PN-ABK-253
7528.8

WORKING PAPER SERIES

FISHERIES STOCK ASSESSMENT

TITLE XII
Collaborative Research Support Program

Fisheries Stock Assessment CRSP Management Office
International Programs, College of Agriculture
The University of Maryland, College Park, Maryland 20742

In cooperation with the United States Agency for International Development (Grant No. DAN-4146-G-SS-5071-00) the Fisheries Stock Assessment CRSP involves the following participating institutions:

The University of Maryland—Center for Environmental and Estuarine Studies
The University of Rhode Island—International Center for Marine Resource Development
The University of Washington—Center for Quantitative Sciences
The University of Costa Rica—Centro de Investigación en Ciencias del Mar y Limnología
The University of the Philippines—Marine Science Institute (Diliman)—College of Fisheries (Visayas)

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WORKING PAPER SERIES

Working Paper 80

Evaluation of the Tuna Resources Potential in Indonesian Waters With Emphasis on East Indonesia

by

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The University of Rhode Island

February 1991

Fisheries Stock Assessment
Title XII
Collaborative Research Support Program

The Fisheries Stock Assessment CRSP (sponsored in part by USAID Grant No. DAN-4146-G-SS-5071-00) is intended to support collaborative research between U.S. and developing countries' universities and institutions on fisheries stock assessment and management strategies.

This Working Paper has been produced by The University of Rhode Island research component in collaboration with the University of the Philippines and in association with the International Center for Living Aquatic Resources Management. Additional copies are also available from:

International Center for Marine Resource Development
The University of Rhode Island
126 Woodward Hall
Kingston, Rhode Island 02881

EVALUATION OF THE TUNA RESOURCES POTENTIAL IN INDONESIAN WATERS WITH EMPHASIS ON EAST INDONESIA

S.B. Saila and J. Uktolseja

FEBRUARY 1991

Fisheries Research & Development Project
Jakarta, Indonesia
USAID #497-0352-C-00-8096-00

Fisheries Stock Assessment
Title XII
Collaborative Research Support Program (CRSP)
Contract # DAN 4146-GSS-5071

Evaluation of the Tuna Resources Potential in Indonesian Waters With Emphasis on East Indonesia

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Table of Contents

	Page
Objective	1
Background	1
Methods	5
Data	5
Model Description	6
The POPSYS Programs	9
Results	11
General	11
Bitung Skipjack Data Analysis	13
Tables	19
Figures	35
Sorong Skipjack Data Analysis	45
Tables	47
Figures	50
Ambon Skipjack Data Analysis	56
Tables	57
Figures	61
Pelabuhan Skipjack Data Analysis	67
Tables	69
Figures	72
Auxis Data Analysis	80
Tables	83
Figures	88
Discussion	95
General	95
Skipjack Tuna	97
Auxis Fishery	100
Tables	101
Recommendations	104
General	104
References	106
Appendix 1	108
Tables	112
Figures	119

Objective—

To contribute to a better understanding of the Indonesian tuna resource potential and to more effective conservation of tuna resources in Indonesian waters.

Background—

Indonesia is the largest archipelagic nation in the world, consisting of more than 17,000 islands, 82,000 km of coastline, and a total territorial and extended economic zone (EEZ) of about 5.8 million km^2. This zone can be divided into two major areas: eastern Indonesian waters (FAO Statistical Area 71) bordering the west Pacific Ocean and western Indonesian waters (FAO Statistical Area 57) bordering the east Indian Ocean.

Pole and line fishing for skipjack tuna (*Katsuwonus pelamis*) and longline fishing for the larger tunas (especially yellowfin, bigeye, and albacore) have been popular in the eastern part of Indonesia where more than 70 percent of total skipjack and large tuna landings take place. The deep sea FAD (fish aggregating device), which is locally called "rompong," combined with a state-funded fisheries nucleus company scheme (PIR, Perusahaan Inti Rakyat) have enhanced the pole and line as well as handline fisheries for tunas. These methods have been well developed since 1983 in the province of Irian Jaya (Sorong), Moluccas (Ambon, Ternate, Labuha), North Celebes (Bitung and Gorontalo), Southeast Celebes (Kendari and Kola Ka), South Celebes (Majene and Mamuju), and Nugatenggara (Maumere).

The Indonesian tuna longline fishery started in 1972 with 22 longliners of 100 gross tons owned by the state enterprise and based in Benoa, Bali. This fishery has developed quickly since 1985. The number of longliners increased from 22 in 1985 to 167 in 1989 due to a high demand for fresh sashumi grade tuna, primarily from Japan. The fishing grounds for large tunas in east Indonesian waters include areas adjacent to North Irian Jaya (the west Pacific Ocean), the Halmahua Sea, the Celebes Sea, Molucca Sea, Banda Sea, Flores Sea, Makassar Strait, Tomini Bay, and the Indian Ocean along the west coast of Sumatera, and the south coasts of Java and Nugatenggara.

Gillnet fishing for skipjack tuna is common in Pelabuhan Ratu, which is the biggest tuna production area in Java. The size of the gillnetters range from three to six gross tons, most of which are equipped with 40 HP outboard motors. The total vessels engaged in tuna fishing increased 45.4 percent from 621 in 1988 to 909 in 1989.

Total tuna landings in Indonesia ranged from 206,756 mt. to 265,739 mt. between 1983-1987. The average annual growth rate was 6.5 percent. These tuna landings accounted for 13.2 percent of the country's total marine fish landings.

Indonesia's total export of fish increased from about 88,364 mt. valued at US$ 257 million in 1983 to 228,659 mt. valued at US$ 832.72 million in 1990. Tuna contributed 22,538 mt. in 1983 valued at US$ 19.254 million in 1983 and increased to 56,677 mt. worth US$ 102.66 million in 1990. This represents a 16.6 percent increase in volume and a 32.2 percent increase in value per year, respectively.

The above data clearly indicate that Indonesia's tuna fishery has been developing very rapidly in the recent past. This recent development has led to projections into the future and also to concerns about conservation and rational management which would permit utilization of these resources in perpetuity. McElroy (1989) has stated that the tuna resources of Indonesia are some of the largest, most valuable and least exploited in the world. He further projected annual landings of large tuna species to rise to about 200,000 mt. by 1990 and thereafter to rise to between 250,000-300,000 mt. by the year 2000. He cited a Directorate General of Fisheries report (DGF/MFRI, 1983) which estimated annual maximum sustainable yields (MSY) for skipjack of 276,000 mt. and sustainable yields for other tuna (yellowfin and bigeye) of 166,000 mt. The 1986 catch represented about 30 percent of the estimated MSY for skipjack and about 23 percent for the large tuna (primarily yellowfin and bigeye). Such optimistic predictions have attracted considerable interest and funding proposals for various schemes to increase the fisheries for these species.

The report on the future prospects of Indonesia's tuna fisheries by McElroy focused primarily on development of tuna fisheries with the goal of maximizing financial benefit

from these fisheries, based on the assumption that the estimated sustainable yields are accurate and precise. This is hardly the case for most of these estimates which are based on tenuous assumptions and inadequate samples. It is an unfortunate fact of life that the so-called surplus production models, which were first formulated by Schaefer (1954) and now have many modifications, may often produce misleading estimates of optimum effort or maximum sustained yield (MSY) if they are applied uncritically. Surplus production models have often been used in tuna assessments. The estimation procedure commonly employed when only an index of of abundance is available involves the assumption of equilibrium conditions. Equilibrium methods overestimate surplus production and optimum fishing effort when applied to data gathered during the development of a fishery. The reason is that this method assumes every catch obtained is sustainable—a condition which cannot hold if the stock were actually decreasing. Although regression and time series fitting methods for surplus production estimates using indices of abundance are recommended for use—unless the data series applied to the model show considerable variation in both stock size and fishing pressure—the model parameters are very poorly estimated. The above problem will be addressed further in the methodology section.

This report is designed to aid in the development of a management plan for Indonesia's tuna resources under an ethic of conservation which recognizes the rights of future generations and attempts to conserve resources for their use. We believe that an important axiom of effective management is the recognition that there is no static optimum sustained yield in most fisheries. Instead there is a situation where stock abundance changes continually in response to both density-dependent, as well as density-independent factors. Thus the management problem involves monitoring and maintaining an economically viable fishery without undue risk to the collapse of the resource. The harvest policies to be provided are based on attempts to minimize the probability of crossing thresholds which represent perceived limiting levels of sustainable population exploitation and which are likely to precipitate undesirable population behavior. We clearly recognize

that social and economic pressures often demand more resources and/or more income from them. Berryman (1980) has nicely summarized this management dilemma by stating that if the resources manager regulates the supply (S) and social and/or economic pressures create the demand for resources by each individual in the population (d), then the supply demand ratio is:

$$S/dN,$$

where N is the size of the consumer population. When the supply of resources from a sustained yield policy exceeds the total demand (i.e., $S/dN > 1$), then there are mainly biological problems in resource management planning. However, when $S/dN < 1$ and demand exceeds supply, the manager is in an even more difficult position. By abandoning a conservative sustained yield policy, the resource supply may be increased, but at the considerably higher risk of future collapse of the resource. We believe a responsible resource manager must insist on a conservative yield policy and maintain a conservation ethic which minimizes the risk of population collapse in spite of strong political and social pressures. Strong sympathetic national interest and regulation is necessary for this to happen. For many tuna species, we believe that policies of threshold management as enunciated by Quinn et al. (1990) are appropriate. That is, for those tuna species which oscillate greatly in relative abundance, a threshold management policy, where harvesting occurs at a constant rate but ceases when a population drops below a threshold is recommended.

Walters (1986) and Hilborn and Sibert (1988a) have addressed the issue of adaptive management of developing fisheries, and we concur with them that some flexibility in adjusting fishing pressure is necessary for effective management. Our approach prescribes a continuing monitoring effort for important fisheries, with mechanisms in place to permit adjustment of fishing effort when it is required. Our approach also involves a gradual development of the catch to a sustainable level, rather than a rapid development to projected maxima based on incomplete and/or imprecise information.

In spite of the general opinion that large tuna species are all highly migratory and require management on a large regional scale rather than at a national level, we tend to agree with the conclusions of Hilborn and Sibert (1988b) that, in the case of skipjack and yellowfin tuna at least, large-scale migrations may be the exception rather than the rule. This suggests that for a country such as Indonesia which has an extremely large EEZ, stocks of these species—as well as all small coastal tunas—may be considered resident for practical management purposes. This does not preclude extensive international collaboration in research and data collection, but harvest regulation can probably be effectively undertaken for the above-mentioned species by Indonesia in an effective manner.

Methods—

Data—Data for this report were gathered from logbooks and catch reports of state fishing enterprises, fishermen's cooperatives, private companies, and regional fisheries offices. One of us (J.U.) determined that data available from state fishing enterprises were very accurate and detailed and were therefore utilized extensively. The primary data used in the analyses which follow consisted of annual averages of catch and effort from specific landing sites from which data had been systematically collected. These data were carefully screened for anomalies and outliers and were adjusted to a standard fishing vessel in the cases where changes in vessel power or gear efficiency changed. For example, it was noticed that the placement of fish attraction devices (FADs)(rompongs) on fishing grounds increased the efficiency of pole and line skipjack tuna fishing by about 38.5 percent. This increased efficiency was corrected for after the deployment of FADs on those grounds where they were used.

Considerably more detailed information has been collected on pole and line fishing, longlining, gillnetting, and handlining than has been used herein. However, the time series of catch and effort for many gear types was too short for use in the analyses which follow.

Emphasis is placed on pole and line skipjack records, seining records, and gillnet data because these met the minimum requirements for analysis.

It is believed that the data collected for this study (if it is combined with similarly detailed records in the future) will serve as an effective data base for regular adaptive updating of the inferences drawn from this initial analysis.

Model Description—Surplus production types of models have been commonly used for stock assessment of tuna. In most cases these surplus production models were applied under the assumption of equilibrium conditions. Schnute (1977) developed a regression method for handling data drawn from non-equilibrium situations. However, we were concerned about the fact that no direct estimates of total biomass were available and that even though methods for handling non-equilibrium conditions were available (such as those of Schnute), the data base at hand would probably not be adequate to provide reasonably conservative information regarding sustained yields and the optimum effort required for maintaining these yields. This concern was substantiated when we attempted to analyze the data. Therefore, another approach, which was thought to be potentially useful, was utilized. A brief description of this methodology follows.

The conceptual population system analysis model applied to the available Indonesian data has been developed by Berryman (1980) and Berryman and Millstein (1990). Only a brief technical description and foundation of the method is provided herein. The reader interested in further details is referred to the citations listed above.

The population analysis system has its foundations in fundamental ecological models. Firstly, the integrated form of the exponential growth equation is written as:

$$N(t) = N(0) \exp(Rt), \qquad (1)$$

where $N(t)$ = population density at time t,

$N(0)$ = initial population density,

R = the rate of increase per individual.

More generally, a recursive relation:

$$N(t) = N(t-1) \exp(R), \tag{2}$$

can be used to define the density of a population at one point in time (N(t) with respect to its density at a previous time N(t-1), and its per-individual rate of increase over that time increment, R. From the above one can easily find an expression for R as:

$$R = \ln N(t) - \ln N(t-1) \tag{3}$$

Thus, it is possible to estimate the per-individual rate of increase from population density counts made at discrete points in time (usually yearly intervals). The dynamic trajectory of a population can be calculated from Eqn. (2) but only under the assumption of a constant per-individual rate of increase. In reality this rate of increase is affected by: a) density-dependent factors which respond to the density of the population and feed back to affect the per-individual growth rate, and b) density-independent factors that act on R independent of population density. These are random or driving variables.

The model is allowed to include these concepts by permitting the per-individual rate of increase to be a function of its own density, plus a random effect of density-independent factors by stating that:

$$R = F[N\{t-T\}] + V \tag{4}$$

where F is the density-dependent R-function, T is a time delay in feed back response, and V is a random variable. The form of the density-dependent feed-back function is:

$$R = A\left(1 - \frac{N(t-1)}{L}\right)\left(1-\left(\frac{N(t-T)}{K}\right)^Q\right) \tag{5}$$

where:

A = the y-axis intercept of the R-function - the value of R at N = 0,

L = the low density root or extinction threshold which intercepts the R = 0 line at some small value of N,

K = the high density root or carrying capacity of the environment which intercepts the R = 0 line at some high value of N,

Q = the coefficient of curvature of the density-dependent R-function.

Density-independent factors are assumed to act on the individual rate of increase independently of the population size. Thus, density-independent effects are demonstrated as random deviations from the determined density-dependent R-function. It is assumed that the distribution of the random density-independent effects is normal with mean zero and a given standard deviation. That is, V = a standard normal deviate, with mean = 0 and standard deviation = S. The complete R-function is then:

$$R = \left(1 - \frac{N(t-1)}{L}\right)\left(1 - \left(\frac{N(t-T)}{K}\right)^{Q}\right) + V(S) \qquad (6)$$

The above R-function has a single stock equilibrium at some positive density. If a population system is found to have more than one convergent equilibrium, a system of two equations—one for the upper and another for the lower attractors—has been developed by Berryman and Millstein (1990). It will not be utilized herein because it was not encountered in the data sets.

The above provides a population model which can simulate some of the dynamics observed in natural systems. The range of behavior the model exhibits can be examined by running it with different values for the parameters. This is accomplished by calculating R from Eqn. (6) and N(t) from Eqn. (2). General patterns of model behavior can be established from running the model with a range of biologically reasonable values of the parameters. Sensitivity analyses are made on important parameters, and a stochastic simulation is utilized to determine how realistically the model mimics the empirical data. Management-type decisions are made by observing model results over 50 or more years under various levels of simulated harvest.

A characteristic of rapidly fluctuating populations is that they return to their mean value quickly after some form of disturbance. This property is captured by the mean response time of the system:

$$MRT = \frac{\sum^{I}_{i=1} C(i)}{I} \qquad (7)$$

where C(i) is the time taken for the ith segment of the trajectory to return to its mean, and I is the total number of times the trajectory crosses the mean.

The variance of the response time is:

$$VRT = \frac{\Sigma^{I}_{i=1} [C(i) - MRT]^2}{I - 1}. \quad (8)$$

The POPSYS Programs—

The computer programs in the POPSYS system assist in the construction of dynamic models of single species populations from a time series of density or density indices over annually censused periods of about ten years or more. They are built around a generalized discrete logistic equation. We assume for these fisheries that cpue is a direct proportional index of abundance, and we recognize that this is probably not true in vey technologically-developed tuna fisheries.

The system contains a data manager for handling hardware and for data management.

An inductive analysis program allows fitting a model to census data (in our case a series of annual observations of adjusted cpue). The user must first decide if the system has one or two equilibrium points from an examination of the R-N phase portrait of the data. The phase portrait shows how the observed values of R = ln [N(t)/N(t-1)] are related to population density N(t-1). The phase portrait may visually indicate the existence of two equilibria, and the MRT and VRT values are also used in making decisions about multiple equilibria. As stated previously, we did not encounter any cases of two or more equilibria. Next, time delays in the system are considered. In general, if the R-N phase portrait shows a clockwise circular orbit and the MRT > 2 with VRT not much greater than MRT, then the time lag (T) should be increased. When the time-delay has been examined or corrected, the R-function is fitted. A linear or non-linear function can be fitted, which includes an estimate of (S) the standard deviation of the data about the regression, and RSQ, the percent variation explained by the R-function model. If a non-linear fit is used, two other

parameters are altered. They are L, an underpopulation parameter initially set at a large negative number, and Q, an overpopulation parameter, or coefficient of density-dependent curvature. This parameter is initially set at 1 and is always greater than zero. $Q > 1$ adds convexity and $Q < 1$ adds concavity to the R-function.

Simulations are next done by calculating N(t), the density of the population at time t, from N(t-1) the prior density, (R) the per-individual rate of increase, and (S) the random variabilty. Simulations were run for periods of time usually equal to the length of the data set. However, they can be run for any lengths of time up to 100 intervals. We made simulations in a mixed deterministic/stochastic environment containing empirically determined parameters and environmental variability. Simulations were plotted as a time series to compare with the observational data as one means of model verification. However, we believe that the comparison of the shapes of the R-N phase trajectories between the data and the model is the more effective method for model validation. The reason for this statement is that the phase trajectory is time independent, whereas the stochastic model incorporates variability anywhere in the time series, and this may make a simulated time series look different from the observed data in spite of the fact that the magnitude of the variability is about the same. Even in the case of the R-N phase-space comparisons, it must be recognized that the simulations may not exactly mimic the data, but they should fall in the same general region of phase-space, if the phase portraits are superimposed.

Sensitivity analysis is done to evaluate the sensitivity of various models to variations in individual parameter values. The sensitivity graphs illustrate the influence of single parameter variations on the behavior of the model. If a stable solution exists for a particular set of values of a parameter, a straight line is evident for this range in the graph. Bifurcation into two lines suggests two-point limit cycles and highly scattered lines which oscillate indicate the presence of complex cycles or chaotic behavior.

Predictions are also possible with the POPSYS system model. A minimum of T data points are necessary for a prediction where T is the length of the time lag. Predictions from this model are made as follows. Firstly, the last T data points are used to calculate the expected per-individual rate of increase, R, using the fitted R-function. Then a random normal deviate V, is drawn from a normal distribution with mean zero and calculated standard deviation. Secondly, the predicted population density is calculated from the exponential equation, and compared to stated collapse or danger thresholds. Finally, the above calculations are repeated 100 times, and the mean standard deviation and 95 percent confidence intervals are calculated and displayed--as well as probabilities of increase or decrease from prior levels.

The final methodological procedure employed by us involved testing management options. In our case this involved various rates of removal (harvest) of the organisms of interest under specified danger levels and population densities at which exploitation is initiated. The simulation was usually run for 50 years in our case. Variation of the harvest rate permitted as estimation of an acceptable harvest rate which minimizes the danger of population collapse for a previously established collapse threshold.

In the analyses which follow we have assumed that the adjusted cpue, expressed as catch-per-standard boat day, is a valid index of of population density for the fisheries examined. This value has been derived from catch expressed in weight rather than numbers. We believe that the harvest strategies derived from the application of the model can apply to both numbers or biomass because the fishery catches only relatively large fish whose average biomass and estimates numerical abundance are assumed to be closely related. This was empirically demonstrated for the bigeye tuna data. See Appendix 1 for correlation between number and biomass.

Results—

General—In order for the reader to better understand and interpret the results of the analyses which follow, a brief description and interpretation of the model parameters

are provided herein. This is in addition to the technical descriptions of the model provided previously.

The parameter K was described as the intercept of the density-dependent R-function with the x-axis at R = 0. Because $^{dn}/_{dt}$ or $^{dB}/_{dt} = 0$ at this point it represents a population equilibrium or sustained carrying capacity. In our study K is conservatively represented as the estimated carrying capacity of the environment. K values were found to change at various developmental stages of the fishery. Changing the value of K moves the equilibrium level, but it does <u>not</u> influence the stability properties of the logistic equation used in this study.

A is an intercept of the density-dependent R-function with the y-axis at N(t-T) = 0. This parameter represents the per-individual rate of increase of the population biomass when its density is very low in the absence of density-dependent feedback. A may also be construed to represent the average favorability of the environment.

Changing the parameter A represents altering the quality of the environment for the population. S, the standard deviation, represents the variation in the density-independent environment.

L is the other intercept of the density-dependent R-function with the x-axis at R = 0. When the value of L is positive, this intercept is called an extinction threshold. In these analyses L is never allowed to be positive under the assumption that the population never enters the extinction domain.

Q is a coefficient of curvature of the R-function that can produce non-linear density-dependent relationships. When Q = 1, the R-function is linear, when Q < 1, it is concave, and when Q > 1, it is convex.

The time delay T in the elemental logistic equation assumes that negative feedback occurs within one time period. That is, N(t) is determined by density one time period previously at N(t-1). This is a case of a time lag of T = 1 in the action of the negative feedback loop. It is possible for time lags of T = 2, T = 3 to occur. We interpret time

delays as a measure of the inertia of the feedback process, and time lags may be introduced into negative feedback loops when populations affect properties of the environment—such as food resources or the presence of predators. We suggest that a time delay of one indicates that density-dependent negative feedback is acting quickly—that is, within the first year of life.

RSQ indicates the percent of the variation in the data which is explained by the fitted R-function. That is, it shows how much of the variation in the data set is determined by density-dependent feedback processes. We infer from this that density-independent factors are responsible for 1 - RSQ of the variation. This provides an estimate of the relative significance of density-dependent and density-independent processes in affecting population fluctuations.

It should be appreciated that annual average catch and effort data were available for analysis. Most of the analyses which follow are based on annual average values for the catch-per-unit effort (cpue) expressed in the form of biomass (kg) per standard boat day. Data were first examined for outliers and typographical errors. They were then adjusted to a standard boat day when this was required. Data used in the analyses may be scaled in order to avoid fractional units in the outputs. We do not address concentration profiles in this report. That is, we assume catch is proportional to effort for these fisheries.

Bitung Skipjack Data Analysis—

See Figure B-1 for the location of Bitung—as well as for the locations of the other data sets which follow. The Bitung data base consists of 21 annual values of catch and effort extending from 1967 to 1988. The record for 1987 was missing. The original data were adjusted for the change from 30- to 40-ton vessels from 1977 on since it was noted that a 38.6 percent increase in average cpue was obtained with the 40-ton vessels (Table B-1). All further analyses were performed on the data which have been adjusted to standard (30-ton) vessels.

The conventional approach to analysis of this type data is by so-called surplus production or Schaefer type of models. We have already indicated concerns about the uncritical use of these models. However, for the purposes of illustrating the feasibility of utilizing this type of model, some results are presented for the Bitung data set, which is one of the largest data sets available for this study. Also, see Appendix 1 for a comparison of various population models and the system model for a published data set on Atlantic bigeye tuna.

Table B-2 illustrates the results of applying the linear approximation to the Schnute model to these data for which the effort has been adjusted to a standard boat after 1976. These results, which indicate values of $\hat{r}$ and q which are less than zero and negative equilibrium catch rates, clearly show that these results are biologically unrealistic. We conclude that these data do not lend themselves to the application of this method, probably because the data do not demonstrate enough contrast in the values of catch and effort.

It is generally recognized that the application of the surplus production model under equilibrium assumptions usually provides what appear to be reasonable answers. However, in the application of the Schaefer model as outlined by Pauly (1984), none of the bivariate regression techniques used (see Table B-3 and Figure B-2), provided slope values of the regression which were negative, and therefore, the model parameters could not be estimated. Figure B-2 illustrates graphically the poor correlation and the indication of a positive slope. The correlation between the two variables was barely six percent. Clearly, this is inadequate for the purposes at hand.

It seemed evident to us in this instance—as well as in others which were tested—that the conventional stock production model using equilibrium assumptions was not effective. We proceed now to interpret the dynamics of the time series of adjusted cpue data based on the simulation model.

Figure B-3 illustrates the trajectory of the Bitung cpue data. The data oscillate rapidly above and below the mean value, and the mean response time (MRT) is less than

two. The response time variance (VRT) is considerably smaller than the mean. This is interpreted to suggest strong density-dependent feedback with only a small delay in the feedback response. The mean period of oscillation (PER) has been found to be about four. This represents the time interval between peaks in the data. The mean aptitude (AMP) represents the average difference between peaks and troughs in the data. The mean represents the mean value of cpue measured as biomass in these data, rather than numerical density as is usually the case when numbers are used. We did not attempt a conversion to numbers with the available data. This seems unnecessary, because the data can easily be interpreted as relative changes in catchable numbers or biomass. Because this is a pole and line fishery, extremes in size ranges are not expected, and it has also been demonstrated that the correlation between numbers and biomass caught per standard effort is very high for such fisheries.

The two methods for determining the kind of R-function underlying a particular data set include: 1) examination of the mean response time, and 2) examining the R-N phase portrait of the trajectory of the data. The R-N phase trajectory of the Bitung data is shown in Figure B-4. This figure has been plotted from the rates of increase and density (cpue) tabled beneath Figure B-3. It should be noted that this phase portrait does not separate into two distinct groups, that the data oscillate rapidly from above to below the equilibrium line and that there is a tight goruping of the data with no need to increase the time lags. One important feature of the R-N phase portrait is that it is time independent. Therefore, visual or graphic comparisons of phase portraits derived from real data versus those derived from simulations provide a good means for assessing the validity of a model.

The fitted R-function is displayed in Figure B-5. Note that a linear model in this case accounted for about 54 percent of the variation in the data. It was not necessary to consider a non-linear model in this case. The R-function extracted from the data is interpreted as a reasonable approximation to the actual governing equation. That is, the R-function is assumed to describe the effect of population density on the rate of increase of

the average organism. It describes the feedback in the system, and combined with random variation it can simulate the dynamics of the population. That is:

$$N(t) = N(t - 1) \times \exp (R + V).$$

These symbols have already been explained, but it should be remembered that R is computed from the R-function and V is a standard normal deviate. A stochastic simulation model of the Bitung skipjack data is shown in Table B-4. The data from this table are plotted in Figure B-6. It is evident that there is some similarity between Figure B-3, the plot of the original data and the plot of the simulation run data of Figure B-6. It should be recognized that a sufficiently long series of simulation runs may ultimately produce one very close to the original data. However, the stochastic nature of the density-dependent variation in a time series does not assure exact similarity although the magnitude of the oscillations around the parameter K may be about the same. Of much more value for comparative purposes are the phase portraits of the trajectories. Since the phase portraits are time-independent, their shapes may be compared directly. It seems clear that superimposing Figure B-7 on Figure B-4 would show a very close correspondence in the phase portraits. We interpret this to indicate that the simulation model provides a reasonable portrayal of the dynamics of this population shown by the original time series. Thus, the modeled R-function and random density-independent effects seems to provide a good approximation to observed data.

The next step in our analysis of the data was to perform sensitivity analyses on the estimated model parameters in order to ascertain the sensitivity of the model to particular values of a given one. Specifically, all fitted model parameters except one are held constant in each sensitivity analysis.

Table B-5 and Figure B-8 illustrate the results of the sensitivity analysis for the parameter A, the per-individual rate of increase. From Figure B-8 it is evident that there is a stable solution for a range of parameter values extending well beyond the observed value. However, at high values (> 2) times the observed value of the y-intercept of the R-

function, there is some evidence of rapid change followed by what appears to be chaotic behavior.

Table B-6 and Figure B-9 illustrate the results of a sensitivity analysis for the parameter S, the random variate. It is evident from Figure B-9 that as random variation increases, the population density (cpue) oscillates at greater levels. However, within the range of values tested (0.02 - 0.68), these oscillations did not induce any evidence of chaotic behavior. Sensitivity analyses for other parameters were not conducted for this model.

There is a prediction capability connected with this model. In order to utilize it a model must have first been built, and there must be one or more independent population density estimates. The number of input data points depends upon the length of the time-delay in the model. Up to ten data points can be inputted, but only T will be used. A low-density danger threshold can be entered. We utilized a value of approximately 20-25 percent of the maximum carrying capacity (K) as our threshold value for all predictions and management simulations.

Specific predictions with the prediction model are made as follows. Firstly, the last T input data points are used to calculate the expected per-individual rate of increase R using the fitted R-function. Then a random normal deviate, V, is drawn from a normal distribution with mean zero and calculated standard deviation. These quantities are summed to provide an estimate of the per-individual rate of increase in a stochastic environment with specified density-dependent random variation. Secondly, the predicted population density is calculated from the exponential equation. The predicted density is compared to the danger threshold and counters are incremented. Finally, all the above calculations are repeated 100 times, and the mean predicted density, standard deviation of the mean prediction, 95 percent confidence intervals of the mean prediction, maximum and minimum predicted densities, and the probabilities for increase or decrease are calculated.

The results of Bitung skipjack predictions utilizing the simulation model are shown in Table B-7. Since this model is a relatively new approach to fishery scientists, we have utilized a more conventional time-series approach to the same data for comparative purposes. The data set was not considered to be long enough for the Box-Jenkins type of time series analysis. Therefore, we used a number of simple time series models as described by Thomopoulos (1980). Tables B-8 to B-11 illustrate the various statistical forecast models applied. Using the criteria of minimum mean squared error, it was found that the single moving average model performed the best and it was therefore used for forecasting. The single moving average model is described as follows. Let N be the number of terms in the moving average M_t. Then:

$$M_t = (x_{t-N+1} + \ldots + x_{t-1} + x_t)/N$$

or

$$M_t = M_{t-1} + (x_t - x_{t-N})/N.$$

The k-period-ahead forecast, given that we start with period t is:

$$F_t(k) = M_t, \; k = 1, 2, \ldots$$

The results from this model compare very favorably with the results from the simulation model forecast.

The final phase of the simulation model study for the Bitung skipjack involved simulated population management. In our case removal of organisms (biomass) was effected through simulated fishing activity. Using the stochastic model described previously and the derived parameters, various levels of mortality were simulated. In this specific instance, a threshold value of 20 percent of K (maximum carrying capacity) was employed. In addition it was assumed that a threshold density of about 20 percent of the carrying capacity would be the lower limit below which fishing would not take place. Removal strategies involving 30,40, 45, and 50 percent of the stock when it was above 250 units were tried. A value of a probability of risk (danger) of 0.05 or less was chosen as a conservative risk factor. The results of these simulations are shown in Tables B-12

and B-13. A removal of 45 percent of the stock is suggested from these data. We interpret this to mean that the stock being examined could tolerate a 45 percent increase in harvest before it would be subject to an unacceptable risk of collapse. That is, the current level of fishing mortality could be incremented by about 45 percent before the stock would encounter a high danger of collapse under the assumptions stipulated above.

Table B-14 shows the results of fitting a second degree polynomial to the Bitung catch and effort data after forcing the curve through the x, y axis origin. The dome of this curve corresponds well with some of the estimates using the Schaefer model. Table B-15 shows the results of a fit of a regression line to the cpue time series. Unfortunately, the data are too scattered to permit any meaningful inferences about the state of the fishery.

Table B-1. Results from a comparison of average cpue values between 30- and 40-ton vessels operating in the Bitung pole and line skipjack tuna fishery.

1967-1976 cpue 30-ton vessels	1977-1988* cpue 40-ton vessels
558	1015
703	873
847	1261
956	1262
751	912
777	1426
808	1240
637	1036
723	765
946	800
	1167

Function: T-TEST

Sample One:		Sample Two:	
Variable 1: Set 1a		Variable 2: Set 1b	
Cases 1 through 10		Cases 1 through 11	
Mean:	746.600	Mean:	1076.091
Variance:	21018.933	Variance:	41738.091
Standard Deviation:	144.979	Standard Deviation:	204.299

F-TEST for the Hypothesis "VARIANCE 1 = VARIANCE"

F VALUE:	1.987
Numerator degrees of freedom:	10
Denominator degrees of freedom:	9
Probability:	0.3166

Result: Non-Significant F - Accept the Hypothesis

T-TEST for the Hypothesis "MEAN 1 = MEAN 2"

T-value:	-4.2206
Degrees of freedom:	19
Probability of t:	0.0005

Result: Significant t - Reject the Hypothesis

Table B-2. Results from fitting Schnute's regression model to the adjusted Bitung skipjack tuna catch and effort data.

FILE NAME BITUNG
DATA PAIRS 21

7	EFFORT	CATCH
1	2302	1283.5
2	1997	1404.1
3	1790	1516.3
4	1651	1570.4
5	1762	1332.4
6	1523	1283.4
7	1134	934.9
8	1356	863.9
9	1144	827.1
10	725	605.9
11	625	457.7
12	565	356
13	1037	944.5
14	1443	1315.4
15	1191	790.9
16	1014	1017.9
17	753	674.5
18	1951	1460.8
19	1450	905.2
20	1943	1123.1
21	2159	1788.3

PARAMETERS ESTIMATED BY LINEAR APROXIMATION (EQ. 41)

R=	-5.028976E-02
K=	8761.318
Q=	-8.832122E-05
A = (Q*Q*K/R) =	-1.359002E-03
B = (Q*K) =	-.7738103
SUMS OF SQUARES =	.8899178
VARIANCE	4.943988E-02
OVEALL FIT OF MODEL	.9642872

THE FOLLOWING CALCULATIONS GIVE THE OPTIMUM CATCH RATE, AND THE EFFORT (E), CATCH PER UNIT EFFORT (U) AND THE BIOMASS (P) AT MAXIMUM SUSTAINABLE YIELD.
CALCULATIONS ARE BASED ON THE LINEARIZED APPROXIMATION.

MAX. EQUILIBRIUM CATCH RATE = -110.1511
UPPER LIMITS OF ESTIMATION = 23.32232
LOWER LIMITS OF ESTIMATION = -243.1852

AT MAXIMUM CATCH RATE :

E = 284.698
U = -.3869051
P = 4380.659

F(3,N-3) = 3.16

Table B-3. Results from fitting various bivariate regressions to the Bitung data. The independent variable (X) is fishing effort, and the dependent variable (Y) is cpue.

```
                    Bivariate regression analysis

                              BIREG

          Including: Orthogonal, least-squares, functional
                     and Bartlett's regressions

Descriptive Statistics:

Mean of X ..........  1218            Mean of Y ........  1042.714
Std dev of X .......  524.4124        Std dev of Y .....  478.3177
Correlation (r) ....  5.935336E-02    N observations ...  21
Covariance .........  297758.8

Orthogonal Regression:

Y-intercept (A) of Y on X ..................   684.3506
  Slope (B) of Y on X ......................   .2942231
Y-intercept (A) of X on Y ..................  -2325.959
  Slope (B) of X on Y ......................   3.398783
Sum of residuals for X .....................   4488149
Sum of residuals for Y .....................   4488149


Least-Squares Regression:

Y-intercept (A) of Y on X ..................   976.7762
  Slope (B) of Y on X ......................   5.413633E-02
Y-intercept (A) of X on Y ..................   1150.147
  Slope (B) of X on Y ......................   6.507314E-02
St error of the slope of Y on X ............   .2088817

Functional Regression:

Slope (B) of the regression ................   .9121022
Intercept (A) ..............................  -68.22632
St error of the slope ......................   .2088817
St error of the intercept ..................   104.4239


Linear Functional Relation by Bartlett's method:

Y-intercept (A) ............................   949.7714
Approximate 95% confidence limits for (A) .. ( 734.7535 , 1164.789 )
Slope of the line (B) ......................   7.630774E-02
95% confidence limits for (B) ..............  ( .55 , -.38 )
t value for significance of regression .....   .3551981
t value for deviations from unit slope .....  -3.871007
t value for deviations from linearity ......  -2.080768
Degrees of freedom for t values ............   18
```

Table B-4. Results from the application of a stochastic model to simulate Bitung skipjack cpue time series data.

```
::::::::::::::::::::::::::::::::::::::

        ADJ. BITUNG SKJ Model

      R = A(i) * (1-N(t)/L(i)) *

       (1-[N(t-T(i))/K(i)]^Q(i)) + V(S)

      where i = 1 when N(t) > E
      and   i = 2 when N(t) < E

      R is the per-capita rate of
      increase, N(t) is the density of
      the population at time t, V is a
      random normal variate, and E is
      the escape threshold.          (F10)
       parameters of your model are

A    = the value of R at N = 0          =  1.0020E+00
K    = the equilibrium point            =  7.6425E+02
L    = the  underpopulation effect      = -1.0000E+06
Q    = the coefficient of curvature     =  1.000E+00
T    = the feedback time-lag            = 1
       and the goodness of fit statistics are

S    = standard deviation               =  1.4471E-01
RSQ  = % of variation explained         =  54.3%

::::::::::::::::::::::::::::::::::::::
```

ADJ. BITUNG SKJ Simulation
Data from Simulation # 2

Time	Density	Rate of Increase	Random Variation
0	5.5800E+02	2.2340E-01	-4.7009E-02
1	6.9768E+02	-2.0532E-01	-2.9260E-01
2	5.6818E+02	3.6809E-01	1.1103E-01
3	8.2101E+02	-2.2855E-01	-1.5413E-01
4	6.5327E+02	1.9560E-01	5.0097E-02
5	7.9440E+02	4.2392E-04	3.9958E-02
6	7.9474E+02	2.2739E-01	2.6737E-01
7	9.9766E+02	-3.8294E-01	-7.6925E-02
8	6.8026E+02	1.4911E-01	3.8985E-02
9	7.8964E+02	-3.8911E-01	-3.5583E-01
10	5.3511E+02	3.5928E-02	-2.6450E-01
11	5.5468E+02	1.4252E-01	-1.3224E-01
12	6.3964E+02	1.1694E-01	-4.6428E-02
13	7.1900E+02	9.6623E-02	3.7289E-02
14	7.9193E+02	3.2543E-02	6.8843E-02
15	8.1813E+02	4.1147E-02	1.1179E-01
16	8.5250E+02	1.5034E-03	1.1721E-01
17	8.5378E+02	-2.7513E-01	-1.5775E-01
18	6.4843E+02	7.8387E-02	-7.3470E-02
19	7.0130E+02	1.5660E-01	7.4068E-02
20	8.2019E+02	5.6317E-02	1.2966E-01
21	8.6771E+02	-1.3819E-01	-2.5473E-03

Standard Deviation of Random Variable = 1.4471E-01

Table B-5. A stochastic simulation model for Bitung skipjack tuna and the data resulting from a simulation for 21 time periods.

ADJ. BITUNG SKJ SENSITIVITY TO PARAMETER A

Parameter Value	POPULATION DENSITY per CPUE Mean	Maximum	Minimum	St. Deviation
5.8000D-01	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
6.8000D-01	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
7.7000D-01	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
8.6000D-01	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
9.5000D-01	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.0400D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.1300D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.2200D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.3100D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.4000D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.4900D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.5800D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.6700D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.7600D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.8500D+00	0.0000D+00	7.6425D+02	7.6425D+02	0.0000D+00
1.9400D+00	0.0000D+00	7.6468D+02	7.6468D+02	0.0000D+00
2.0300D+00	0.0000D+00	9.2904D+02	9.2904D+02	0.0000D+00
2.1200D+00	0.0000D+00	1.0734D+03	1.0734D+03	0.0000D+00
2.2100D+00	0.0000D+00	1.1573D+03	1.1573D+03	0.0000D+00
2.3000D+00	0.0000D+00	1.2171D+03	1.2171D+03	0.0000D+00
2.3900D+00	0.0000D+00	1.2631D+03	1.2631D+03	0.0000D+00
2.4800D+00	0.0000D+00	1.2998D+03	1.2998D+03	0.0000D+00
2.5700D+00	0.0000D+00	1.5295D+02	1.5295D+02	0.0000D+00
2.6600D+00	0.0000D+00	1.2314D+02	1.2314D+02	0.0000D+00
2.7500D+00	0.0000D+00	2.3367D+02	2.3367D+02	0.0000D+00
2.8400D+00	0.0000D+00	1.3408D+03	1.3408D+03	0.0000D+00
2.9300D+00	0.0000D+00	1.7967D+03	1.7967D+03	0.0000D+00
3.0200D+00	0.0000D+00	1.5625D+03	1.5625D+03	0.0000D+00
3.1100D+00	0.0000D+00	2.5107D+02	2.5107D+02	0.0000D+00
3.2000D+00	0.0000D+00	8.8004D+00	8.8004D+00	0.0000D+00
3.2900D+00	0.0000D+00	1.1145D+03	1.1145D+03	0.0000D+00
3.3800D+00	0.0000D+00	2.7422D+01	2.7422D+01	0.0000D+00
3.4700D+00	0.0000D+00	1.0903D+03	1.0903D+03	0.0000D+00
3.5600D+00	0.0000D+00	1.7184D+03	1.7184D+03	0.0000D+00
3.6500D+00	0.0000D+00	1.1979D+03	1.1979D+03	0.0000D+00
3.7400D+00	0.0000D+00	5.6320D+02	5.6320D+02	0.0000D+00
3.8300D+00	0.0000D+00	6.5862D+02	6.5862D+02	0.0000D+00
3.9200D+00	0.0000D+00	1.9100D+02	1.9100D+02	0.0000D+00
4.0100D+00	0.0000D+00	1.8771D+01	1.8771D+01	0.0000D+00
4.1000D+00	0.0000D+00	1.8289D+02	1.8289D+02	0.0000D+00
4.1900D+00	0.0000D+00	2.3267D+00	2.3267D+00	0.0000D+00
4.2800D+00	0.0000D+00	6.7490D-03	6.7490D-03	0.0000D+00
4.3700D+00	0.0000D+00	1.1314D+01	1.1314D+01	0.0000D+00
4.4600D+00	0.0000D+00	3.4099D-01	3.4099D-01	0.0000D+00
4.5500D+00	0.0000D+00	2.8478D+03	2.8478D+03	0.0000D+00
4.6400D+00	0.0000D+00	6.1933D+03	6.1933D+03	0.0000D+00
4.7300D+00	0.0000D+00	5.5130D+02	5.5130D+02	0.0000D+00
4.8200D+00	0.0000D+00	8.2179D-04	8.2179D-04	0.0000D+00
4.9100D+00	0.0000D+00	0.0000D+00	0.0000D+00	0.0000D+00

Table B-6. Tabular presentation of sensitivity analysis results for parameter A for Bitung skipjack.

ADJ. BITUNG SKJ SENSITIVITY TO PARAMETER S

Parameter Value	POPULATION DENSITY per CPUE Mean	Maximum	Minimum	St. Deviation
2.0860D-02	0.0000D+00	7.7518D+02	7.7518D+02	0.0000D+00
3.4720D-02	0.0000D+00	7.8557D+02	7.8557D+02	0.0000D+00
4.8580D-02	0.0000D+00	7.8965D+02	7.8965D+02	0.0000D+00
6.2440D-02	0.0000D+00	7.1351D+02	7.1351D+02	0.0000D+00
7.6300D-02	0.0000D+00	8.4255D+02	8.4255D+02	0.0000D+00
9.0160D-02	0.0000D+00	8.5415D+02	8.5415D+02	0.0000D+00
1.0402D-01	0.0000D+00	7.9489D+02	7.9489D+02	0.0000D+00
1.1788D-01	0.0000D+00	6.3881D+02	6.3881D+02	0.0000D+00
1.3174D-01	0.0000D+00	9.9041D+02	9.9041D+02	0.0000D+00
1.4560D-01	0.0000D+00	8.2218D+02	8.2218D+02	0.0000D+00
1.5946D-01	0.0000D+00	7.3897D+02	7.3897D+02	0.0000D+00
1.7332D-01	0.0000D+00	8.0815D+02	8.0815D+02	0.0000D+00
1.8718D-01	0.0000D+00	7.2803D+02	7.2803D+02	0.0000D+00
2.0104D-01	0.0000D+00	5.8753D+02	5.8753D+02	0.0000D+00
2.1490D-01	0.0000D+00	1.1035D+03	1.1035D+03	0.0000D+00
2.2876D-01	0.0000D+00	6.4943D+02	6.4943D+02	0.0000D+00
2.4262D-01	0.0000D+00	5.1236D+02	5.1236D+02	0.0000D+00
2.5648D-01	0.0000D+00	6.7448D+02	6.7448D+02	0.0000D+00
2.7034D-01	0.0000D+00	5.6891D+02	5.6891D+02	0.0000D+00
2.8420D-01	0.0000D+00	5.7720D+02	5.7720D+02	0.0000D+00
2.9806D-01	0.0000D+00	4.9929D+02	4.9929D+02	0.0000D+00
3.1192D-01	0.0000D+00	6.2262D+02	6.2262D+02	0.0000D+00
3.2578D-01	0.0000D+00	4.5884D+02	4.5884D+02	0.0000D+00
3.3964D-01	0.0000D+00	5.2625D+02	5.2625D+02	0.0000D+00
3.5350D-01	0.0000D+00	6.8292D+02	6.8292D+02	0.0000D+00
3.6736D-01	0.0000D+00	3.9591D+02	3.9591D+02	0.0000D+00
3.8122D-01	0.0000D+00	8.2253D+02	8.2253D+02	0.0000D+00
3.9508D-01	0.0000D+00	7.2205D+02	7.2205D+02	0.0000D+00
4.0894D-01	0.0000D+00	1.4934D+03	1.4934D+03	0.0000D+00
4.2280D-01	0.0000D+00	6.8967D+02	6.8967D+02	0.0000D+00
4.3666D-01	0.0000D+00	5.8971D+02	5.8971D+02	0.0000D+00
4.5052D-01	0.0000D+00	6.1868D+02	6.1868D+02	0.0000D+00
4.6438D-01	0.0000D+00	6.8040D+02	6.8040D+02	0.0000D+00
4.7824D-01	0.0000D+00	1.7114D+03	1.7114D+03	0.0000D+00
4.9210D-01	0.0000D+00	2.5241D+02	2.5241D+02	0.0000D+00
5.0596D-01	0.0000D+00	3.9766D+02	3.9766D+02	0.0000D+00
5.1982D-01	0.0000D+00	3.8670D+02	3.8670D+02	0.0000D+00
5.3368D-01	0.0000D+00	3.1888D+02	3.1888D+02	0.0000D+00
5.4754D-01	0.0000D+00	1.2351D+03	1.2351D+03	0.0000D+00
5.6140D-01	0.0000D+00	4.3079D+02	4.3079D+02	0.0000D+00
5.7526D-01	0.0000D+00	2.2773D+02	2.2773D+02	0.0000D+00
5.8912D-01	0.0000D+00	2.9081D+02	2.9081D+02	0.0000D+00
6.0298D-01	0.0000D+00	1.5323D+03	1.5323D+03	0.0000D+00
6.1684D-01	0.0000D+00	5.8330D+02	5.8330D+02	0.0000D+00
6.3070D-01	0.0000D+00	1.1776D+02	1.1776D+02	0.0000D+00
6.4456D-01	0.0000D+00	1.4319D+03	1.4319D+03	0.0000D+00
6.5842D-01	0.0000D+00	6.9336D+02	6.9336D+02	0.0000D+00
6.7228D-01	0.0000D+00	5.8310D+02	5.8310D+02	0.0000D+00
6.8614D-01	0.0000D+00	1.3537D+03	1.3537D+03	0.0000D+00

ADJ. BITUNG SKJ PREDICTIONS

Table B-7. Results of predictions using the simulation model for Bitung skipjack.

POPULATION DENSITY per CPUE

Time	Mean	Maximum	Minimum	St. Deviation	95% Interval
		I N P U T D A T A			
1	7.1100E+02	.....			
2	9.1200E+02	.....			
3	6.6400E+02	.....			
4	7.2200E+02	.....			
5	8.9600E+02	.....			
6	7.4900E+02	.....			
		P R E D I C T E D D A T A			
7	7.7228E+02	1.1952E+03	5.0043E+02	1.2335E+02	+- 2.4669E+02
8	7.5898E+02	1.0083E+03	5.1931E+02	9.7247E+01	+- 1.9449E+02
9	7.6123E+02	1.0111E+03	5.3798E+02	1.0557E+02	+- 2.1114E+02

ADJ. BITUNG SKJ PREDICTIONS

P R O B A B I L I T I E S

Time	P(increase)	P(decrease)	P(damage)	P(danger)
7	0.54	0.46	0.00	0.00
8	0.53	0.47	0.00	0.00
9	0.51	0.49	0.00	0.00

Table B-8. Raw data, summary statistics, and autocorrelation function for Bitung skipjack time series forecasts.

```
TOTAL NO. OF OBSNS = 21
OBSN          1          558
OBSN          2          703
OBSN          3          847
OBSN          4          956
OBSN          5          751
OBSN          6          777
OBSN          7          868
OBSN          8          637
OBSN          9          723
OBSN          10         946
OBSN          11         732
OBSN          12         630
OBSN          13         711
OBSN          14         912
OBSN          15         664
OBSN          16         722
OBSN          17         896
OBSN          18         749
OBSN          19         624
OBSN          20         578
OBSN          21         828
MINIMUM =  558
MAXIMUM =  956
MEAN    =  752.9524
STD DEV =  118.4975

TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988

          -   -1.00
-   -0.50
-    0.00
-    0.50
-    1.00

LAG   AUTOCORR.  +
  0 -1.0000000                    I********************
  1 -0.0049163                    I
  2 --.4829618          **********I
  3 -0.0588892                    I*
  4 -0.2194314                    I****
  5 --.2975546              ******I
  6 --.1472542                 ***I
  7 -0.4614912                    I*********
  8 --.0621761                   *I
  9 —.3902843            ********I
 10 -0.0834517                    I**
LAG   AUTOCORR.  +
          -   -1.00
-   -0.50
-    0.00
-    0.50
-    1.00
```

Table B-9. First differences and three statistical models applied to Bitung skipjack tuna series.

```
TIME SERIES : FIRST DIFFERENCE OF ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988

           -   -1.00
-   -0.50
-    0.00
-    0.50
-    1.00

LAG   AUTOCORR.  +
  0 -1.0000000                    I********************
  1 --.1835436                ****I
  2 --.5119317           **********I
  3 -0.2368956                    I*****
  4 -0.2669720                    I*****
  5 --.3311783            *******I
  6 --.2052154                ****I
  7 -0.4874404                    I**********
  8 --.0476231                   *I
  9 --.3381512             *******I
 10 -0.0871573                    I**
LAG   AUTOCORR.  +
           -   -1.00
-   -0.50
-    0.00
-    0.50
-    1.00
```

```
SMAVE     -SINGLE MOVING AVERAGE
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
NUMBER OF ERROR OBSNS        17
MEAN % ERROR OR BIAS        -4.5637
MEAN ABSOLUTE % ERROR        13.03117
MEAN SQUARED ERROR (MSE)     12943.65
MEAN ABSOLUTE ERROR          95.0588
```

```
SMAVE     -SINGLE MOVING AVERAGE
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
NUMBER OF ERROR OBSNS        18
MEAN % ERROR OR BIAS        -3.132095
MEAN ABSOLUTE % ERROR        15.6654
MEAN SQUARED ERROR (MSE)     19263.4
MEAN ABSOLUTE ERROR          118.386
```

```
LMAVE     -LINEAR MOVING AVERAGE
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
NUMBER OF ERROR OBSNS        14
MEAN % ERROR OR BIAS        -3.476735
MEAN ABSOLUTE % ERROR        17.0981
MEAN SQUARED ERROR (MSE)     21077.4
MEAN ABSOLUTE ERROR          126.507
```

Table B-9 (cont'd). First differences and three statistical models applied to Bitung skipjack tuna series.

```
REGRESS  -LINEAR REGRESSION WITH FIXED PERIODS
NUMBER OF PERIODS IN THE REGRESSION =  4
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
NUMBER OF ERROR OBSNS        17
MEAN % ERROR OR BIAS        -4.42817
MEAN ABSOLUTE % ERROR        24.37808
MEAN SQUARED ERROR (MSE)     46727.62
MEAN ABSOLUTE ERROR          184.7647

REGRESS  -LINEAR REGRESSION WITH FIXED PERIODS
NUMBER OF PERIODS IN THE REGRESSION =  3
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
NUMBER OF ERROR OBSNS        18
MEAN % ERROR OR BIAS        -2.790827
MEAN ABSOLUTE % ERROR        29.0933
MEAN SQUARED ERROR (MSE)     61930.36
MEAN ABSOLUTE ERROR          218.963

X        -SINGLE EXPONENTIAL SMOOTHING
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
ALPHA =  .2
INITIAL SMOOTHED AVERAGE =  558
LAST PERIOD ESTIMATE OF SMOOTHED AVERAGE =  731.2598
NUMBER OF ERROR OBSNS        20
MEAN % ERROR OR BIAS         3.34783
MEAN ABSOLUTE % ERROR        15.67324
MEAN SQUARED ERROR (MSE)     21337.89
MEAN ABSOLUTE ERROR          121.6956

XX       -DOUBLE EXPONENTIAL SMOOTHING
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
ALPHA =  .2
INITIAL ESTIMATE OF INTERCEPT =  558
INITIAL ESTIMATE OF SLOPE     =  0
LAST PERIOD ESTIMATE OF INTERCEPT =  725.0606
LAST PERIOD ESTIMATE OF SLOPE     = -1.5498
NUMBER OF ERROR OBSNS        20
MEAN % ERROR OR BIAS        -2.670865
MEAN ABSOLUTE % ERROR        17.70215
MEAN SQUARED ERROR (MSE)     21761.38
MEAN ABSOLUTE ERROR          132.5425

XXX      -TRIPLE EXPONENTIAL SMOOTHING
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
ALPHA =  .2
INITIAL ESTIMATE OF A =  558
INITIAL ESTIMATE OF B =  0
INITIAL ESTIMATE OF C =  0
LAST PERIOD ESTIMATE OF A =  713.297
LAST PERIOD ESTIMATE OF B = -8.749601
LAST PERIOD ESTIMATE OF C = -.8207046
NUMBER OF ERROR OBSNS        20
MEAN % ERROR OR BIAS        -2.993822
MEAN ABSOLUTE % ERROR        18.31053
MEAN SQUARED ERROR (MSE)     24565.65
MEAN ABSOLUTE ERROR          137.8309
```

Table B-10. The final three models applied to Bitung skipjack time series.

```
ADAPT    -ADAPTIVE RESPONSE RATE EXPO. SMOOTH.
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
BETA =  .1
INITIAL SMOOTHED AVERAGE =  558
INITIAL SMOOTHED ERROR =  0
INITIAL SMOOTHED ABSOLUTE ERROR =  0
LAST PERIOD ESTIMATE AVERAGE =  713.8452
LAST PREIOD SMOOTHED ERROR = -15.69782
LAST PERIOD SMOOTHED ABSOLUTE ERROR =  102.8075
NUMBER OF ERROR OBSNS       20
MEAN % ERROR OR BIAS       -2.654904
MEAN ABSOLUTE % ERROR       17.04686
MEAN SQUARED ERROR (MSE)    21314.16
MEAN ABSOLUTE ERROR         128.1591

HOLT    -HOLT 2-PARAMETERS LINEAR EXPO. SMOOTH.
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
ALPHA =  .2
BETA  =  .1
INITIAL ESTIMATE OF INTERCEPT =  558
INITIAL ESTIMATE OF SLOPE = 127
LAST PERIOD ESTIMATE OF INTERCEPT = 866.8761
LAST PERIOD ESTIMATE OF SLOPE = 7.849975
NUMBER OF ERROR OBSNS       20
MEAN % ERROR OR BIAS       -42.10525
MEAN ABSOLUTE % ERROR       42.78897
MEAN SQUARED ERROR (MSE)    123303.6
MEAN ABSOLUTE ERROR         303.3641

WINTERS -WINTERS 3-PARAMETERS LINEAR EXPO. SMOOTH.
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988
ALPHA =  .2
BETA =  .1
GAMMA =  .1
INITIAL ESTIMATE OF INTERCEPT =  770.8438
INITIAL ESTIMATE OF SLOPE     = -1.9375
LAST PERIOD ESTIMATE OF INTERCEPT =  743.2821
LAST PERIOD ESTIMATE OF SLOPE = -2.226777

SEASONAL FACTOR INITIAL EST.  FINAL EST.
        1        - 0.855984    - 0.922111
        2        - 0.969784    - 1.006202
        3        - 1.126415    - 1.066515
        4        - 1.047818    - 1.005172
NUMBER OF ERROR OBSNS       21
MEAN % ERROR OR BIAS       -3.712039
MEAN ABSOLUTE % ERROR       17.74907
MEAN SQUARED ERROR (MSE)    22938.47
MEAN ABSOLUTE ERROR         129.5826
```

Table B-11. The output from the single moving average model using a four-year average for the Bitung skipjack data with forecast values.

```
SMAVE     -SINGLE MOVING AVERAGE
TIME SERIES : ADJ. BITUNG SKIPJACK CPUE 1967 TO 1988

PERIOD     ACTUAL FORECAST   ERROR  %ABS ERROR
   5  -   751.00 -  766.00 -  -15.00 -  2.00
   6  -   777.00 -  814.25 -  -37.25 -  4.79
   7  -   868.00 -  832.75 -   35.25 -  4.06
   8  -   637.00 -  838.00 - -201.00 - 31.55
   9  -   723.00 -  758.25 -  -35.25 -  4.88
  10  -   946.00 -  751.25 -  194.75 - 20.59
  11  -   732.00 -  793.50 -  -61.50 -  8.40
  12  -   630.00 -  759.50 - -129.50 - 20.56
  13  -   711.00 -  757.75 -  -46.75 -  6.58
  14  -   912.00 -  754.75 -  157.25 - 17.24
  15  -   664.00 -  746.25 -  -82.25 - 12.39
  16  -   722.00 -  729.25 -   -7.25 -  1.00
  17  -   896.00 -  752.25 -  143.75 - 16.04
  18  -   749.00 -  798.50 -  -49.50 -  6.61
  19  -   624.00 -  757.75 - -133.75 - 21.43
  20  -   578.00 -  747.75 - -169.75 - 29.37
  21  -   828.00 -  711.75 -  116.25 - 14.04
 22          -   694.75
 23          -   714.50
 24          -   765.50
 25          -   828.00
 26          -   828.00
NUMBER OF ERROR OBSNS       17
MEAN % ERROR OR BIAS       -4.5637
MEAN ABSOLUTE % ERROR       13.03117
MEAN SQUARED ERROR (MSE)    12943.65
MEAN ABSOLUTE ERROR         95.05882
```

Table B-12. Results from three management strategy simulations of the Bitung skipjack fishery.

```
==============================================================
          MANAGEMENT STRATEGY  1 for ADJ. BITUNG SKJ
--------------------------------------------------------------
REMOVAL STRATEGY:
    30.00% of organisms removed when population >  2.5000E+02
    Number removed over    50 time periods          = 9.9761E+03
    Average removed per time period                 = 1.9952E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 4.6555E+02
    Number of dangerous episodes                    =   0
    Probability of danger (risk)                    =  0.00
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  2 for ADJ. BITUNG SKJ
--------------------------------------------------------------
REMOVAL STRATEGY:
    40.00% of organisms removed when population >  2.5000E+02
    Number removed over    50 time periods          = 1.2634E+04
    Average removed per time period                 = 2.5268E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 3.7903E+02
    Number of dangerous episodes                    =   0
    Probability of danger (risk)                    =  0.00
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  3 for ADJ. BITUNG SKJ
--------------------------------------------------------------
REMOVAL STRATEGY:
    50.00% of organisms removed when population >  2.5000E+02
    Number removed over    50 time periods          = 1.1123E+04
    Average removed per time period                 = 2.2245E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 2.2245E+02
    Number of dangerous episodes                    =  19
    Probability of danger (risk)                    =  0.38
==============================================================
```

Table B-13. Final management strategy simulation for Bitung skipjack.

```
==============================================================
          MANAGEMENT STRATEGY  4 for ADJ. BITUNG SKJ
--------------------------------------------------------------
REMOVAL STRATEGY:
    45.00% of organisms removed when population >  2.5000E+02
    Number removed over    50 time periods          = 1.1958E+04
    Average removed per time period                 = 2.3916E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 2.9231E+02
    Number of dangerous episodes                    =   0
    Probability of danger (risk)                    =  0.00
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  4 for ADJ. BITUNG SKJ
--------------------------------------------------------------
REMOVAL STRATEGY:
    45.00% of organisms removed when population >  2.5000E+02
    Number removed over   150 time periods          = 3.7679E+04
    Average removed per time period                 = 2.5119E+02
    Number of removal episodes                      =  150
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  = 150
    Mean population density                         = 3.0702E+02
    Number of dangerous episodes                    =   1
    Probability of danger (risk)                    =  0.01
==============================================================
```

Table B-14. Results of fitting a second degree polynomial to the Bitung skipjack catch and effort data after forcing the origin to be zero.

REPORT OF RESULTS FROM FRENCH CURVE PROGRAM FOR 01-27-1991

POLYNOMIAL REGRESSION

ORDER: 2	S= 179.5243
INTCPT=-11.86427	stdev= 57.58464
B(1)= 1.326954	stdev= .1437993
B(2)=-3.077159E-04	stdev= 7.383687E-05

DATA SET:BITUNG SKIPJACK CATCH AND EFFORT, WITH 30 POINTS.

X	Y(OBS)	Y(CALC)	DEV	DEV/SIGMA
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
0	0	-11.86427	11.86427	0.066
400	356	469.6828	-113.6828	-0.633
451	457.7	524.0023	-66.30225	-0.369
544	674.5	618.9346	55.56543	0.310
725	605.9	788.4343	-182.5342	-1.017
732	1017.9	794.5845	223.3155	1.244
749	944.5	809.3953	135.1047	0.753
860	790.9	901.7295	-110.8295	-0.617
1042	1315.4	1036.715	278.6851	1.552
1047	905.3	1040.136	-134.8358	-0.751
1134	934.9	1097.193	-162.2925	-0.904
1144	827.1	1103.452	-276.3523	-1.539
1356	863.9	1221.677	-357.7771	-1.993
1403	1123.1	1244.141	-121.0415	-0.674
1409	1460	1246.911	213.0886	1.187
1523	1183.4	1295.331	-111.9308	-0.623
1559	1788.3	1308.959	479.3406	2.670
1651	1570.4	1340.165	230.2355	1.282
1762	1332.4	1370.88	-38.48047	-0.214
1790	1516.8	1377.431	139.369	0.776
1997	1404.1	1410.889	-6.789185	-0.038
2302	1233.5	1412.135	-178.6348	-0.995

Table B-15. OLS regression line fitted to the Bitting adjusted skipjack cpue time series data.

```
The Number of data Pairs is   21

Input the value of alpha
to be used in setting Confidence Intervals ? .05

The selected value of alpha is  .05
The t statistic is =  2.0935

Do you want a listing of the data ? YY
Independent Variable (X)      Dependent Variable (Y)

 1              1                          558
 2              2                          703
 3              3                          847
 4              4                          956
 5              5                          751
 6              6                          777
 7              7                          868
 8              8                          637
 9              9                          723
 10             10                         946
 11             11                         732
 12             12                         632
 13             13                         711
 14             14                         912
 15             15                         664
 16             16                         722
 17             17                         896
 18             18                         749
 19             19                         624
 20             20                         578
      Independent Variable (X)      Dependent Variable (Y)

 21             21                         828

Correlation Coefficient =  -0.095

Minimum (X) =     1.000          Maximum (X) =    21.000
Minimum (Y) =   558.000          Maximum (Y) =   956.000

Mean of X =    11.000             Mean of Y =   753.048

F Statistic for Hypothesis Test of Beta 1 = 0
F =    0.17      with  1  and  19 Degrees of Freedom

This F Statistic would be significant at an Alpha level of  0.687
      MODEL:     Y = B0 + B1*X
Sum of Squares for Regression (SSR) =  2516.447
Sum of Squares for Error (SSE) =  277828.6
Total Sum of Squares (SST) =  280345
Unconditional Variance of 'Y'  S(Y) = 15574.72
Conditional Error Variance S(Y/X) =  14622.56
Estimate of B0 =    772.933          Variance =   2994.142
Estimate of B1 =     -1.808          Variance =     18.990
Correlation between B0 and B1 = -.876
 95% Confidence Limits on B0 and B1
Probability (  772.93 < B0 <   772.93) =  95%
Probability (   -1.81 < B1 <    -1.81) =  95%
```

Figure B-1. Map of Indonesia showing locations of the major tuna fishing bases.

Remark :

1. Banda Aceh
2. Padang
3. Pel. Ratu
4. Bali
5. Ende
6. Maumere
7. Majene
8. Mamuju
9. Kendari
10. Kolaka
11. Ternate
12. Labuha
13. Ambon
14. Sorong
15. Bitung
16. Gorontalo

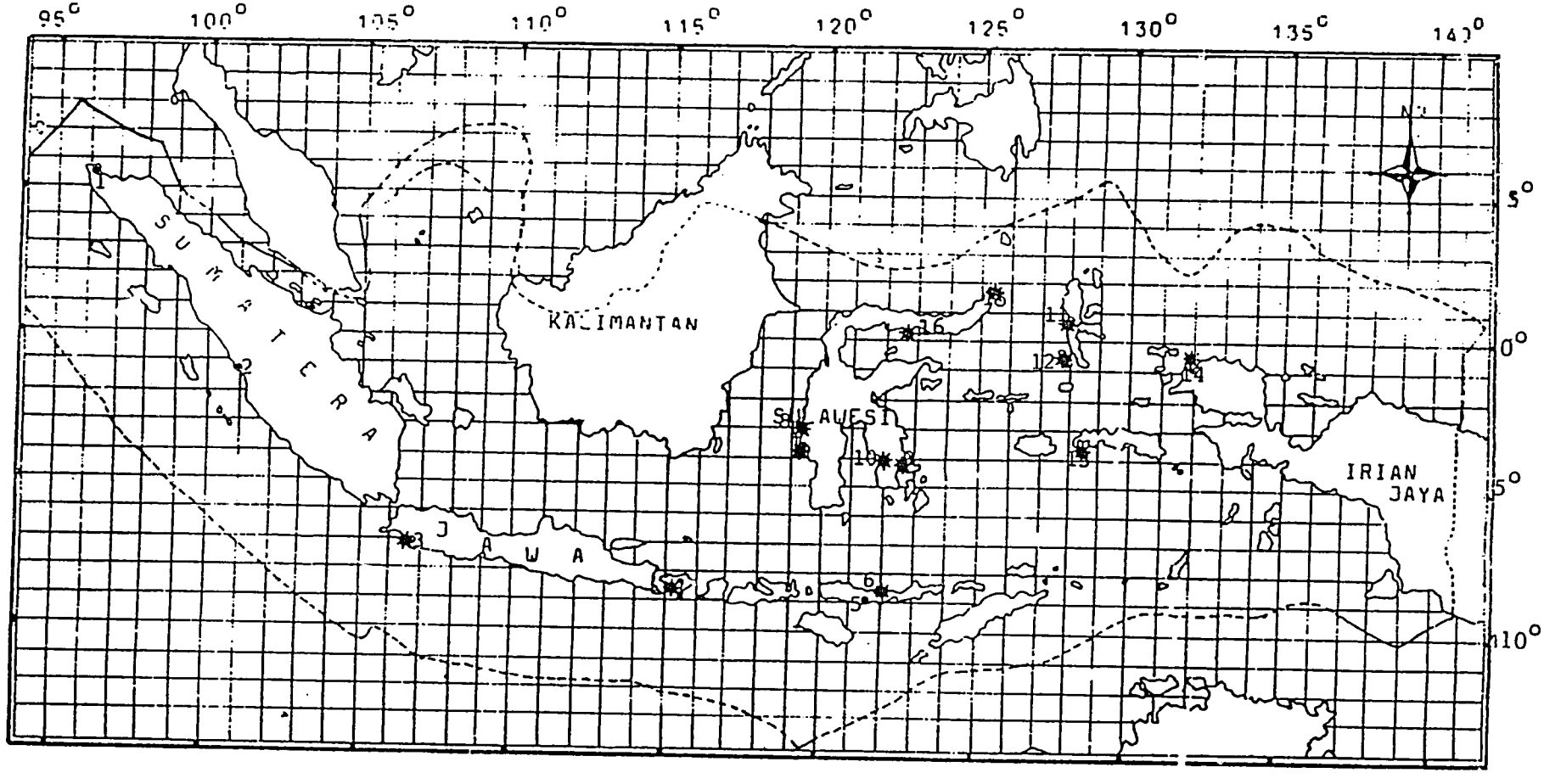


Figure B-2. Plot of catch-per-unit effort (cpue) on fishing effort. The fitted line in this case is an OLS line. Data from the Bitung skipjack fishery (1967-1988).

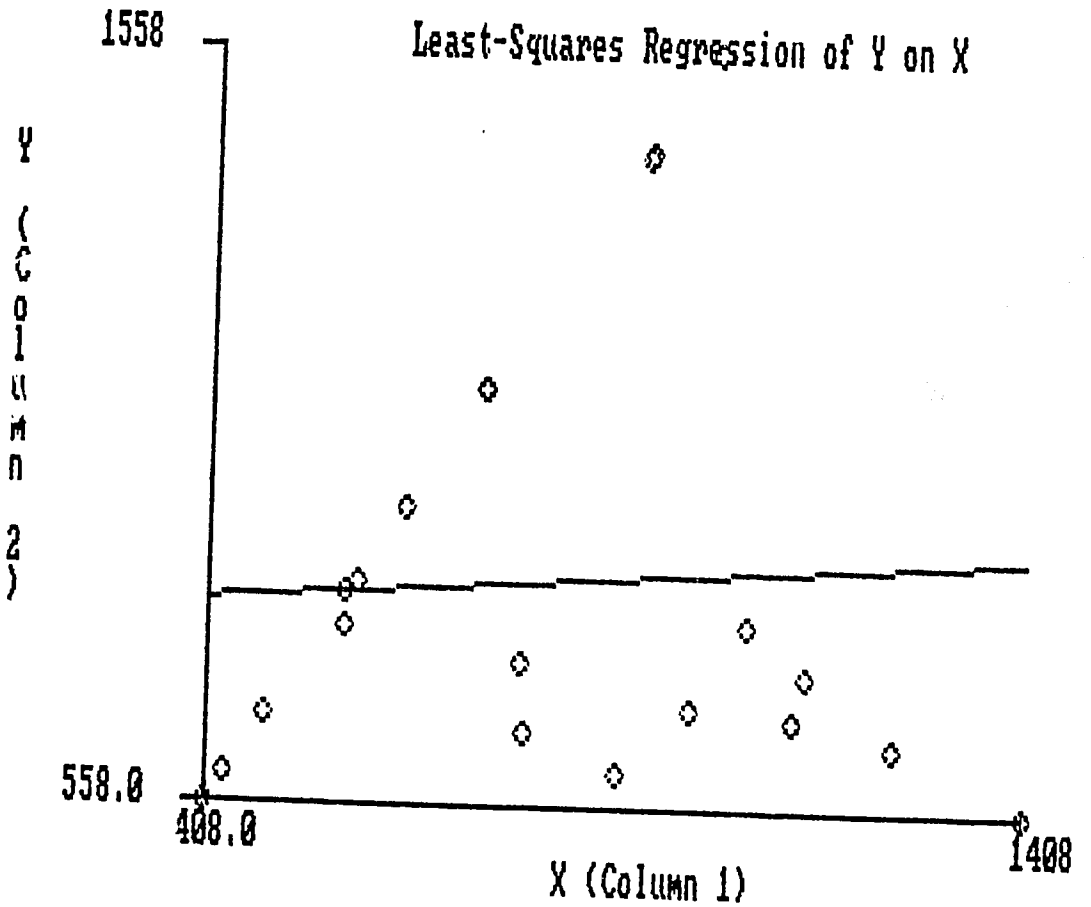
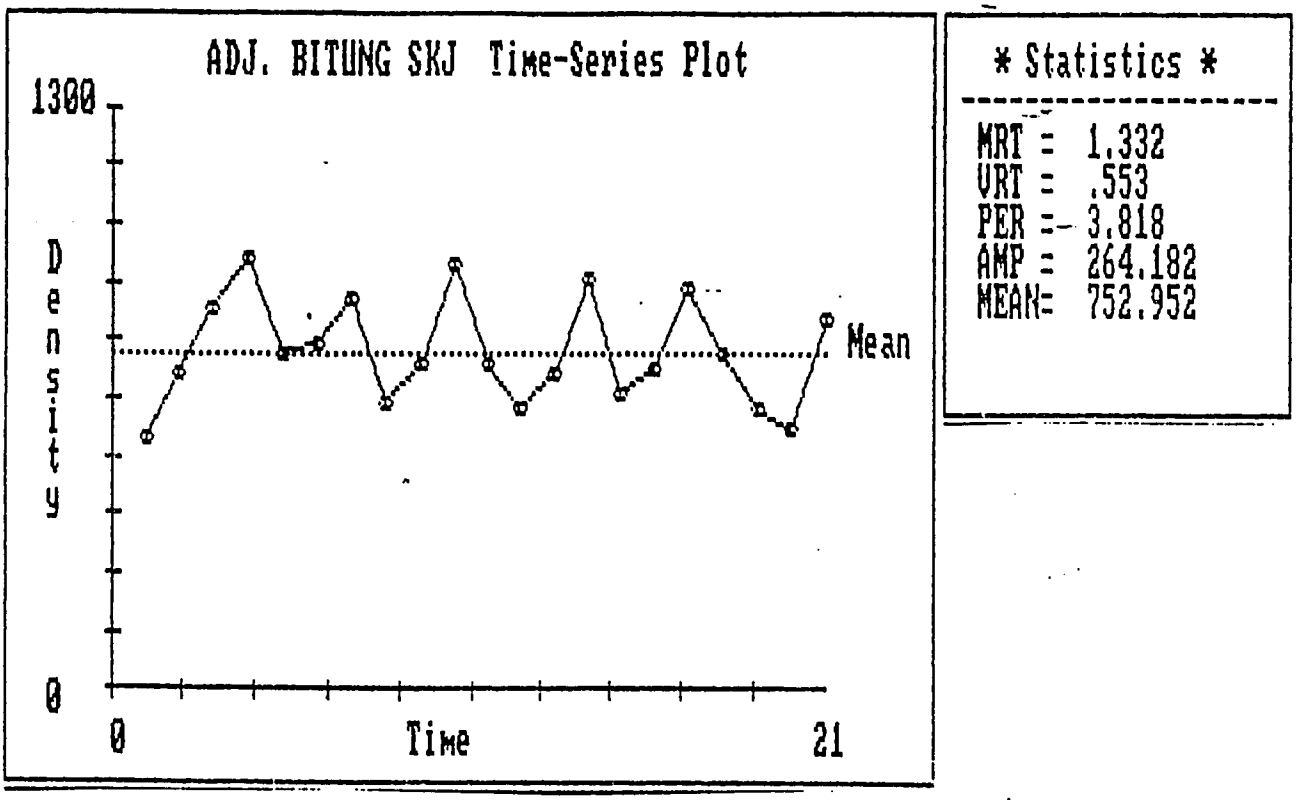


Figure B-3. Bitung skipjack time series plot of cpue from 1967 to 1988. Density refers to cpue in kg/boat day.



ADJ. BITUNG SKJ Data
Density per 1.00 CPUE

Time	Density	Rate of Increase
1	5.5800E+02	2.3100E-01
2	7.0300E+02	1.8634E-01
3	8.4700E+02	1.2106E-01
4	9.5600E+02	-2.4135E-01
5	7.5100E+02	3.4035E-02
6	7.7700E+02	1.1075E-01
7	8.6800E+02	-3.0942E-01
8	6.3700E+02	1.2664E-01
9	7.2300E+02	2.6883E-01
10	9.4600E+02	-2.5646E-01
11	7.3200E+02	-1.5006E-01
12	6.3000E+02	1.2095E-01
13	7.1100E+02	2.4897E-01
14	9.1200E+02	-3.1736E-01
15	6.6400E+02	8.3743E-02
16	7.2200E+02	2.1592E-01
17	8.9600E+02	-1.7920E-01
18	7.4900E+02	-1.8259E-01
19	6.2400E+02	-7.6577E-02
20	5.7800E+02	3.5944E-01
21	8.2800E+02	0.0000E+00

Mean response time: MRT = 1.3316E+00

Response time variance: VRT = 5.5342E-01

Mean period of oscillation: PER = 3.8182E+00

Mean amplitude of oscillation: AMP = 2.6418E+02

Mean density of population: MEAN = 7.5295E+02

Figure B-4. Bitung skipjack R-N phase trajectory for data from Figure B-3.

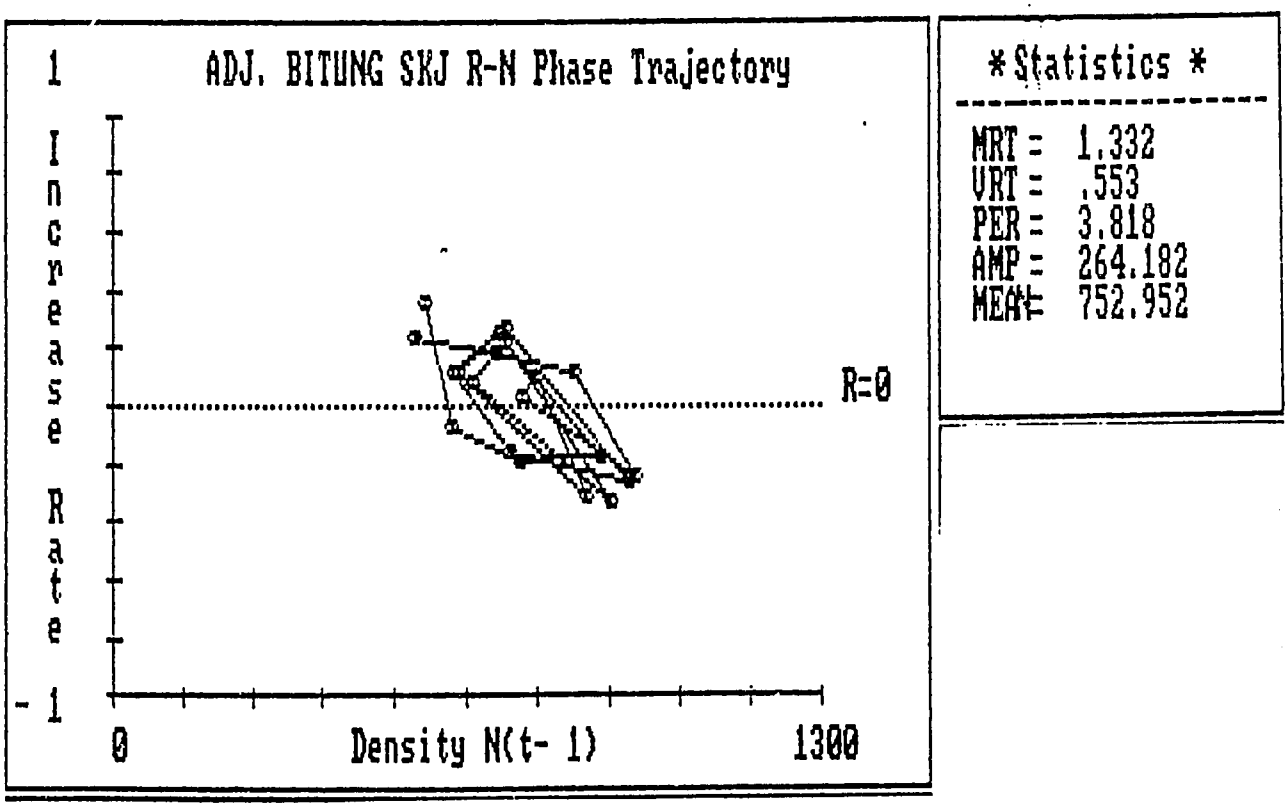
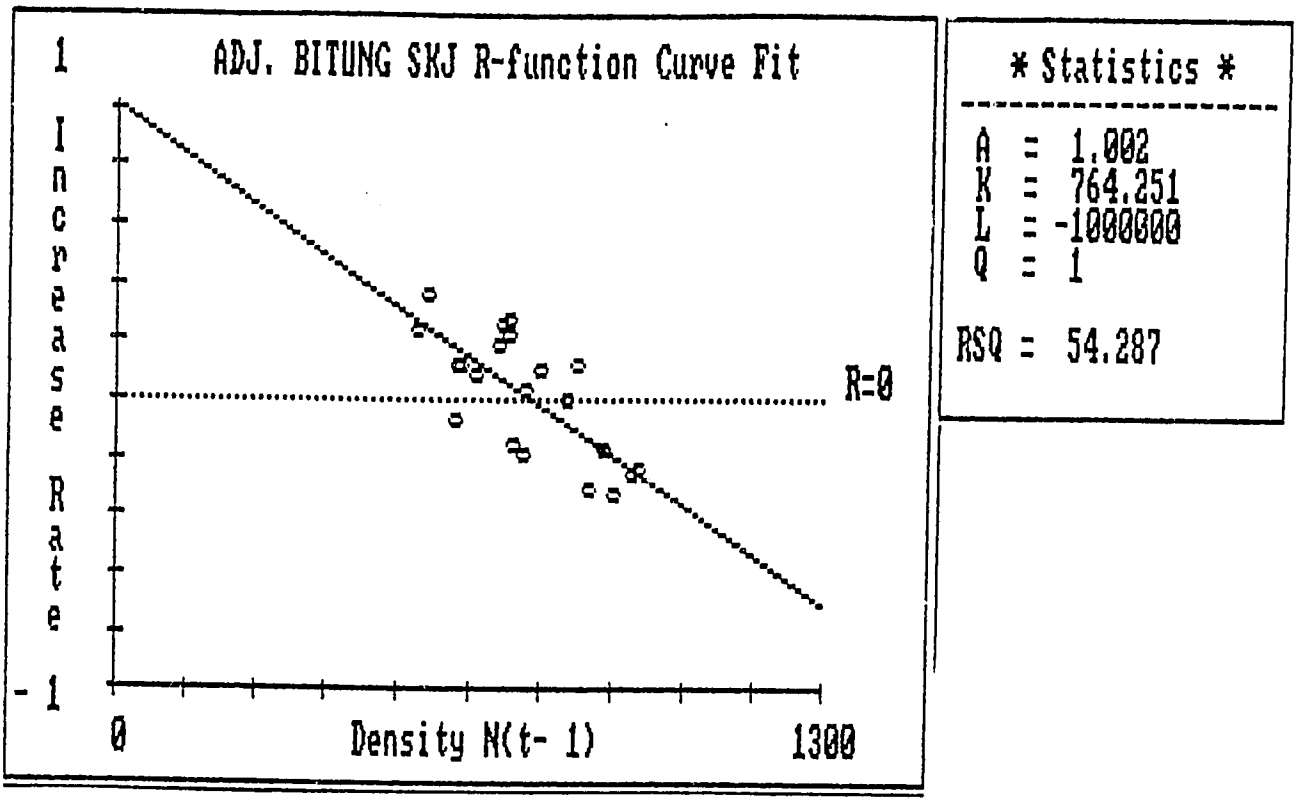


Figure B-5. Bitung skipjack R-function curve fit.



ADJ. BITUNG SKJ MODEL PARAMETERS
Density Measured per CPUE

	VALUE	SYMBOL
The modeled R-function has a single equilibrium at	764.251	K(1)
The R-function intercept at zero population density	1.002	A(1)
The negative root of the function is	-1000000	L(1)
The coefficient of curvature of the function is	1	Q(1)
The density-dependent time delay is	1	T(1)
Percentage variation explained by density-dependence	54.287	RSQ(1)
Standard deviation of the density-independence is	.1447143	S(1)

The model is N(t) = exp(R) * N(t-1)
R = A(1) * { 1 - N(t-1) / L(1)} * { 1 - [N(t-T(1)) / K(1)] ^Q(1)}
+ V[0,S(1)] = standard normal deviate; mean 0, standard deviation S(1)

Figure B-6. Results of a stochastic simulation of Bitung skipjack based on the derived R-function and the observed random variability.

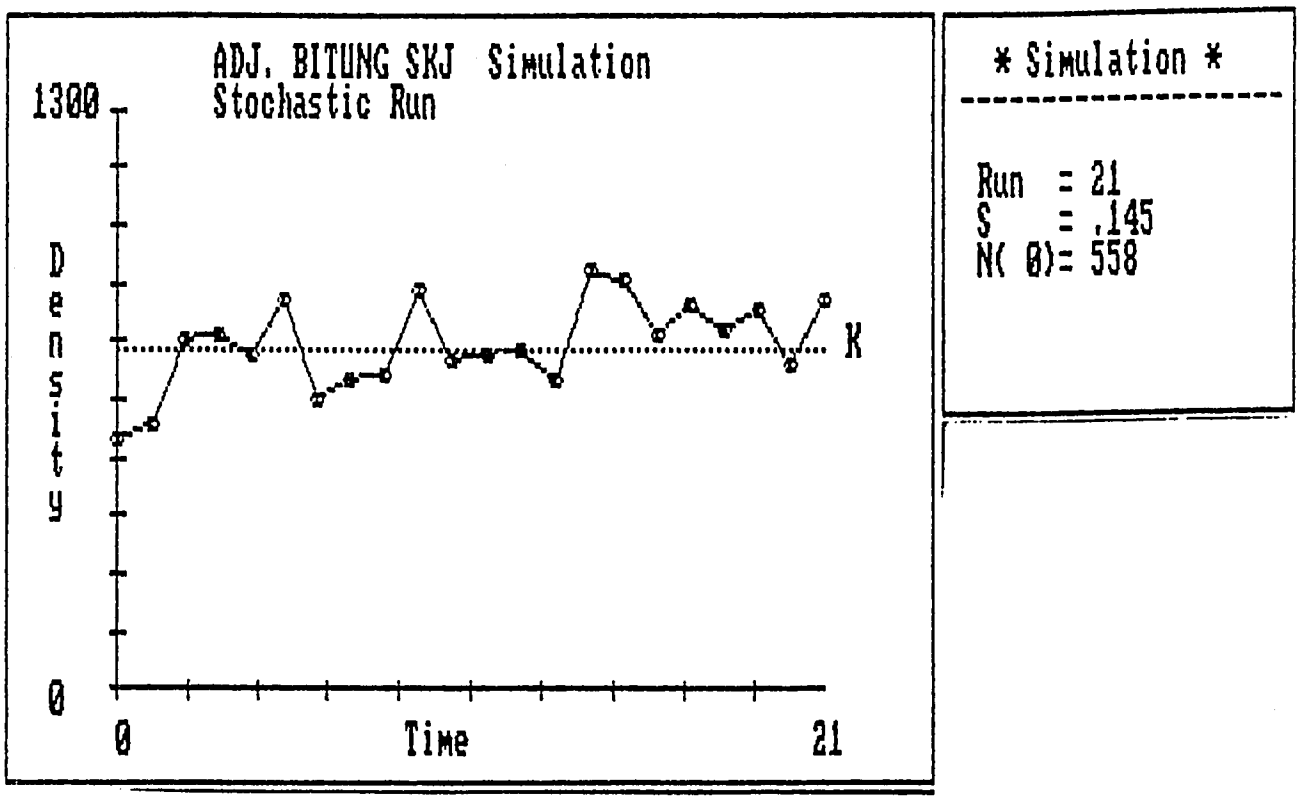


Figure B-7. Phase portrait verification of Bitung skipjack model based on model and data from Table B-4.

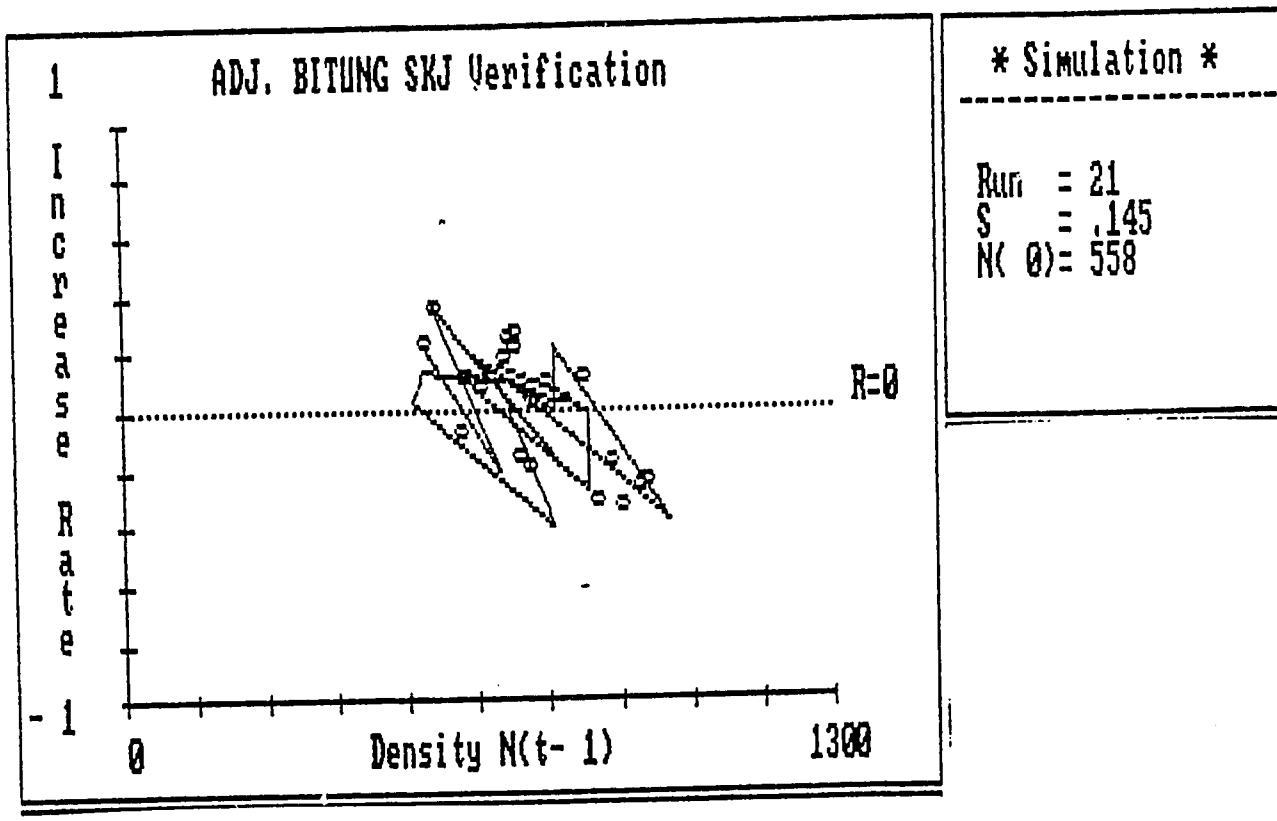


Figure B-8. Results of a sensitivity analysis for the parameter A. The vertical line in the figure indicates the calculated value, and the range in this instance is from 0.5 to 5.0.

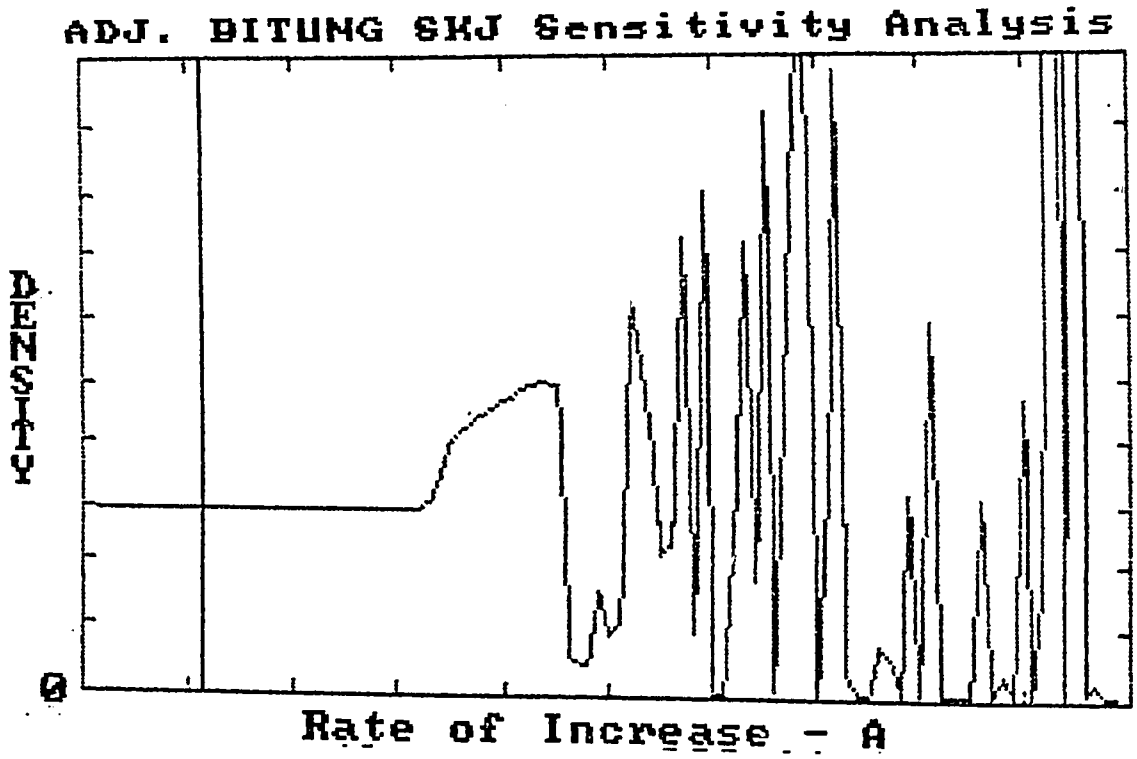


Figure B-9. Results of a sensitivity analysis for the parameter S. the range of S was from 0.02 to 0.6.

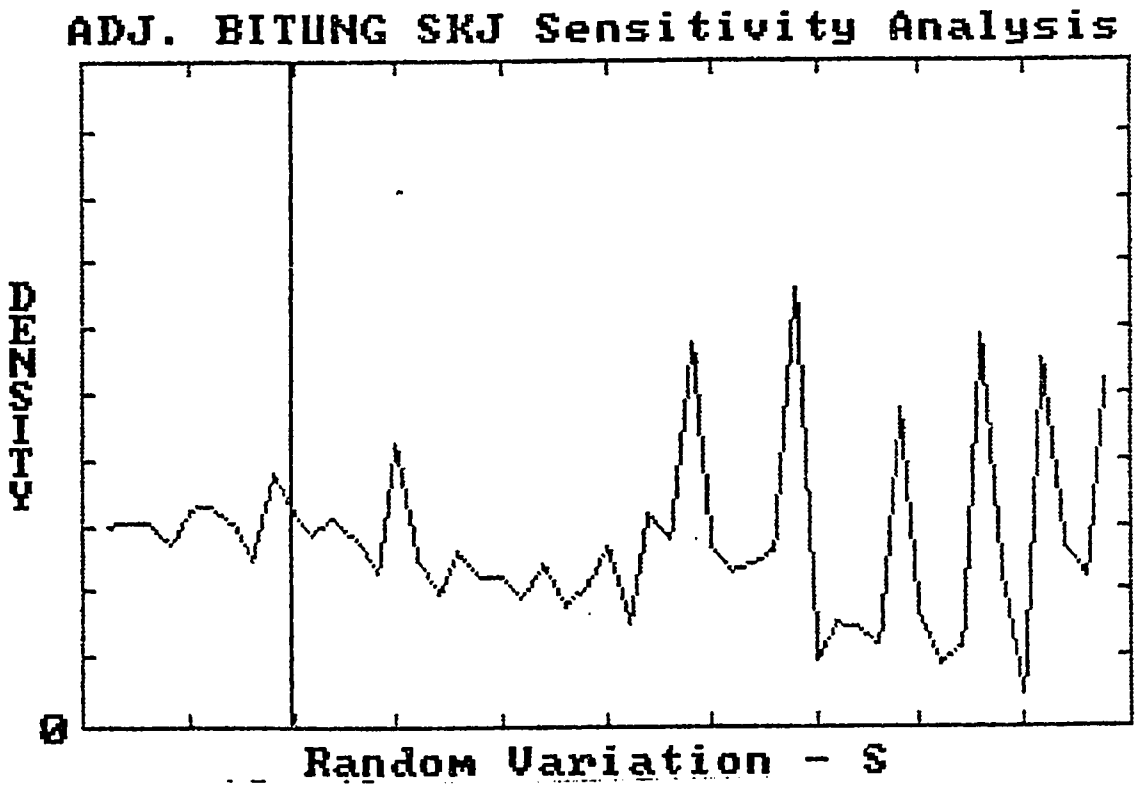


Figure B-10. The relationship between observed and calculated values for Bitung skipjack using the single moving average model and forecasts.

```
                                  -  500.00 -  625.00 -  750.00 -  875.00 - 1000.00
PERIOD ACTUAL FORECAST            +----------+----------+----------+----------+
  1 -  558.00 -          -                 O
  2 -  703.00 -          -                                          O
  3 -  847.00 -          -
O
  4 -  956.00 -          -
                 O
  5 -  751.00 -  766.00 -                                                  O+
  6 -  777.00 -  814.25 -                                                      O    +
  7 -  868.00 -  832.75 -                                                                 +
  O
  8 -  637.00 -  838.00 -                          O                                      +
  9 -  723.00 -  758.25 -                                                O    +
 10 -  946.00 -  751.25 -                                                     +
                 O
 11 -  732.00 -  793.50 -                                                O      +
 12 -  630.00 -  759.50 -                          O                        +
 13 -  711.00 -  757.75 -                                                O      +
 14 -  912.00 -  754.75 -                                                     +
          O
 15 -  664.00 -  746.25 -                                O                +
 16 -  722.00 -  729.25 -                                                +
 17 -  896.00 -  752.25 -                                                     +
        O
 18 -  749.00 -  798.50 -                                                     O      +
 19 -  624.00 -  757.75 -                          O                        +
 20 -  578.00 -  747.75 -                 O                                +
 21 -  828.00 -  711.75 -                                                +                    O
 22          -  694.75 -                                             +
 23          -  714.50 -                                                +
 24          -  765.50 -                                                        +
 25          -  828.00 -                                                                      +
 26          -  828.00 -                                                                      +
PERIOD ACTUAL FORECAST            +----------+----------+----------+----------+
                                  -  500.00 -  625.00 -  750.00 -  875.00 - 1000.00
```

Sorong Skipjack Data Analysis—

The data set for the Sorong skipjack fishery was first adjusted to a standard fishing vessel prior to its use in the analyses. The data extended from 1976-1988. However, FADs (fish attraction devices) had been introduced into the fishing area since 1985. It was found that the deployment of FADs increased the efficiency of a standard vessel by about 38 percent. Adjustments to standardize data were made since 1985.

Figure S-1 illustrates the Sorong time-series plot of cpue after adjustment. It is evident from the figure that mean response time (MRT) and its variance (VRT) suggested a relatively short time lag of about one year. In our interpretation of this, we suggest that the population is probably being limited by interactions within trophic levels. We speculate that during the first year of life that competition for food and/or predation in early life history stages may be examples of the kinds of limitations existing for this fishery. This may also suggest that a large fraction of the observed variation in relative abundance of skipjack in this fishery may be due to some external driving variable—such as the abundance of food for early life history stages.

It seems desirable to next demonstrate the consequences of using uncorrected data in the time series plot and analyses. Figure S-2 shows the raw data plot for the Sorong time series. Although only four years were corrected for fishing power changes, the contrast between the two figures is very vivid. The apparent mean return time is more than doubled, and its variance is increased by an order of magnitude. The mean and the amplitude also changed significantly. All material which follows refers only to the adjusted data..

Figure S-3 illustrates the R-N phase trajectory for this fishery. Note that this phase portrait is fairly tightly clustered. The linear R-function curve fit shown in Figure S-4 shows a relatively good fit to the data with about 64 percent of the variation explained by density-dependent processes and about 36 percent due to density-independent factors. The simulation model is shown in Figure S-5, and the phase portrait for model verification is

shown in Figure S-6. Clearly, the phase portrait derived from the data and the phase portrait derived from the simulation model match quite well. In fact, the data from the simulation seem to show a bit less stochastic variation than the real data. In any event, the model seems to be a reasonable representation of these data.

Sensitivity analyses on the parameters A, S and K were run. Some evidence of bifurcation (instability) were seen at A values greater than twice the calculated value. Increasing S induced larger stock fluctuations and density increased linearly with increasing K values.

The results of the management strategy simulations are shown in Tables S-1a and S-1b. Because the density-independent variation in this data set is fairly small (35 percent) the probability of danger from higher levels of exploitation seems more limited than for the Bitung data, and a higher proportion of the carrying capacity can be harvested. This increment in harvest rate of up to 50 percent is the highest that we have calculated for the skipjack tuna data available from Indonesia. Note that in Table S-1b similar harvest strategies result in variable risks of collapse. This is due to the density-independent component of variability in the stock, which is random.

Table S-2 shows the results of fitting a linear regression to the cpue time series. It is evident that the slope of this regression is positive, but the regression is not statistically significant.

Table S-1a. Final management strategy simulation for Sorong skipjack.

```
==============================================================
          MANAGEMENT STRATEGY  1 for SORONG SKIPJACK
--------------------------------------------------------------
REMOVAL STRATEGY:
    40.00% of organisms removed when population >  1.0000E+02
    Number removed over    50 time periods          = 1.4025E+04
    Average removed per time period                 = 2.8050E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 4.2075E+02
    Number of dangerous episodes                    =   0
    Probability of danger (risk)                    =  0.00
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  3 for SORONG SKIPJACK
--------------------------------------------------------------
REMOVAL STRATEGY:
    60.00% of organisms removed when population >  1.0000E+02
    Number removed over    50 time periods          = 1.3022E+04
    Average removed per time period                 = 2.6044E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 1.7363E+02
    Number of dangerous episodes                    =  40
    Probability of danger (risk)                    =  0.80
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  4 for SORONG SKIPJACK
--------------------------------------------------------------
REMOVAL STRATEGY:
    50.00% of organisms removed when population >  1.0000E+02
    Number removed over    50 time periods          = 1.4695E+04
    Average removed per time period                 = 2.9390E+02
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 2.9390E+02
    Number of dangerous episodes                    =   1
    Probability of danger (risk)                    =  0.02
==============================================================
```

Table S-1b. Final management strategy simulation for Sorong skipjack.

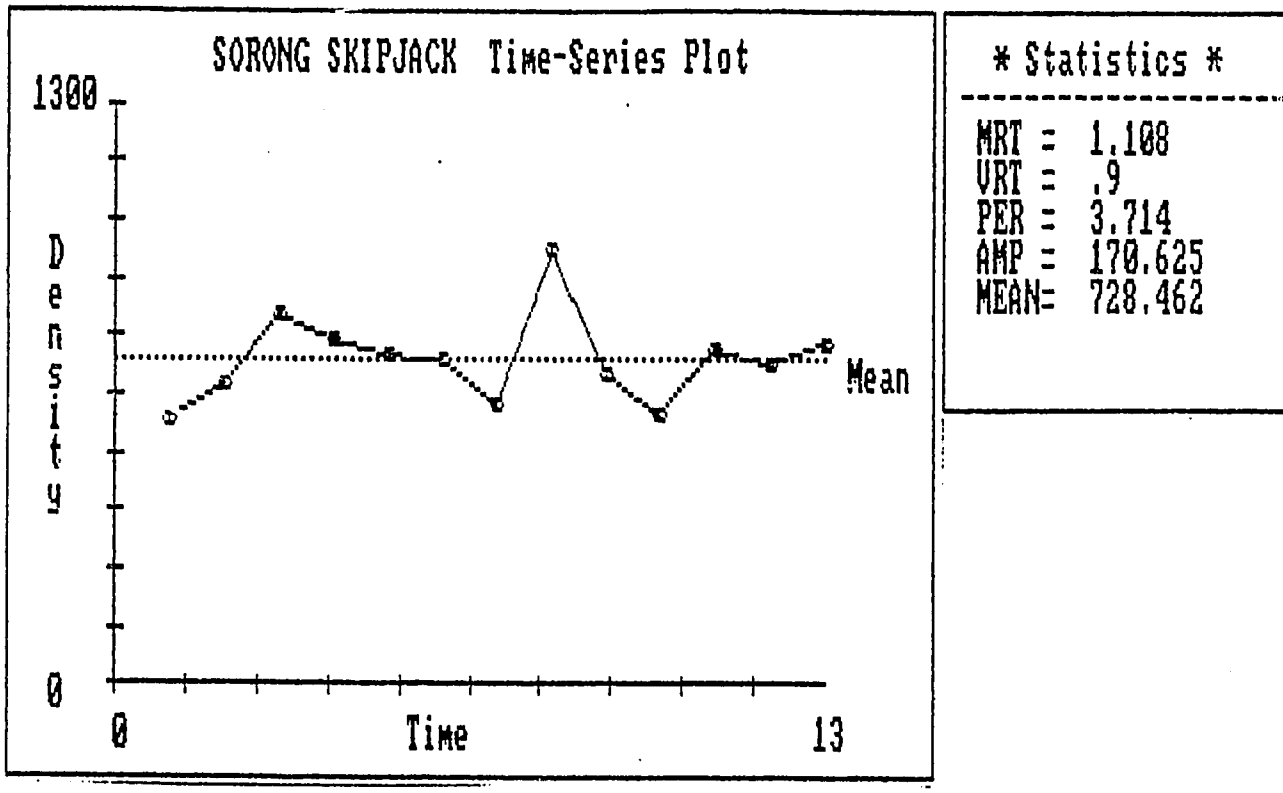
```
==============================================================
          MANAGEMENT STRATEGY  5 for SORONG SKIPJACK
--------------------------------------------------------------
REMOVAL STRATEGY:
    55.00% of organisms removed when population >  1.0000E+02
    Number removed over     50 time periods        = 1.4219E+04
    Average removed per time period                = 2.8438E+02
    Number of removal episodes                     =    50
    Proportion of time removals are made           = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 2.3267E+02
    Number of dangerous episodes                   =   6
    Probability of danger (risk)                   =  0.12
==============================================================
```

```
--------------------------------------------------------------
          MANAGEMENT STRATEGY  8 for SORONG SKIPJACK
--------------------------------------------------------------
REMOVAL STRATEGY:
    55.00% of organisms removed when population >  1.0000E+02
    Number removed over     50 time periods        = 1.4397E+04
    Average removed per time period                = 2.8794E+02
    Number of removal episodes                     =    50
    Proportion of time removals are made           = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 2.3558E+02
    Number of dangerous episodes                   =  10
    Probability of danger (risk)                   =  0.20
==============================================================
```

Table S-2. OLS regression line fitted to the Sorong skipjack cpue time series data.

```
The Number of data Pairs is   13

Input the value of alpha
to be used in setting Confidence Intervals ? .05.05

The selected value of alpha is  .05
The t statistic is =  2.2016

Independent Variable (X)      Dependent Variable (Y)

 1                1                          598
 2                2                          667
 3                3                          830
 4                4                          772
 5                5                          735
 6                6                          731
 7                7                          627
 8                8                          977
 9                9                          691
 10               10                         609
 11               11                         754
 12               12                         722
 13               13                         757

Correlation Coefficient =  +0.126

Minimum (X) =     1.000          Maximum (X) =    13.000
Minimum (Y) =   598.000          Maximum (Y) =   977.000

Mean of X =     7.000             Mean of Y =   728.462

F Statistic for Hypothesis Test of Beta 1 = 0
F =    0.18      with  1  and  11 Degrees of Freedom

This F Statistic would be significant at an Alpha level of  0.681
                  Y = B0 + B1*X
Sum of Squares for Regression (SSR) =  1938.659
Sum of Squares for Error (SSE) =  120362.6
Total Sum of Squares (SST) =  122301.2
Unconditional Variance of 'Y'  S(Y) = 12230.12
Conditional Error Variance S(Y/X) =  10942.05
Estimate of B0 =    705.615          Variance =   3787.633
Estimate of B1 =      3.264          Variance =     60.121
Correlation between B0 and B1 = -.882
 95% Confidence Limits on B0 and B1
Probability (  705.62 < B0 <   705.62) =  95%
Probability (    3.26 < B1 <     3.26) =  95%
```

Figure S-1. Time-series plot of Sorong skipjack cpue after correcting for changes in fishing power since 1985. The time series extends from 1976-1988.



SORONG SKIPJACK Data
Density per 1.00 YR.CPUE

Time	Density	Rate of Increase
1	5.9800E+02	1.0920E-01
2	6.6700E+02	2.1864E-01
3	8.3000E+02	-7.2441E-02
4	7.7200E+02	-4.9114E-02
5	7.3500E+02	-5.4570E-03
6	7.3100E+02	-1.5347E-01
7	6.2700E+02	4.4354E-01
8	9.7700E+02	-3.4635E-01
9	6.9100E+02	-1.2632E-01
10	6.0900E+02	2.1357E-01
11	7.5400E+02	-4.3367E-02
12	7.2200E+02	4.7338E-02
13	7.5700E+02	0.0000E+00

Mean response time: MRT = 1.1084E+00

Response time variance: VRT = 9.0032E-01

Mean period of oscillation: PER = 3.7143E+00

Mean amplitude of oscillation: AMP = 1.7063E+02

Mean density of population: MEAN = 7.2846E+02

Figure S-2. Time-series plot of Sorong skipjack cpue data without adjustment for changes in fishing power. Note how the last four data periods differ from those of Figure S-1.

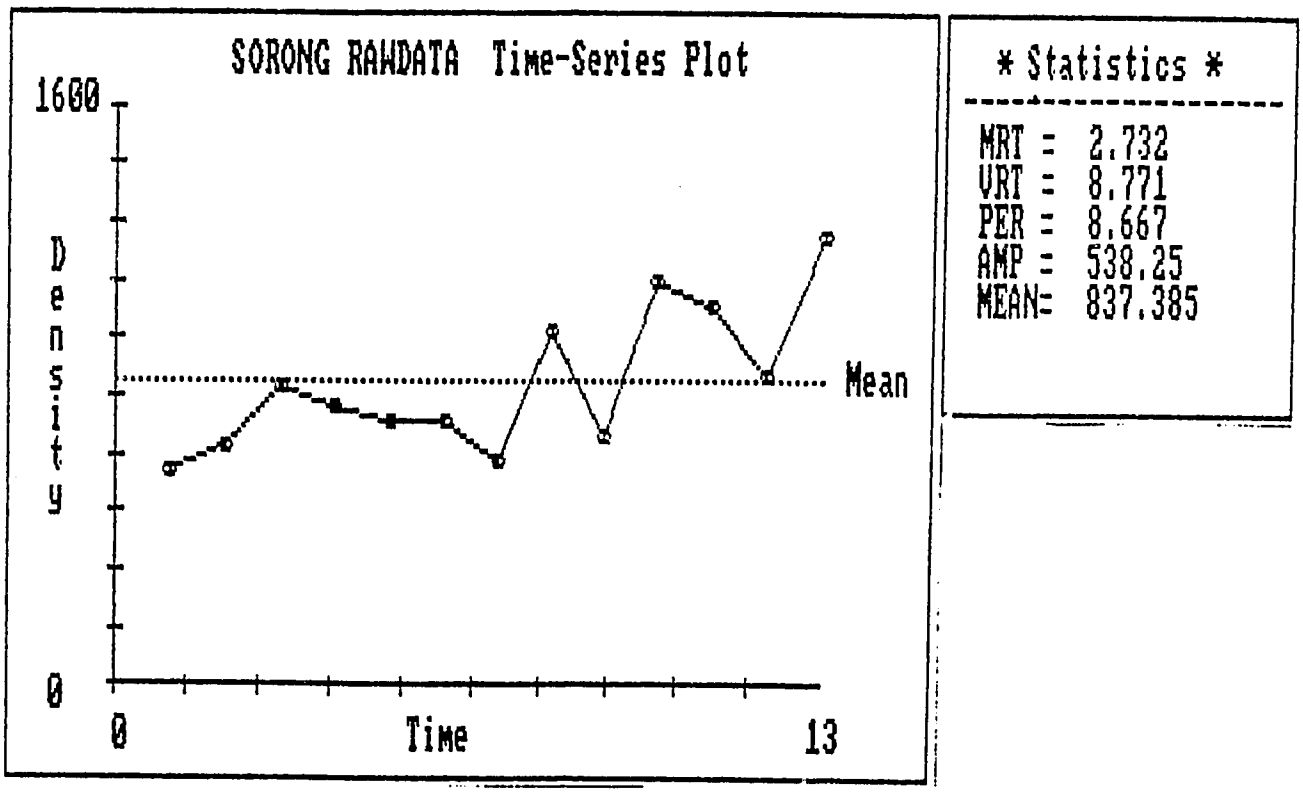


Figure S-3. Phase portrait of Sorong skipjack data.

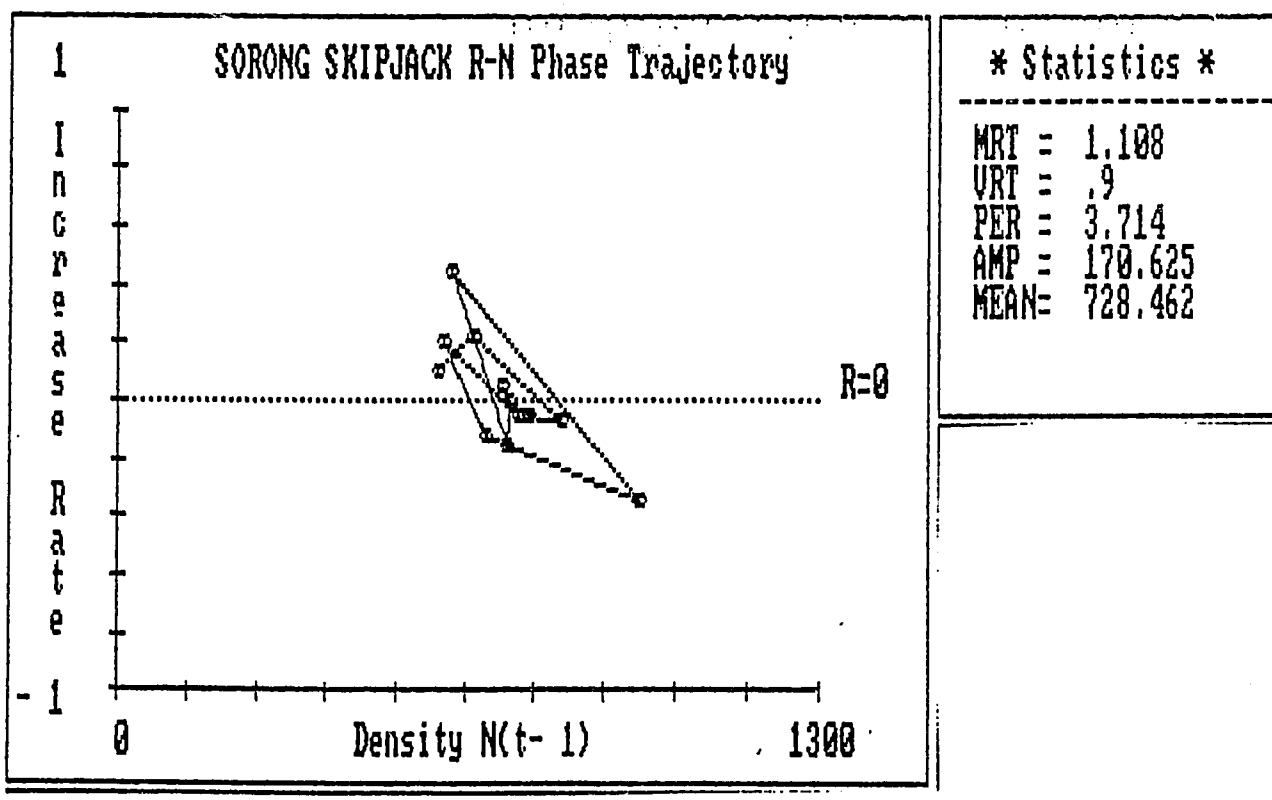
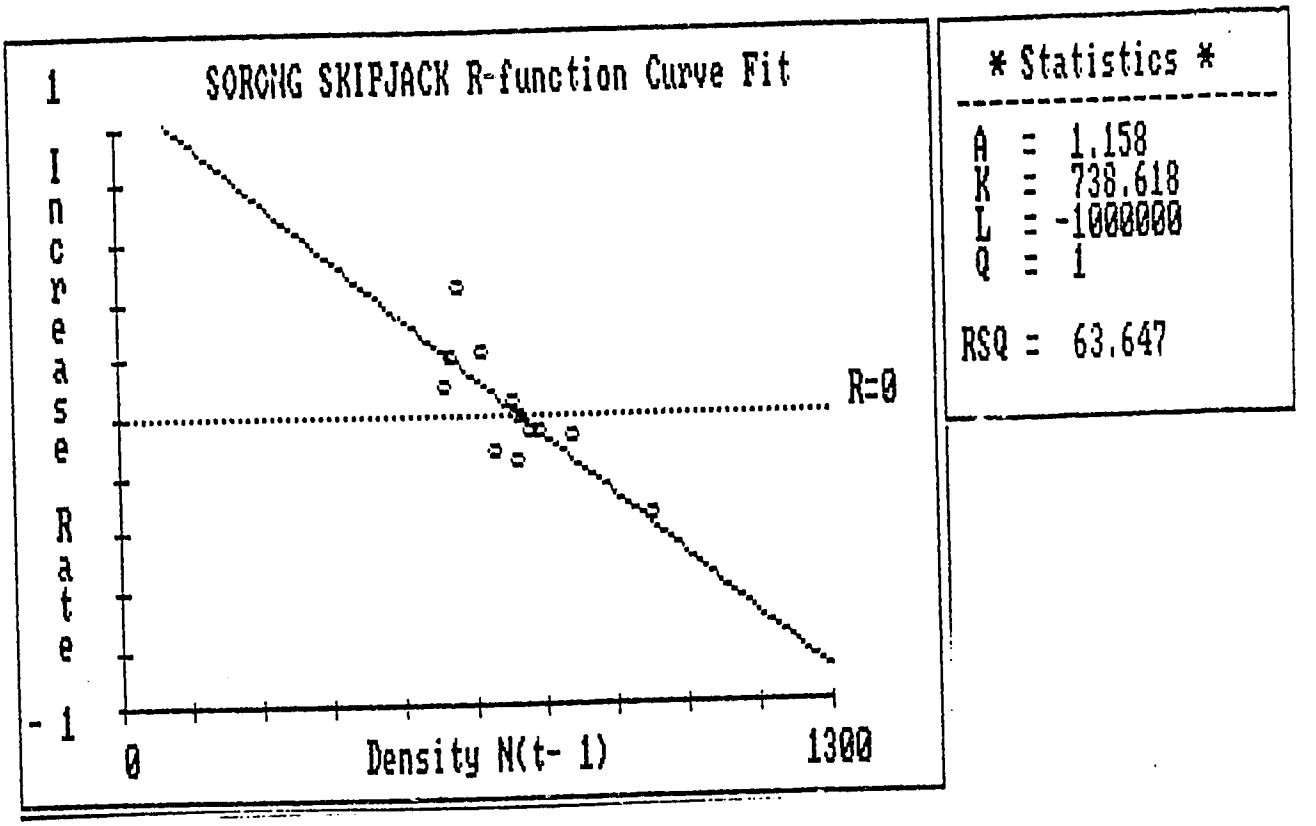


Figure S-4. The linear R-function fit to Sorong Data.



SORONG SKIPJACK Regression of R-function

Regression Intercept at N = 0:	A(1) =	1.1580E+00
Equilibrium Point at R = 0:	K(1) =	7.3862E+02
Lower Root of Function:	L(1) =	-1.0000E+06
Coefficient of Curvature:	Q(1) =	1.0000E+00
Feedback Time-lag:	T(1) =	1.0000E+00
Standard Deviation about Line:	S =	1.2446E-01
Percentage Variation Explained:	RSQ =	63.6%

Figure S-5. Verification of the stochastic simulation model for Sorong skipjack based on the derived phase portrait.

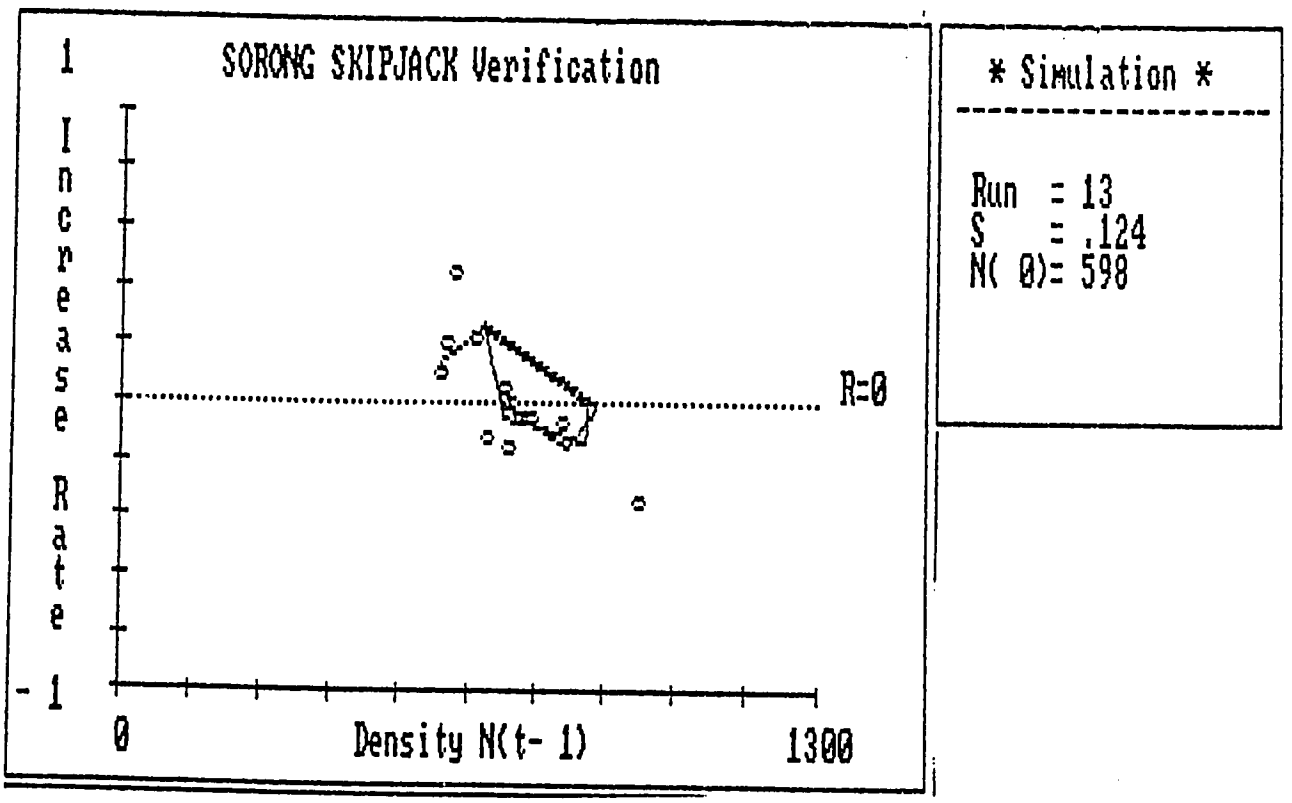
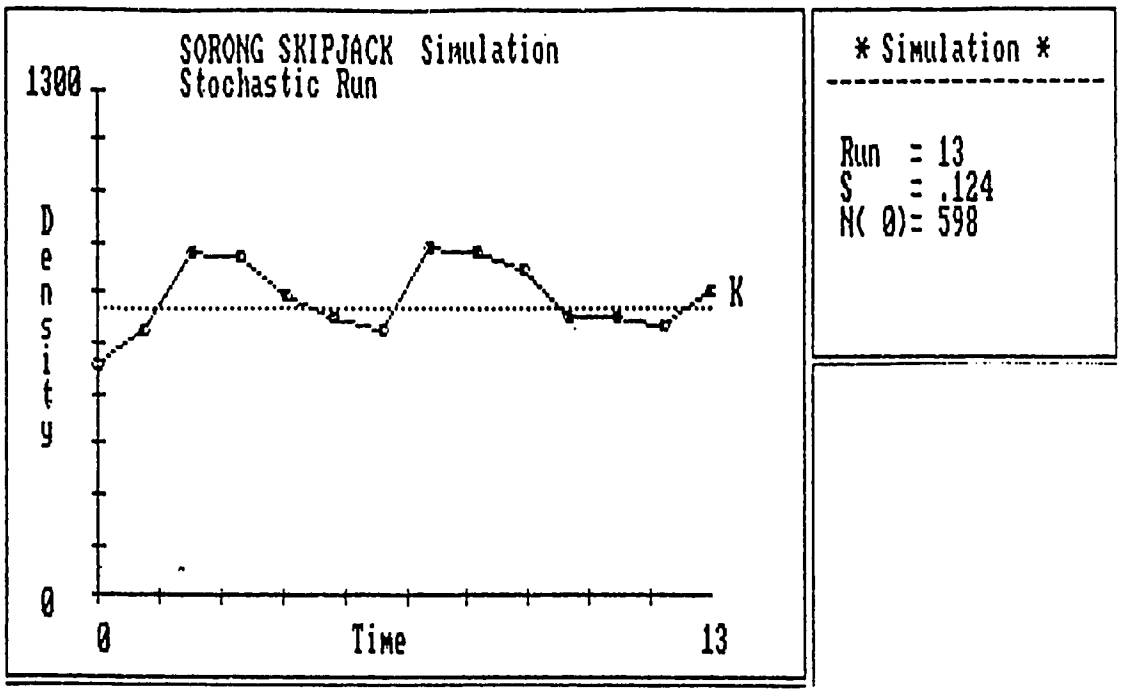


Figure S-6. The results of a simulation run of the derived skipjack model for Sorong skipjack.



R = A(i) * (1-N(t)/L(i)) *

(1-[N(t-T(i))/K(i)]^Q(i)) + V(S)

where i = 1 when N(t) > E
and i = 2 when N(t) < E

R is the per-capita rate of increase, N(t) is the density of the population at time t, V is a random normal variate, and E is the escape threshold. (F10)
parameters of your model are

A	= the value of R at N = 0	=	1.1580E+00
K	= the equilibrium point	=	7.3862E+02
L	= the underpopulation effect	=	-1.0000E+06
Q	= the coefficient of curvature	=	1.000E+00
T	= the feedback time-lag	=	1

and the goodness of fit statistics are

S	= standard deviation	=	1.2446E-01
RSQ	= % of variation explained	=	63.6%

::::::::::::::::::::::::::::::::::::::

SORONG SKIPJACK Simulation
Data from Simulation # 1

Time	Density	Rate of Increase	Random Variation
0	5.9800E+02	1.2949E-01	-9.0975E-02
1	6.8067E+02	2.5786E-01	1.6701E-01
2	8.8089E+02	-7.6342E-03	2.1542E-01
3	8.7419E+02	-1.2866E-01	8.3897E-02
4	7.6866E+02	-6.5643E-02	-1.8548E-02
5	7.1982E+02	-5.5179E-02	-8.4650E-02
6	6.8118E+02	2.7121E-01	1.8115E-01
7	8.9340E+02	-7.8561E-03	2.3480E-01
8	8.8640E+02	-5.3329E-02	1.7837E-01
9	8.4037E+02	-1.5403E-01	5.5001E-03
10	7.2041E+02	-4.4200E-03	-3.2972E-02
11	7.1723E+02	-2.5573E-02	-5.9106E-02
12	6.9912E+02	1.0859E-01	4.6667E-02
13	7.7931E+02	7.6119E-02	1.3992E-01

Ambon Skipjack Data Analysis—

The data base for Ambon consists of a record of 22 years of catch and effort data for pole and line caught skipjack. Figures A-1 and A-2 illustrate these data as a time-series plot of cpue and a phase plane plot. Table A-1 contains the data and the initial parameters estimated from them.

Figure A-3 illustrates a non-linear fit to the R-function for these data. The non-linear fit was a slight improvement over the linear model which was attempted initially. This non-linear fit produces a convex R-function and provides a value for the overpopulation parameter (Q), which is greater than 1. This is interpreted to suggest that individual reproduction and/or survival may be more strongly affected by density-dependent feedback when populations are very large. High predation at high population densities is another possible explanation. It should be recognized that the equilibrium point also becomes less stable as the Q coefficient increases.

Figures A-4 and A-5 display the simulated time series for Ambon skipjack—as well as the phase portrait derived from the simulation. By comparing Figures A-2 and A-5 visually, it is evident that the phase portraits correspond quite well. This indicates that the simulation model effectively mimics the real data. Table A-2 describes the model used for the simulation figures cited above.

Table A-3 illustrates the results of various harvest strategies using the Ambon skipjack model. From these data it seems that the fishery in the Ambon area might safely be incremented by about 20 percent. The low value may be due somewhat to the non-linear R-function which provides a value for the parameter A (the maximum per-individual rate of increase) which is considerably smaller than that derived from a linear model. On the other hand field observations of the Ambon fishery suggest that skipjack arriving in the Ambon area had already been subjected to harvesting from areas both to the north and south of Ambon. Figure A-6 illustrates the results of a regression on the cpue time series. The regression is significant, and the slope is positive, suggesting that this fishery is still capable of some further development.

Table A-1. The Ambon skipjack time series of cpue values and summary statistics.

AMBON SKIPJACK Data
Density per 1.00 CPUE

Time	Density	Rate of Increase
1	6.0700E+02	-1.7412E-01
2	5.1000E+02	-9.8523E-03
3	5.0500E+02	3.4912E-01
4	7.1600E+02	2.1078E-01
5	8.8400E+02	2.8796E-01
6	1.1790E+03	-3.7539E-01
7	8.1000E+02	-1.4310E-01
8	7.0200E+02	4.0480E-02
9	7.3100E+02	1.9681E-01
10	8.9000E+02	-1.8999E-01
11	7.3600E+02	2.1441E-01
12	9.1200E+02	-1.4108E-01
13	7.9200E+02	-7.6052E-02
14	7.3400E+02	2.3668E-01
15	9.3000E+02	-4.0598E-02
16	8.9300E+02	2.6417E-01
17	1.1630E+03	-6.3551E-01
18	6.1600E+02	3.9786E-01
19	9.1700E+02	2.4792E-01
20	1.1750E+03	-2.0209E-01
21	9.6000E+02	-3.2590E-01
22	6.9300E+02	0.0000E+00

Mean response time: MRT = 1.7120E+00

Response time variance: VRT = 1.2318E+00

Mean period of oscillation: PER = 4.4000E+00

Mean amplitude of oscillation: AMP = 4.0400E+02

Mean density of population: MEAN = 8.2068E+02

Table A-2. The Ambon skipjack model with parameter estimates and the numerical results from a simulation run.

::::::::::::::::::::::::::::::::::::::

AMBON SKIPJACK Model

R = A(i) * (1-N(t)/L(i)) *

(1-[N(t-T(i))/K(i)]^Q(i)) + V(S)

where i = 1 when N(t) > E
and i = 2 when N(t) < E

R is the per-capita rate of increase, N(t) is the density of the population at time t, V is a random normal variate, and E is the escape threshold. (F10)
parameters of your model are

A	= the value of R at N = 0	=	2.3840E-01
K	= the equilibrium point	=	8.8482E+02
L	= the underpopulation effect	=	-1.0000E+06
Q	= the coefficient of curvature	=	3.416E+00
T	= the feedback time-lag	=	1

and the goodness of fit statistics are

S	= standard deviation	=	2.0042E-01
RSQ	= % of variation explained	=	46.0%

::::::::::::::::::::::::::::::::::::::

AMBON SKIPJACK Simulation
Data from Simulation # 1

Time	Density	Rate of Increase	Random Variation
0	6.0700E+02	-2.5597E-01	-4.2855E-01
1	4.6992E+02	3.0747E-01	9.6525E-02
2	6.3908E+02	-4.2965E-03	-1.6422E-01
3	6.3634E+02	-9.1517E-02	-2.5259E-01
4	5.8069E+02	1.2047E-01	-6.1357E-02
5	6.5503E+02	4.0744E-01	2.5441E-01
6	9.8449E+02	1.5996E-01	2.6484E-01
7	1.1553E+03	-7.0081E-01	-3.4638E-01
8	5.7323E+02	-6.9779E-03	-1.9125E-01
9	5.6924E+02	1.8765E-01	2.0994E-03
10	6.8674E+02	1.2039E-01	-1.7690E-02
11	7.7459E+02	4.9335E-02	-3.7722E-02
12	8.1377E+02	-1.3577E-01	-1.9505E-01
13	7.1045E+02	1.3864E-01	1.2894E-02
14	8.1610E+02	1.6993E-01	1.1241E-01
15	9.6726E+02	-4.0838E-02	4.3950E-02
16	9.2856E+02	-9.3544E-02	-5.0833E-02
17	8.4563E+02	-2.0828E-01	-2.4245E-01
18	6.8664E+02	3.1414E-01	1.7601E-01
19	9.4006E+02	-3.8477E-01	-3.2998E-01
20	6.3982E+02	-1.7832E-01	-3.3794E-01
21	5.3532E+02	7.0618E-01	5.1063E-01
22	1.0847E+03	-5.4559E-01	-3.0601E-01

Standard Deviation of Random Variable = 2.0042E-01

Table A-3. Results of some management strategy simulations for Ambon skipjack.

```
-----------------------------------------------------------------------------------
                MANAGEMENT STRATEGY 5 FOR AMBON SKIPJACK
-----------------------------------------------------------------------------------

REMOVAL STRATEGY:
    30.00% of organisms removed when population >  2.0000E+02
    Number removed over    50 time periods         = 3.4563E+03
    Average removed per time period                = 6.9126E+01
    Number of removal episodes                     =   37
    Proportion of time removals are made           = 0.740
-------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 2.0552E+02
    Number of dangerous episodes                   =  23
    Probability of danger (risk)                   =  0.46
=============================================================
```

```
=============================================================
            MANAGEMENT STRATEGY  7 for AMBON SKIPJACK
-------------------------------------------------------------
REMOVAL STRATEGY:
    25.00% of organisms removed when population >  2.0000E+02
    Number removed over    50 time periods         = 4.3823E+03
    Average removed per time period                = 8.7646E+01
    Number of removal episodes                     =   40
    Proportion of time removals are made           = 0.800
-------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 2.9922E+02
    Number of dangerous episodes                   =  15
    Probability of danger (risk)                   =  0.30
=============================================================
```

```
=============================================================
            MANAGEMENT STRATEGY  8 for AMBON SKIPJACK
-------------------------------------------------------------
REMOVAL STRATEGY:
    20.00% of organisms removed when population >  2.0000E+02
    Number removed over    50 time periods         = 5.7028E+03
    Average removed per time period                = 1.1406E+02
    Number of removal episodes                     =   49
    Proportion of time removals are made           = 0.980
-------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 4.5966E+02
    Number of dangerous episodes                   =   1
    Probability of danger (risk)                   =  0.02
=============================================================
```

Table A-4. Ordinary least squares regression analysis of Ambon skipjack cpue time series. Note the size of the correlation coefficient and slope of the regression.

The Number of data Pairs is 22

Input the value of alpha
to be used in setting Confidence Intervals ? .05

The selected value of alpha is .05
The t statistic is = 2.0865

```
Independent Variable (X)      Dependent Variable (Y)

 1                1                          [illegible]
 2                2                          510
 3                3                          505
 4                4                          716
 5                5                          884
 6                6                          1179
 7                7                          810
 8                8                          702
 9                9                          731
 10               10                         890
 11               11                         736
 12               12                         912
 13               13                         792
 14               14                         734
 15               15                         930
 16               16                         893
 17               17                         1163
 18               18                         616
 19               19                         917
 20               20                         [illegible]75
PressDDDYIndependent Variable (X)      Dependent Variable (Y)

 21               21                         960
 22               22                         693
PressDDDY
Correlation Coefficient =  +0.443

Minimum (X) =      1.000          Maximum (X) =    22.000
Minimum (Y) =    505.000          Maximum (Y) =  1179.000

Mean of X =     11.500             Mean of Y =   820.682

F Statistic for Hypothesis Test of Beta 1 = 0
F =    4.89      with  1  and  20 Degrees of Freedom

This F Statistic would be significant at an Alpha level of  0.037
[illegible]MODEL:    Y = B0 + B1*X
Sum of Squares for Regression (SSR) =  153812.1
Sum of Squares for Error (SSE) =  629066.7
Total Sum of Squares (SST) =  782878.8
Unconditional Variance of 'Y'  S(Y) = 41204.15
Conditional Error Variance S(Y/X) =  31453.34
Estimate of B0 =    669.117          Variance =   6127.273
Estimate of B1 =     13.180          Variance =     35.520
Correlation between B0 and B1 = -.876
 95% Confidence Limits on B0 and B1
Probability (  505.79 < B0 <   832.44) =  95%
Probability (    0.74 < B1 <    25.61) =  95%
```

Figure A-1 Time-series plot of Ambon skipjack data from 1967-1988 for a pole and line fishery.

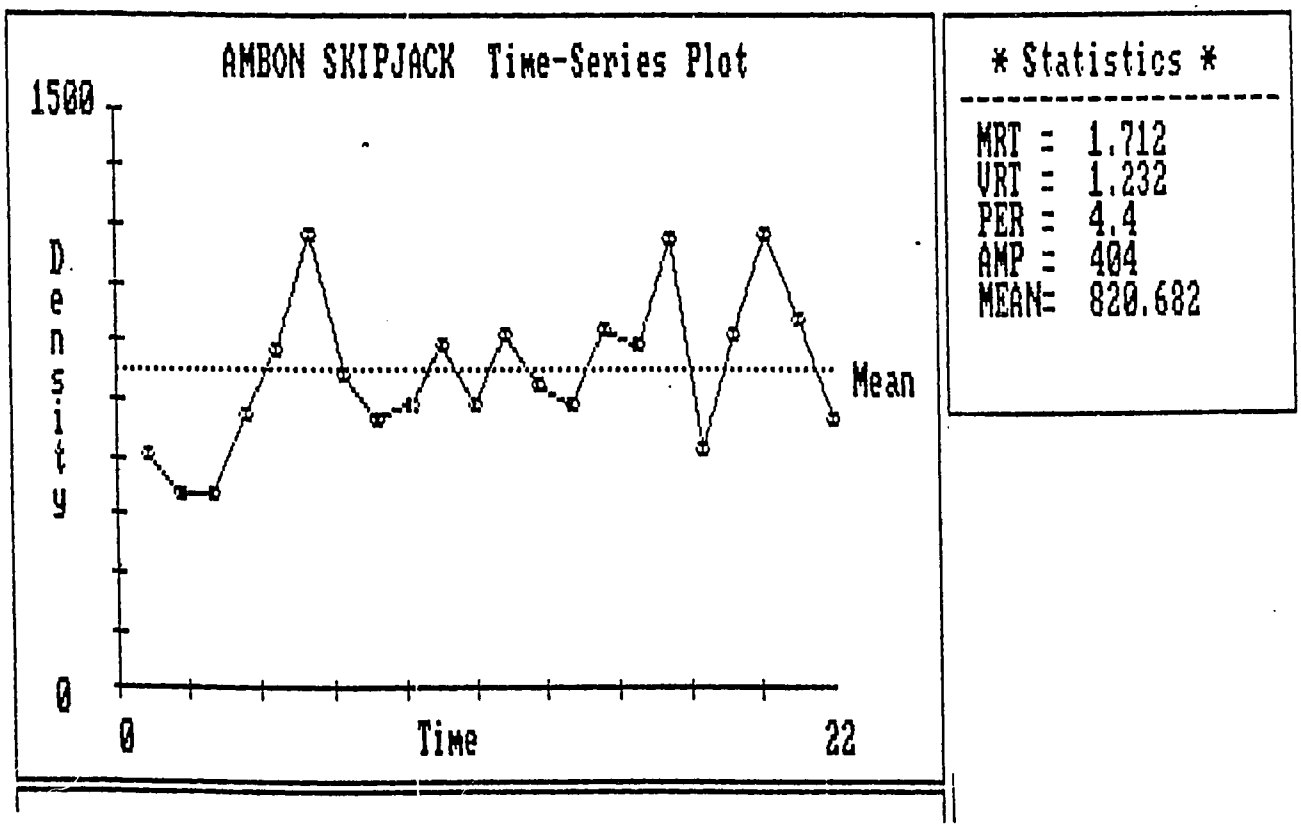


Figure A-2 Phase portrait of the Ambon skipjack data.

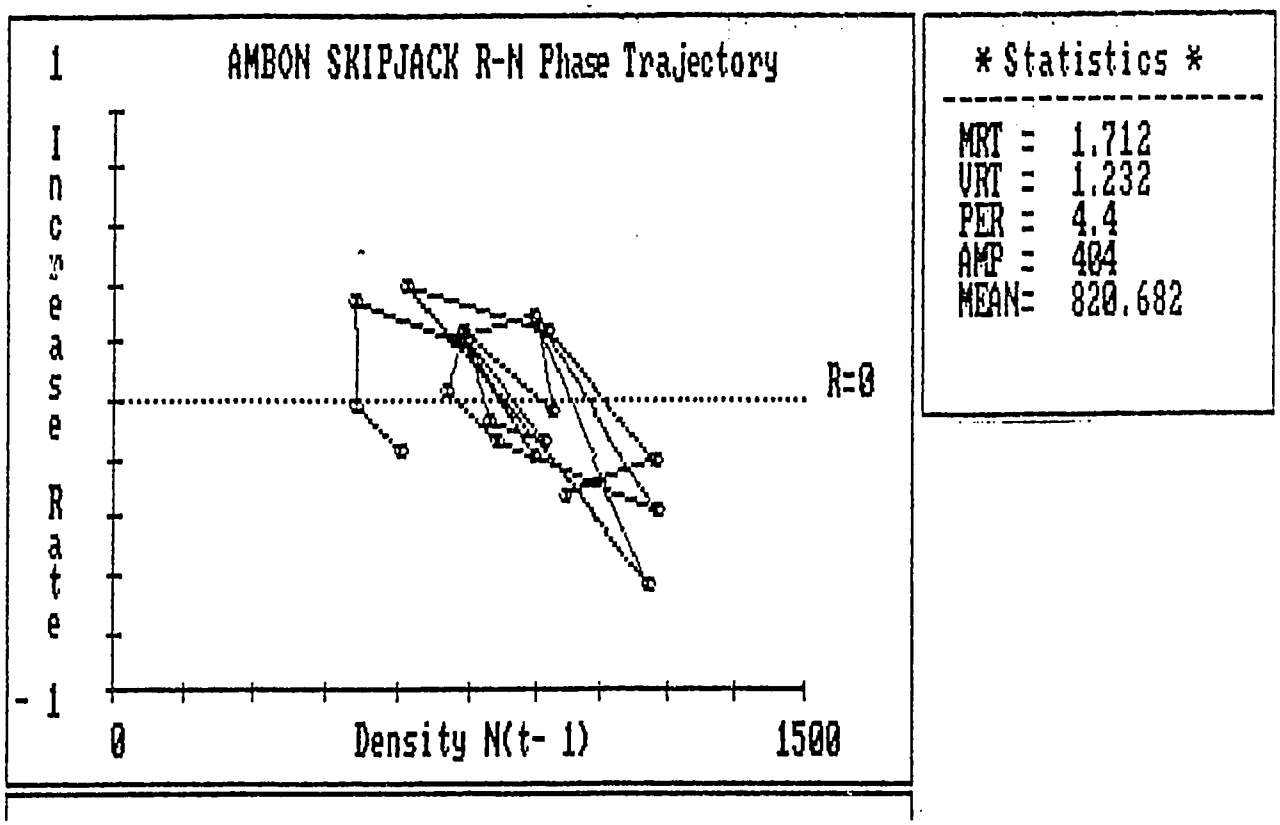
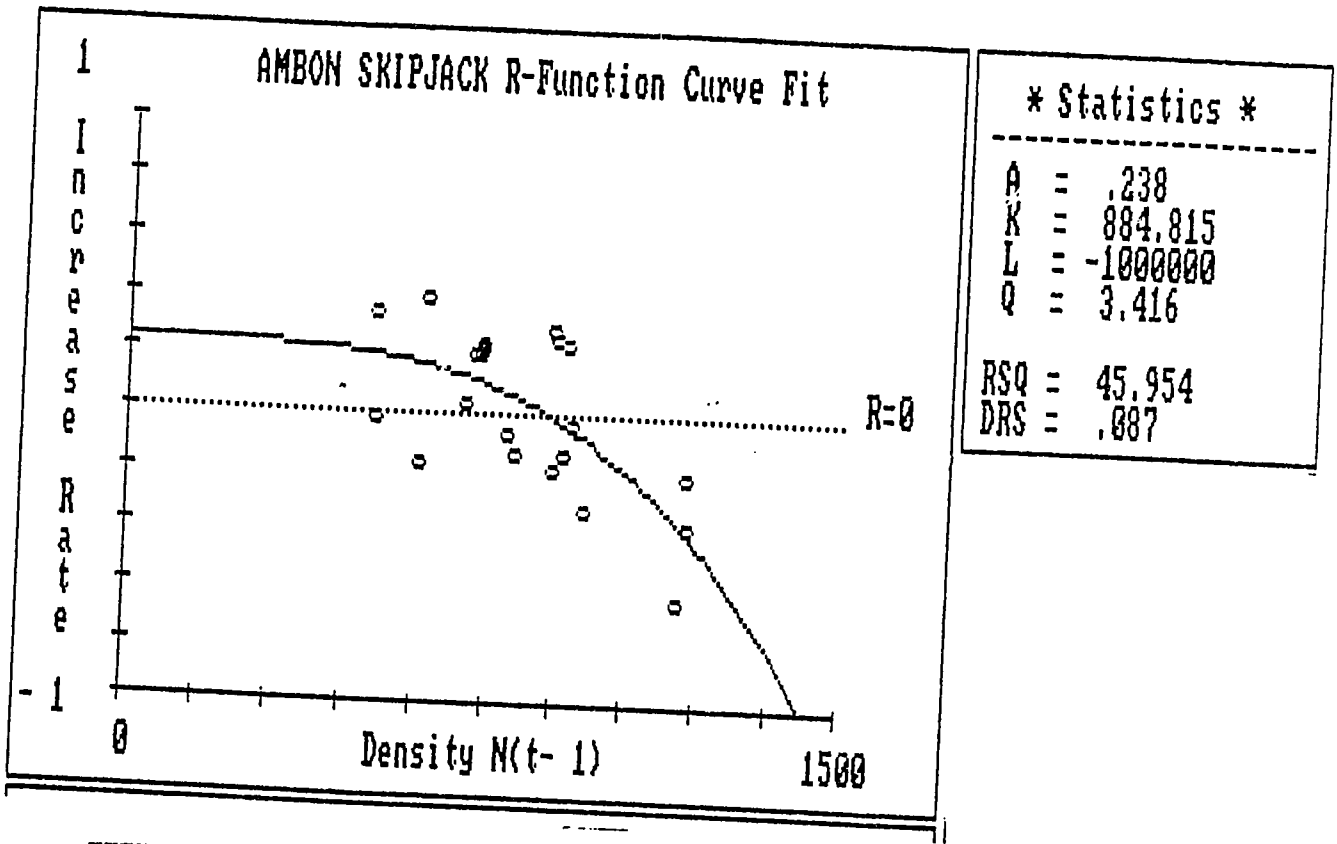


Figure A.-3 Non-linear R-function curve fit to the Amdon skipjack data.




```
==============================================
    AMBON SKIPJACK Regression of R-function
==============================================

Regression Intercept at N = 0:A(1) =  2.3840E-01
Equilibrium Point at R = 0:   K(1) =  8.8482E+02
Lower Root of Function:       L(1) = -1.0000E+06
Coefficient of Curvature:     Q(1) =  3.4155E+00
Feedback Time-lag:            T(1) =  1.0000E+00
Standard Deviation about Line: S   =  2.0042E-01
Percentage Variation Explained:RSQ =  46.0%
==============================================
```

Figure A-4 'Time-series plot of the simulation model of Ambon skipjack.

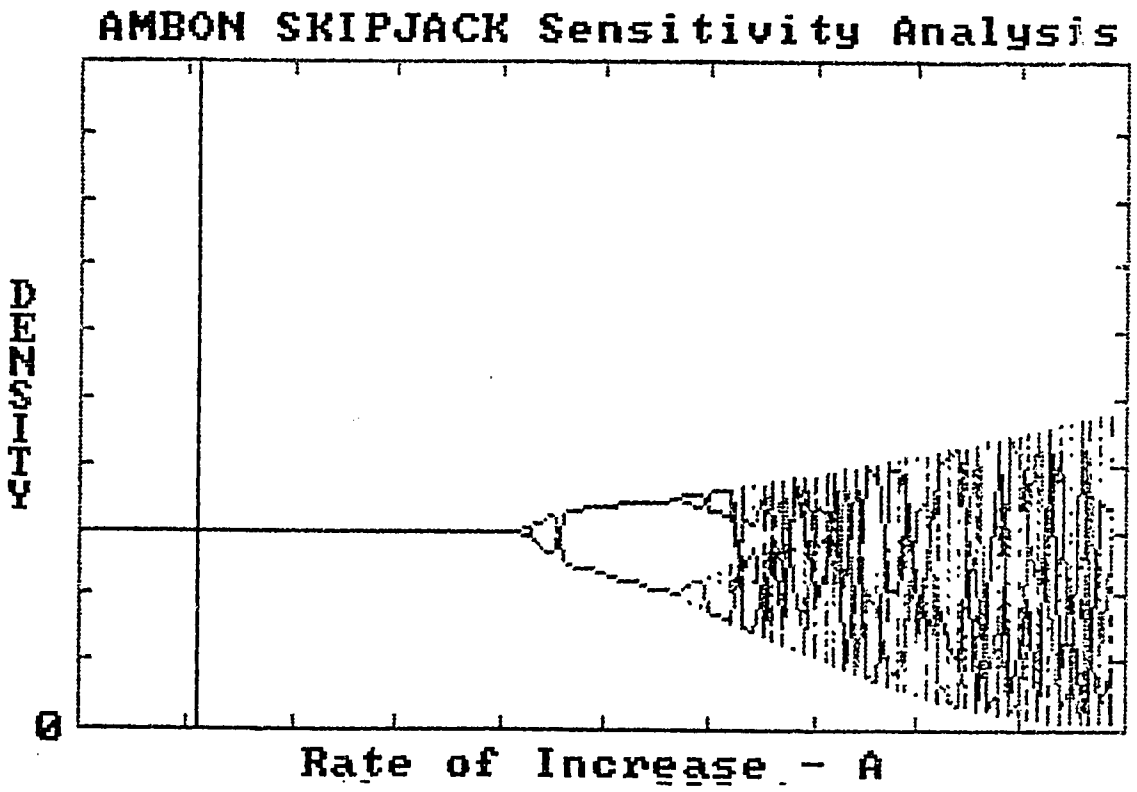


Figure A-5 Phase portrait derived from the simulation model of Ambon skipjack.

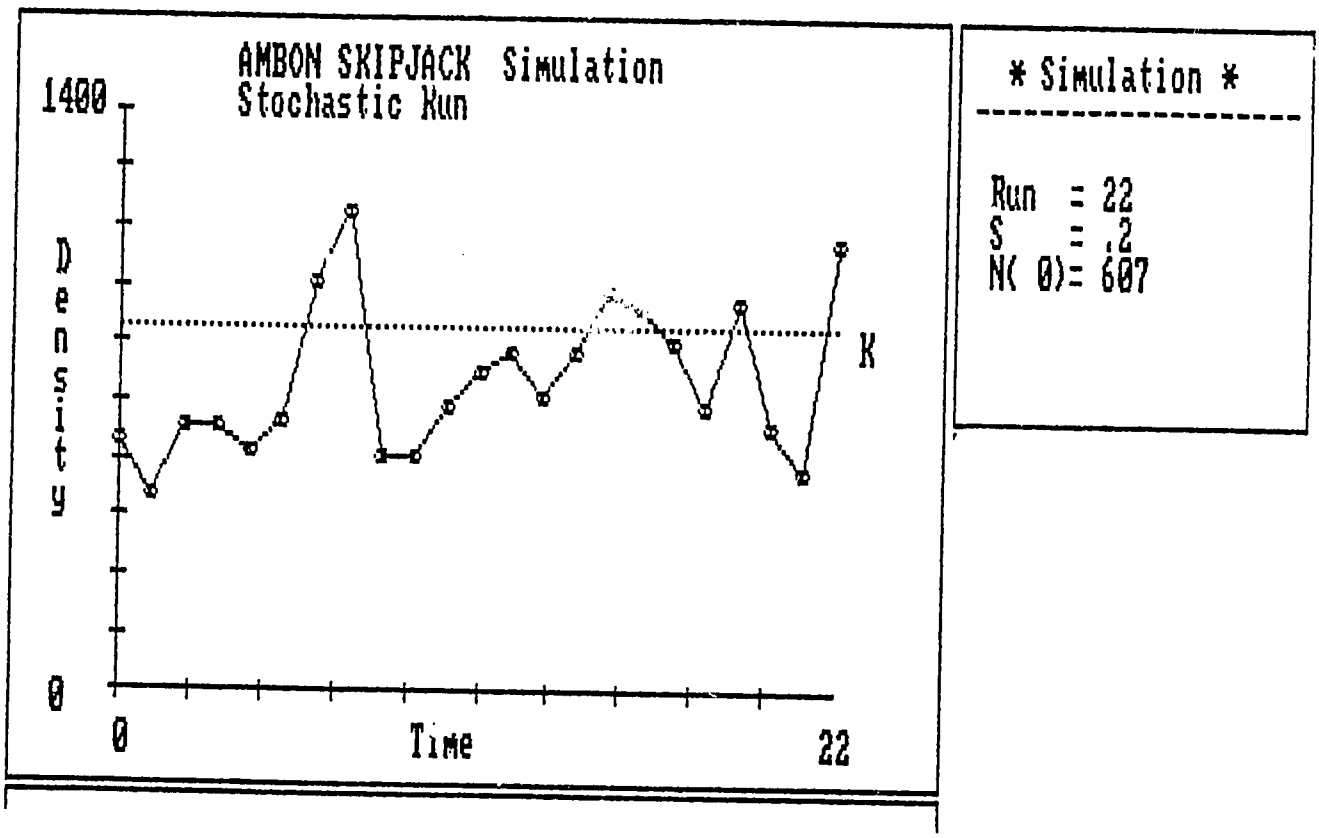
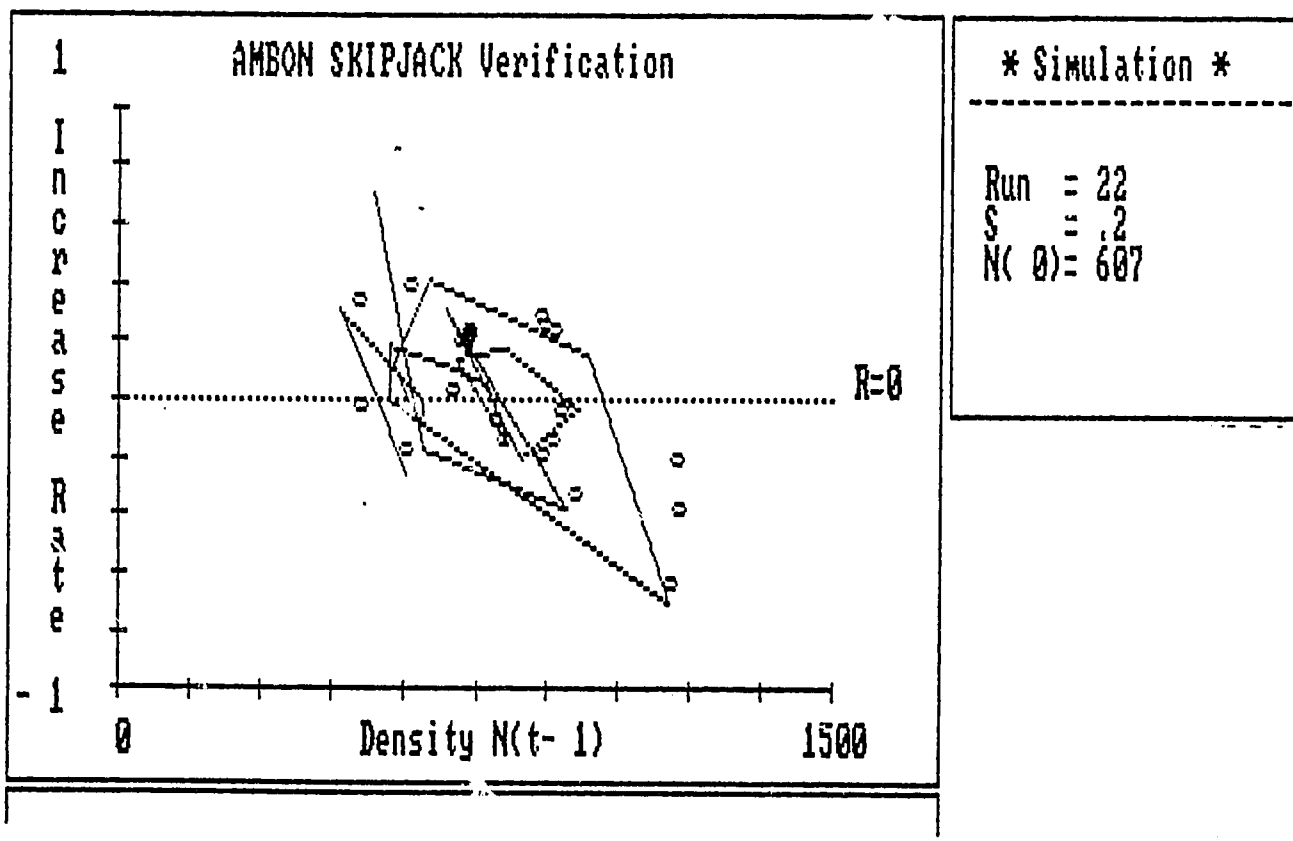


Figure A-6. Verification phase portrait for the simulation model derived for the Ambon skipjack data.



Pelabuhan Skipjack Data Analysis—

The data available for the Pelabuhan gillnet skipjack fishery extended over a period of ten years from 1981 to 1990. This is clearly a developing fishery which shows a trend in increased efficiency. Figure P-1 illustrates the time series of cpue data—as well as some summary statistics. The mean response time (MRT) was less than two, and the variance was somewhat higher than the mean. Periodicity is estimated as being higher than for the previously studied skipjack fisheries. However, the data base is considered to be only marginally acceptable due to its short length. Figure P-2 illustrates the phase portrait for this data set.

The R-function curve fitting procedure (Figure P-3) resulted in producing a curvilinear fit to the data which maximized the RSQ value. A Q value of less than 1 indicated concavity in the regression line. Approximately 50 percent of the variation in the data was explained by the curvilinear regression line. As indicated previously, this is an estimate of variation due to density-dependent factors. The other half of the variation is due to density-independent factors.

A stochastic simulation model of this fishery was developed, and Figure P-4 illustrates the results from one of the simulation runs. Table P-1 shows the simulation model formulation and data from a simulation run. It may be compared with Figure P-1 (lower panel) which illustrates the raw data. Clearly there is a good resemblance between Figures P-1 and P-4. However, other simulation runs provided similar variability, but the time series did not correspond as well. We again suggest that a comparison of the phase portraits from the original data (Figure P-2) versus the simulation verification (Figure P-5) is appropriate to indicate model fidelity. These two figures also correspond very well. Because the phase diagrams are time independent, we suggest this is a more valid comparison than directly comparing the simulated versus real time series data.

We will illustrate some of the results of sensitivity analyses for the Pelabuhan data. Sensitivity analyses were performed for all data, but the results are illustrated in detail in

only some cases. Figures P-5, P-6, and P-7 graphically illustrate the results of simulation analyses in which all parameters—except the one tested—were held constant. We illustrate sensitivity analyses for random variation (S) in Figure P-5, equilibrium density (K) in Figure P-6, and rate of increase (A) in Figure P-7. The first and last of these analyses are most interesting. Nearly chaotic behavior can be induced in the model as (S), the amount of random variability is increased. In the case of increasing (K) the carrying capacity, it is evident that there is a weak linear increase in average density with increasing K, but there is no abrupt change. On the other hand the rate of increase parameter (A) does not change until its value reaches about 2.7, after which bifurcation and apparently chaotic behavior take place. Our derived parameter estimates for both S and A are well below those which might induce violent oscillations in the population.

Tables P-2 and P-3 illustrate the results of using the simulation model in a management gaming situation. These tables suggest that a conservative increment in the fishery at Pelabuhan may be about 30 percent above the current amount harvested.

Table P-1. The model definition and estimated parameters for the Pelabuhan skipjack tuna fishery simulation. The bottom half illustrates data from a simulation run of ten years.

```
::::::::::::::::::::::::::::::::::::::

      pelabuhan skipj Model

    R = A(i) * (1-N(t)/L(i)) *

     (1-[N(t-T(i))/K(i)]^Q(i)) + V(S)

    where i = 1 when N(t) > E
    and   i = 2 when N(t) < E

    R is the per-capita rate of
    increase, N(t) is the density of
    the population at time t, V is a
    random normal variate, and E is
    the escape threshold.        (F10)
     parameters of your model are

A    = the value of R at N = 0        =  1.3085E+00
K    = the equilibrium point          =  2.7189E+02
L    = the  underpopulation effect    = -1.0000E+06
Q    = the coefficient of curvature   =  5.503E-01
T    = the feedback time-lag          = 1
       and the goodness of fit statistics are

S    = standard deviation             =  2.8391E-01
RSQ  = % of variation explained       =  50.1%

::::::::::::::::::::::::::::::::::::::
```

pelabuhan skipj Simulation
Data from Simulation # 1

Time	Density	Rate of Increase	Random Variation
0	9.9000E+01	4.9543E-01	-6.2648E-02
1	1.6248E+02	4.5618E-02	-2.7724E-01
2	1.7006E+02	3.5840E-01	6.0600E-02
3	2.4336E+02	2.4108E-01	1.6365E-01
4	3.0971E+02	-1.1058E-01	-1.3336E-02
5	2.7729E+02	-1.8613E-02	-4.3675E-03
6	2.7218E+02	3.6856E-01	3.6932E-01
7	3.9347E+02	1.8948E-01	4.8466E-01
8	4.7556E+02	-3.6581E-01	1.0564E-01
9	3.2987E+02	-1.4253E-01	4.3434E-03
10	2.8605E+02	-2.9416E-01	-2.5708E-01

Standard Deviation of Random Variable = 2.8391E-01

Table P-2. Some results of using the simulation model for management purposes, illustrating 50 and 40 percent removal strategies above a critical population size.

```
==============================================================
          MANAGEMENT STRATEGY  1 for pelabuhan skipj
--------------------------------------------------------------
REMOVAL STRATEGY:
    40.00% of organisms removed when population >  7.0000E+01
    Number removed over    50 time periods          = 4.2184E+03
    Average removed per time period                 = 8.4367E+01
    Number of removal episodes                      =   50
    Proportion of time removals are made            = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 1.2655E+02
    Number of dangerous episodes                    =   8
    Probability of danger (risk)                    =  0.16
==============================================================
```

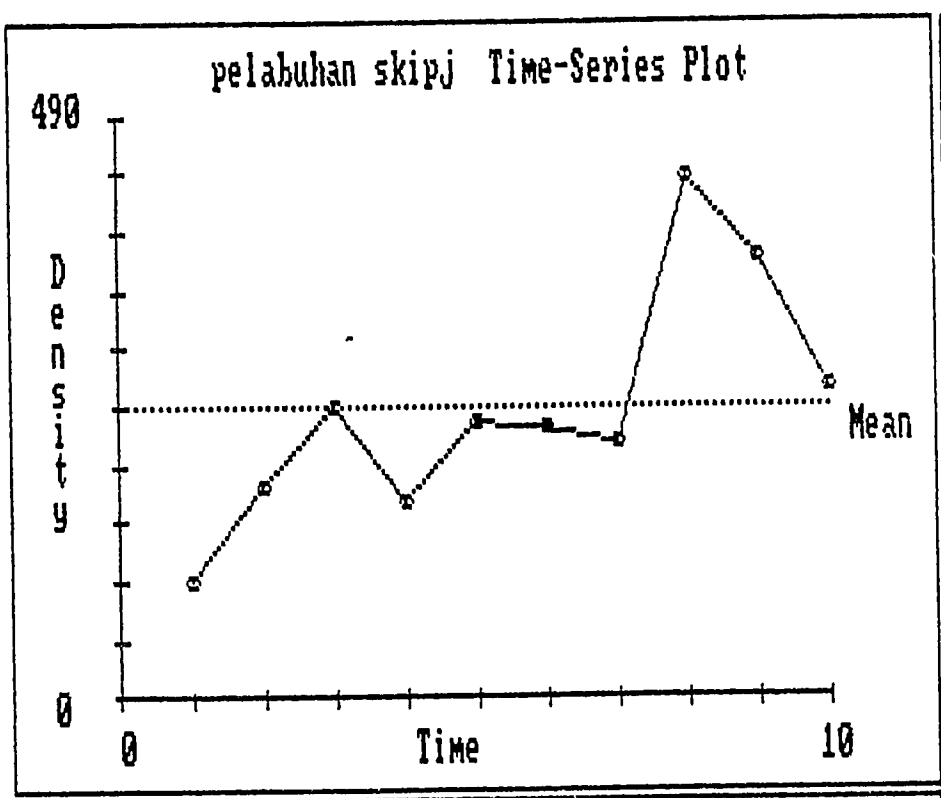
```
==============================================================
          MANAGEMENT STRATEGY  2 for pelabuhan skipj
--------------------------------------------------------------
REMOVAL STRATEGY:
    50.00% of organisms removed when population >  7.0000E+01
    Number removed over    50 time periods          = 3.7830E+03
    Average removed per time period                 = 7.5660E+01
    Number of removal episodes                      =   47
    Proportion of time removals are made            = 0.940
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 7.9453E+01
    Number of dangerous episodes                    =  30
    Probability of danger (risk)                    =  0.60
==============================================================
```

Table P-3. This is a continuation of Table P-2 and illustrates an estimate of a conservative exploitation rate with no risk of reaching critical levels under the model assumptions.

```
==============================================================
          MANAGEMENT STRATEGY  3 for pelabuhan skipj
--------------------------------------------------------------
REMOVAL STRATEGY:
    35.00% of organisms removed when population >  7.0000E+01
    Number removed over     50 time periods        = 3.5811E+03
    Average removed per time period                = 7.1621E+01
    Number of removal episodes                     =    50
    Proportion of time removals are made           = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =   50
    Mean population density                        = 1.3301E+02
    Number of dangerous episodes                   =    3
    Probability of danger (risk)                   =   0.16
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  4 for pelabuhan skipj
--------------------------------------------------------------
REMOVAL STRATEGY:
    30.00% of organisms removed when population >  7.0000E+01
    Number removed over     50 time periods        = 3.3846E+03
    Average removed per time period                = 6.7691E+01
    Number of removal episodes                     =    50
    Proportion of time removals are made           = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =   50
    Mean population density                        = 1.5795E+02
    Number of dangerous episodes                   =    0
    Probability of danger (risk)                   =   0.00
==============================================================
```

Figure P-1. Time series plot of Pelabuhan skipjack tuna cpue from a gillnet fishery extending from 1981-1990. The cpue values and surrounding statistics are shown in the lower panel.



* Statistics *

MRT = 1.708
VRT = 2.445
PER = 6.667
AMP = 238.333
MEAN= 243.2

pelabuhan skipj Data
Density per 1.00 cpue

Time	Density	Rate of Increase
1	9.9000E+01	5.8666E-01
2	1.7800E+02	3.2355E-01
3	2.4600E+02	-4.0547E-01
4	1.6400E+02	3.5117E-01
5	2.3300E+02	-1.2959E-02
6	2.3000E+02	-7.2103E-02
7	2.1400E+02	7.1396E-01
8	4.3700E+02	-1.6914E-01
9	3.6900E+02	-3.4245E-01
10	2.6200E+02	0.0000E+00

Mean response time: MRT = 1.7080E+00

Response time variance: VRT = 2.4447E+00

Mean period of oscillation: PER = 6.6667E+00

Mean amplitude of oscillation: AMP = 2.3833E+02

Figure P-2. Phase portrait of Pelabuhan skipjack tuna data.

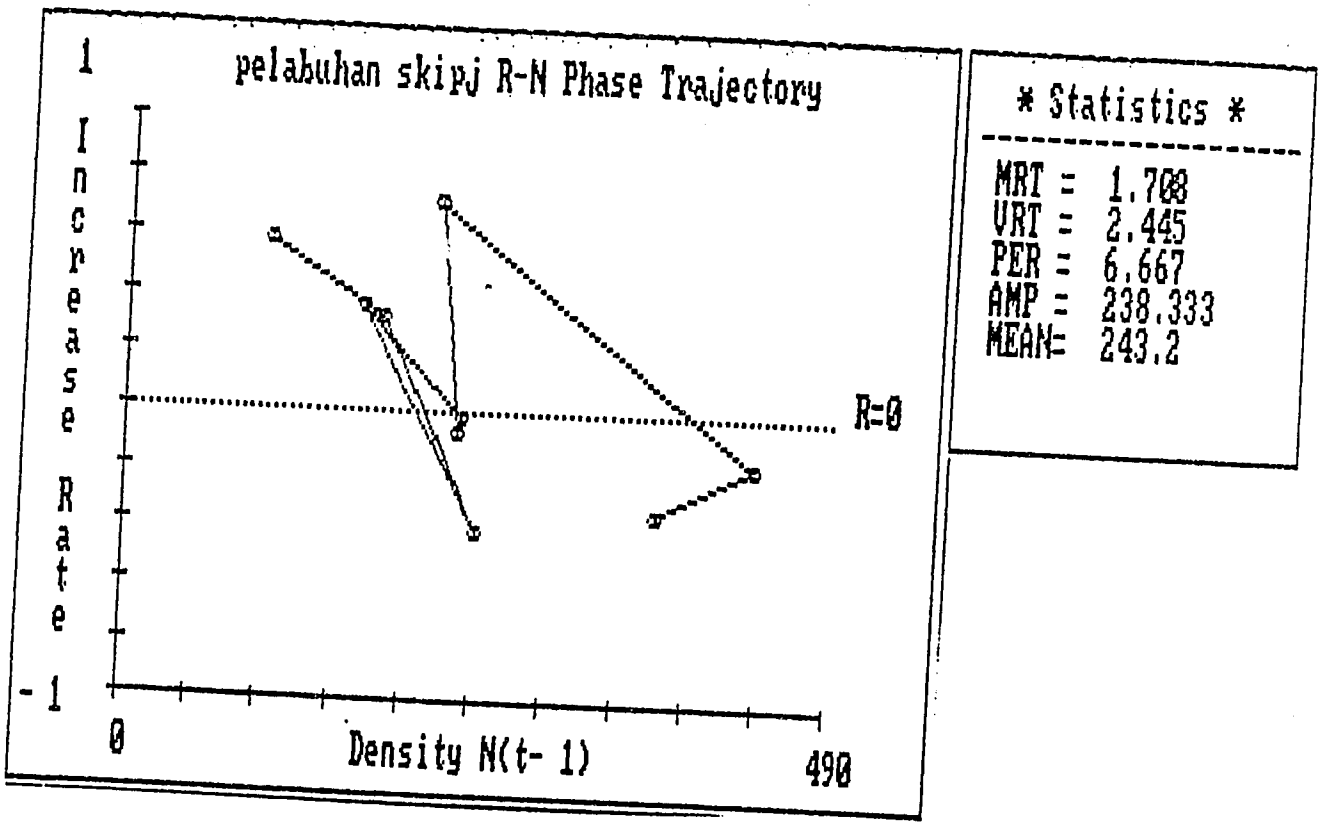
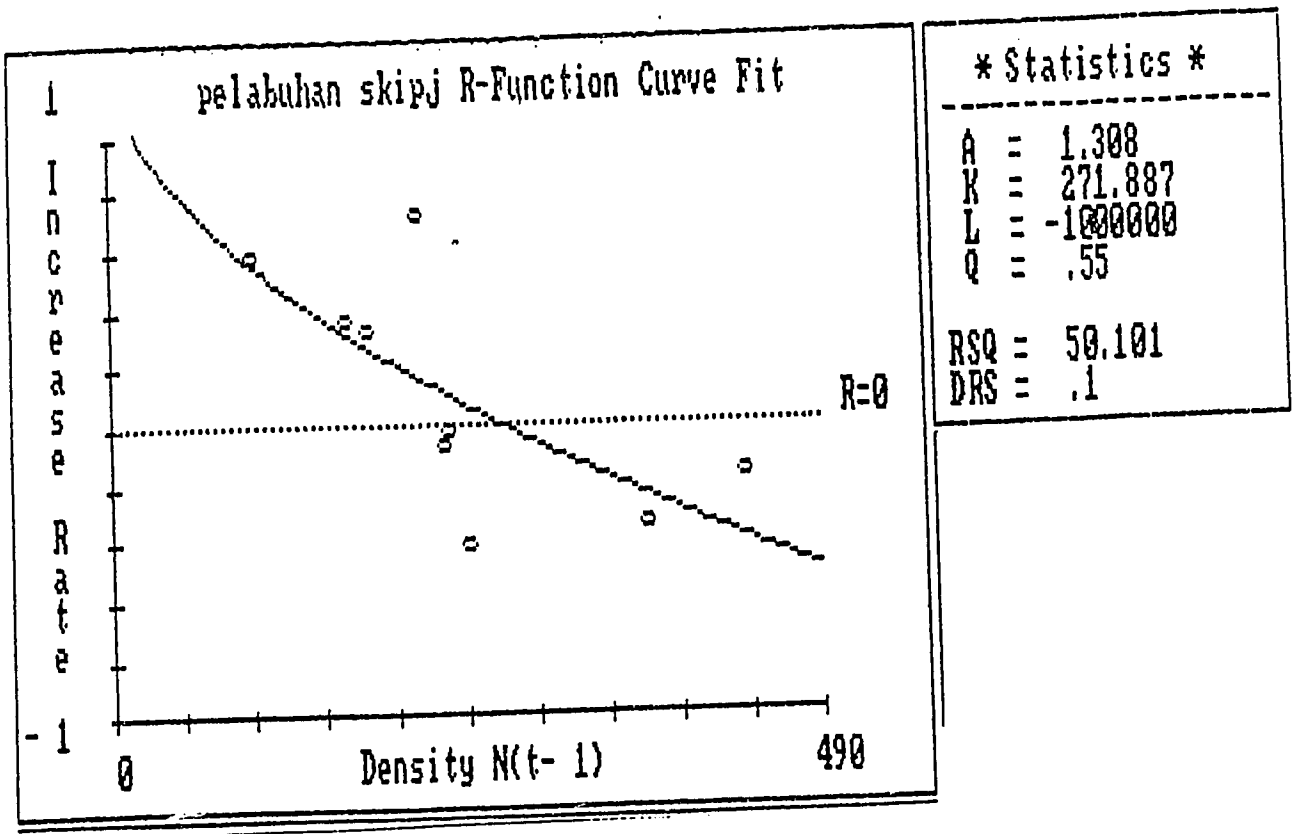


Figure P-3. A curvilinear R-function fitted to the Pelabuhan skipjack tuna data. The rate of increase is shown on the ordinate, and the density at time (t-1) is shown on the abscissa. Summary statistics and model parameters are shown in the lower panel.




```
==========================================
   pelabuhan skipj Regression of R-function
==========================================

Regression Intercept at N = 0:A(1) =  1.3085E+00
Equilibrium Point at R = 0:   K(1) =  2.7189E+02
Lower Root of Function:       L(1) = -1.0000E+06
Coefficient of Curvature:     Q(1) =  5.5035E-01
Feedback Time-lag:            T(1) =  1.0000E+00
Standard Deviation about Line: S   =  2.8391E-01
Percentage Variation Explained:RSQ =  50.1%
==========================================
```

Figure P-4. A stochastic simulation for the Pelabuhan skipjack data. This figure can be compared with Figure P-1.

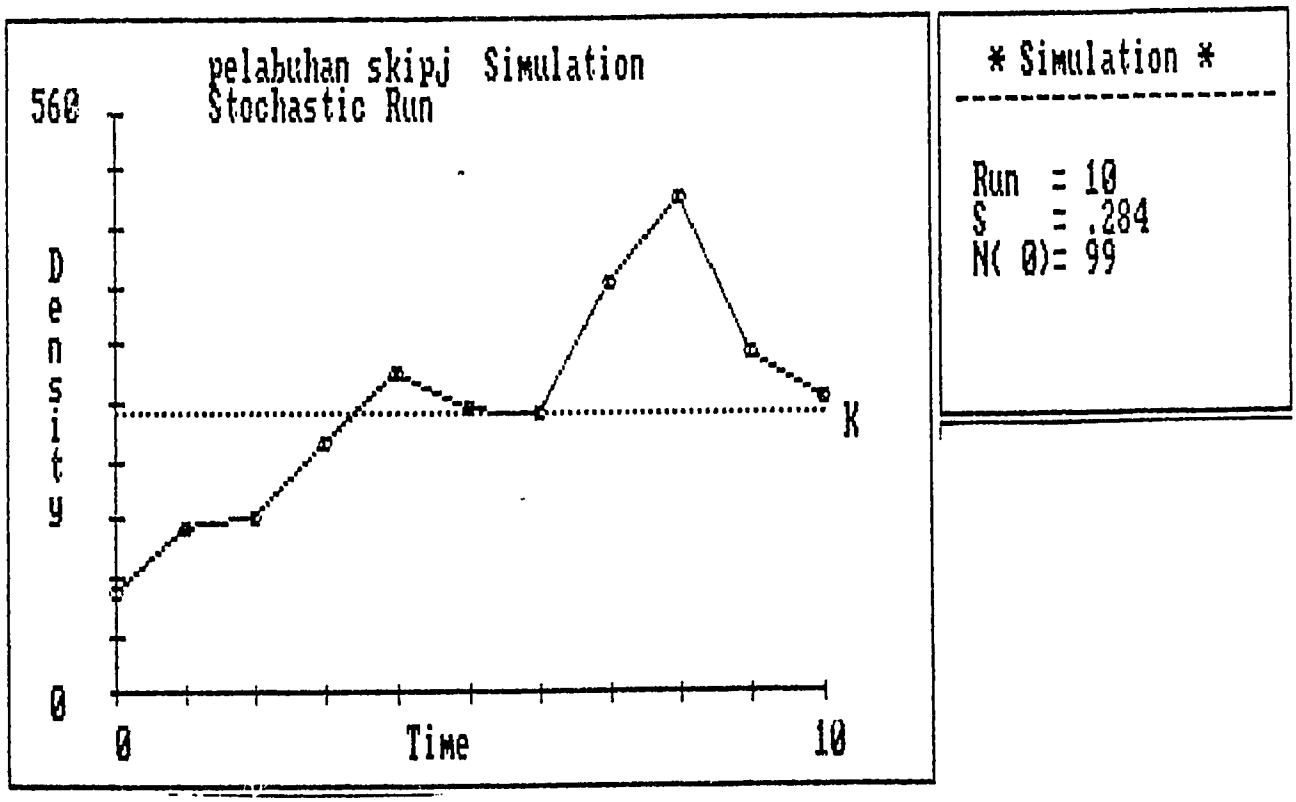


Figure P-5. The Pelabuhan skipjack tuna verification phase portrait.

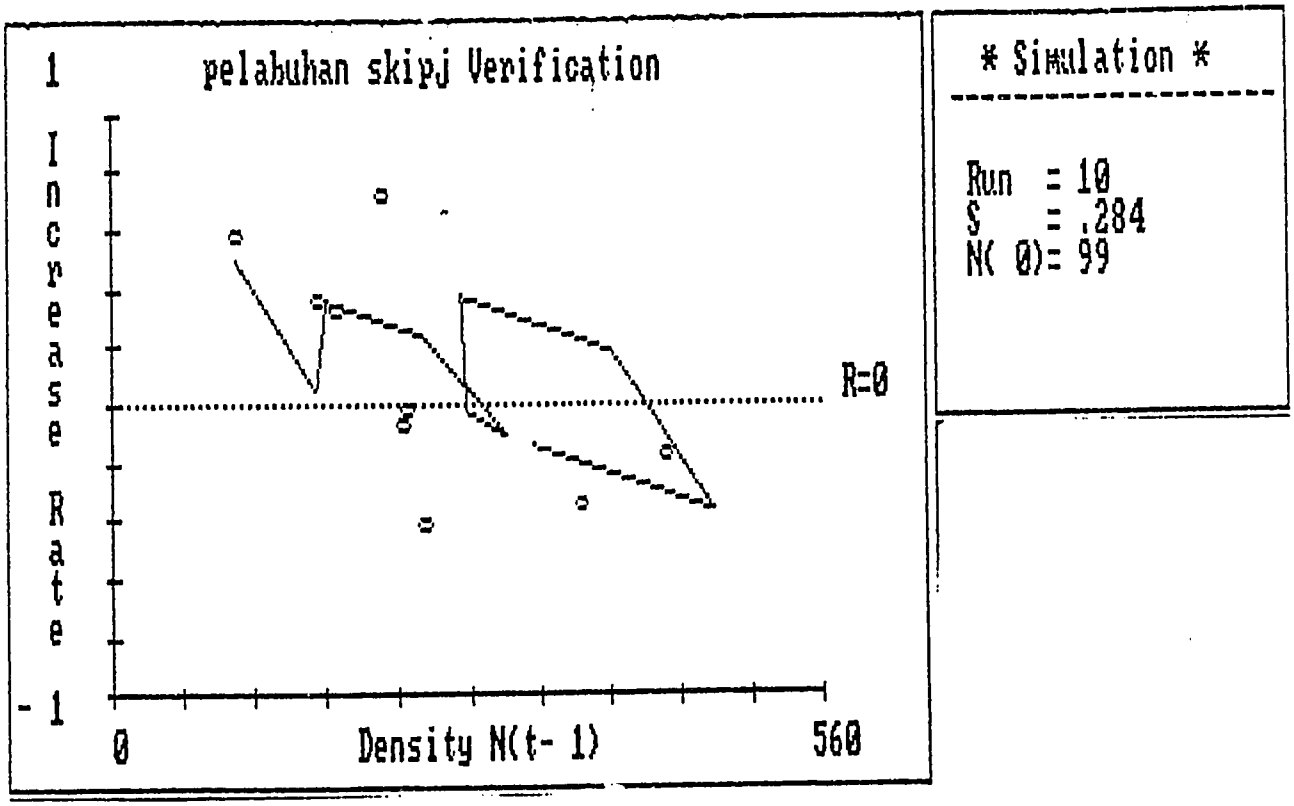


Figure P-6. The effort of increasing random variation shown in a sensitivity analysis. The vertical line denotes the calculated amount of random variation for Pelabuhan skipjack.

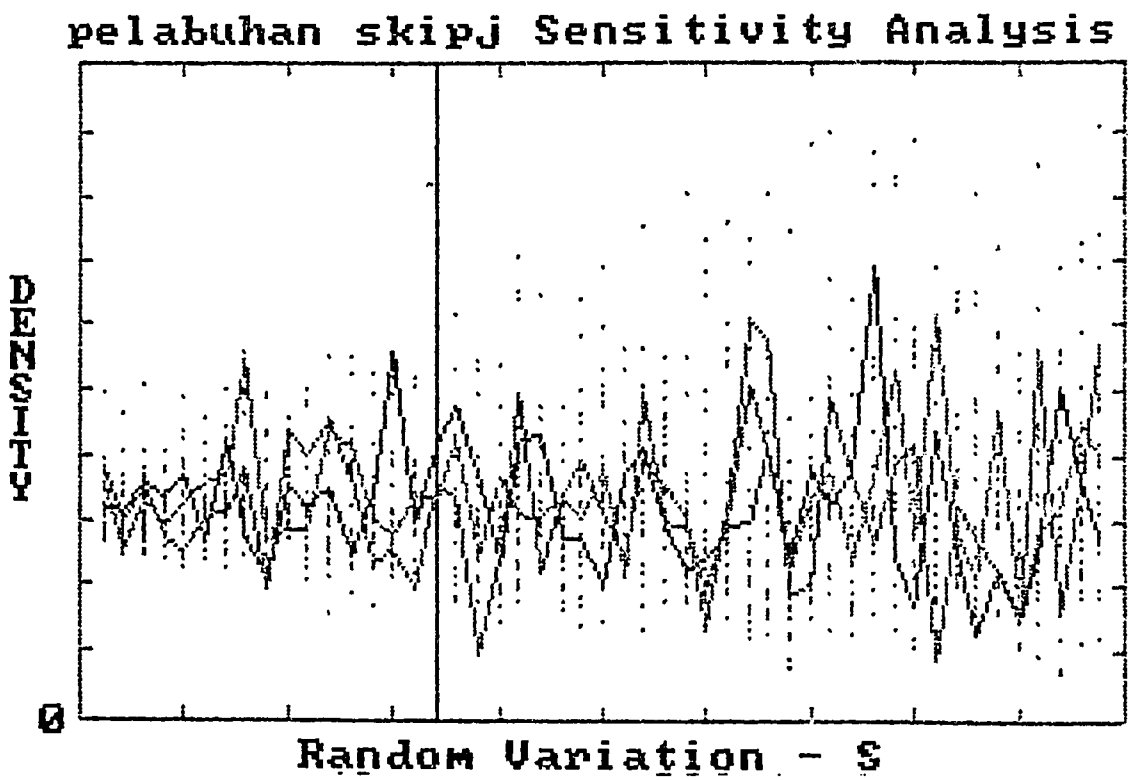


Figure P-7. A sensitivity analysis showing the effects of increasing density K for the Pelabuhan skipjack fishery.

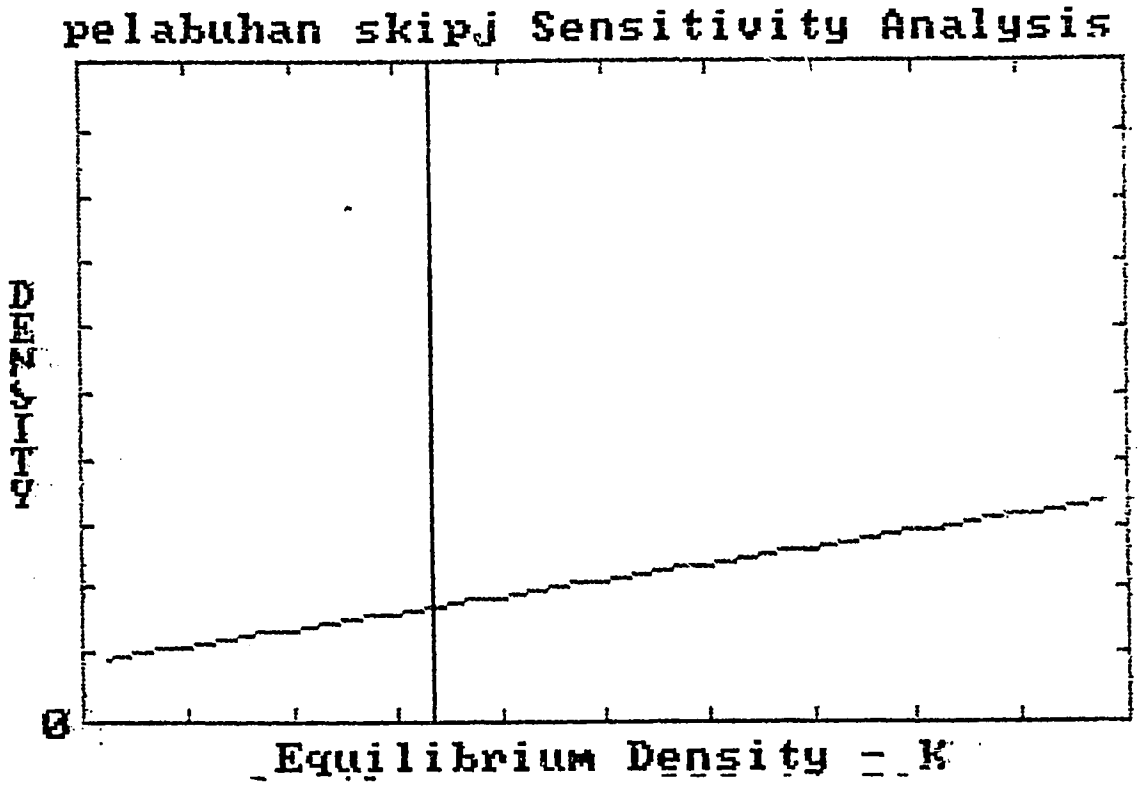
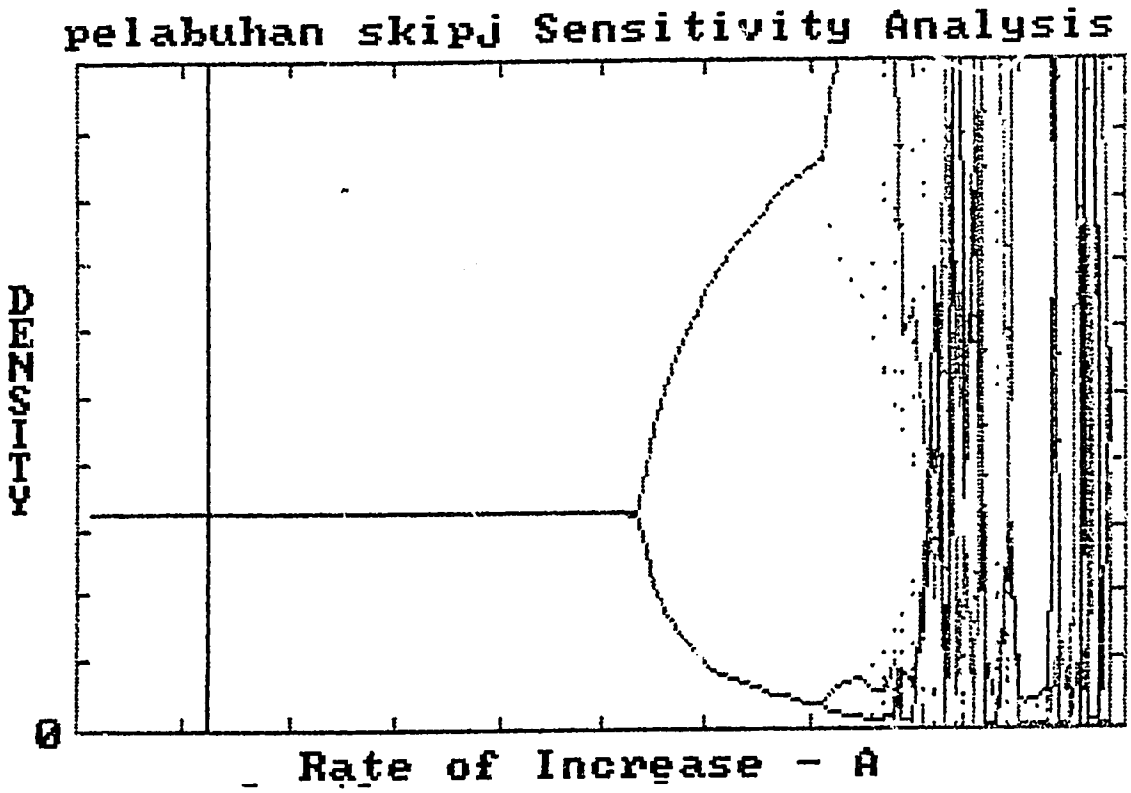


Figure P-8. A sensitivity analysis showing the effect of varying the values of the rate of increase parameter A for Pelabuhan skipjack.



***Auxis* Data Analysis—**

The *Auxis* data set consists of a ten-year time series of cpue obtained from seine netters at Pelabuhan Ratu, the same location as the skipjack gillnet fishery. In contrast to skipjack tuna, *Auxis* spp. are relatively small coastal species. Members of the genus *Auxis* are frequently called frigate mackerel. This record of catch and effort is the first available for small coastal tunas in Indonesia, and it, therefore, is of some relevance in management planning.

The *Auxis* cpue data is illustrated in Table Au-1, and the time series plot and related statistics are shown in Figure Au-1. It is evident from the figure that the population is subject to rather severe oscillations. However, the mean return time (MRT) is about one, and the variance of the return time (VRT) is less than one. The estimated periodicity is four, and the amplitude of the oscillations is greater than the mean. From this one would expect a phase trajectory which is not tightly grouped, and this is certainly the case in Figure Au-2. In addition the R-function curve fit is not as good as that found for the skipjack. Only about 26 percent of the variation is estimated to be density-dependent, with the remaining 74 percent being density-independent. An attempt was made to develop a simulation model from the derived parameters. Figure Au-4 illustrates the results of one simulation run which contains a spike somewhat similar to that found in Figure Au-1. This large amount of variability found in the simulation runs is directly related to the fact that the estimated density-independent variability was about three times higher than the density-dependent variation. Also, the per-individual rate of increase (A) was estimated to be lower than the values obtained for skipjack.

The phase portrait shown in Figure Au-5 bears some resemblance to that derived from the raw data. This is a verification diagram, and it should be compared with Figure Au-2 obtained from the original data. A description of the stochastic model, the estimated model parameters, and the results of a simulation run are illustrated in Table Au-2.

In view of the high variability on the time series data, some sensitivity analyses were performed on the model. Figure Au-7 shows a very interesting condition, namely that increasing values of the model parameter (S), which is random variability, quickly produces what appears to be chaotic results. This is related to the observation made previously that the *Auxis* population has a high level of density-independent variability. With respect to the rate of increase parameter (A), it was found that the model was insensitive to changes until A reached rather high values of about 2.7. When bifurcation was observed (see Figure Au-8), chaotic behavior soon followed. However, these conditions were well outside the estimated value of the parameter derived from the data.

The derived model was also utilized for prediction purposes in view of its interesting behavior. Table Au-3 illustrates predictions for two years ahead—as well as probabilities associated with these predictions. It is of particular interest to note the probabilities of encountering a dangerous condition (i.e., density at or below a critical level, estimated to be between 20-25 percent of the maximum carrying capacity). These danger probabilities were relatively high, suggesting that the forecasting and control of a fishery with such high density-independent variability would not be easy.

Our concerns about the stability of the fishery under a constant proportional harvest rate management regime were justified by the results of the management gaming exercises based on the simulation model which are illustrated in Tables Au-3 and Au-4. From Table Au-3 it is evident that even moderate rates of removal beyond a critical density provided extremely high risks of danger. This is further confirmed by Table Au-5 which illustrates even lower harvest rates of removal of 15 and 10 percent of the stock above a critical minimum. The third panel of Table Au-5 illustrates the results of a manual management strategy. In this strategy a proportion of the estimated stock is removed to bring it back to the threshold level. This strategy also produces a high level of risk as indicated by the bottom line in the table. This result is largely due to the fact that the population oscillates above and below the critical value due to the large amount of density-independent

variability. In this case no management strategy short of forecasting the year's abundance and adjusting fishing effort each year to account for the large stochastic variation seems reasonable.

Table Au-1. *Auxis* cpue data and preliminary statistics. This is a ten-year record of cpue for a seine fishery operating out of Pelabuhan from 1981 to 1990.

Auxis cpue Data
Density per 1.00 seine cpue

Time	Density	Rate of Increase
1	1.9100E+02	5.4682E-01
2	3.3000E+02	-7.7521E-01
3	1.5200E+02	-4.3891E-01
4	9.8000E+01	6.9824E-01
5	1.9700E+02	-6.1037E-01
6	1.0700E+02	1.3698E+00
7	4.2100E+02	-3.4554E-01
8	2.9800E+02	-2.2314E+00
9	3.2000E+01	-2.8768E-01
10	2.4000E+01	0.0000E+00

Mean response time: MRT = 1.1667E+00

Response time variance: VRT = 6.0313E-01

Mean period of oscillation: PER = 4.0000E+00

Mean amplitude of oscillation: AMP = 2.1183E+02

Mean density of population: MEAN = 1.8500E+02

Table Au-2. Model definition and results of a simulation run for the *Auxis* data set.

```
::::::::::::::::::::::::::::::::::::::::

                Auxis cpue Model
         The model you have chosen to
        describe the data is given by:

        R = A(i) * (1-N(t)/L(i)) *

         (1-[N(t-T(i))/K(i)]^Q(i)) + V(S)

        where i = 1 when N(t) > E
        and   i = 2 when N(t) < E

        R is the per-capita rate of
        increase, N(t) is the density of
        the population at time t, V is a
        random normal variate, and E is
        the escape threshold.        (F10)
         parameters of your model are

A    = the value of R at N = 0        =  6.1700E-01
K    = the equilibrium point          =  1.4774E+02
L    = the  underpopulation effect    = -1.0000E+06
Q    = the coefficient of curvature   =  1.000E+00
T    = the feedback time-lag          = 1
        and the goodness of fit statistics are

S    = standard deviation             =  8.9094E-01
RSQ  = % of variation explained       =  25.6%

::::::::::::::::::::::::::::::::::::::::
```

Auxis cpue Simulation
Data from Simulation # 5

Time	Density	Rate of Increase	Random Variation
0	1.9100E+02	-6.1452E-01	-4.3385E-01
1	1.0331E+02	-3.7153E-01	-5.5707E-01
2	7.1252E+01	-2.6437E-01	-5.8380E-01
3	5.4699E+01	-1.7966E-01	-5.6822E-01
4	4.5704E+01	6.0025E-02	-3.6610E-01
5	4.8532E+01	-6.1264E-01	-1.0270E+00
6	2.6300E+01	2.3395E+00	1.8323E+00
7	2.7289E+02	-1.7060E+00	-1.1833E+00
8	4.9556E+01	-3.7358E-01	-7.8362E-01
9	3.4108E+01	-2.0248E-01	-6.7703E-01
10	2.7856E+01	1.1386E+00	6.3797E-01

Standard Deviation of Random Variable = 8.9094E-01

Table Au-3. *Auxis* population predictions based on the stochastic simulation model. Projected damage and danger levels are also indicated for the forecasts.

Auxis cpue PREDICTIONS

POPULATION DENSITY per seine cpue					
Time	Mean	Maximum	Minimum	St. Deviation	95% Interval
		I N P U T D A T A			
1	1.9100E+02				
2	3.3000E+02				
3	1.5200E+02				
4	9.8000E+01				
5	1.9700E+02				
6	1.0700E+02				
7	4.2100E+02				
8	2.9800E+02				
9	3.2000E+01				
10	2.4000E+01				
		P R E D I C T E D D A T A			
11	6.3500E+01	3.9772E+02	4.7434E+00	6.8159E+01	+- 1.3632E+02
12	9.5721E+01	4.1092E+02	2.2769E+00	9.8995E+01	+- 1.9799E+02

Auxis cpue PREDICTIONS

P R O B A B I L I T I E S				
Time	P(increase)	P(decrease)	P(damage)	P(danger)
11	0.74	0.26	0.00	0.49
12	0.64	0.36	0.00	0.38

Table Au-4. Examples of specific management strategies based on use of the *Auxis* stochastic simulation model.

```
==============================================================
          MANAGEMENT STRATEGY  1 for Auxis cpue
--------------------------------------------------------------
REMOVAL STRATEGY:
    40.00% of organisms removed when population >  7.5000E+01
    Number removed over    50 time periods         = 1.3165E+03
    Average removed per time period                = 2.6330E+01
    Number of removal episodes                     =   16
    Proportion of time removals are made           = 0.320
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 6.5672E+01
    Number of dangerous episodes                   =  43
    Probability of danger (risk)                   =  0.86
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  2 for Auxis cpue
--------------------------------------------------------------
REMOVAL STRATEGY:
    30.00% of organisms removed when population >  7.5000E+01
    Number removed over    50 time periods         = 2.1423E+03
    Average removed per time period                = 4.2846E+01
    Number of removal episodes                     =   20
    Proportion of time removals are made           = 0.400
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 1.2288E+02
    Number of dangerous episodes                   =  35
    Probability of danger (risk)                   =  0.70
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  3 for Auxis cpue
--------------------------------------------------------------
REMOVAL STRATEGY:
    20.00% of organisms removed when population >  7.5000E+01
    Number removed over    50 time periods         = 1.1525E+03
    Average removed per time period                = 2.3049E+01
    Number of removal episodes                     =   30
    Proportion of time removals are made           = 0.600
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 1.1091E+02
    Number of dangerous episodes                   =  25
    Probability of danger (risk)                   =  0.50
==============================================================
```

Table Au-5. Additional management strategies for *Auxis*. The bottom panel illustrates a completely manual strategy based on estimated abundances and exploitation only above critical levels.

```
==============================================================
          MANAGEMENT STRATEGY  4 for Auxis cpue
--------------------------------------------------------------
REMOVAL STRATEGY:
    15.00% of organisms removed when population >  7.5000E+01
    Number removed over     50 time periods        = 1.2343E+03
    Average removed per time period                = 2.4686E+01
    Number of removal episodes                     =    30
    Proportion of time removals are made           = 0.600
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 1.5555E+02
    Number of dangerous episodes                   =  22
    Probability of danger (risk)                   =  0.44
==============================================================
```

```
==============================================================
          MANAGEMENT STRATEGY  5 for Auxis cpue
--------------------------------------------------------------
REMOVAL STRATEGY:
    10.00% of organisms removed when population >  7.5000E+01
    Number removed over     50 time periods        = 7.7963E+02
    Average removed per time period                = 1.5593E+01
    Number of removal episodes                     =    37
    Proportion of time removals are made           = 0.740
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 1.5173E+02
    Number of dangerous episodes                   =  18
    Probability of danger (risk)                   =  0.36
==============================================================
```

```
==============================================================
          MANUAL MANAGEMENT OF Auxis cpue
--------------------------------------------------------------
REMOVAL STRATEGY:
    Number removed over     30 time periods        = 2.9552E+03
    Average removed per time period                = 9.8507E+01
    Number of removal episodes                     =    15
    Proportion of time removals are made           = 0.500
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  30
    Mean population density                        = 8.3080E+01
    Number of dangerous episodes                   =  18
    Probability of danger (risk)                   =  0.60
==============================================================
```

Figure Au-1. *Auxis* cpue time series plot for ten years (1981 to 1990) in the Pelabuhan seine net fishery.

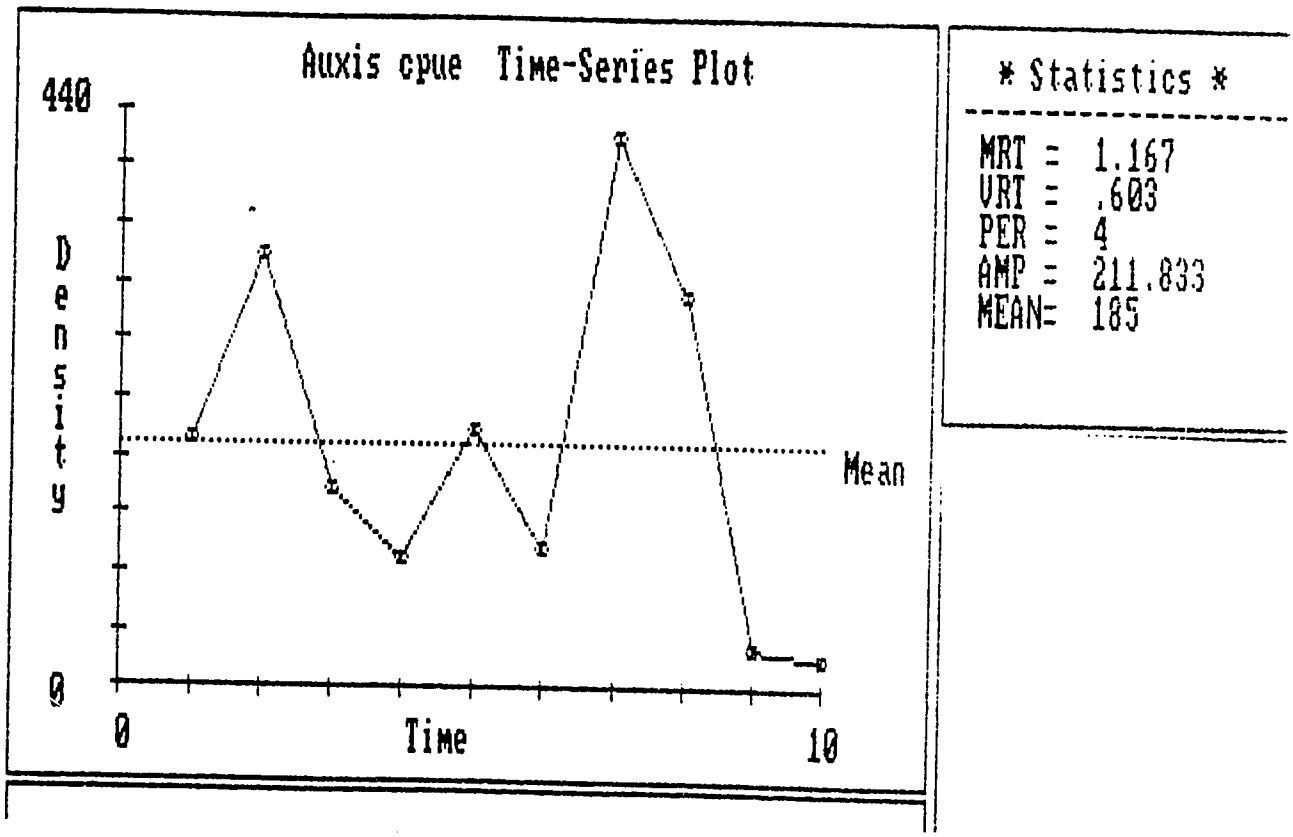


Figure Au-2. *Auxis* R-N phase trajectory derived from the data of Table Au-1.

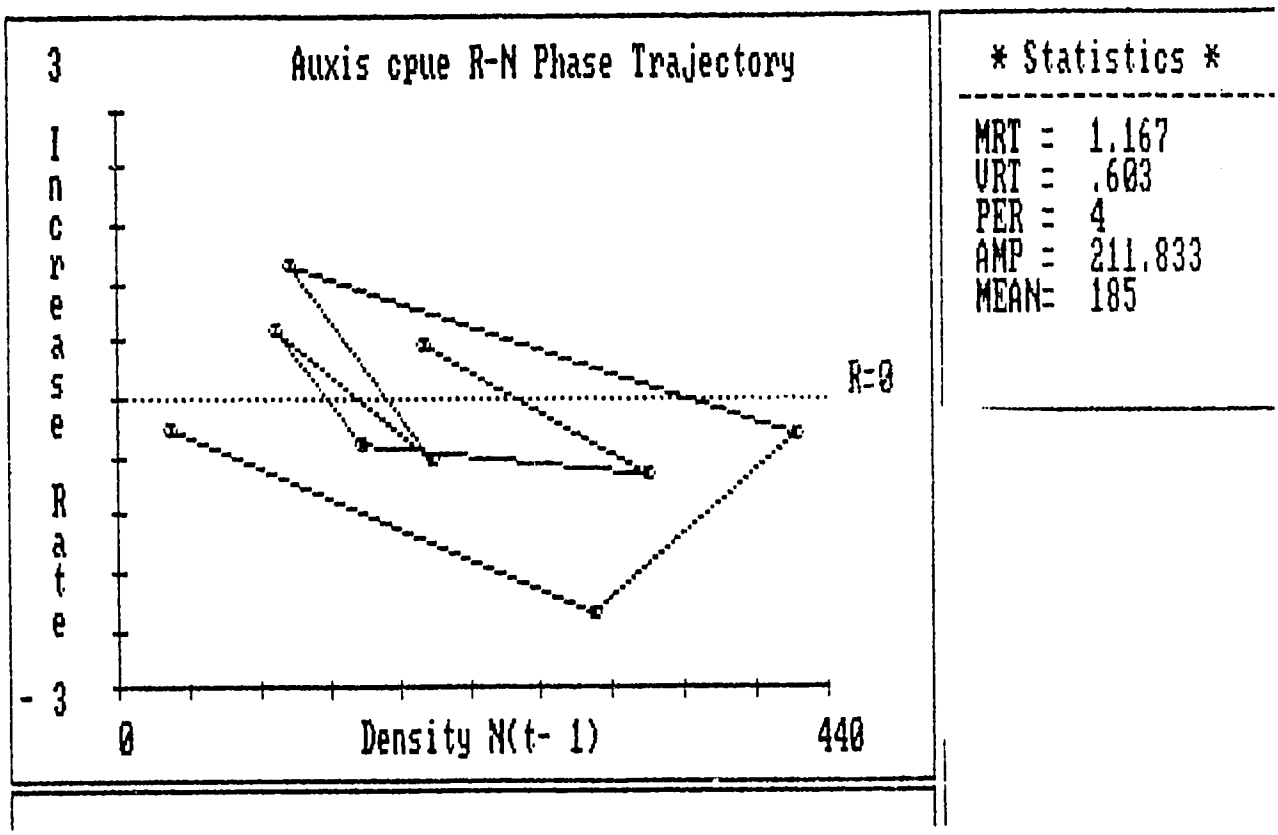
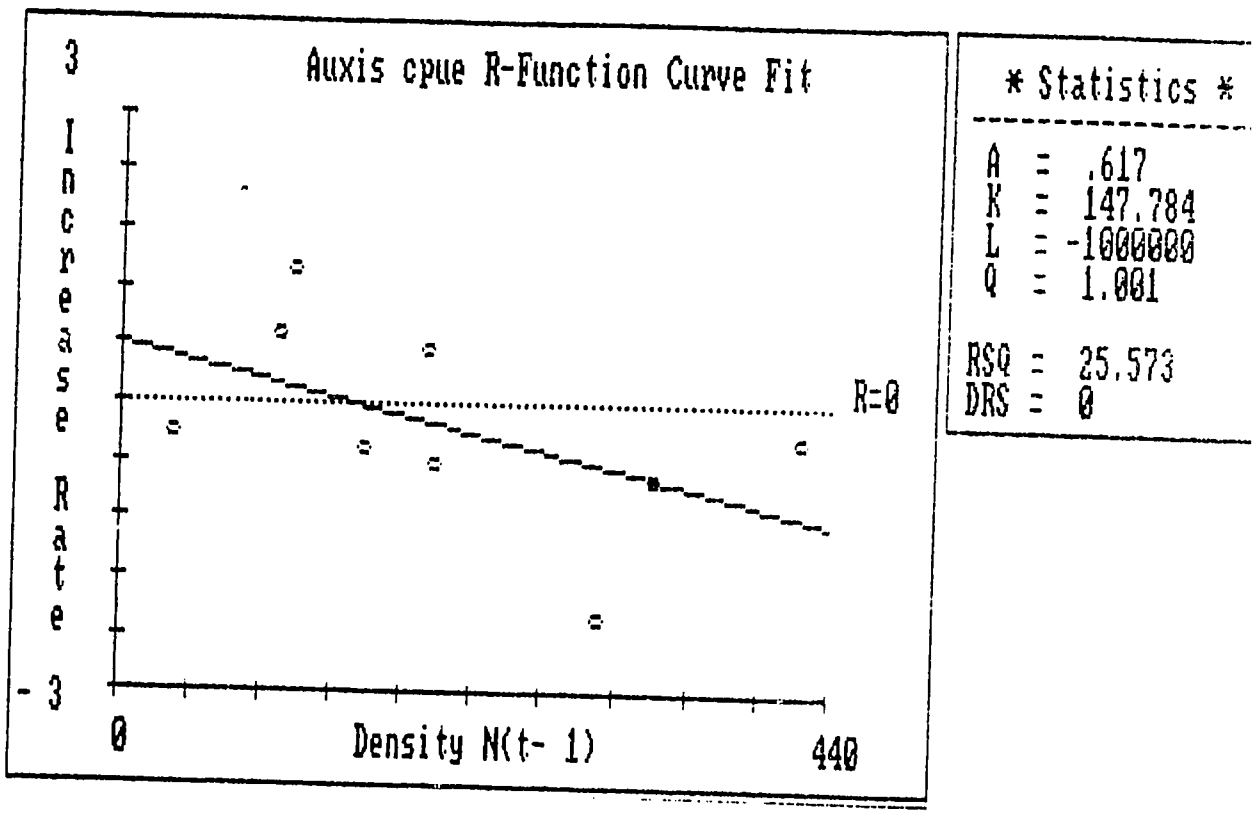


Figure Au-3. *Auxis* is R-function curve fit. The parameters of the linear regression model are shown below this figure.




```
==============================================
        Auxis cpue Regression of R-function
==============================================
Regression Intercept at N = 0:A(1) =  6.1700E-01
Equilibrium Point at R = 0:   K(1) =  1.4774E+02
Lower Root of Function:       L(1) = -1.0000E+06
Coefficient of Curvature:     Q(1) =  1.0000E+00
Feedback Time-lag:            T(1) =  1.0000E+00
Standard Deviation about Line: S   =  8.9094E-01
Percentage Variation Explained:RSQ =  25.6%
==============================================
```

Figure Au-4. Results of a simulation run for the stochastic simulation model of the *Auxis* data.

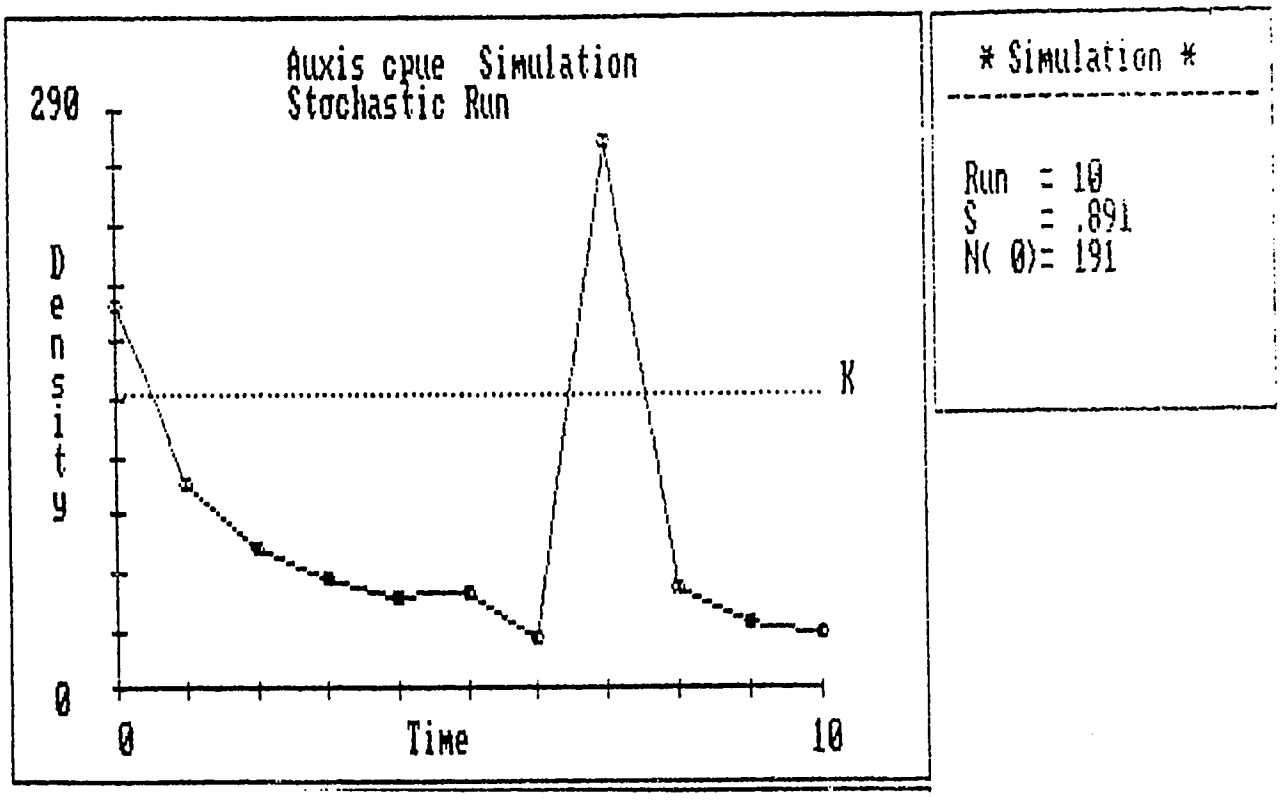


Figure Au-5. *Auxis* cpue simulation model verification results.

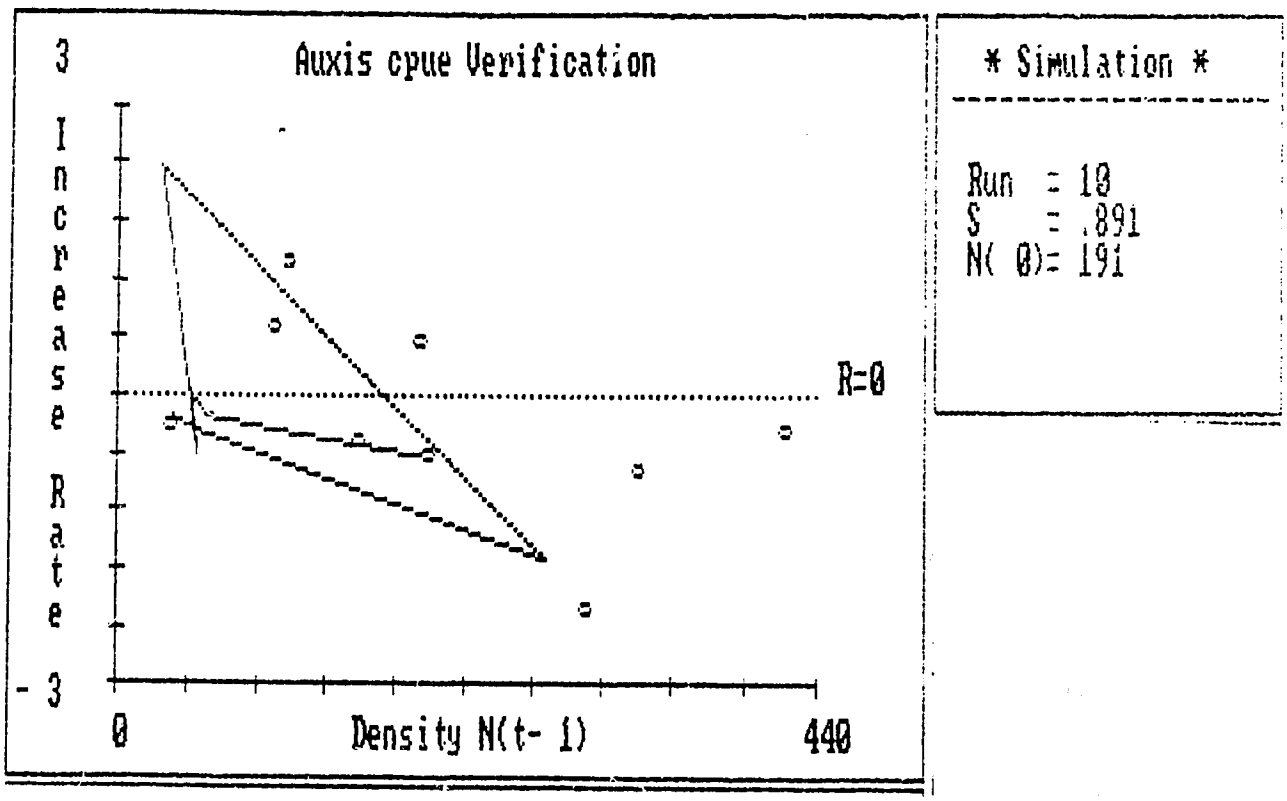


Figure Au-6. Results of sensitivity analysis of random variation (S) for the stochastic simulation model.

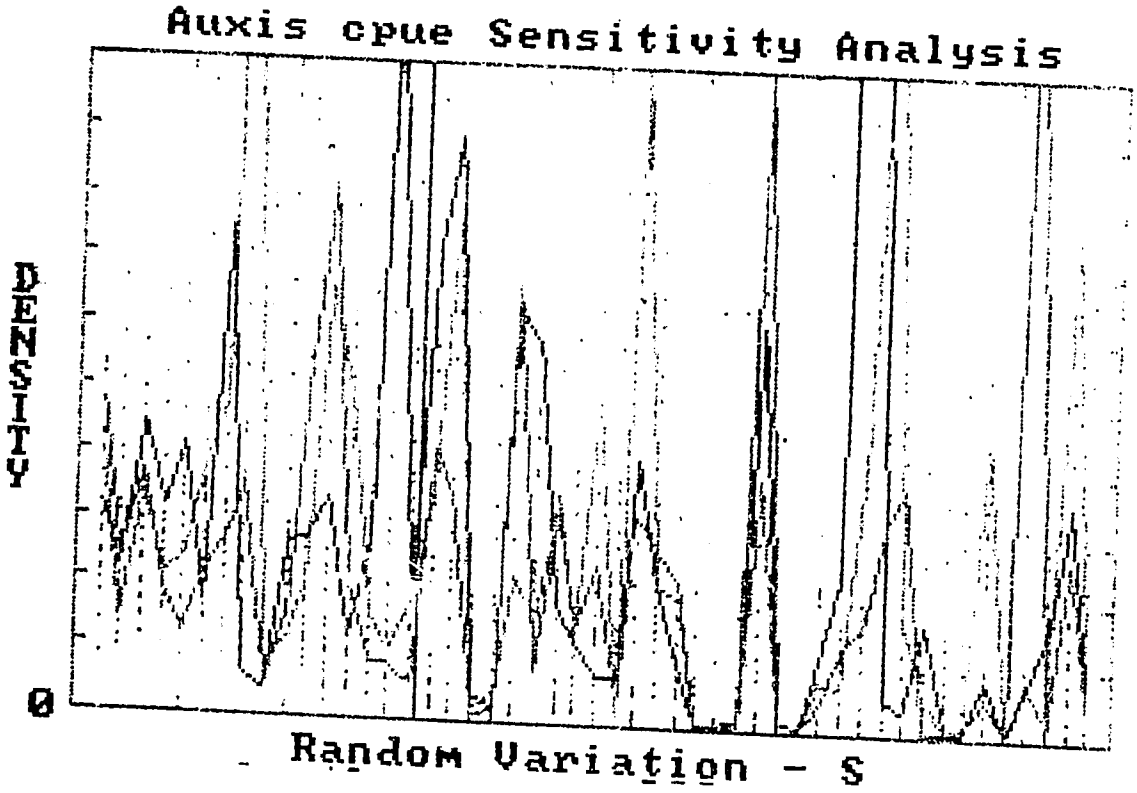
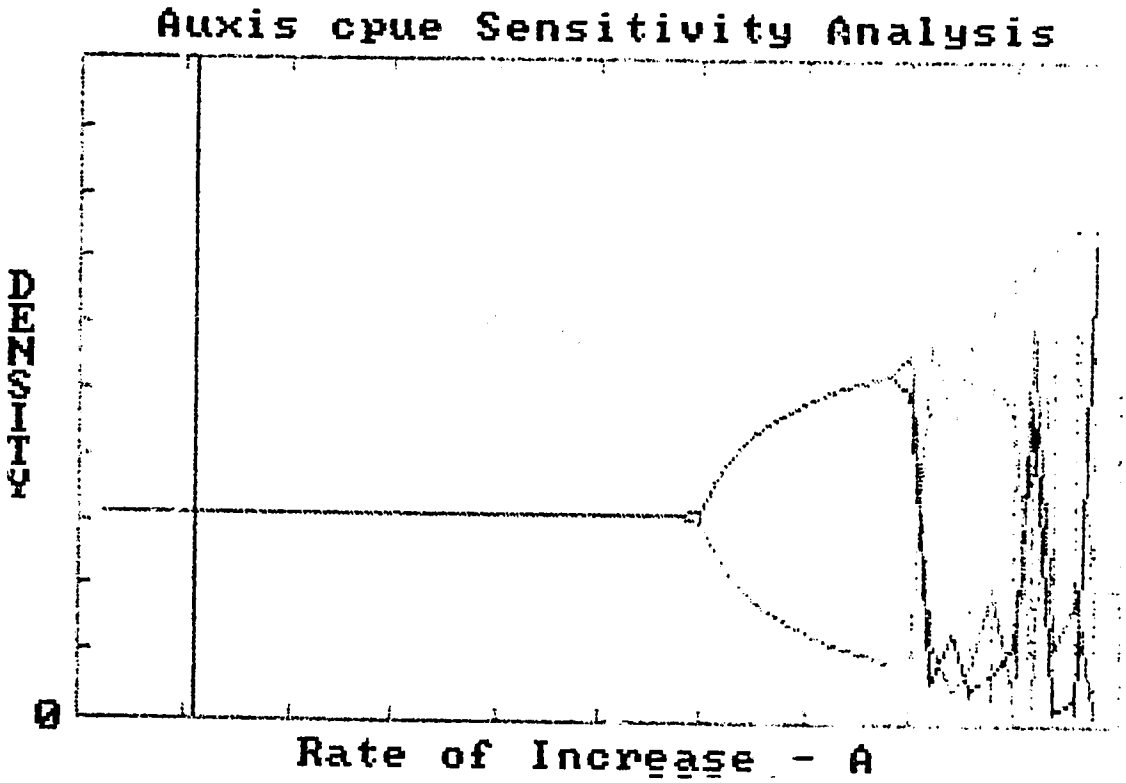


Figure Au-7. Results of sensitivity analysis for increments in the rate of increase parameter (A).



Discussion

General--

This section will briefly refer to studies of resource potentials thought to be useful in putting present assessments into perspective and also for providing comparisons with the specific results of this study.

Zijlstra and Baars (1990) have described the productivity and fisheries potential of the Banda Sea ecosystem in general terms. They believed that upwelling occurs during the southeast monsoon period and that productivity of the system may be enhanced by a factor of 2-3 during this time. They also suggest that pelagic fish resources estimated by acoustic methods are probably greatly underexploited. However, no indication was given of the species breakdown.

Perhaps the most comprehensive assessment of the potential yield of marine fishery resources in Southeast Asia has been made by Chikuni (1987). This report provided estimates of the total potential yield from all harvest fisheries in this region of about 7.8 to 8.9 million mt., which is about 36 to 56 percent more than the catch of about 5.7 million mt. taken in 1984. Coastal pelagic resources were estimated to have a potential of about 50 percent more than the reported catch at that time. With respect to skipjack tuna, it was stated that the exploitation of the entire stock in the Pacific Ocean still remains at a moderate level. The potential for skipjack in the Southeast Asia region (which include the eastern side of Indonesian waters) was estimated to be 230,000 mt. against a 1984 yield of 113,000 mt. We note here that the Southeast Asia region described above contains significantly more area than the eastern EEZ of Indonesia. Therefore, these estimates do not apply without adjustments.

A more recent RAPA publication (1989) deals with Indonesian waters, but it does not provide detailed information by species groups.

Although this report does not deal explicitly with analysis of southern bluefin tuna, the work by Bahar and Naamin (1989) puts the potential of this species into perspective. The above authors state that Indonesian bluefin landings to date have not exceeded ten metric tons per year. The status of the fishery for this species clearly indicates that it will not be a major contributor to Indonesian tuna landings in the future or to tuna resource development.

A recent report on Indian Ocean yellowfin tuna assessment by Pitcher and Hemphill (1989) indicated a sustainable yield of about 113,000 mt. per year. This assessment was based on application of the Csirke-Caddy production model, and the authors acknowledge the limitations of the method. However, they indicate that even a cautious interpretation of these results for the Indian Ocean stock of yellowfin suggest that catch levels now exceed MSY by a dangerous margin. From available evidence and without detailed data, it seems reasonable to suggest that yellowfin and tuna stocks in Indonesian waters would probably tolerate only moderate expansion in exploitation rates.

With specific reference to skipjack tuna in Indonesian waters, Naamin and Gafa (1988) provide an estimate of 550,000 mt./year as a potential annual yield. McElroy (1989) presented another assessment result for skipjack and yellowfin, which indicated an estimated MSY for skipjack of 270,000 mt. and 160,000 mt. for large tunas (primarily yellowfin and bigeye) in Indonesian waters. The 1986 catch represented about 30 percent of this projected MSY and about 23 percent for the large tuna group. McElroy projects total large tuna landings in Indonesia to reach 250,000 to 300,000 mt. by the year 2000. We question the logic for extrapolating current growth rates (without regard to the carrying capacity of the stocks) as has been done in the report described by McElroy.

It seems clear from the above-mentioned published reports that there is a high degree of variability and optimism in the estimates of MSY, especially with reference to skipjack. Equally important is the fact that some of these estimates have been based on stock production models or as simple extrapolations of current growth rates. We state

again that stock production models based on equilibrium assumptions provide overly optimistic predictions if the data are gathered during fishery development, during which time the stock is in decline. Also, extrapolation of current growth rates without recognizing an asymptotic approach to maxima is considered extremely naive.

In summary, we tentatively conclude that the only fishery for which there appears to be considerable latitude for expansion seems to be the skipjack, based on the above information. The discussion which follows describes our assessment of the skipjack resource in Indonesia, which is based primarily on a dynamic analysis of cpue time series from fishing ports, namely Bitung, Sorong, Ambon, and Pelabuhan. One time series of *Auxis* tuna data provides some information on the status and problems of small coastal tuna species.

Appendix 1 of this report attempts to provide a detailed justification for our approach to the analyses of these data. In the section to follow, our goal is to briefly describe an extrapolation of the available data and how it relates to the resource potential in Indonesian waters.

Skipjack Tuna—Since most of the data available for this analysis refers to skipjack tuna, we will attempt to summarize the findings for this species based on the data base available. Table D-1 is a summary table of some of the parameters estimated at specific fishing bases. We will examine the table in detail. The mean response time (MRS) is < 2 in all cases examined, and tends to show only moderate variability by site (fishing base). With the exception of the Pelabuhan gillnet fishery, the variance of the response time (VRT) is less than the mean. These two statistics suggest that for the Indonesian skipjack tuna there seems to be a strong density-dependent feedback with relatively little delay in the feedback response. In all the skipjack data analyzed, the R.N. phase trajectory derived from the empirical data showed rapid crossings of the $\dot{R} = 0$ line from one side to the other. The amplitude (AMP) and the mean (MEAN), as well as the estimated periodicity (PER), were also fairly constant. Clearly, the Pelabuhan gillnet fishing data do

not compare directly with the other skipjack data which are from pole and line fisheries. The periodicity of all data seems reasonably similar with an average value of about four. It is suggested that the periodicity may relate to the life span of the species. Again the Pelabuhan gillnet data is anomalous, and there is no rational explanation other than that it is a short-time series, and the gillnet may be more variable as a sampling tool than the pole and line effort.

As stated previously, the form of the density-dependent feedback function is:

$$R = A * \left(1 - \frac{N(t-1)}{L}\right) * \left(1 - \left(\frac{N(t-T)}{K}\right)^{Q}\right)$$

Density-independent effects are modeled as random deviations from the density-dependent R-function (i.e., as deviations from the fitted curve). We assume the distribution of density-independent effects is normal with mean zero and a given standard deviation. This adds a term V(S) to the above equation to give:

$$R = A * \left(1 - \frac{N(t-1)}{L}\right) * \left(1 - \left(\frac{N(t-T)}{K}\right)^{Q}\right) + V(S)$$

Let us examine the statistics of the R-function curve fit to the Indonesian data. Firstly, a linear R-function seemed appropriate for most cases. The exceptions were the Ambon pole and line fishery and the Pelabuhan gillnet fishery. A linear model was also fitted to the Ambon data to illustrate the differences between a linear and non-linear model. The RSQ value was improved somewhat by the non-linear model.

In the logistic model, the parameter A is defined as the maximum per-individual rate of change of the population when its density is very low. It is the intercept of the R-function with the y-axis, and it represents a rate of increase in the absence of density-dependent feedback. Note that all values of A are less than two, and they are fairly similar with the exception of the non-linear fit to the Ambon data.

The parameter K refers to the carrying capacity of the environment measured in units of cpue in our case.It is the maximum sustainable density of the population in a given environment based on the available data. Note that the values for K in the pole and line fishery for skipjack are very consistent. However, the maximum cpue values for seine and gillnet fisheries are very different as might be expected.

The parameters L and Q will not be considered further here except to state that Q changed for each of the non-linear R-function fits illustrated in Table D-2. Time delays in the form of the parameter T were not found to vary from unity.

In general, for the pole and line fishery for skipjack, about one-half of the variation in the data is explained by the fitted R-function.

S is the standard deviation of the residual variation around the density-dependent R-function. It, therefore, measures deviations from the deterministic function due to density-independent effects. The calculated values for S are quite consistent for the entire data set which was examined.

The "bottom line" from these analyses is the outcome from the series of management simulations, which were done with each of the skipjack data sets. They resulted in the following indications of potential increases in the fishery above their current level:

Bitung	45%
Sorong	50%
Ambon	20%
Pelabuhan	30%

It is clear that the average overall anticipated safe level of increased harvest is on the order of 35 percent for the skipjack fishery. This estimate is considerably lower than that projected by other authors. On the other hand, these estimates are based on minimizing the risk of adversely affecting the fishery for reasonable threshold danger values of 20 to 25 percent of virgin biomass.

Ordinary least squares regression lines were fitted to a time series of cpue for the three pole and line fisheries for skipjack. The purpose of this was to attempt to determine whether the fishery was still in a developing phase or whether the fishery was at or above an optimum level based on the slope of the regression. The results from the analyses were not encouraging. Only one of the regressions was statistically significant. The Ambon pole and line fishery cpue had a positive slope. This may suggest that the fishery is still in a developing phase. However, the results for the other fishing bases are too ambiguous to interpret with this technique

Auxis Fishery—The results from analysis of this fishery clearly indicate that it is subject to violent oscillations in abundance. Adaptive management as outlined by Quinn et al. (199) seems to be the only rational way to attempt to manage the fishery. The outlook for coastal tuna species is not overly optimistic—if the results of this analysis are indicative of results for other coastal species not yet analyzed in detail.

Table D-1. Summary table of some parameters of the fitted system models to Indonesian tuna data.

Location	Fishery	MRT	VRT	PER	AMP	MEAN	Spp.
Bitung	pole & line	1.3	0.6	3.8	264.2	752.9	skipjack
Sorong	pole & line	1.1	0.9	3.7	170.6	728.5	skipjack
Ambon	pole & line	1.7	1.2	4.4	404.0	820.7	skipjack
Pelabuhan	gillnet	1.7	2.4	6.7	283.3	243.2	skipjack
Pelabuhan	seine net	1.2	0.6	4.0	211.8	185.0	*Auxis*

Table D-2. Summary of R-function curve fit parameters for the Indonesian tuna data.

Location	Fishery	Model	A	K	L	Q	T	RSQ	S	Spp.
Bitung	pole & line	L	1.002	764.3	-/000000	1.00	1	54.3	.145	skipjack
Sorong	pole & line	L	1.158	738.6	-1000000	1.00	1	63.6	.124	skipjack
Ambon	pole & line	L	0.730	833.9	-1000000	1.00	1	39.4	.212	skipjack
Ambon	pole & line	C	0.238	884.8	-1000000	3.41	1	46.0	.200	skipjack
Pelabuhan	gillnet	C	1.308	271.9	-1000000	.55	1	50.1	.284	Skipjack
Pelabuhan	seine net	L	0.617	147.8	-1000000	1.00	1	25.8		*Auxis*

Table D-3. Summary table of fits of an OLS regression model to the available CPUE time series data for the Indonesian pole and line fishery for skipjack tuna

Location	Fishery	F stat. r	for b = 0	Var. b	b	Var. a	a
Bitung	pole & line	-0.095	0.17	-1.808	18.99	772.93	2994.1
Sorong	pole & line	+0.126	0.18	3.26	60.12	705.02	3787.6
Ambon	pole & line	+0.443	4.89	13.18	35.52	669.12	6127.3

Conclusions

General—

We clearly recognize the difficulties in providing realistic estimates of the potential yields of tuna resources in Indonesian waters—as well as the limitations of our data base and the analyses. However, we have attempted to consolidate available information from the literature and have applied a dynamic analysis of time series of cpue data for selected fisheries for which data were available. We have demonstrated the robustness and consistency of our approach in contrast to the usual surplus production model. However, we realize that the approach m=used herein is probably not suitable for highly-developed and large-scale pelagic fisheries.

We believe that the economic theory of common property resources explains why uncontrolled fishery development tends to attract excessive capital and labor, and why such fisheries usually become fished well beyond the point of optimum sustained yields. We also believe that technological innovations—such as FADs which increase the catching power of fishermen initially, as well as their income—may lead (without careful control) to more rapid harvesting and subsequent declines in cpue or stock size. Our overall approach to tuna management is oriented toward adaptive management with suggestions for moderate increases in fishing effort which should be carefully monitored and evaluated prior to attempting another incremental increase.

Specifically, we recommend the following:

1) Our analyses suggest that moderate increases in the skipjack fishery are possible. Our estimate is on the order of a 35 percent increase beyond the present level. In view of the large amount of density-independent variability in the data (about 50 percent), it is not reasonable to expect any analysis of time series of catch and effort data to provide very accurate or precise estimates of stock abundance. In view of this we strongly urge that a continuing active monitoring and measurement system be maintained for the

entire fishery in order to assess the consequences of further development. We also urge that development of the fishery take place in gradual stages to avoid the dire consequences of over-expansion.

2) The dynamic analyses which have been applied in this report are believed to be well suited to continued monitoring and assessment of stocks which show considerable random and periodic variability and for which the proportional catch-effort relation seems reasonable.

3) There are a number of socio-economic problems related to the potential development of the Indonesian tuna fisheries. Methods for maximizing social benefits and methods for preventing overcapitalization are important subjects for future study.

4) On the basis of available published reports, we do not think that there is significant scope for increases in the yields of yellowfin tuna. A modest increase in effort is recommended with careful monitoring and measurement of results.

5) Due to the large amount of density-independent variability observed in the *Auxis* data, we believe that the fisheries for coastal tuna species should employ adaptive strategies by concentrating effort on abundant species and minimizing effort on those which appear to be at lower levels of abundance. This involves developing better monitoring schemes.

6) We have no specific information on bigeye tuna except from the Atlantic Ocean.

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Appendix 1

Comparison of Various Stock Production Model Results with the Population System Model POPSYS)

A data set consisting of 23 years of catch and effort data for the Atlantic bigeye tuna between 1961-1983 described by Kume (1986) was utilized in an effort to compare the results of the approach used in this report with results from using various conventional stock production models.

The entire set of data from Kume's (1986) Table 3 is reproduced as Appendix Table 1 so that the results to be described may be checked or reproduced if desired from the original data.

Firstly, results form applying various stock production models will be considered. The data of Appendix Table 1 were examined as an entire data set and also as reduced data sets consisting of only the last ten years (1974-1983) and the first ten years (1961-1970) to determine how consistent the results of parameter estimates were when the data set was reduced. Appendix Table 2a contains estimated population parameters derived by Kume (1986) from his Table 4 which were estimated by utilizing the PRODFIT model. Appendix Table 2b lists some estimated parameters derived by using the simple Schaefer and Fox models, in which equilibrium conditions were assumed. It also includes results of applying Schnute's regression model, which does not require the equilibrium assumption. Appendix Table 2c contains the results from applying the same models described in 2b above to a reduced data set consisting of ten pairs of observations (1974-1983).

It is evident from an examination of the results described in Appendix Table 2 that there is a fair amount of variability in the estimates—especially with reference to the optimum effort, as well as to a slightly lower extent for MSY. The optimum f value ranged from 361-922 (x 10^6), almost a factor of three, whereas the MSY values ranged from about 61 to 146, a factor of only a little more than two. The parameter estimation process is

clearly model dependent. We have already referred to problems in using equilibrium methods, and have suggested that data which show poor contrast between fishing effort and stock abundance often do not provide reasonable results even if regression methods are utilized.

We also took the opportunity to utilize the data of Kume (1986) Table 3 to establish a relationship between hook rate (No/100 hooks) and hook rate (kg/100 hooks). The high correlation coefficient of 0.96 in Appendix Figure 1 indicates that is is reasonable to exchange numbers for biomass and vice versa for the bigeye tuna. We believe a similarly strong relation exists for weight and numbers per unit effort for skipjack and other hook-caught tuna species. Thus, we feel justified in interchanging biomass and numbers when required—especially in the case of skipjack in the POPSYS model application.

Although the basic model for our analysis is developed from a simple logistic growth model, the interpretation and results are different from those of the typical stock production model. However, a comparison has been made between the POPSYS model results obtained from applying the model to the entire data set of Appendix Table 1 and to the reduced data sets consisting of the periods 1974-1983 and 1961-1970. It is believed that if the results of these analyses showed more internal consistency than those obtained from the stock production models, then this would provide some further justification for their application to the Indonesian tuna fisheries.

Appendix Figure 2 shows the time-series plot for the 23 years of data. These data illustrate the time change on cpue, and certain calculated statistics described in the Methods section. Although the value of MRT (mean response time) was > 2, using a time delay of T = 2 did not improve the quality of the phase portrait, and, therefore, this lag was not used. Also, the variance (VRT) of mean return time was > MRT, suggesting no need for the extended time delay. If one compares these data with those derived from the abbreviated data sets shown in Appendix Table 5, it is evident that the abbreviated data were better behaved with respect to MRT and the variance of the mean return time (VRT).

The period of oscillation was also higher for the full data as was the mean density of the population. This is as might be expected since the longer data sets included some of the early development of the fishery.

Returning to the initial full data set, a phase portrait of the data is shown in Appendix Figure 3. This phase portrait can be compared with the verification phase portrait derived from the stochastic simulation run ((Appendix Figure 6). The good correspondence between the two figures when superimposed suggest that the derived model is a reasonable portrayal of the field data. Also, the stochastic run time series can be compared with the control field data. Again, the correspondence is fairly good, recognizing that the stochastic variability is of the right magnitude although it is not located similarly on the time scale. Appendix Table 5 shows the derived simulation model and the data from the simulation run for a 23-year time period. These data are plotted in Appendix Figure 5, and they may be compared directly with the observed data of Appendix Figure 2. The R-function plot (Appendix Figure 4) is presented to show how density-dependent and density-independent variability was partitioned in the data set. Clearly density-independent variation was greater than density-dependent variability in this case.

The results of various management strategies are shown in Appendix Table 4. This table indicates that for a low risk of danger to the stock of $\leq .05$ the harvest rate within the sampled stock should not exceed 25 percent of the current level. However, for the case of the 1974-1983 abbreviated data set, the harvest rate could be around 35 percent beyond current level. This apparent anomaly is explained by the fact that density-independent variation was considerably greater for the smaller data set. Therefore, the risk of collapse or danger is reduced, and a higher harvest rate may be possible. It must be recognized that the POPSYS model derives a carrying capacity from each data set and measures of density-dependent and density-independent variation from the same data set. It is of importance to note that the order of the values of the calculated carrying capacities were highest for the

initial ten-year period, second for the combined data, and lowest for the last ten-year period. This is as one might expect and suggests that the fishery may currently be operating at higher than optimum levels.

The output from the POPSYS model does not provide a direct estimate of the population size for MSY nor an optimum rate of exploitation for the biomass. Instead it permits a validation of the model derived directly from a given data set and some indication of the factors responsible for the observed variability in the data. The management option provides an estimate of an acceptable level of harvest based on the observed data set. This value can be continually updated as new data are obtained and provides an adaptive system for monitoring and management. It is believed to be a conservative procedure, which has a high probability of maintaining the stock for perpetuity.

We interpret the sustainable harvest levels derived from the management strategy exercises as roughly representing the percent of expansion beyond the current level of exploitation to which the stock is currently being subjected. Clearly, it is possible to convert the annual percent removal to an instantaneous fishing mortality rate increment beyond the current level. However, since this is not known with any precision, this does not seem worthwhile.

Appendix Table 1. Data for the model comparisons used in this study, taken from Table 3 of Kume (1986).

Input fishery data in the production model analyses for Atlantic bigeye tuna, 1961-83.
Deep longline effort was adjusted for 1980-83.

YEAR	HOOK RATE (NO/100 HOOKS)	MEAN WEIGHT (KG)	HOOK RATE (KG/100 HOOKS)	TOTAL CATCH (1000 MT)	TOTAL EFFORT (MILLION)
1961	0.818	45	36.8	17.0	46.2
1962	0.681	43	29.3	23.1	78.9
1963	0.602	51	30.7	26.0	84.7
1964	0.564	50	28.2	23.5	83.3
1965	0.550	50	27.5	39.2	142.5
1966	0.481	48	23.1	25.0	108.3
1967	0.567	50	28.4	24.7	87.1
1968	0.654	48	31.4	23.0	73.3
1969	0.691	44	30.4	35.4	116.4
1970	0.559	49	27.4	41.5	151.5
1971	0.462	47	21.7	54.9	252.8
1972	0.434	44	19.1	46.3	242.5
1973	0.508	40	20.3	56.3	277.1
1974	0.664	47	31.2	63.5	203.5
1975	0.396	50	19.8	60.6	306.1
1976	0.338	47	15.9	44.6	280.8
1977	0.519	49	25.4	54.1	212.7
1978	0.428	45	19.3	51.5	267.4
1979	0.435	44	19.1	45.1	235.6
1980	0.458	45	20.6	62.6	303.7
1981	0.368	45	16.6	67.0	404.6
1982	0.469	47	22.0	72.9	330.7
1983	0.453	43	19.5	62.2	319.3
1984	0.453	43	19.5	62.2	319.3

Appendix Table 2. Some estimated population parameters from production model analyses of Appendix Table 1 data.

a) Estimated population parameters obtained from production model analysis for Atlantic bigeye tuna, 1961-1984, from Kume (1986), based on the full data set.

m (shape parameter)	Degree of fit index	(million hooks)	f-optimum Y-max (1,000 MT)	1981-84 Catch (1,000 MT)
variable	.528		145.7	
0	.528		145.9	62.2-72.9
1.00'	.524	631	76.1	
2	.518	421	66.5	

b) Other production parameters estimated from the full data set of Appendix Table 1.

Model type	MSY	FMSY
Schaefer (OLS)	61.3	361
Fox	61.8	518
Schnute regression (linear approximation)	70.4	424

c) Population parameters estimated from a reduced data set of ten years (1974-1983) from Appendix Table 1.

Model type	MSY	FMSY
Schaefer (OLS)	62.8	363
Fox	61.1	480
Schnute regression (linear approximation)	106.8	922

Appendix Table 3. A description of the Atlantic bigeye model and results from simulation run #1, based on the above model.

::::::::::::::::::::::::::::::::::::::

ATLANTIC BIGEYE Model

R = A(i) * (1-N(t)/L(i))

(1-[N(t-T(i))/K(i)]^Q(i)) + V(S)

where i = 1 when N(t) > E
and i = 2 when N(t) < E

R is the per-capita rate of increase, N(t) is the density of the population at time t, V is a random normal variate, and E is the escape threshold. (F10)
parameters of your model are

A	= the value of R at N = 0	=	5.6588E-01
K	= the equilibrium point	=	2.3331E+01
L	= the underpopulation effect	=	-1.0000E+06
Q	= the coefficient of curvature	=	8.924E-01
T	= the feedback time-lag	=	1

and the goodness of fit statistics are

S	= standard deviation	=	1.9288E-01
RSQ	= % of variation explained	=	28.6%

::::::::::::::::::::::::::::::::::::::

ATLANTIC BIGEYE Simulation
Data from Simulation # 1

Time	Density	Rate of Increase	Random Variation
0	3.7000E+01	-3.9639E-01	-1.0584E-01
1	2.4891E+01	6.7854E-02	1.0002E-01
2	2.6639E+01	3.0592E-01	3.7539E-01
3	3.6173E+01	-1.6033E-01	1.1257E-01
4	3.0814E+01	-3.8172E-01	-2.2317E-01
5	2.1036E+01	-1.6706E-01	-2.1716E-01
6	1.7800E+01	-1.2309E-01	-2.4225E-01
7	1.5738E+01	4.8022E-01	3.1707E-01
8	2.5440E+01	-2.2898E-01	-1.8510E-01
9	2.0234E+01	5.2990E-02	-1.4236E-02
10	2.1335E+01	-1.6090E-01	-2.0463E-01
11	1.8164E+01	4.2065E-01	3.0925E-01
12	2.7663E+01	-1.3905E-03	8.9915E-02
13	2.7624E+01	-2.1831E-01	-1.2783E-01
14	2.2206E+01	-8.1617E-02	-1.0675E-01
15	2.0466E+01	3.7791E-01	3.1564E-01
16	2.9865E+01	-2.2805E-01	-8.9759E-02
17	2.3775E+01	1.4349E-01	1.5182E-01
18	2.7443E+01	-2.4361E-01	-1.5700E-01
19	2.1510E+01	2.1617E-01	1.7617E-01
20	2.6700E+01	-3.2674E-01	-2.5598E-01
21	1.9258E+01	2.6946E-01	1.8141E-01
22	2.5213E+01	-2.2930E-02	1.6110E-02
23	2.4642E+01	9.0496E-02	1.1734E-01

Standard Deviation of Random Variable = 1.9288E-01

Appendix Table 4. Illustration of simulation runs of the Atlantic bigeye model at three levels of exploitation

```
==================================================================
          MANAGEMENT STRATEGY  1 for ATLANTIC BIGEYE
------------------------------------------------------------------
REMOVAL STRATEGY:
    25.00% of organisms removed when population >  6.0000E+00
    Number removed over    50 time periods          = 1.8610E+02
    Average removed per time period                 = 3.7220E+00
    Number of removal episodes                      =    50
    Proportion of time removals are made            = 1.000
------------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 1.1166E+01
    Number of dangerous episodes                    =   0
    Probability of danger (risk)                    =  0.00
==================================================================
```

```
==================================================================
          MANAGEMENT STRATEGY  2 for ATLANTIC BIGEYE
------------------------------------------------------------------
REMOVAL STRATEGY:
    30.00% of organisms removed when population >  6.0000E+00
    Number removed over    50 time periods          = 2.0175E+02
    Average removed per time period                 = 4.0350E+00
    Number of removal episodes                      =    50
    Proportion of time removals are made            = 1.000
------------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 9.4151E+00
    Number of dangerous episodes                    =   5
    Probability of danger (risk)                    =  0.10
==================================================================
```

```
==================================================================
          MANAGEMENT STRATEGY  3 for ATLANTIC BIGEYE
------------------------------------------------------------------
REMOVAL STRATEGY:
    35.00% of organisms removed when population >  6.0000E+00
    Number removed over    50 time periods          = 1.7472E+02
    Average removed per time period                 = 3.4944E+00
    Number of removal episodes                      =    47
    Proporti  ı of time removals are made           = 0.940
------------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                  =  50
    Mean population density                         = 6.8221E+00
    Number of dangerous episodes                    =  36
    Probability of danger (risk)                    =  0.72
==================================================================
```

Appendix Table 5. Data for 1974-1983 Atlantic bigeye tuna with relevant summary statistics. The parameters for the fitted linear R-function are shown in the lower panel of this table.

74-83 BIGEYE Data
Density per 100.00 CPUE

Time	Density	Rate of Increase
1	3.1200E+01	-4.5474E-01
2	1.9800E+01	-2.1936E-01
3	1.5900E+01	4.6843E-01
4	2.5400E+01	-2.7464E-01
5	1.9300E+01	-1.0417E-02
6	1.9100E+01	7.5603E-02
7	2.0600E+01	-2.1589E-01
8	1.6600E+01	2.8164E-01
9	2.2000E+01	-1.2063E-01
10	1.9500E+01	0.0000E+00

Mean response time: MRT = 1.3149E+00

Response time variance: VRT = 1.6423E+00

Mean period of oscillation: PER = 4.0000E+00

Mean amplitude of oscillation: AMP = 7.4167E+00

Mean density of population: MEAN = 2.0940E+01

74-83 BIGEYE Regression of R-function

Regression Intercept at N = 0:A(1) = 1.0550E+00

Equilibrium Point at R = 0: K(1) = 2.0104E+01

Lower Root of Function: L(1) = -1.0000E+06

Coefficient of Curvature: Q(1) = 1.0000E+00

Feedback Time-lag: T(1) = 1.0000E+00

Standard Deviation about Line: S = 1.5100E-01

Percentage Variation Explained:RSQ = 72.8%

Appendix Table 6. The parameters of the simulation model developed from the 1974-1983 Atlantic bigeye data. The lower panel illustrates the results of one simulation run with an exploitation rate of 30 percent.

74-83 BIGEYE MODEL PARAMETERS

The modeled R-function has a single equilibrium at	20.10
The R-function intercept at zero population density	1.05
The negative root of the function is	-1000000
The coefficient of curvature of the function is	1.00
The density-dependent time delay is	1
Percentage variation explained by density-dependence	72.84
Standard deviation of the density-independence is	0.15

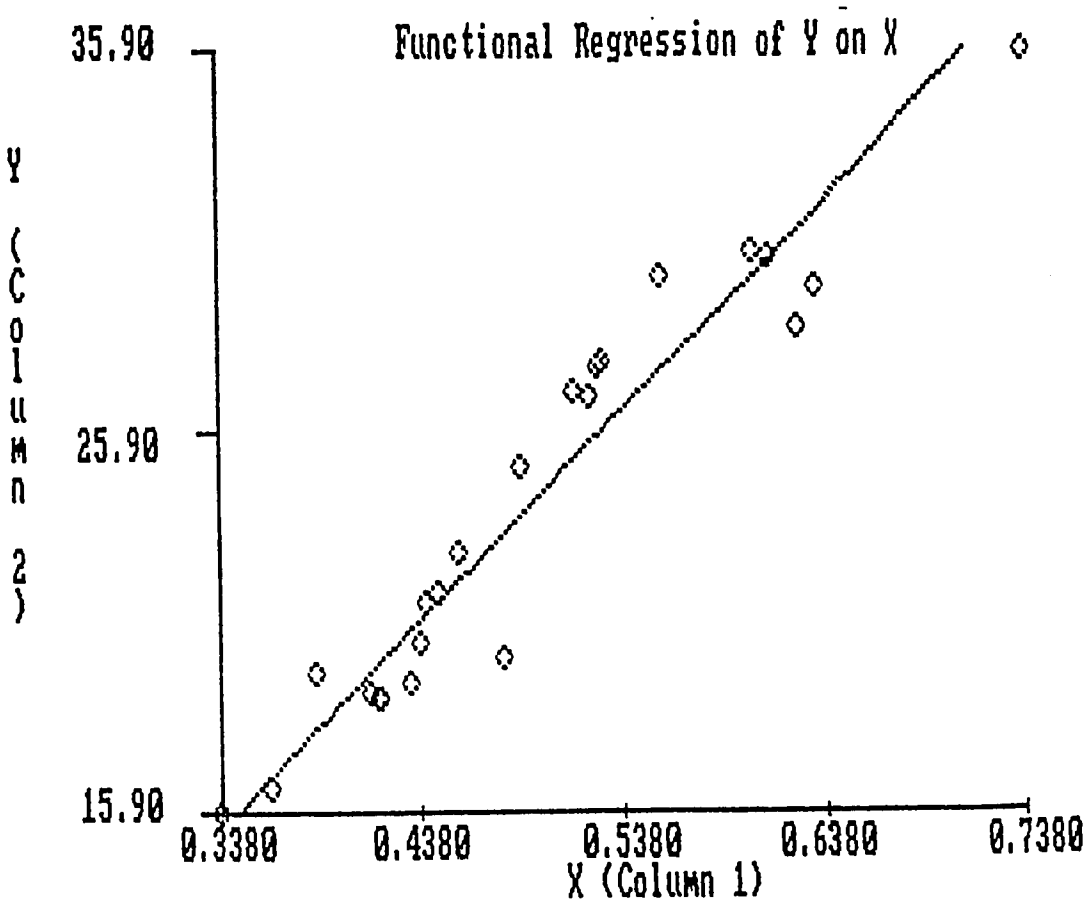
```
==============================================================
          MANAGEMENT STRATEGY  1 for 74-83 BIGEYE
--------------------------------------------------------------
REMOVAL STRATEGY:
    30.00% of organisms removed when population >  7.0000E+00
    Number removed over    50 time periods         = 2.8794E+02
    Average removed per time period                = 5.7588E+00
    Number of removal episodes                     =   50
    Proportion of time removals are made           = 1.000
--------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 1.3437E+01
    Number of dangerous episodes                   =   0
    Probability of danger (risk)                   =  0.00
==============================================================
```

Appendix Table 6. (continued) The results of two other simulated management strategies for Atlantic bigeye based on the 1974-1983 data.

```
==================================================================
          MANAGEMENT STRATEGY  2 for 74-83 BIGEYE
------------------------------------------------------------------
REMOVAL STRATEGY:
    40.00% of organisms removed when population >  7.0000E+00
    Number removed over     50 time periods        = 3.3208E+02
    Average removed per time period                = 6.6416E+00
    Number of removal episodes                     =    50
    Proportion of time removals are made           = 1.000
------------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 9.9624E+00
    Number of dangerous episodes                   =   4
    Probability of danger (risk)                   =  0.08
==================================================================
```

```
==================================================================
          MANAGEMENT STRATEGY  3 for 74-83 BIGEYE
------------------------------------------------------------------
REMOVAL STRATEGY:
    35.00% of organisms removed when population >  7.0000E+00
    Number removed over     50 time periods        = 3.1615E+02
    Average removed per time period                = 6.3229E+00
    Number of removal episodes                     =    50
    Proportion of time removals are made           = 1.000
------------------------------------------------------------------
POPULATION DYNAMICS:
    Total length of simulation run                 =  50
    Mean population density                        = 1.1743E+01
    Number of dangerous episodes                   =   0
    Probability of danger (risk)                   =  0.00
==================================================================
```

Appendix Figure 1. Linear functional regression of Kg/100 holes (y) on hook rate, No./100 hooks (x) for Atlantic bigeye tuna. Data from Kume (1986). Other descriptive statistics are provided.



Descriptive Statistics:

Mean of X	.5260436	Mean of Y	24.50869
Std dev of X	.1178907	Std dev of Y	5.660543
Correlation (r)	.9613879	N observations ...	23
Covariance	14.11429		

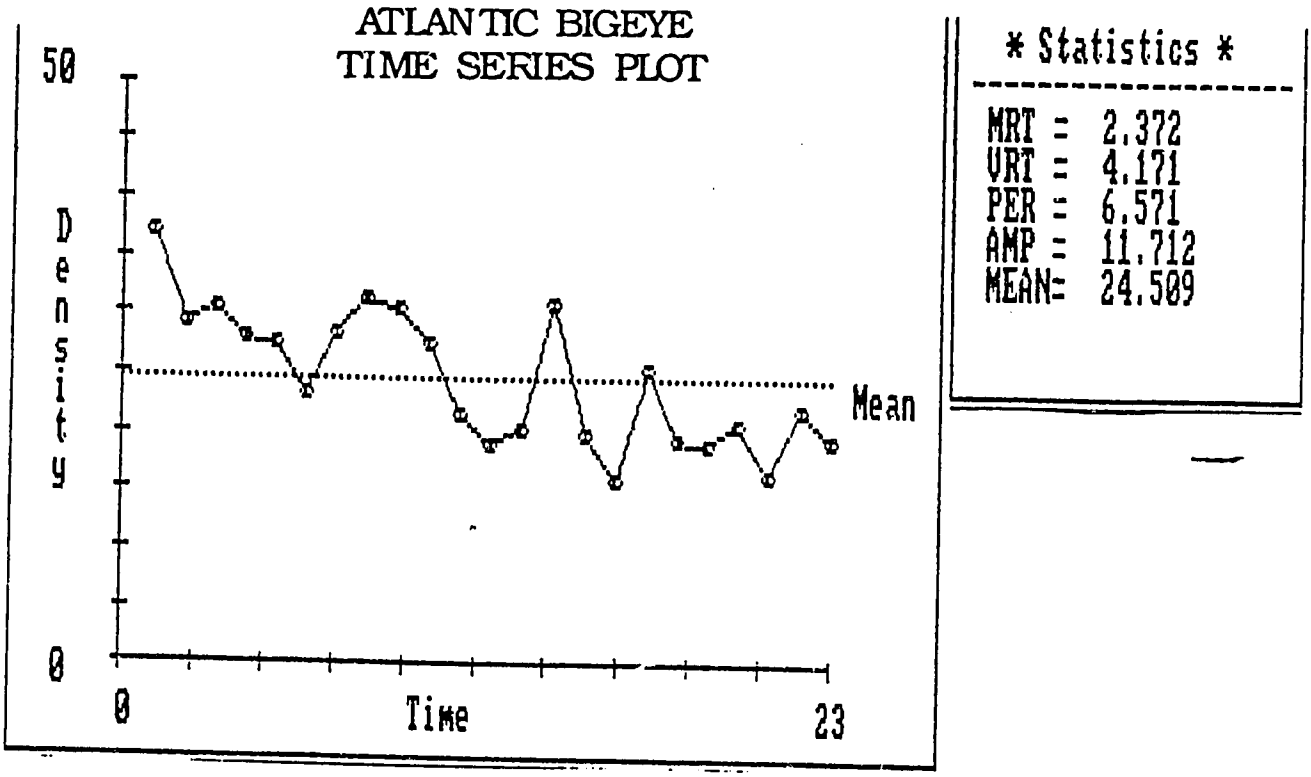
Functional Regression:

Slope (B) of the regression	48.01516
Intercept (A)	-.7493706
St error of the slope	2.88345
St error of the intercept	2.024564

Least-Squares Regression:

Y-intercept (A) of Y on X	.2258988
Slope (B) of Y on X	46.16119
Y-intercept (A) of X on Y	3.531596E-02
Slope (B) of X on Y	2.002259E-02
St error of the slope of Y on X	2.88345

Appendix Figure 2. Atlantic bigeye tuna time series plot (all data) and derived statistics based on data from Kume (1986).



ATLANTIC BIGEYE Data
Density per 100.00 HOOK RATE

Time	Density	Rate of Increase
1	3.6800E+01	-2.2791E-01
2	2.9300E+01	4.6675E-02
3	3.0700E+01	-8.4941E-02
4	2.8200E+01	-2.5136E-02
5	2.7500E+01	-1.7435E-01
6	2.3100E+01	2.0656E-01
7	2.8400E+01	1.0042E-01
8	3.1400E+01	-3.2365E-02
9	3.0400E+01	-1.0390E-01
10	2.7400E+01	-2.3323E-01
11	2.1700E+01	-1.2762E-01
12	1.9100E+01	6.0932E-02
13	2.0300E+01	4.2980E-01
14	3.1200E+01	-4.5474E-01
15	1.9800E+01	-2.1936E-01
16	1.5900E+01	4.6843E-01
17	2.5400E+01	-2.7464E-01
18	1.9300E+01	-1.0417E-02
19	1.9100E+01	7.5603E-02
20	2.0600E+01	-2.1589E-01
21	1.6600E+01	2.8164E-01
22	2.2000E+01	-1.2063E-01
23	1.9500E+01	0.0000E+00

Mean response time: MRT = 2.3723E+00

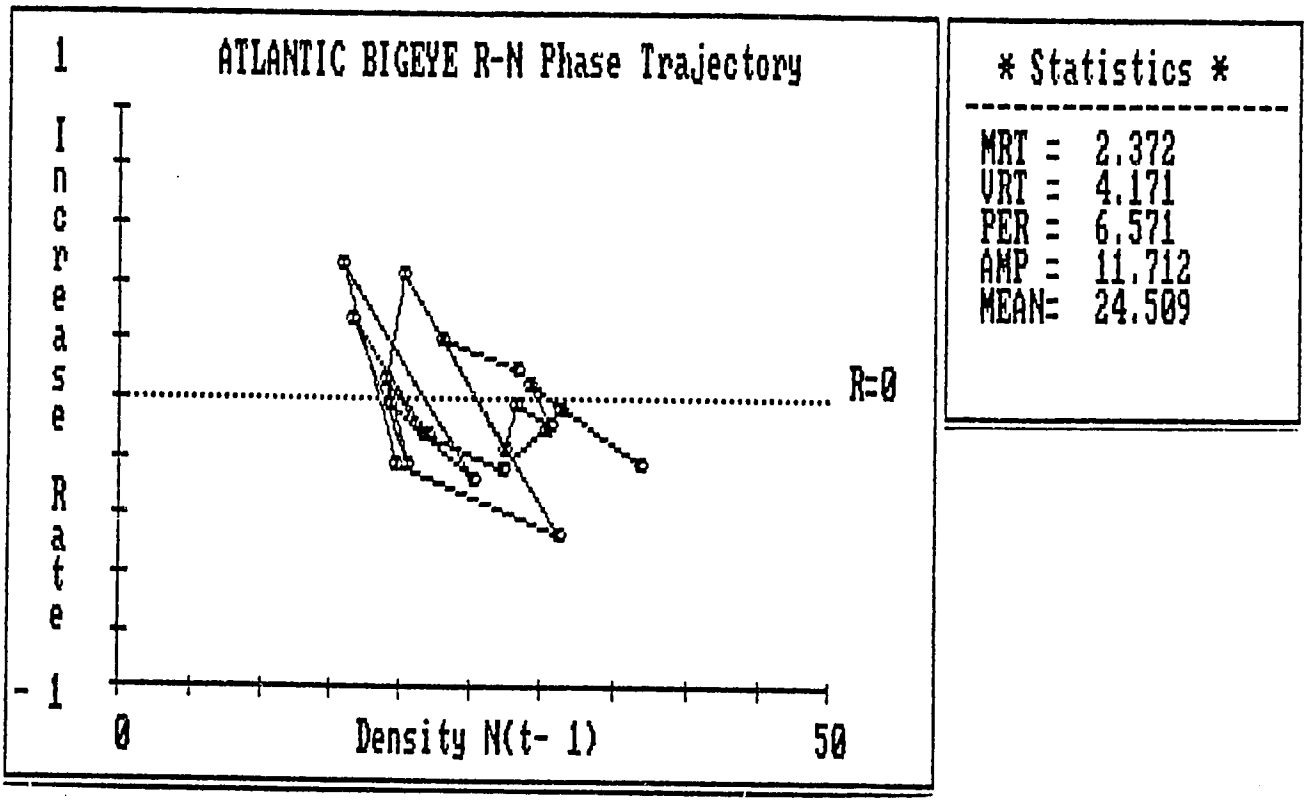
Response time variance: VRT = 4.1705E+00

Mean period of oscillation: PER = 6.5714E+00

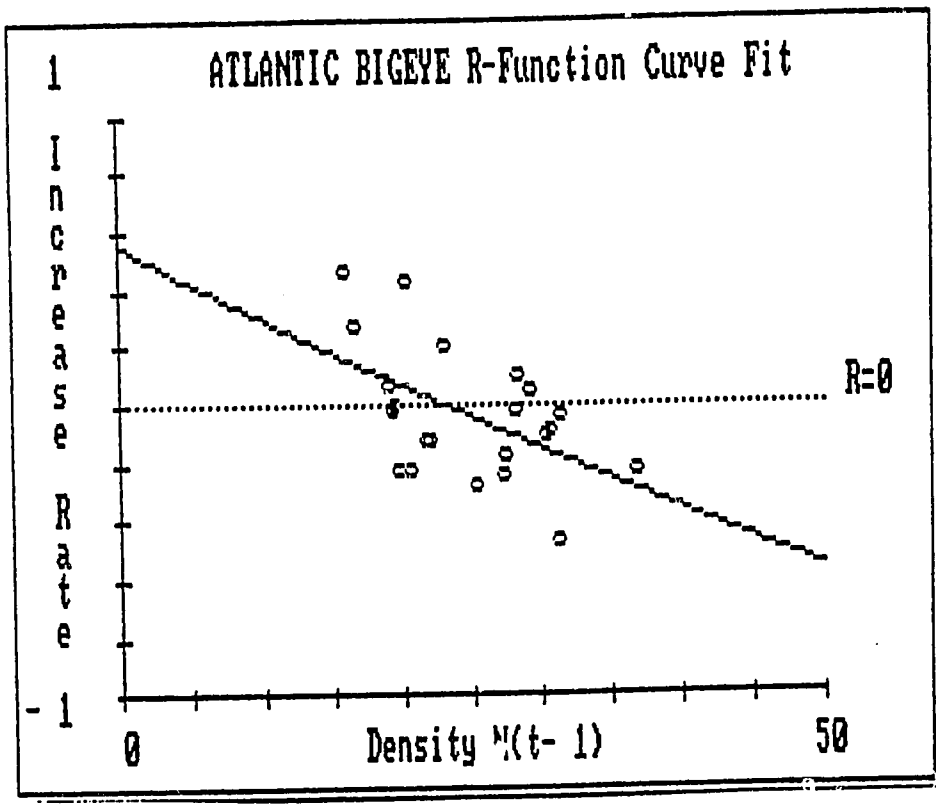
Mean amplitude of oscillation: AMP = 1.1712E+01

Mean density of population: MEAN = 2.4509E+01

Appendix Figure 3. Atlantic bigeye phase-trajectory from empirical data.



Appendix Figure 4. The R-function curve fit for Atlantic bigeye tuna. A non-linear equation was fitted to these data.

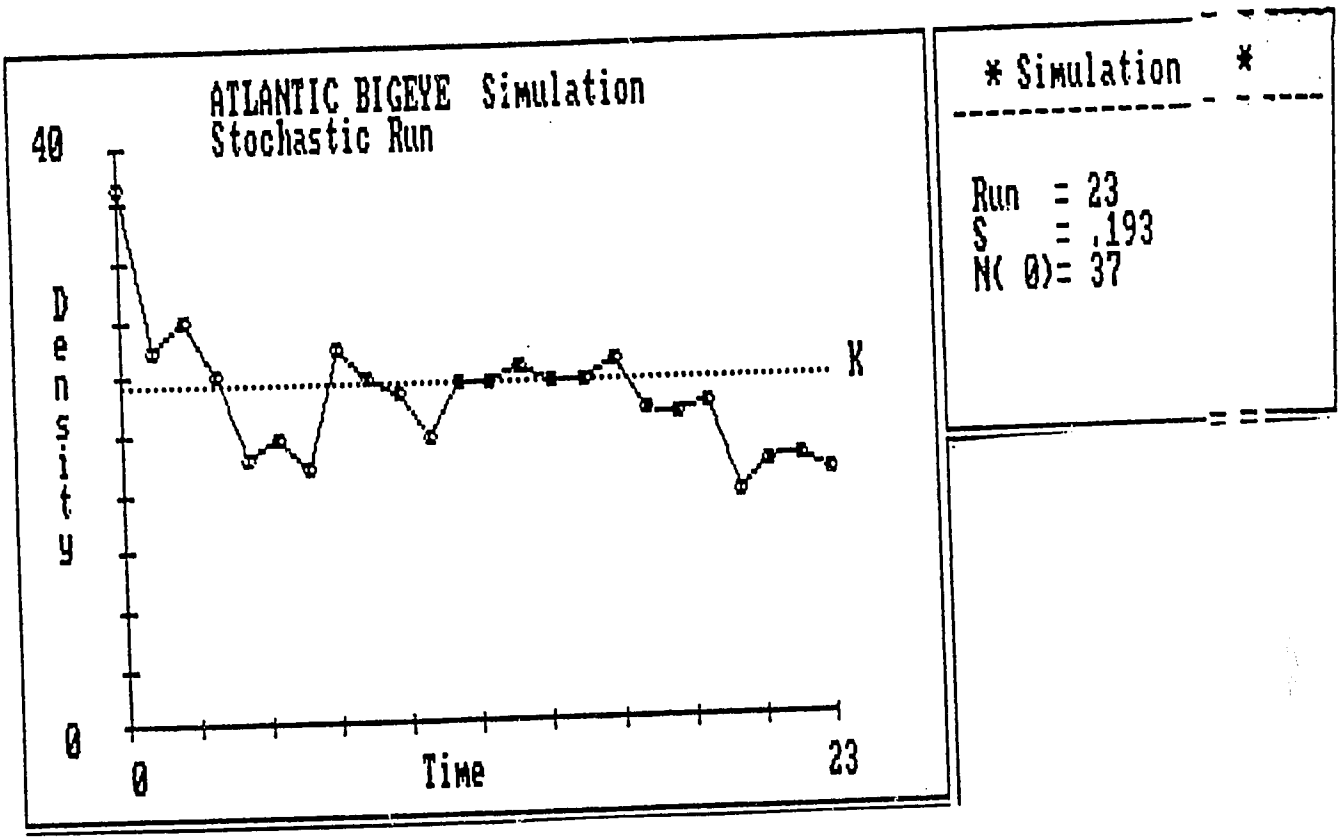
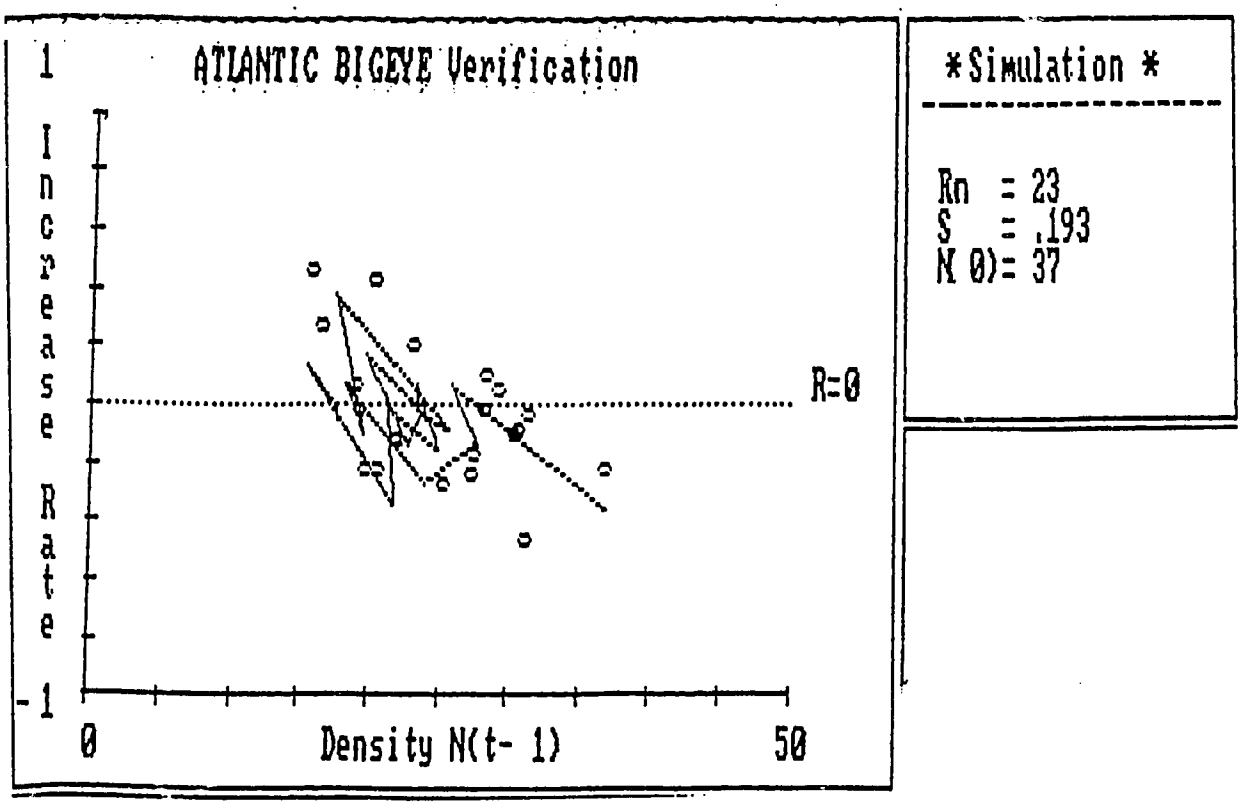


* Statistics *

A = .566
K = 23.331
L = -1000000
Q = .892

RSQ = 28.579
DRS = .098

Appendix Figure 5. Results of a stochastic simulation of Atlantic bigeye tuna based on empirically derived parameters.



Appendix Figure 6. Phase portrait from the simulation run for Atlantic bigeye tuna.