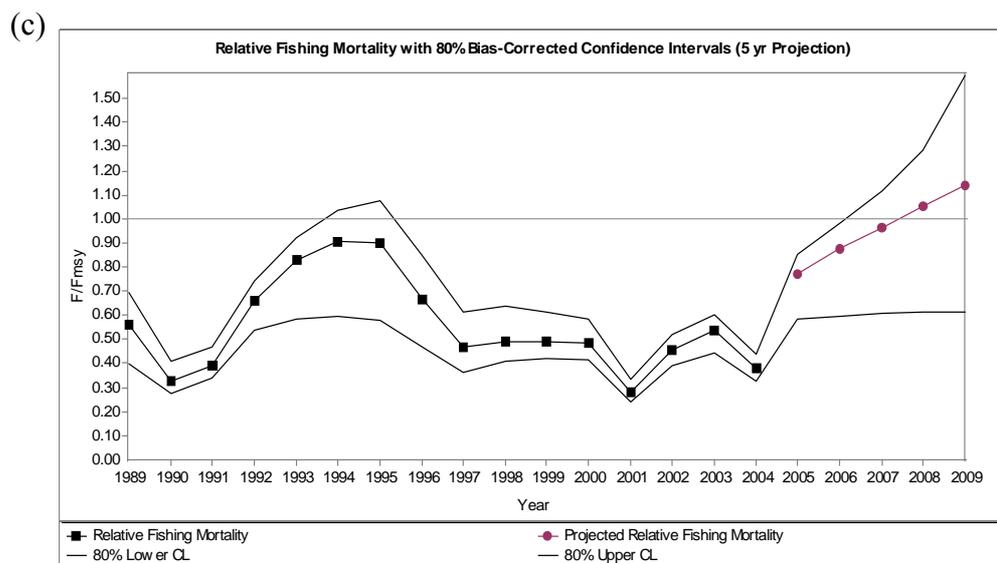
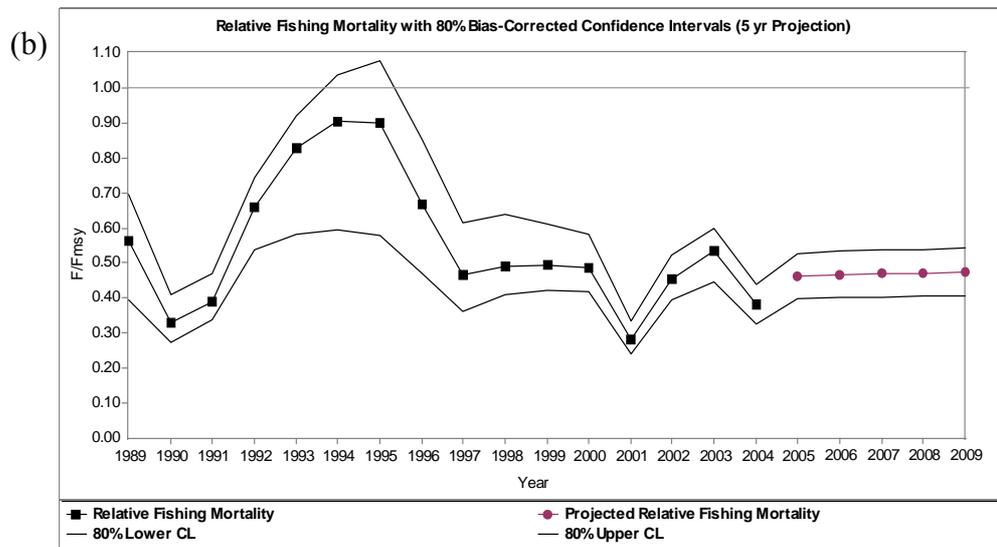


Figure 14: Five year projection (2005 to 2009) trajectories of relative fishing mortality (F/F_{MSY}) with annual catch at the MSY level of 2,886 t (a), annual catch at 2,070 t (b) and annual catch at 3,200 t (c) on Saya de Malha bank.

4.4.2 Nazareth bank

Catch and effort data from Nazareth bank gave normal convergence, by all the three models fitted. However for most of the years, the observed and predicted CPUE did not fit closely (Figure 15). The estimated biomass fluctuated from 5,800 to 6,750 t. It was estimated lowest in 2003 and highest in 1997 (Figure 16). The annual surplus production was estimated in the range of 650 to 1,516 t. Generally, the yield has followed the same trend as the surplus production levels. However, for the years 1992 to 1997 the estimated surplus production was lower than the yield (Figure 16).

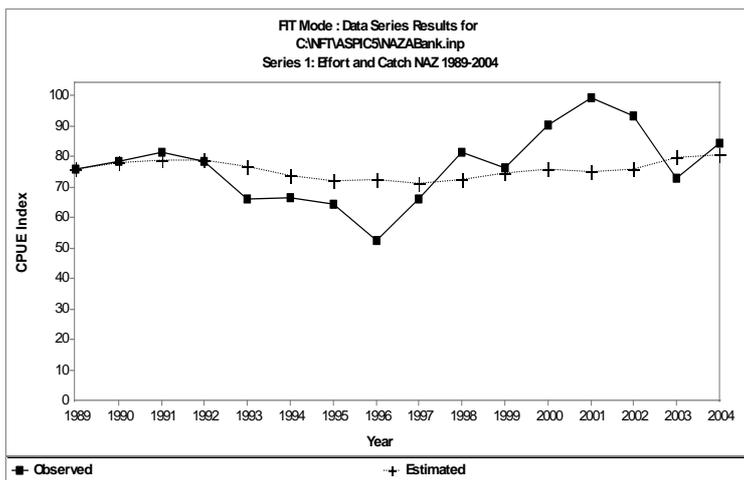


Figure 15: Observed and predicted values of the CPUE index on the Nazareth bank using the non-equilibrium Logistic model in ASPIC.

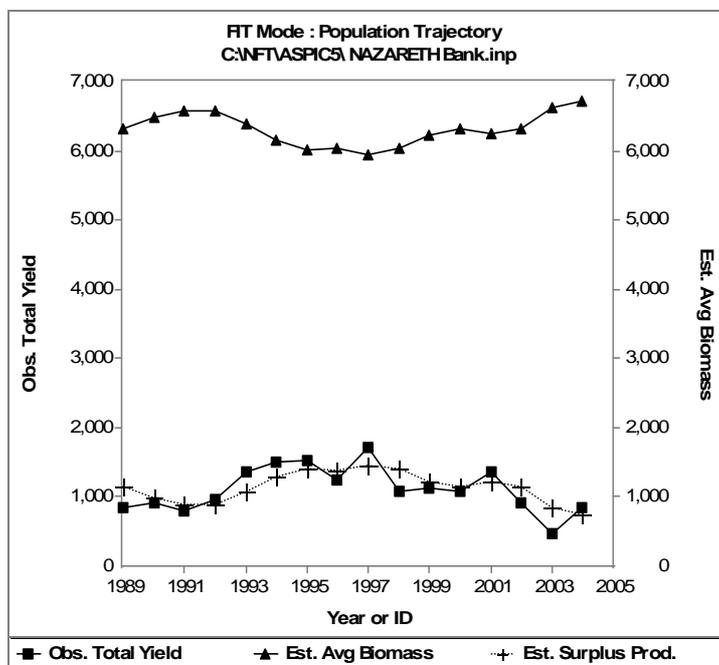


Figure 16: Observed yield, estimated surplus production and average biomass on Nazareth bank using the Logistic model in ASPIC 5 for the period 1989-2004.

The estimated MSY from the models varied from 1,493 to 3,004 t and the f_{MSY} ranged between 22,450 and 91,300 fdays. The estimated B_{MSY} fluctuated from 2,742 to 5,541 t. Point estimates for all estimated parameters are given in Table 8.

The estimates of MSY and f_{MSY} for the Nazareth bank, the 95% upper and lower confidence limits and their inter quartile ranges are shown in Table 8 and Appendix 3.

Table 8: Estimated parameters on Nazareth bank using ASPIC FIT mode.

MODELS	MSY	f_{MSY}	B_1/K	K	B_{MSY}	F_{MSY}	q
Logistic	2,377	53,890	0.84	7,350	3,675	0.65	0.012
Fox	3,004	91,300	0.82	7,452	2,742	1.09	0.012
Generalized, Estimate Exponent	1,493	22,450	0.88	6,926	5,541	0.27	0.012

Table 9: Estimates of MSY and f_{MSY} from bootstrapped analysis in ASPIC with bias corrected confidence limits for the Nazareth bank.

MODELS	Bias-corrected approximate confidence limits					
	MSY			f_{MSY}		
	95 % <i>lower</i>	95 % <i>upper</i>	<i>IQ</i> <i>range</i>	95 % <i>lower</i>	95 % <i>upper</i>	<i>IQ</i> <i>range</i>
Logistic	1,623	3,465	947	32,280	88,780	27,400
Fox	2,431	3,458	247	70,260	116,100	12,760
Generalized, Estimate Exponent	1,204	3,017	461	15,010	50,750	6,213

IQ- Inter quartile

The projected estimates of the biomass levels using the Logistic fit model are different for the three different catch levels set. When catch was set at the estimated MSY level (2,377 t), the biomass is assumed to stabilise at 4,500 t after five years within relatively narrow confidence bounds of 80% (Figure 17a). Assuming an annual yield of 1,200 t, as has been the average catch over the last ten years on the Nazareth bank, the biomass levels may increase and stabilise at slightly over 6,000 t (Figure 17b). The confidence limit interval is relatively narrow and uniform. However, if 2,500 t were to be taken from the stock for the next five years, the projection outputs show that the biomass may decrease to about 4,000 t (Figure 17c).

The relative biomass (B/B_{MSY}) may approach a value close to 1 when the annual yield is set at estimated MSY (Figure 18a). The 80% confidence interval bounds are diverging at the end of the five year projection period. In the case of the annual catch set at 1,200 t, the relative biomass index is within a relatively narrow range between 1.6 and 1.8 over the next five years (Figure 18b). The relative biomass is expected to decrease to 1 for the projected years, if more than 2,500 t is to be harvested from the Nazareth bank (Figure 18c).

The relative fishing mortality shows a quite similar trend as the B/B_{MSY} ratio. For a catch set at the estimated MSY, the ratio is close to 1 and the bounds of the 80% confidence intervals are wide (Figure 19a). An average annual catch of 1,200 t is

estimated to stabilise the F/F_{MSY} ratio at about 0.3 for the next five years (Figure 19b). If catch was to be above the estimated MSY level or 2,500 t, the relative fishing mortality (F/F_{MSY}) would approach 1 in only five years (Figure 19c).

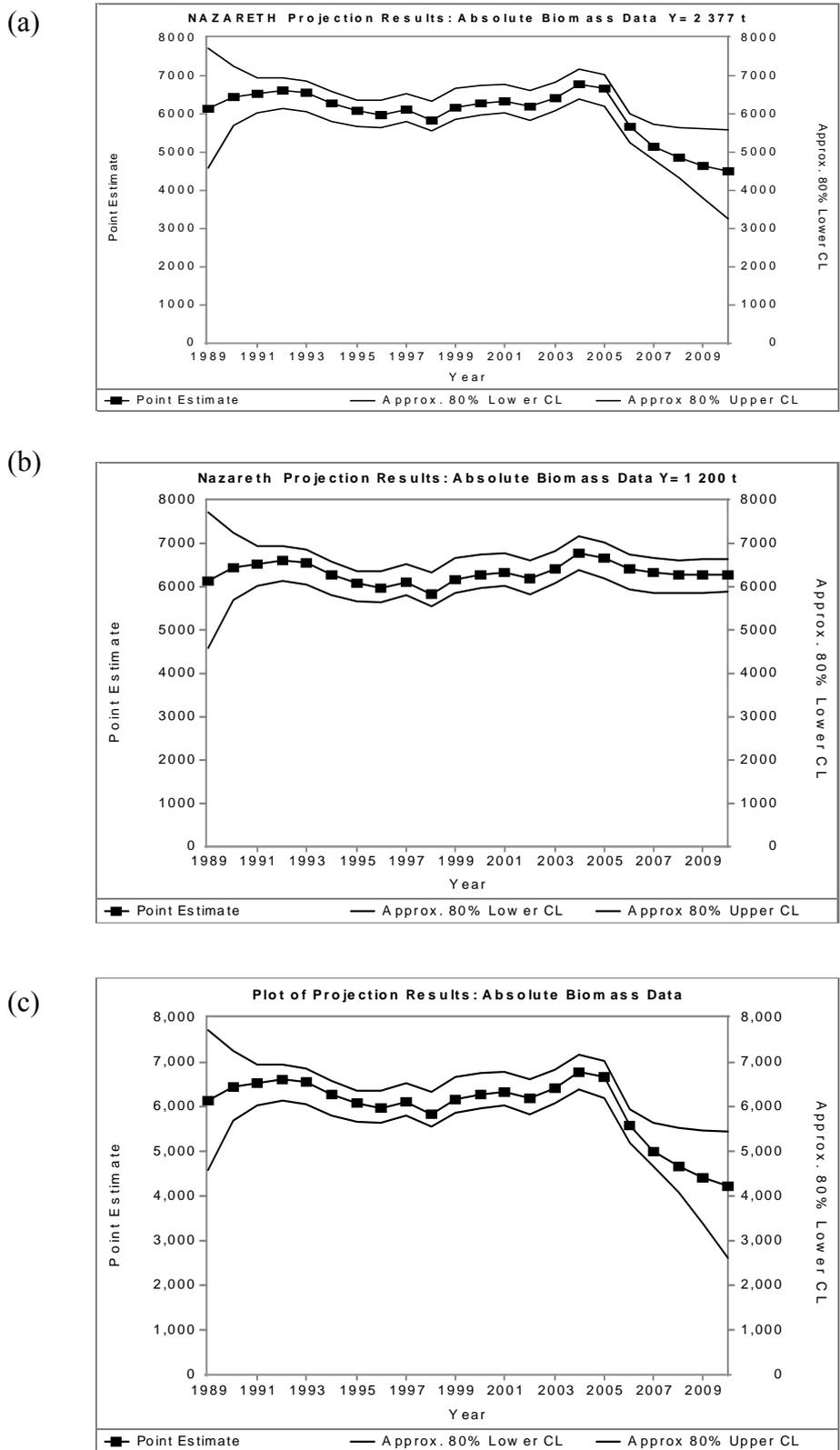


Figure 17: Five year projection (2005 to 2009) trajectories of absolute biomass with annual catch at the estimated MSY level of 2,377 t (a), annual catch at 1,200 t (b) and annual catch at 2,500 t (c) on Nazareth bank.

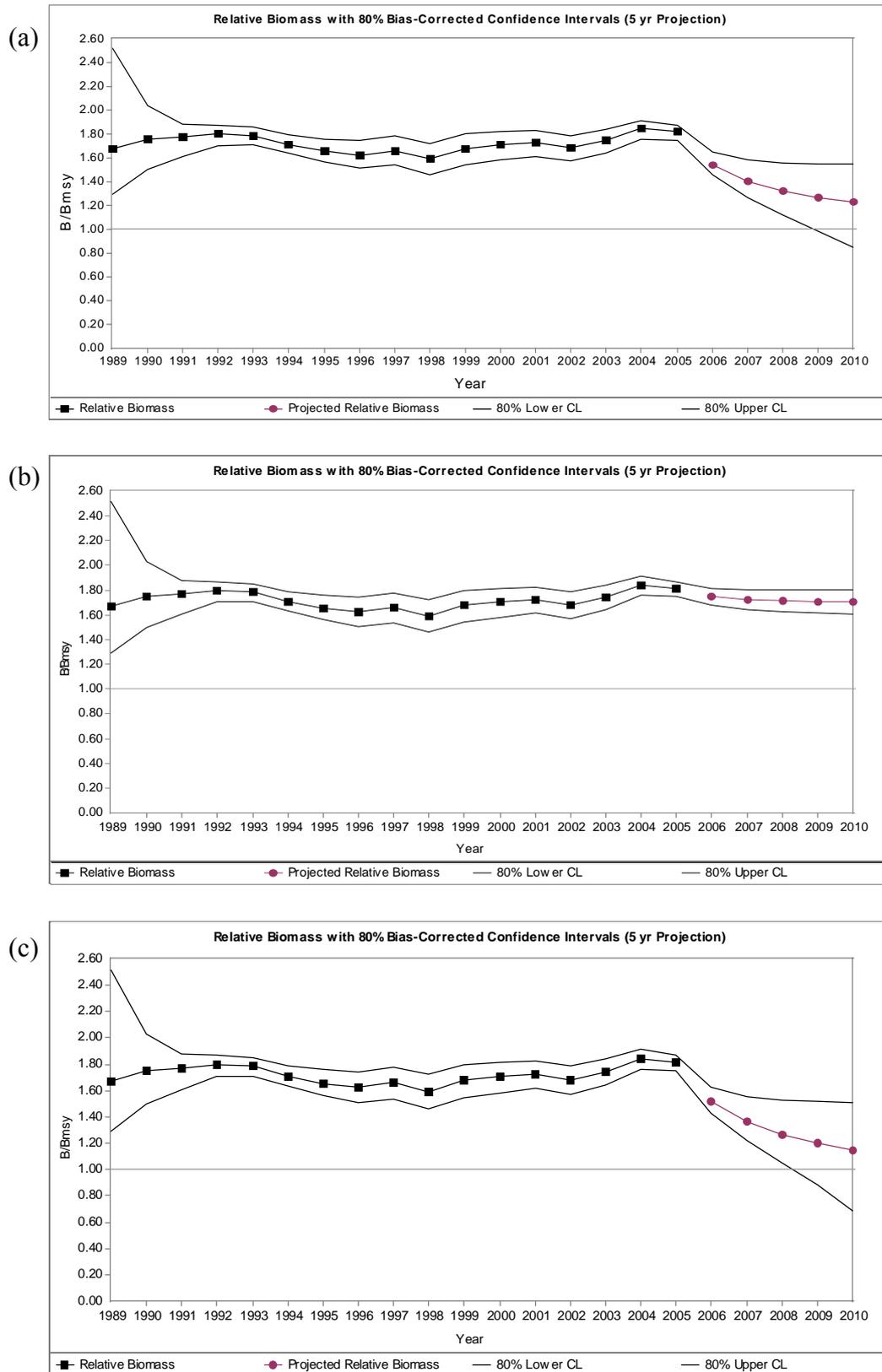


Figure 18: Five year projection (2005 to 2009) trajectories of relative biomass (B/B_{MSY}) with annual catch at the estimated MSY level of 2,377 t (a), annual catch at 1,200 t (b) and annual catch at 2,500 t (c) on Nazareth bank.

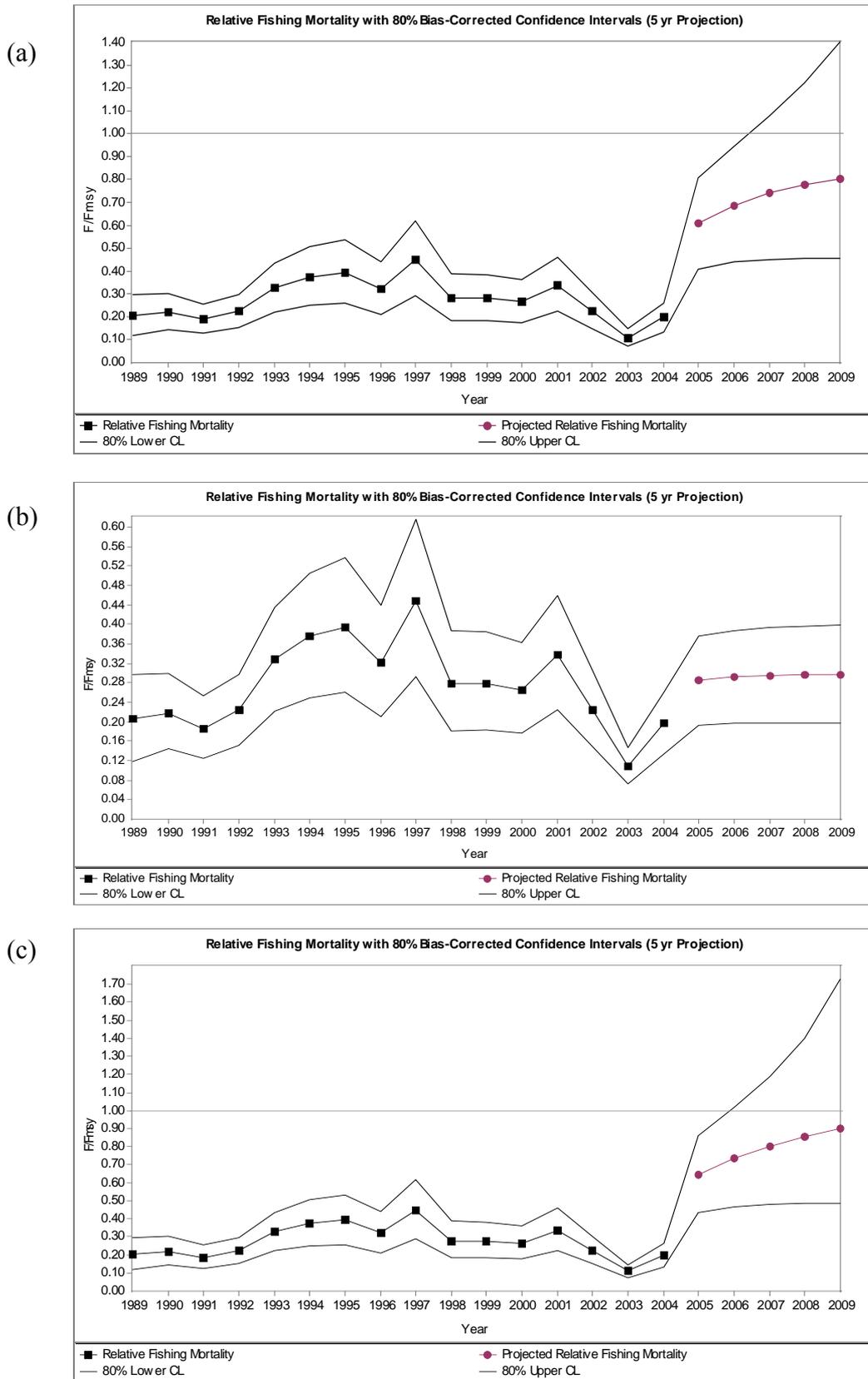


Figure 19: Five year projection (2005 to 2009) trajectories of relative fishing mortality (F/F_{MSY}) with annual catch at the estimated MSY level of 2,377 t (a), annual catch at 1,200 t (b) and annual catch at 2,500 t (c) on Nazareth bank.

4.5 Hind-casting trials

The estimates of MSY and f_{MSY} for the two banks varied when series of data from period 1989-1995 to period 1989-2004 were considered and also when period 1989-2004 to period 1998-2004 were analysed (Table 10).

For the Saya de Malha bank convergence was obtained in the model only as from number of years 13 to 16. For period 1989-2004 to 1998-2004 a gradual decrease in MSY and f_{MSY} is observed, with a corresponding decrease in the number of years analysed. In the latter period considered, convergence was observed for all the number of years analysed (Table 10).

Successively increasing the number of years for the Nazareth bank, from period 1989-1995 to 1989-2004, shows that MSY and f_{MSY} estimates increase in magnitude (Table 10). However, analysing data from period 1989-2004 to 1998-2004, a different trend in MSY and f_{MSY} estimates is noted. A decrease in number of years shows no particular trend other than variations in parameter estimates. Convergence was observed for all the time series considered in the Logistic model fitting, except for the number of years 7 and 8 (Table 10).

Table 10: MSY and f_{MSY} estimates from hind-casting trial analysis of Saya de Malha and Nazareth banks catch and effort data (1989-2004), using the Logistic model fit in ASPIC.

Data period	No. of years	Saya de Malha			Nazareth		
		MSY	f_{MSY}	Remarks	MSY	f_{MSY}	Remarks
1989-1995	7			NC	1,358	29,080	Convergence
1989-1996	8			NC	942	16,320	Convergence
1989-1997	9			NC	1,475	32,810	Convergence
1989-1998	10			NC	2,094	49,950	Convergence
1989-1999	11			NC	2,243	53,750	Convergence
1989-2000	12			NC	2,366	56,004	Convergence
1989-2001	13	2,599	42,630	Convergence	2,388	55,020	Convergence
1989-2002	14	2,694	47,310	Convergence	2,382	53,840	Convergence
1989-2003	15	2,750	49,670	Convergence	2,443	55,900	Convergence
1989-2004	16	2,866	54,390	Convergence	2,377	53,890	Convergence
1990-2004	15	2,857	53,590	Convergence	2,386	54,170	Convergence
1991-2004	14	2,864	53,960	Convergence	2,340	52,850	Convergence
1992-2004	13	2,912	54,280	Convergence	1,568	37,390	Convergence
1993-2004	12	2,773	50,850	Convergence	1,721	31,160	Convergence
1994-2004	11	2,583	46,040	Convergence	1,840	34,240	Convergence
1995-2004	10	2,267	36,960	Convergence	2,105	40,870	Convergence
1996-2004	9	2,131	31,760	Convergence	3,285	69,720	Convergence
1997-2004	8	2,101	30,590	Convergence			NC
1998-2004	7	2,123	31,280	Convergence			NC

NC- no convergence

4.6 Length frequency distribution analysis

4.6.1 Length distribution data

The total number of *L. mahsena* sampled from Saya de Malha bank for the period 2002-2005 was 14,522. The total length (TL) of *L. mahsena* ranged from 20 to 63 cm. The bulk of the catch (90%) consisted of fish ranging from 29 to 41 cm (Figure 20). The mean total length varied from 33.3 to 37.5 cm (Table 11).

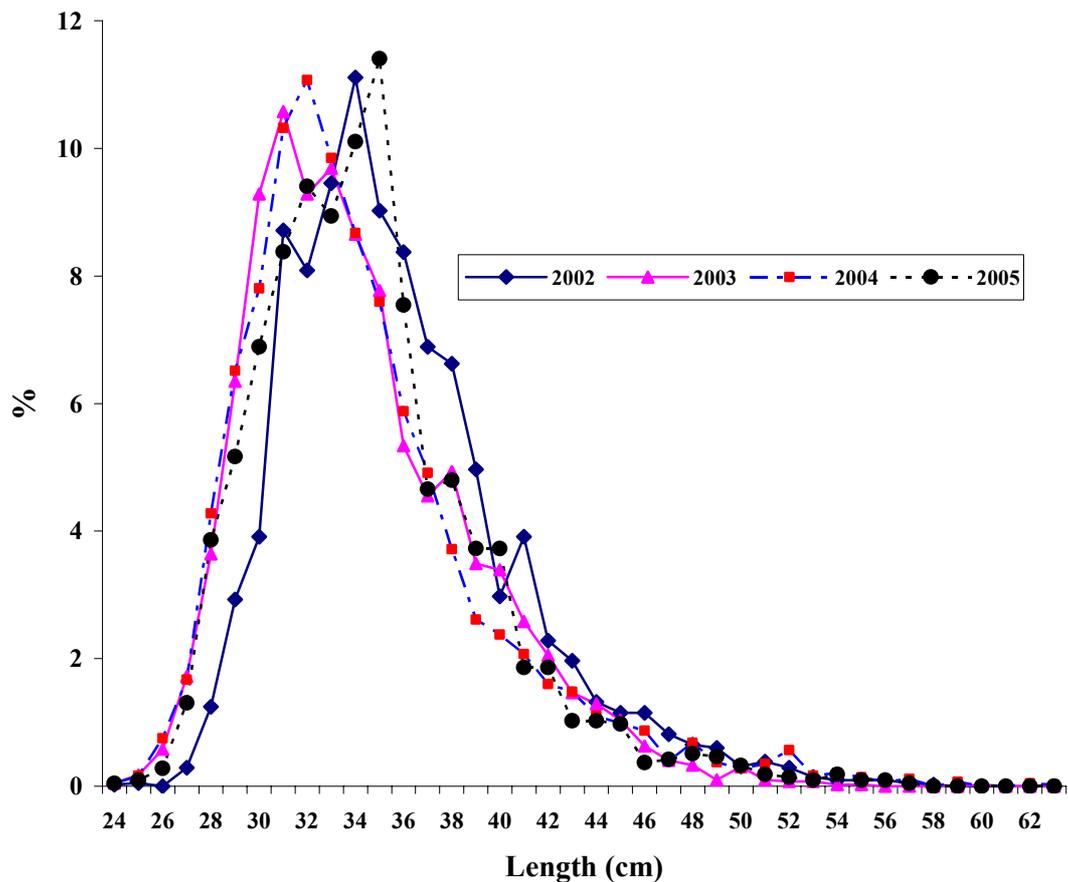


Figure 20: Length distribution of *L. mahsena* in the catch of Saya de Malha bank for the period 2002-2005.

Table 11: Number of *L. mahsena* sampled by month, mean length (cm), confidence intervals and total length range (cm) 2002-2005.

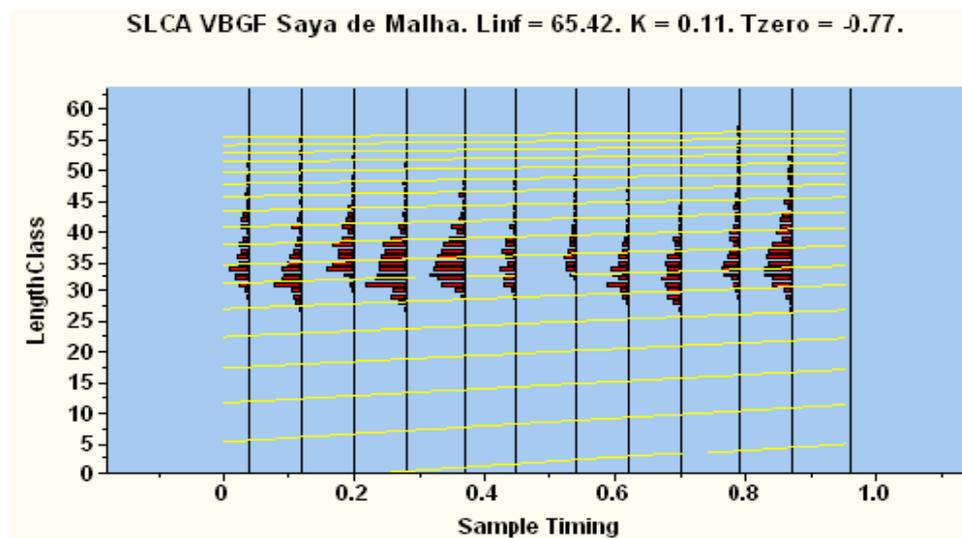
Year		Month												Total	Total length range (cm)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2002	Number	339	332	338	610	624	340	149	244	326	314	551	NA		
	Mean TL	37.4	34.4	37.3	34.7	36.0	36.2	37.5	33.7	33.6	37.4	36.8	NA	4167	24 – 58
	CI	0.6	0.5	0.4	3.4	0.4	0.5	0.7	0.4	0.4	0.6	0.4	NA		
2003	Number	288	382	394	606	855	234	242	280	376	134	NA	162		
	Mean TL	33.2	36.1	33.9	35.9	33.9	35.1	35.2	33.2	34.4	35.3	NA	33.2	3953	24 – 60
	CI	0.5	0.5	0.6	0.4	0.6	0.7	0.6	0.6	0.5	0.7	NA	0.6		
2004	Number	NA	NA	90	813	315	601	286	280	684	329	281	575		
	Mean TL	NA	NA	33.7	34.8	32.8	34.8	35.9	33.4	35.4	33.4	33.4	33.3	4254	20 – 63
	CI	NA	NA	1.0	0.5	0.5	0.4	0.6	0.6	0.4	0.5	0.4	0.4		
2005	Number	NA	286	326	353	300	557	326	NA	NA	NA	NA	NA		
	Mean TL	NA	33.8	34.7	34.5	34.2	35.9	33.5	NA	NA	NA	NA	NA	2148	24 – 57
	CI	NA	0.4	0.5	0.4	0.5	0.4	0.7	NA	NA	NA	NA	NA		
CI = 95 % confidence interval of the mean ($\alpha=0.05$)							NA - data not available								

4.6.2 Growth parameters estimation in LFDA

4.6.2.1 SLCA method

Estimated growth rate (k) for the years 2002-2005 ranged from 0.11 to 0.20 and the length at infinity (L_{∞}) ranged from 65.2 to 69.7 cm (Table 12). The total mortality rates (Z) estimated 0.60 to 1.09. The values of Z , F and M showed an increase in trend from 2002 to 2005. The exploitation rates (E) ranged from 0.44 to 0.59. The values for the growth performance index were 2.7 - 2.9 for the period 2002-2005. Using the age slice in SLCA, the age ranged from 3 to 16 years and the predominant nominal ages were 5-8 years (Figures 21a and 21b).

(a)



(b)

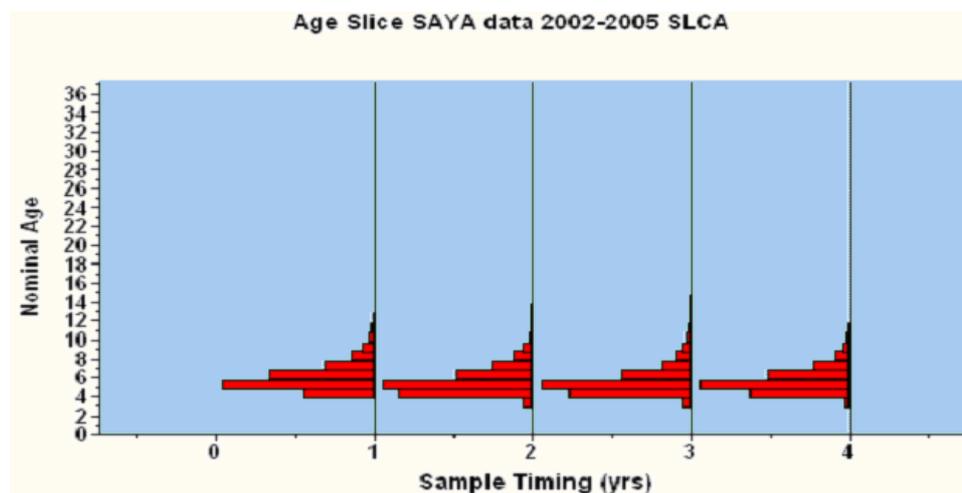


Figure 21: VBGF fitted on the length frequency distribution of *L. mahsena* (2002) using the SLCA method in LFDA (a) and age slice of length frequency data (2002-2005) from Saya de Malha bank (b).

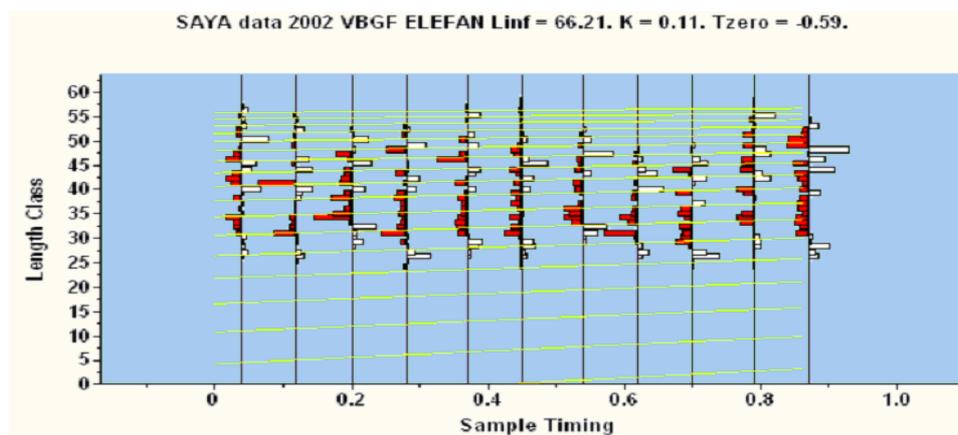
Table 12: Growth parameters, mortality rates, exploitation rates and growth performance index of *L. mahsena* from Saya de Malha bank using the SLCA method (2002-2005).

Year	Search ranges		Estimated parameters								
	k	L_{∞}	k	L_{∞}	t_0	Z_{LCCC}	Z_{B-Holt}	M	F	E	ϕ
2002	0.1-0.13	62 - 70	0.11	65.4	-0.77	0.63	0.60	0.34	0.26	0.44	2.7
2003	0.1 - 0.14	61 - 70	0.12	69.7	-0.68	0.74	0.82	0.34	0.48	0.59	2.7
2004	0.1 - 0.20	61 - 72	0.18	65.5	-0.61	0.89	0.91	0.46	0.45	0.50	2.9
2005	0.1 - 0.20	60 - 70	0.20	65.2	-0.54	1.03	1.09	0.49	0.60	0.55	2.9

4.6.2.2 ELEFAN method

Growth rate (k) ranged from 0.1 to 0.18 and L_{∞} from 66.2 to 69.1 cm. Z varied between 0.58 and 1.1 (Table 13). The values for 2005 were high. M and F ranged between 0.31 and 0.45 and from 0.33 to 0.53, respectively. E was close to 0.5. The growth performance index ranged from 2.7 to 2.9. Age slicing revealed ages from 3 to 19 years, while most of the fish in the catch were in the range 5 to 9 years (Figure 22a and 22b).

(a)



(b)

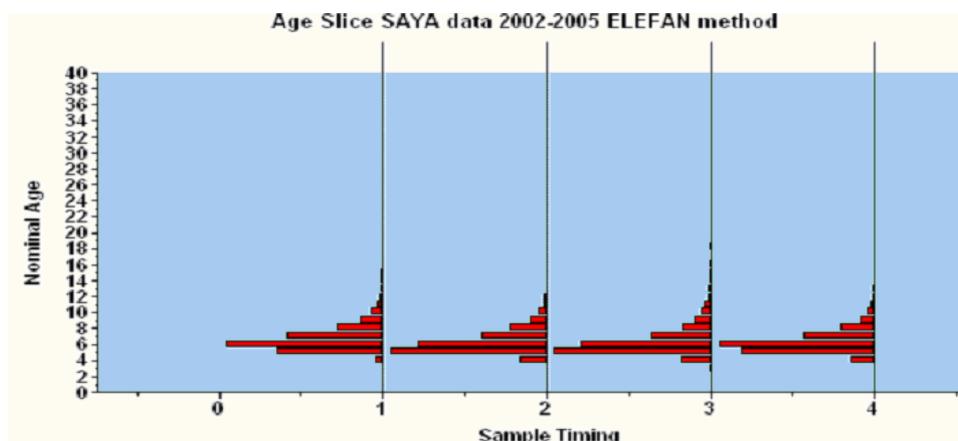


Figure 22 : VBGF fitted on the length frequency distribution of *L. mahsena* (2002) using the ELEFAN method in LFDA (a) and age slice of length frequency data (2002-2005) from Saya de Malha bank (b).

Table 13: Growth parameters, mortality rates, exploitation rates and growth performance index of *L. mahsena* from Saya de Malha bank using the ELEFAN method (2002-2005).

Year	Search ranges		Estimated parameters									
	k	L_{∞}	k	L_{∞}	t_o	Z_{LCCC}	Z_{B-Holt}	M	F	E	ϕ	
2002	0.1 - 0.14	60-70	0.11	66.2	-0.59	0.58	0.66	0.33	0.33	0.49	2.7	
2003	0.1 - 0.13	63-67	0.10	66.9	-0.61	0.58	0.65	0.31	0.34	0.52	2.7	
2004	0.1 - 0.14	60-70	0.13	69.1	-0.60	0.72	0.80	0.36	0.44	0.54	2.8	
2005	0.1 - 0.20	60-70	0.18	67.3	-0.84	1.10	0.98	0.45	0.53	0.54	2.9	

The mean k estimated by the SLCA method is slightly greater than that estimated by the ELEFAN method (Figure 23). The average L_{∞} is estimated 0.9 cm longer by the ELEFAN method as compared to the SLCA. The maximum age attainable by *L. mahsena* is from 25-30 yrs. The growth curves from the SLCA and ELEFAN methods are shown in Figure 23.

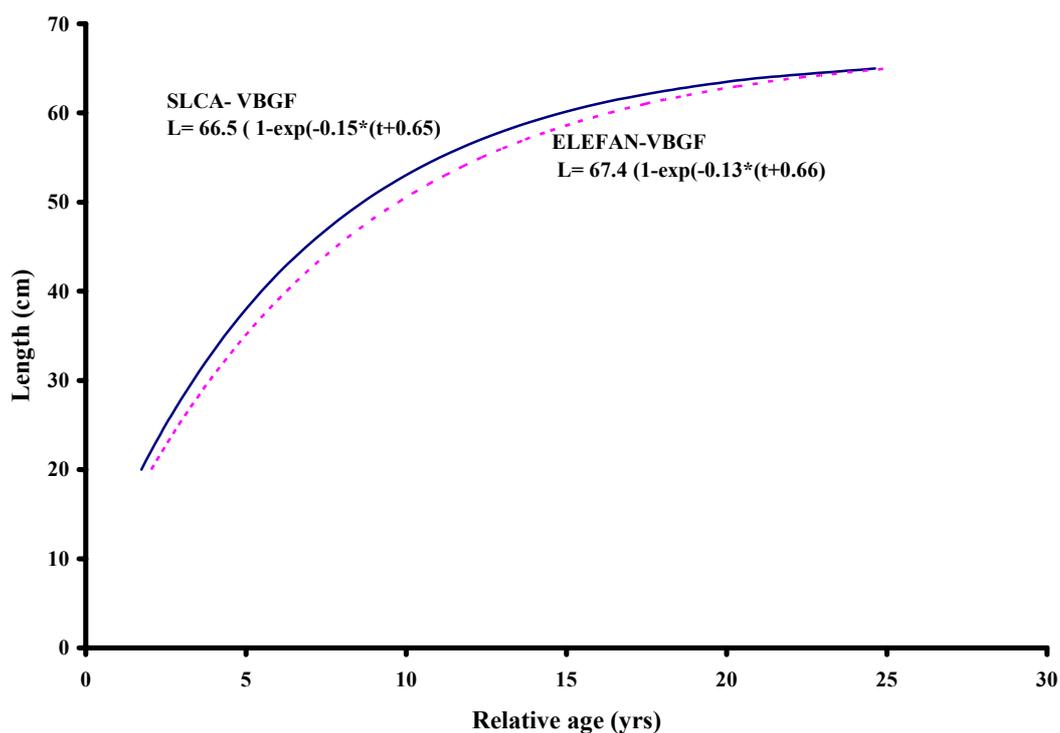


Figure 23 : VBGF curves of *L. mahsena* length frequency from Saya de Malha bank (2002-2005) fitted using the SLCA and the ELEFAN methods.

5 DISCUSSION

The results from this study do not indicate any serious problems arising from the use of dynamic biomass models when applied to time-series of catch and effort data from the Saya de Malha and the Nazareth banks. Not many options were available for estimation of biological reference points and management benchmarks, with only catch and effort data available. Ageing of fish is quite problematic at least for this fishery, in the sense that it is impractical, difficult and costly. With limited data on catch at age, dynamic biomass models can be a useful method for stock assessment (Sullivan *et al.* 1990, Sullivan 1992, Chen and Andrew 1998, Quinn and Deriso 1999, Haddon 2001). These models simply pool together recruitment, growth, mortality and age/size structure, as an entity. Ludwig and Walters (1985, 1989) have shown that using such models may provide very useful management parameters, provided only with good quality catch and effort data. For the Mauritian banks this type of dynamic biomass model seems the most practical method presently available for quantitative assessment and management.

The catch and effort data from the Mauritian banks fishery is thought to be reliable. Submission of logbooks is a prime condition in the fishing licence. Furthermore, all logbooks are verified at time of unloading and checked for discrepancies and the catch data is counter verified by the landings recorded by the Mauritius Port Authority. However, a number of deemed toxic fish and undersized fish, not accepted by fishing companies, are used as bait and hence not recorded in the catch. There may also be unreported catch from Saya de Malha bank since it is outside the EEZ.

The relatively low fishing efforts exerted in the late 1980s, followed by a sharp increase in the early 1990s, with a subsequent decrease in effort from 1996 to 2001, on both the Saya de Malha and the Nazareth banks, may satisfy the contrast criteria in the fitting of the model. Estimation of parameters with normal convergence in ASPIC and without problems in R reflects some contrast in the catch and effort data. Hilborn (1979) described some possible problems in the parameter estimation with insufficient contrast in the effort or CPUE. There may also be confounding between parameters unless the stock has an exploitation history covering a wide range of biomass and fishing effort levels (Hilborn and Walters 1992).

Although estimates of MSY and f_{MSY} using the equilibrium assumption in the Schaefer and Fox models are close or even less than the point estimates of the dynamic biomass models, it does not imply that they are good. The assumption in equilibrium production models is that any catch is sustainable in the long term and that a stock in equilibrium has little or no change over time in biomass, growth rate and age structure (Paine 1984). This implies that a stock responds immediately to changes in fishing effort, which is not true as this assumption does not take into account the time taken by fish stocks to respond to changes in fishing mortality. The time series nature of data, under this assumption is also ignored, which is a flaw in the methodology (Haddon 2001). This view is also supported by Hilborn and Walters (1992) who warn against fitting data with equilibrium assumption models, which do not recognise the dynamics of a fish population.

Besides, the basic assumption of linear correlation of abundance and biomass, there are other major assumptions such as: the environment is stable, there is a single stock,

catch and effort data are accurate, fish are non-migratory, there are no species interactions and above all that the data has enough information (i.e. contrast) for the model to provide reliable stock estimates. For the Mauritian banks fishery some of these assumptions may hold but not others. Uncertainty is unpleasantly common in stock assessment and finding ways to approach it is a vital part of fisheries modeling (Polacheck *et al.* 1993, Haddon 2001).

In the Mauritian banks fishery the number of hooks used per fisherman, type and method of fishing has changed little since 1989. However, some effort creep may have occurred when considering the increase in experience of fishers with time and probably use of better outboard motors. These types of continual improvements in fishing practices should have slightly increased the effectiveness of each unit of effort over time. An example is the Australian prawn fishery where such effort creep with the use of GPS, radar and plotters brought about a 12% increase in fishing power in just three or four years (Robins *et al.* 1998). Catchability increase is a factor that should be considered while using dynamic biomass models (Haddon 2001). Some discarding takes place in the fishery, as companies usually do not accept fish smaller than about 30 cm. Therefore, these small fishes are sometimes used as bait. These discards are not included in the catch, and may affect the estimation of CPUE.

A fishery-independent research survey could be used to estimate bias in the CPUE. The index of abundance in the dynamic biomass models used here is CPUE data, but results from fishery-independent research surveys are preferred as an index of abundance (Cooke and Beddington 1984, Quinn and Deriso 1999).

The estimates of MSY and f_{MSY} from this study support the findings of other investigations. The MSY and f_{MSY} values at point estimates by the dynamic biomass models are near to the previously estimated figures by Sanders (1989) for Saya de Malha but higher than those estimated for Nazareth bank. The methods are however different as Sanders used equilibrium models.

From 1992 to 1995, concurrent with landings of about 3,000 t, the relative biomass is estimated to have declined to a value close to 1. The relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}) have been found to be more robust than absolute values of biomass and fishing mortality and are more objectively recommended in the management processes (Prager 1994 Cadrin 2000). Values for relative biomass lesser than 1 are not appropriate for the fishery, which will produce a level of harvest less than the MSY and reduce the biomass below the B_{MSY} level. From 1996 to 2004, as the catch has averaged at about 2,000 t, the B/B_{MSY} and F/F_{msy} have stabilised according to the results, showing a rational exploitation rate on the Saya de Malha bank during this particular period. In this period the absolute biomass levels have been stable at around 5,000 t, further supporting the claim of rational exploitation on the Saya de Malha bank.

On the Nazareth bank, comparing the absolute biomass, relative biomass and relative fishing mortality from 1989 to 2004 with the corresponding yields, sustainable exploitation seems probable. However, the fit of the observed values of CPUE with those of the predicted CPUE (Figure 13) suggests that the outputs from the model should be carefully interpreted. Analysis of Nazareth bank data show that the difference in range of MSY estimates from different models in ASPIC is about 1,500

t, while for the Saya de Malha bank the difference is only 500 t. The bias corrected 95% confidence limits of MSY for the Logistic model are quite large (1,500 t) and so is the inter quartile range (947 t).

Being conservative and adopting a precautionary approach for the Saya de Malha and Nazareth banks, the lower limits of the MSY from the Logistic model after bootstrapping seems a good management benchmark. It implies that the MSY of the Saya de Malha and the Nazareth bank can be taken as 2,531 t and 1,623 t, respectively. The corresponding f_{MSY} could be 40,390 fdays and 32,280 fdays respectively. At the 1992 FAO Technical Consultation on High Seas Fishing, the non-precautionary nature of traditional MSY reference points was highlighted and emphasis was placed on the need for a more precautionary management strategy with new reference points (FAO 1992). At the 1996 FAO Technical Consultation on the Precautionary Approach to Capture Fisheries, annual catch of 2/3 of the MSY or $f_{2/3MSY}$ was suggested for conservation of higher levels of biomass, aiming at reducing the risk of over-fishing (FAO 1996). According to the projection scenarios, the setting of catch levels at the average yields for both banks in the years 1995-2004, also seems to be a feasible option from a precautionary point of view.

Hind-casting trials show that besides data quality, selection of years of data has some impact on estimations of MSY and f_{MSY} . However, the difference was not substantial. To obtain confidence intervals and bias corrected estimates using bootstrap, it is important that adequate data is available (Efron and Tibshirani 1993, Haddon 2001). Based on the hind casting results, the model seems more or less stable, when more than 12 years are included in the analysis.

From 1994 to 2001, the Mauritian bank fishery was managed through output controls in the form of a total allowable catch (TAC). Investigation of the effects of setting different catch levels is relatively simple with dynamic biomass models projection (Prager 2005). Projection trends on both banks for the years 2005-2009, in the two scenarios where catch was set at the estimated MSY and over the estimated MSY level, show a decreasing trend in absolute and relative biomass and increasing fishing mortality. For annual catch according to the estimated MSY the implications are that the parameters will stabilise, though only at lower biomass levels. However, confidence interval bounds were considerable. If ever the MSY levels are overestimated due to data failure, observation errors or the inaccurate estimation of the model parameters, there is a potential risk of overexploitation.

Analysis of length data for *L. mahsena* from the Saya de Malha bank shows that estimated growth and mortality parameters are similar for the SLCA and ELEFAN methods. The major difference is for 2005, possibly because only six month data were available. The L_{∞} is higher than the previously estimated value by (Soondron and Mamode 1999), while other parameters are comparable. The growth rate of *L. mahsena* from Chagos waters is comparatively low at 0.08 but the L_{∞} value is close at 66.5 cm (Pilling and Mees 2000). The age slice of the catch composition from Saya de Malha bank shows similar predominant ages (5-8 years), when analysed by the SLCA and ELEFAN methods in LFDA.

Length based methods are not appropriate in view of stock assessment for slow growing and long-lived species like *L. mahsena* (MacDonald 1987). Length based

methods incorporate many uncertainties on growth parameters estimated and subsequent age extrapolation from them (Rowling and Reid 1992, Posada and Appeldoorn 1996). As a result, one source of uncertainty in length based fish stock assessments is the use of potentially biased growth parameter estimates in further calculations; for example, in the estimation of mortality, yield-per-recruit and ultimately stock evaluation (Mees and Rousseau 1995).

6 CONCLUSIONS AND RECOMMENDATIONS

Dynamic biomass models are the most appropriate option presently available for stock assessment for the offshore Mauritian banks fishery. Nonetheless, results should be interpreted carefully, giving consideration to the assumptions of the models and limitations of the input data.

From a management point of view, risk assessment is important to inform resource managers about the risk levels associated with estimates of management benchmarks. If the Mauritian banks fishery is to be controlled by TAC, a projections exercise including bias estimates is required to assess the risks involved, at least in the short term. Ideal performance indicators from this study are fluctuations in the levels of biomass, relative biomass and relative fishing mortality, over time.

Growth parameters, mortality rate, exploitation rate and age slicing estimated from length frequency data using SLCA and ELEFAN methods gave similar results. The results show that *L. mahsena* is a slow growing and long-lived species. A conclusion is that the estimates may be biased, since slow growing species offer limited and uncertain information about growth and recruitment. For this species length based methods for stock assessment purposes may not be appropriate.

Main recommendations from the study are:

1. TAC based on a quota system should be re-introduced for the Mauritian banks fishery.
2. TAC for the Saya de Malha and the Nazareth banks may be set at about 1,700 t and 1,100 t, respectively, based on a precautionary management strategy. These are based on the principle of exploiting 2/3 of the lower limits of the MSY (FAO 1996).
3. A fishery independent survey should be initiated in order to gather fishery-independent and unbiased stock indices for the management of both offshore banks. The catchability coefficient q , which has a direct implication in the model fitting, is the parameter that needs emphasis.
4. Research should continue on the biology and ecology of *L. mahsena* and other species inhabiting the banks. More focus is required on length data sampling, amounts of discards, maturity studies, food and feeding habits, tagging experiments for study of growth and movements and DNA analysis of stock structure.
5. Application of age determination programme and age structured models (VPA/cohort analysis or statistical catch at age analysis) should be undertaken in the long run, not as a substitute but as a complement to dynamic biomass models for stock assessment of the Mauritian banks fishery.

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APPENDIX

1. R codes for non-equilibrium dynamic biomass model for Saya de Malha and Nazareth banks

```
# Y= Yield(catch) in tons I= abundance index (cpue)kg

#SAYA Catch and Effort data 1989-2004 DYNAMIC BIOMASS MODEL
yrs <- 1989:2004
Y <- c( 2177, 1410, 1782, 2825, 3173, 3142, 2957, 2283, 1798, 2054, 2107, 2099, 1283, 2090, 2354, 1689)
I <- c( 74.3, 73.0, 88.0, 67.7, 69.1, 66.6, 67.0, 57.8, 71.8, 75.9, 70.1, 77.8, 124.1, 83.3, 80.1, 71.2)

#NAZARETH catch and effort data DYNAMIC BIOMASS MODEL 1989-2004
yrs <- 1989:2004
Y <- c( 837,914,793,952,1358,1494,1533,1253,1720,1086,1121,1080,1366,918,468,855)
I <- c( 75.7,78.5,81.3,78.2,66.1,66.5,64.3,52.5,66.1,81.4,76.2,90.5,99.2,93.3,72.8,84.2)

# FORMULA==      By+1 = By + r By(1 - By/K) - Yy
# Yy=yield/catch
# Initial parameters of starting biomass B0, Carrying capacity K and the rate of pop. growth r
# q= coefficient catchability
# There are four parameters to be estimated K, B0,r and q
#It is not advisable to estimate all- first estimate K, B0 and r with fixed q, then estimate r and q, then all

B0<-2*mean(Y) # biomass greater than catch
K<-B0*1.3     # K>B0- carrying capacity
r<-1          # rate of population growth
q<-mean(I)/B0 # as I=qB

input<-c(K,B0,r)
B<-B0
par(mfrow=c(3,3))
###
ssefn<-function(input){
  K<-input[1]
  B0<-input[2]
  r<-input[3]

  B<-B0
  Yvec<-NULL
  Bvec<-NULL
  lhat<-NULL
  yrs<-1:length(Y)
  for (y in yrs){
    SY<-r*B*(1-B/K)
    Bvec<-c(Bvec,B)
    lhat<-c(lhat,q*B)
    B<-B+SY-Y[y]
    B<-ifelse(B<0,0,B)
  }
  SSE<-sum((I-lhat)^2)
  return(SSE)
}
#### to optimise
estA<-nlm(ssefn,input,typsize=input,iterlim=1000) # nlm- non linear minimization
estA<-nlm(ssefn,estA$est,typsize=input,iterlim=1000) # using the result of the first estimate we estimate again
estA

#### estimate r and q
K <- estA$est[1]
B0 <- estA$est[2]
r <- estA$est[3]
q <- mean(I)/B0

input2 <- c(r,q) # now we estimate the two parameters
B <- B0
ssefn2<-function(input){
  r<-input[1]
  q<-input[2]

  B<-B0
  Yvec<-NULL
```

```

Bvec<-NULL
lhat<-NULL
yrs<-1:length(Y)
for (y in yrs){
  SY<-r*B*(1-B/K)
  Bvec<-c(Bvec,B)
  lhat<-c(lhat,q*B)
  B<-B+SY-Y[y]
  B<-ifelse(B<0,0,B)
}
SSE<-sum((I-lhat)^2)
# plot(yrs,I, type="b", xlab="year", ylab="CPUE")
# lines(lhat, col="red")
return(SSE)
}

estB <- nlm(ssefn2,input2,typsize=input2,iterlim=1000)
estB <- nlm(ssefn2,estB$est,typsize=estB$est,iterlim=1000)
estB
#####
# plotting these data
# to calculate the predicted biomass for all ages and the predicted index
K<-estA$est[1]
B0<-estA$est[2]
r<-estB$est[1]
q<-estB$est[2]
B<-B0
Yvec<-NULL
Bvec<-NULL
lhat<-NULL
yrs<-1:length(Y)
for (y in yrs){
  SY<-r*B*(1-B/K)
  Bvec<-c(Bvec,B)
  lhat<-c(lhat,q*B)
  B<-B+SY-Y[y]
}

par(mfrow=c(3,3))
plot(yrs, Y, type="b", xlab="year", ylab="yield", main="Yield Trajectory NAZARETH", ylim=c(0, max(Y)*1.05))
plot(yrs, Bvec, type="b", xlab="year", ylab="biomass", main="Biomass Trajectory", ylim=c(0, max(Bvec)*1.05))
plot(Y, Bvec, xlab="yield", ylab="predicted Biomass", main="Corr. between yield and biomass")

cor(Bvec, Y)
plot(Bvec, I, xlab="Bvec-biomass", ylab="I-cpue", main="Corr. between biomass and CPUE")
lines(lowess(Bvec, I), col=2)
plot(log(Bvec), log(I), xlab="Bvec-biomass", ylab="I-cpue", main="Corr. between biomass and CPUE")
plot(yrs,I, type="b",xlab="Year", ylab="CPUE", ylim=c(0, max(I)*1.05))
plot(I, lhat, xlab="observed CPUE", ylab="lhat", xlim=c(0, max(c(I,lhat))), ylim=c(0, max(c(I,lhat))))
plot(yrs, I, xlab="years", ylab="CPUE", ylim=c(0, max(I)*1.05), type="b")
lines(yrs, lhat, col=2, type="b")

cor(Bvec, I)

## the equilibrium yield

Blevels <- seq(0,3000,10) # biomass levels
EYlevels <- r*Blevels*(1-Blevels/K) # equilibrium yield levels
EYlevels <- ifelse(EYlevels<0, 0, EYlevels)
plot(Blevels, EYlevels, type="l", xlab="Biomass", ylab="Yield", main="Yield Curve NAZARETH",
ylim=c(0,max(c(EYlevels,Yvec))))
lines(Bvec,Yvec,type="b", col=2)

Elevels <- seq(0,10000,1000)
plot(Elevels, EYlevels, type="l")

MSY <- r*K/4 # MSY
Bmsy <- K/2
Emsy <- r/(2*q)*1000 # optimum effort
Fmsy <- r/2
MSY
Emsy
abline(h=MSY, type="b",col=2)
abline(v=Bmsy, col=2)

```

2. ASPIC output (FIT and BOT mode)- Saya de Malha bank

saya1989-2004 Wednesday, 22 Feb 2006 at 16:21:29
 ASPIC -- A Surplus-Production Model Including Covariates (Ver. 5.10)
 FIT program mode
 Author: Michael H. Prager; NOAA Center for Coastal Fisheries and Habitat Research LOGISTIC model mode
 101 Pivers Island Road; Beaufort, North Carolina 28516 USA YLD conditioning
 Mike.Prager@noaa.gov SSE optimization
 Reference: Prager, M. H. 1994. A suite of extensions to a nonequilibrium ASPIC User's Manual is available
 surplus-production model. Fishery Bulletin 92: 374-389. gratis from the author.

CONTROL PARAMETERS (FROM INPUT FILE) Input file: c:\nft\aspic5\saya1989-2004.inp

Operation of ASPIC: Fit logistic (Schaefer) model by direct optimization.
 Number of years analyzed: 16 Number of bootstrap trials: 0
 Number of data series: Bounds on MSY (min, max): 5.000E+02 5.000E+03
 Objective function: Least squares Bounds on K (min, max): 1.000E+03 1.000E+04
 Relative conv. criterion (simplex): 1.000E-08 Monte Carlo search mode, trials: 0 50000
 Relative conv. criterion (restart): 3.000E-08 Random number seed: 9685472
 Relative conv. criterion (effort): 1.000E-04 Identical convergences required in fitting: 6
 Maximum F allowed in fitting: 8.000

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) error code 0
 Normal convergence
 Number of restarts required for convergence: 5

GOODNESS-OF-FIT AND WEIGHTING (NON-BOOTSTRAPPED ANALYSIS)

Loss component number and title	Weighted SSE	Weighted N	Weighted MSE	Current weight	Inv. var. weight	R-squared in CPUE
Loss(-1) SSE in yield	0.000E+00					
Loss(0) Penalty for B1 > K	0.000E+00	1	N/A	0.000E+00	N/A	
Effort-Catch Saya1989-2004	2.396E-01	16	1.712E-02	1.000E+00	1.000E+00	0.361
TOTAL OBJECTIVE FUNCTION, MSE, RMSE: 2.39611522E-01 .997E-02 1.413E-01						
Estimated contrast index (ideal = 1.0):	0.2610			C* = (Bmax-Bmin)/K		
Estimated nearness index (ideal = 1.0):	0.9352			N* = 1 - min(B-Bmsy) /K		

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	User/pgm guess	2nd guess	Estimated	User guess
B1/K Starting relative biomass (in 1989)	6.526E-01	5.000E-01	6.193E-01	1	1
MSY Maximum sustainable yield	2.866E+03	3.000E+03	1.871E+03	1	1
K Maximum population size	7.968E+03	6.500E+03	8.200E+03	1	1
phi Shape of production curve (Bmsy/K)	0.5000	0.5000	0	1	
Catchability Coefficients by Data Series --q(1)	Effort-Catch Saya1989-2004	1.323E-02	1.730E-02	4.750E-01	1 1

MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	Logistic formula	General formula
MSY Maximum sustainable yield	2.866E+03	----	----
Bmsy Stock biomass giving MSY	3.984E+03	K/2	$K * n^{**}(1/(1-n))$
Fmsy Fishing mortality rate at MSY	7.194E-01	MSY/Bmsy	MSY/Bmsy
n Exponent in production function	2.0000	----	----
g Fletcher's gamma	4.000E+00	$[n^{**}(n/(n-1))]/[n-1]$	
B./Bmsy Ratio: B(2005)/Bmsy	1.581E+00	----	----
F./Fmsy Ratio: F(2004)/Fmsy	3.805E-01	----	----
Fmsy/F. Ratio: Fmsy/F(2004)	2.628E+00	----	----
Y.(Fmsy) Approx. yield available at Fmsy in 2005	4.532E+03	MSY*B./Bmsy	MSY*B./Bmsy
.as proportion of MSY	1.581E+00	----	----
Ye. Equilibrium yield available in 2005	1.898E+03	$4 * MSY * (B/K - (B/K)**2)$	$g * MSY * (B/K - (B/K)**n)$
...as proportion of MSY	6.621E-01		
----- Fishing effort rate at MSY in units of each CE or CC series -----			
fmsy(1) Effort-Catch Saya1989-2004	5.439E+01	Fmsy/q(1)	Fmsy/q(1)

RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) Effort-Catch Saya1989-2004

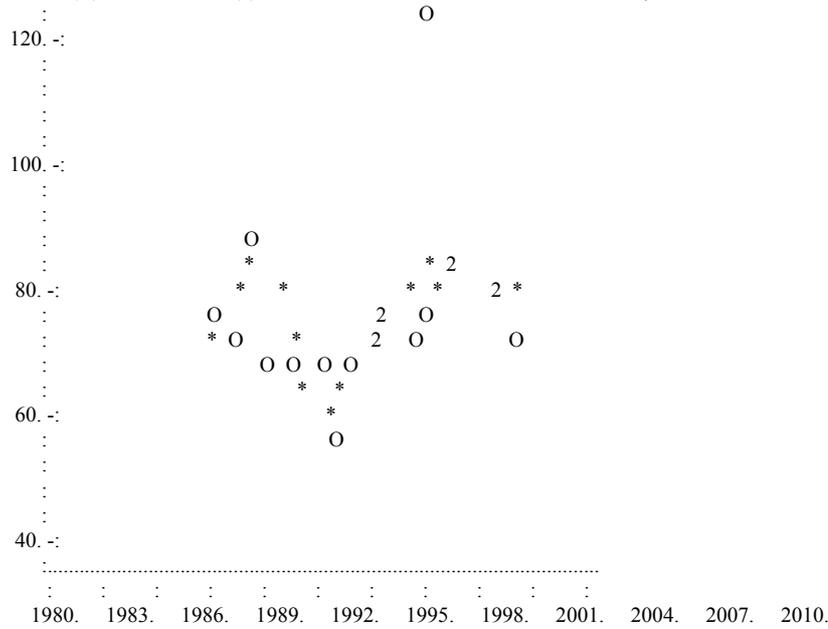
Data type CE: Effort-catch series							Series weight: 1.000
Obs	Year	CPUE	Estimated CPUE	Estim F	Observed yield	Model yield	Resid in log scale
1	1989	7.433E+01	7.129E+01	0.4038	2.177E+03	2.177E+03	-0.04175
2	1990	7.300E+01	7.882E+01	0.2366	1.410E+03	1.410E+03	0.07681
3	1991	8.797E+01	8.369E+01	0.2816	1.782E+03	1.782E+03	-0.04983
4	1992	6.772E+01	7.887E+01	0.4737	2.825E+03	2.825E+03	0.15244

5	1993	6.906E+01	7.035E+01	0.5965	3.173E+03	3.173E+03	0.01845
6	1994	6.664E+01	6.379E+01	0.6513	3.142E+03	3.142E+03	-0.04367
7	1995	6.696E+01	6.039E+01	0.6476	2.957E+03	2.957E+03	-0.10328
8	1996	5.779E+01	6.302E+01	0.4791	2.283E+03	2.283E+03	0.08654
9	1997	7.180E+01	7.108E+01	0.3345	1.798E+03	1.798E+03	-0.01002
10	1998	7.591E+01	7.678E+01	0.3538	2.054E+03	2.054E+03	0.01141
11	1999	7.006E+01	7.850E+01	0.3549	2.107E+03	2.107E+03	0.11376
12	2000	7.778E+01	7.921E+01	0.3504	2.099E+03	2.099E+03	0.01831
13	2001	1.241E+02	8.388E+01	0.2023	1.283E+03	1.283E+03	-0.39151
14	2002	8.332E+01	8.476E+01	0.3261	2.090E+03	2.090E+03	0.01708
15	2003	8.015E+01	8.083E+01	0.3852	2.354E+03	2.354E+03	0.00845
16	2004	7.118E+01	8.161E+01	0.2737	1.689E+03	1.689E+03	0.13673

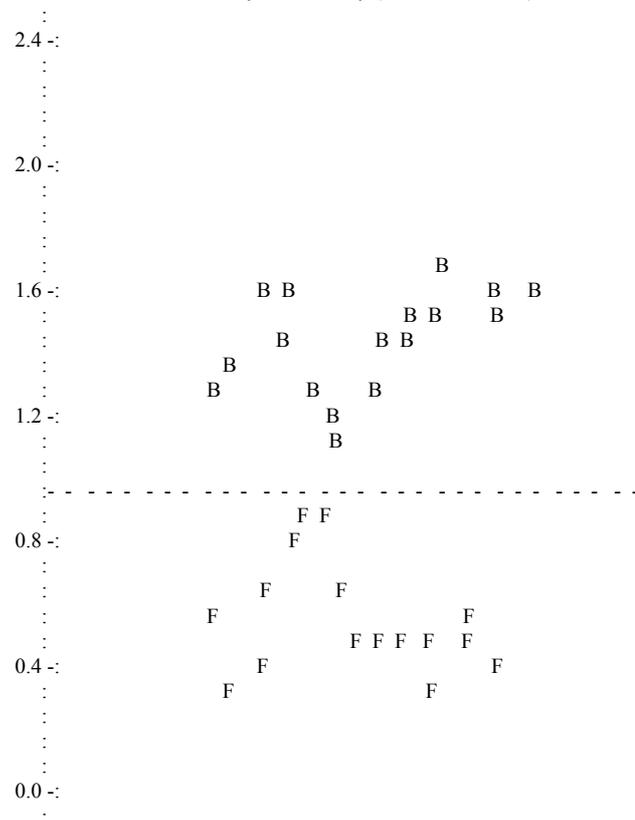
saya1989-2004

Page 4

Observed (O) and Estimated (*) CPUE for Data Series # 1 -- Effort-Catch Saya1989-2004



Time Plot of Estimated F/Fmsy and B/Bmsy (dashed line = 1.0)



1980. 1983. 1986. 1989. 1992. 1995. 1998. 2001. 2004.

ESTIMATES FROM BOOTSTRAPPED ANALYSIS- saya de malha bank 1989-2004 ASPIC

Param name	Point estimate	Estimated bias in pt estimate	Estimated relative bias	Bias-corrected approximate confidence limits				Inter-quartile range	Relative IQ range
				80% lower	80% upper	95% lower	95% upper		
B1/K	6.526E-01	1.682E-02	2.58%	5.602E-01	1.512E+00	4.968E-01	2.423E+00	2.048E-01	0.314
K	7.968E+03	-1.450E+03	-18.19%	6.608E+03	9.873E+03	5.006E+03	9.892E+03	1.798E+03	0.226
q(1)	1.322E-02	4.728E-03	35.76%	9.622E-03	1.506E-02	9.438E-03	1.874E-02	2.661E-03	0.201
MSY	2.866E+03	7.034E+01	2.45%	2.632E+03	3.297E+03	2.531E+03	3.925E+03	2.894E+02	0.101
Ye(2005)	1.898E+03	-3.166E+01	-1.67%	1.860E+03	1.969E+03	1.799E+03	1.995E+03	4.832E+01	0.025
Y.@Fmsy	4.532E+03	1.666E+02	3.68%	3.978E+03	5.450E+03	3.715E+03	6.807E+03	6.633E+02	0.146
Bmsy	3.984E+03	-7.252E+02	-18.19%	3.304E+03	4.936E+03	2.503E+03	4.946E+03	8.990E+02	0.226
Fmsy	7.191E-01	2.971E-01	41.31%	5.219E-01	9.266E-01	5.070E-01	1.273E+00	1.876E-01	0.261
fmsy(1)	5.439E+01	1.608E+00	2.96%	4.538E+01	6.891E+01	4.039E+01	8.678E+01	1.064E+01	0.196
B./Bmsy	1.581E+00	1.211E-02	0.77%	1.506E+00	1.653E+00	1.460E+00	1.716E+00	7.538E-02	0.048
F./Fmsy	3.805E-01	-5.013E-03	-1.32%	3.145E-01	4.330E-01	2.505E-01	4.622E-01	5.588E-02	0.147
Ye./MSY	6.623E-01	-1.819E-02	-2.75%	5.737E-01	7.437E-01	4.838E-01	7.855E-01	8.685E-02	0.131

INFORMATION FOR REPAST (Prager, Porch, Shertzer, & Caddy. 2003. NAJFM 23: 349-361)

Unitless limit reference point in F (Fmsy/F.): 2.628
 CV of above (from bootstrap distribution): 0.1659

NOTES ON BOOTSTRAPPED ESTIMATES:

- Bootstrap results were computed from 1000 trials.
- Results are conditional on bounds set on MSY and K in the input file.
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The default 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.

Trials replaced for lack of convergence: 0 Trials replaced for MSY out of bounds: 16
 Trials replaced for q out-of-bounds: 0
 Trials replaced for K out-of-bounds: 358 Residual-adjustment factor: 1.1547

3. ASPIC output (FIT and BOT mode)- Nazareth bank

Nazareth1989-2004effortcatch Page 1 Wednesday, 22 Feb 2006 at 19:16:46
 ASPIC -- A Surplus-Production Model Including Covariates (Ver. 5.10) FIT program mode
 Author: Michael H. Prager; NOAA Center for Coastal Fisheries and Habitat Research LOGISTIC model mode
 101 Pivers Island Road; Beaufort, North Carolina 28516 USA YLD conditioning
 Mike.Prager@noaa.gov SSE optimization
 Reference: Prager, M. H. 1994. A suite of extensions to a nonequilibrium ASPIC User's Manual is available
 surplus-production model. Fishery Bulletin 92: 374-389. gratis from the author.

CONTROL PARAMETERS (FROM INPUT FILE) Input file: c:\nft\aspic5\naz1989-2004.inp

Operation of ASPIC: Fit logistic (Schaefer) model by direct optimization.
 Number of years analyzed: 16 Number of bootstrap trials: 0
 Number of data series: 1 Bounds on MSY (min, max): 5.000E+02 3.500E+03
 Objective function: Least squares Bounds on K (min, max): 1.000E+03 1.000E+04
 Relative conv. criterion (simplex): 1.000E-08 Monte Carlo search mode, trials: 0 50000
 Relative conv. criterion (restart): 3.000E-08 Random number seed: 5641237
 Relative conv. criterion (effort): 1.000E-04 Identical convergences required in fitting: 6
 Maximum F allowed in fitting: 8.000

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) error code 0

Normal convergence
 Number of restarts required for convergence: 5
 GOODNESS-OF-FIT AND WEIGHTING (NON-BOOTSTRAPPED ANALYSIS)

Loss component number and title	Weighted SSE	Weighted N	Weighted MSE	Current weight	Inv. var. weight	R-squared in CPUE
Loss(-1) SSE in yield		0.000E+00				
Loss(0) Penalty for B1 > K		0.000E+00	1	N/A	0.000E+00	N/A
Loss(1) Effort and Catch NAZ 1989-2004	335E-01	16	2.382E-02	1.000E+00	1.000E+00	0.115

TOTAL OBJECTIVE FUNCTION, MSE, RMSE: 3.33536603E-01 2.566E-02 1.602E-01
 Estimated contrast index (ideal = 1.0): 0.1276 C* = (Bmax-Bmin)/K
 Estimated nearness index (ideal = 1.0): 0.7048 N* = 1 - |min(B-Bmsy)|/K
 MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	User/pgm guess	2nd guess	Estimated	User guess		
B1/K	Starting relative biomass (in 1989)		8.352E-01	5.000E-01	7.342E-01	1	1
MSY	Maximum sustainable yield		2.377E+03	2.000E+03	9.429E+02	1	1
K	Maximum population size		7.350E+03	5.000E+03	5.657E+03	1	1
phi	Shape of production curve (Bmsy/K)		0.5000	0.5000	0	1	
----- Catchability Coefficients by Data Series -----							
q(1)	Effort and Catch NAZ 1989-2004		1.200E-02	1.200E-02	4.750E-01	0	1

MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	Logistic formula	General formula
MSY	Maximum sustainable yield	2.377E+03	----
Bmsy	Stock biomass giving MSY	3.675E+03	K/2 K*n**(1/(1-n))
Fmsy	Fishing mortality rate at MSY	6.467E-01	MSY/Bmsy MSY/Bmsy
n	Exponent in production function	2.0000	----
g	Fletcher's gamma	4.000E+00	---- [n**(n/(n-1))]/[n-1]
B./Bmsy	Ratio: B(2005)/Bmsy	1.816E+00	----
F./Fmsy	Ratio: F(2004)/Fmsy	1.968E-01	----
Fmsy/F.	Ratio: Fmsy/F(2004)	5.081E+00	----

Y.(Fmsy) Approx. yield available at Fmsy in 2005 4.316E+03 MSY*B./Bmsy MSY*B./Bmsy
 ...as proportion of MSY 1.816E+00 ---- ----
 Ye. Equilibrium yield available in 2005 7.935E+02 4*MSY*(B/K-(B/K)**2) g*MSY*(B/K-(B/K)**n)
 .as proportion of MSY 3.339E-01 ---- ----
 Fishing effort rate at MSY in units of each CE or CC series -----
 fmsy(1) Effort and Catch NAZ 1989-2004 5.389E+01 Fmsy/q(1) Fmsy/q(1)
 Nazareth1989-2004effortcatch Page 2

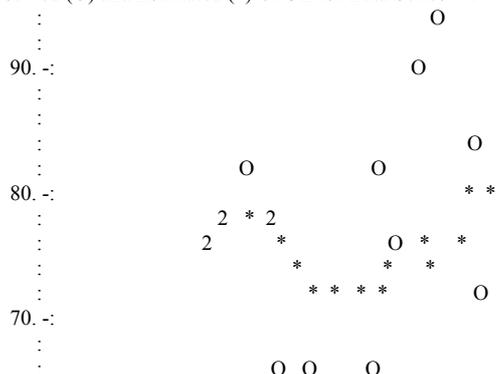
RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) Effort and Catch NAZ 1989-2004

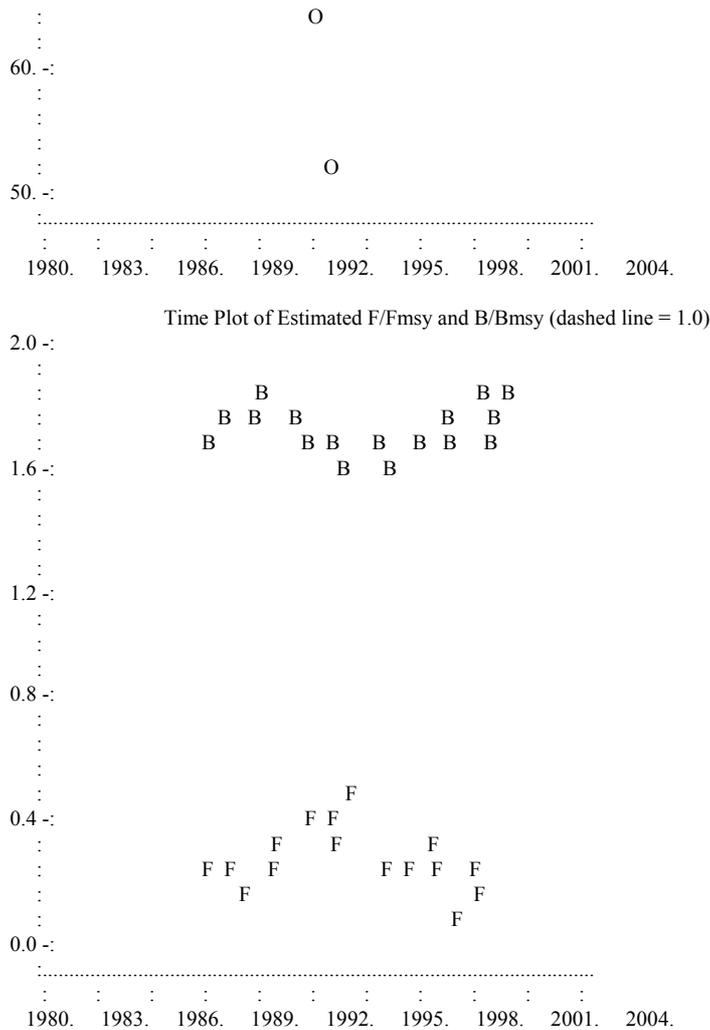
Data type CE: Effort-catch series Series weight: 1.000

Obs	Year	Observed CPUE	Estimated CPUE	Estim F	Observed yield	Model yield	Resid in log scale
1	1989	7.568E+01	7.583E+01	0.1325	8.370E+02	8.370E+02	0.00192
2	1990	7.846E+01	7.785E+01	0.1409	9.140E+02	9.140E+02	-0.00777
3	1991	8.127E+01	7.892E+01	0.1206	7.930E+02	7.930E+02	-0.02940
4	1992	7.824E+01	7.897E+01	0.1447	9.520E+02	9.520E+02	0.00937
5	1993	6.611E+01	7.668E+01	0.2125	1.358E+03	1.358E+03	0.14834
6	1994	6.651E+01	7.388E+01	0.2427	1.494E+03	1.494E+03	0.10520
7	1995	6.428E+01	7.209E+01	0.2552	1.533E+03	1.533E+03	0.11456
8	1996	5.254E+01	7.249E+01	0.2074	1.253E+03	1.253E+03	0.32199
9	1997	6.614E+01	7.138E+01	0.2891	1.720E+03	1.720E+03	0.07627
10	1998	8.143E+01	7.233E+01	0.1802	1.086E+03	1.086E+03	-0.11844
11	1999	7.620E+01	7.470E+01	0.1801	1.121E+03	1.121E+03	-0.01988
12	2000	9.047E+01	7.576E+01	0.1711	1.080E+03	1.080E+03	-0.17748
13	2001	9.918E+01	7.500E+01	0.2186	1.366E+03	1.366E+03	-0.27948
14	2002	9.332E+01	7.583E+01	0.1453	9.180E+02	9.180E+02	-0.20751
15	2003	7.283E+01	7.957E+01	0.0706	4.680E+02	4.680E+02	0.08853
16	2004	8.420E+01	8.061E+01	0.1273	8.550E+02	8.550E+02	-0.04360

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Observed (O) and Estimated (*) CPUE for Data Series # 1 -- Effort and Catch NAZ 1989-2004





Operation of ASPIC: Fit logistic (Schaefer) model by direct optimization with bootstrap.
 Number of years analyzed: 16 Number of bootstrap trials: 1000
 Number of data series: 1 Bounds on MSY (min, max): 5.000E+02 3.500E+03
 Objective function: Least squares Bounds on K (min, max): 1.000E+03 1.000E+04
 Relative conv. criterion (simplex): 1.000E-08 Monte Carlo search mode, trials: 0 50000
 Relative conv. criterion (restart): 3.000E-08 Random number seed: 5641237
 Relative conv. criterion (effort): 1.000E-04 Identical convergences required in fitting: 6
 Maximum F allowed in fitting: 8.000

PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS) error code 0
 Normal convergence

GOODNESS-OF-FIT AND WEIGHTING (NON-BOOTSTRAPPED ANALYSIS)

Loss component number and title	Weighted SSE	Weighted N	Current MSE	Inv. var. weight	R-squared weight	in CPUE
Loss(-1) SSE in yield	0.000E+00					
Loss(0) Penalty for B1 > K	0.000E+00	1	N/A	0.000E+00	N/A	
Loss(1) Effort and Catch NAZ 1989-2004	3.335E-01	16	2.382E-02	1.000E+00	1.000E+00	0.115

TOTAL OBJECTIVE FUNCTION, MSE, RMSE: 3.33536603E-01 2.566E-02 1.602E-01
 Estimated contrast index (ideal = 1.0): 0.1276 C* = (Bmax-Bmin)/K
 Estimated nearness index (ideal = 1.0): 0.7049 N* = 1 - |min(B-Bmsy)|/K

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	User/pgm guess	2nd guess	Estimated	User guess
B1/K Starting relative biomass (in 1989)	8.352E-01	8.352E-01	7.342E-01	1	1
MSY Maximum sustainable yield	2.376E+03	2.377E+03	9.429E+02	1	1
K Maximum population size	7.350E+03	7.350E+03	5.657E+03	1	1
phi Shape of production curve (Bmsy/K)	0.5000	0.5000	----	0	1

----- Catchability Coefficients by Data Series -----

q(1) Effort and Catch NAZ 1989-2004 1.200E-02 1.200E-02 4.750E-01 0 1

MANAGEMENT and DERIVED PARAMETER ESTIMATES (NON-BOOTSTRAPPED)

Parameter	Estimate	Logistic formula	General formula
MSY	Maximum sustainable yield	2.376E+03	----
Bmsy	Stock biomass giving MSY	3.675E+03	K/2 K*n**(1/(1-n))
Fmsy	Fishing mortality rate at MSY	6.467E-01	MSY/Bmsy MSY/Bmsy
n	Exponent in production function	2.0000	----
g	Fletcher's gamma	4.000E+00	---- [n**(n/(n-1))]/[n-1]
B./Bmsy	Ratio: B(2005)/Bmsy	1.816E+00	----
F./Fmsy	Ratio: F(2004)/Fmsy	1.968E-01	----
Fmsy/F.	Ratio: Fmsy/F(2004)	5.081E+00	----
Y.(Fmsy)	Approx. yield available at Fmsy in 2005	4.316E+03	MSY*B./Bmsy MSY*B./Bmsy
...as proportion of MSY		1.816E+00	----
Ye.	Equilibrium yield available in 2005	7.935E+02	4*MSY*(B/K-(B/K)**2) g*MSY*(B/K-(B/K)**n)...as
proportion of MSY		3.339E-01	----
----- Fishing effort rate at MSY in units of each CE or CC series -----			
fmsy(1)	Effort and Catch NAZ 1989-2004	5.389E+01	Fmsy/q(1) Fmsy/q(1)

ESTIMATES FROM BOOTSTRAPPED ANALYSIS Nazareth bank

Param name	Estimated Point estimate	Estimated bias in pt estimate	relative bias	Bias-corrected approximate confidence limits				Inter-quartile range	Relative IQ range
				80% lower	80% upper	95% lower	95% upper		
B1/K	8.352E-01	1.396E-02	1.67%	6.556E-01	1.325E+00	5.711E-01	1.692E+00	3.182E-01	0.381
K	7.350E+03	5.639E+02	7.67%	6.425E+03	7.852E+03	6.044E+03	8.458E+03	6.765E+02	0.092
q(1)	1.200E-02	1.405E-16	0.00%	1.200E-02	1.200E-02	1.200E-02	1.200E-02	4.545E-16	0.000
MSY	2.376E+03	-3.467E+02	-14.59%	1.967E+03	3.430E+03	1.623E+03	3.465E+03	9.471E+02	0.399
Ye(2005)	7.935E+02	5.790E+01	7.30%	7.911E+02	7.951E+02	7.911E+02	8.106E+02	7.306E-01	0.001
Y.@Fmsy	4.316E+03	-7.548E+02	-17.49%	3.470E+03	6.434E+03	2.720E+03	6.505E+03	1.903E+03	0.441
Bmsy	3.675E+03	2.820E+02	7.67%	3.213E+03	3.926E+03	3.022E+03	4.229E+03	3.383E+02	0.092
Fmsy	6.467E-01	-1.176E-01	-18.18%	5.023E-01	1.034E+00	3.874E-01	1.065E+00	3.288E-01	0.508
fmsy(1)	5.389E+01	-9.798E+00	-18.18%	4.186E+01	8.617E+01	3.228E+01	8.878E+01	2.740E+01	0.508
B./Bmsy	1.816E+00	-8.956E-02	-4.93%	1.765E+00	1.875E+00	1.678E+00	1.877E+00	5.455E-02	0.030
F./Fmsy	1.968E-01	7.122E-02	36.19%	1.317E-01	2.455E-01	1.305E-01	3.152E-01	5.967E-02	0.303
Ye./MSY	3.339E-01	1.250E-01	37.42%	2.335E-01	4.155E-01	2.308E-01	5.409E-01	9.233E-02	0.277

INFORMATION FOR REPAST (Prager, Porch, Shertzer, & Caddy. 2003. NAJFM 23: 349-361)

Unitless limit reference point in F (Fmsy/F.): 5.081
 CV of above (from bootstrap distribution): 0.2809

NOTES ON BOOTSTRAPPED ESTIMATES:

- Bootstrap results were computed from 1000 trials.
- Results are conditional on bounds set on MSY and K in the input file.
- All bootstrapped intervals are approximate. The statistical literature recommends using at least 1000 trials for accurate 95% intervals. The default 80% intervals used by ASPIC should require fewer trials for equivalent accuracy. Using at least 500 trials is recommended.

Trials replaced for lack of convergence: 0 Trials replaced for MSY out of bounds: 700
 Trials replaced for q out-of-bounds: 0
 Trials replaced for K out-of-bounds: 273 Residual-adjustment factor: 1.1094