A SIMULATION BIO-ECONOMIC MODEL APPLICATIONS FOR FISHERY MANAGEMENT INTRODUCING UNCERTAINTY

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ABSTRACT

Simulation bio-economic models are powerful tools to understand the impact of exogenous factors, natural or economic, on fisheries dynamics and to help decision making in fisheries management.

We have developed a model with three components (resource, fleet and management) which is especially oriented to analyse the impact of different management policies, in deterministic or stochastic context.

This model is not used for optimisation (maximisation of an objective variable), but to analyse the response of many state variables (biomass, economic results, catch) in response to current and passed decisions.

This model is particularly adapted to explore bias situations (economic or biological). A friendly PC software has been developed and will be presented. Simulations can be easily run for fishery dynamics analysis and management policy evaluation, in relation with different sets of hypothesis.

KEYWORDS : simulation, bio-economic model, resource, fleet, management.

ABSTRAK

Model-model simulasi bio-ekonomi merupakan alat yang cukup berguna untuk memahami dampak dari berbagai faktor"exogenous" alami atau ekonomi, terhadap dinamika perikanan dan untuk membantu dalam penentuan keputusan dari manajemen perikanan.

Kami telah mengembangkan sebuah model dengan tiga komponen (sumber daya, armada dan manajemen) yang secara khusus ditujukan untuk menganalisis dampak dari berbagai kebijakan pengelolaan dalam konteks deterministik ataupun stokastik.

Model ini tidak dipergunakan untuk optimisasi (maksimisasi dari suatu variabel obyektif), tetapi ia ditujukan untuk menganalisis respon dari sejumlah status variabel (biomassa, hasil-hasil ekonomi, hasil tangkapan) dan hubungannya terhadap berbagai keputusan yang sedang dijalankan maupun yang telah berlalu.

Model ini terutama diadaptasikan untuk menelaah situasi-situasi disekilibrium (secara ekonomi atau biologi). Suatu perangkat lunak PC yang mudah dioperasikan telah dikembangkan dan akan disajikan. Beberapa simulasi dapat dengan mudah dijalankan untuk menganalisis berbagai dinamika perikanan dan untuk evaluasi kebijakan manajemen, kaitannya dengan berbagai rangkaian hipotesa yang berbeda.

KATA KUNCI : Simulasi, model bio-ekonomi, sumber daya, armada, manajemen.

PRESENTATION OF THE MODEL

We have developed a bio-economic model oriented to the representation and analysis of the relationships between natural capital (biologic resource) dynamics and the dynamics of the economic activity exploiting that resource. This model was developed using the traditional framework for standard bio-economic modelling (Anderson, 1977; Clarck, 1985; Hannesson, 1978; Revéret, 1991). It is a mono-specific single-gear model. Despite these limitations, such models may be very useful to understand fishery dynamics and assess management policies. Such models are also a useful tool to combine different disciplinary approaches (biological and economic) and to analyse the viability conditions of fisheries in their natural and economic dimensions.

CHARACTERISTICS OF THE MODEL

The economic activity is represented in a quite simple way, through a variable called « fishing effort » in the same way it is used by fisheries biologists (nominal effort). The model is running on a year time step (though shorter time step relationships are taken in account in the biological part of the model).

This model has the following main characteristics :

- It is not an optimisation model. It does not determine the best possible solution for a given objective variable (for example economic rent) in relation with economic and biologic constraints. This model is aimed to fishery simulation and management policies analysis.
- It is not an equilibrium model from the economic or biologic point of view. The fishery dynamics is first characterised by the possibility of short and long term bias which can - or can not - be resorbed and converge to stability points.
- This model includes an endogenous dynamics of nominal fishing effort related to resource abundance, past economic results and current management decisions.
- Yearly management decisions can be simple (only one tool used) or complex (many tools used at the same time).

STRUCTURE OF THE MODEL

The principal relationships used in a year simulation cycle are presented in Figure 1. This model has three main components :

1- An economic component which includes :

- the relations between quantities and prices. The demand functions are linear; horizontal (i.e. prices and demanded quantities are independent) or downward sloping (demanded quantities are decreasing when prices are increasing). Other price mechanisms may be included, for instance the linkage between size of fish and price, which may be more relevant for particular fisheries (i.e. shrimp and industrial tuna fisheries);
- the cost function which may be linear (in term of effort), as in most bio-economic models, or non-linear (when the cost of labour is determined by a sharing system, and then proportional to the net incomes of fishing units);
- the determination of private profit (difference between private revenues and costs) and economic rent (private profit corrected for taxes/subsidies and other transfers between private firms and state);
- the entry-exit function for the fleet (economic capital dynamics). The velocity of the fleet dynamics is related to past economic results (during the last year or the fours past years) and to a sensibility coefficient.

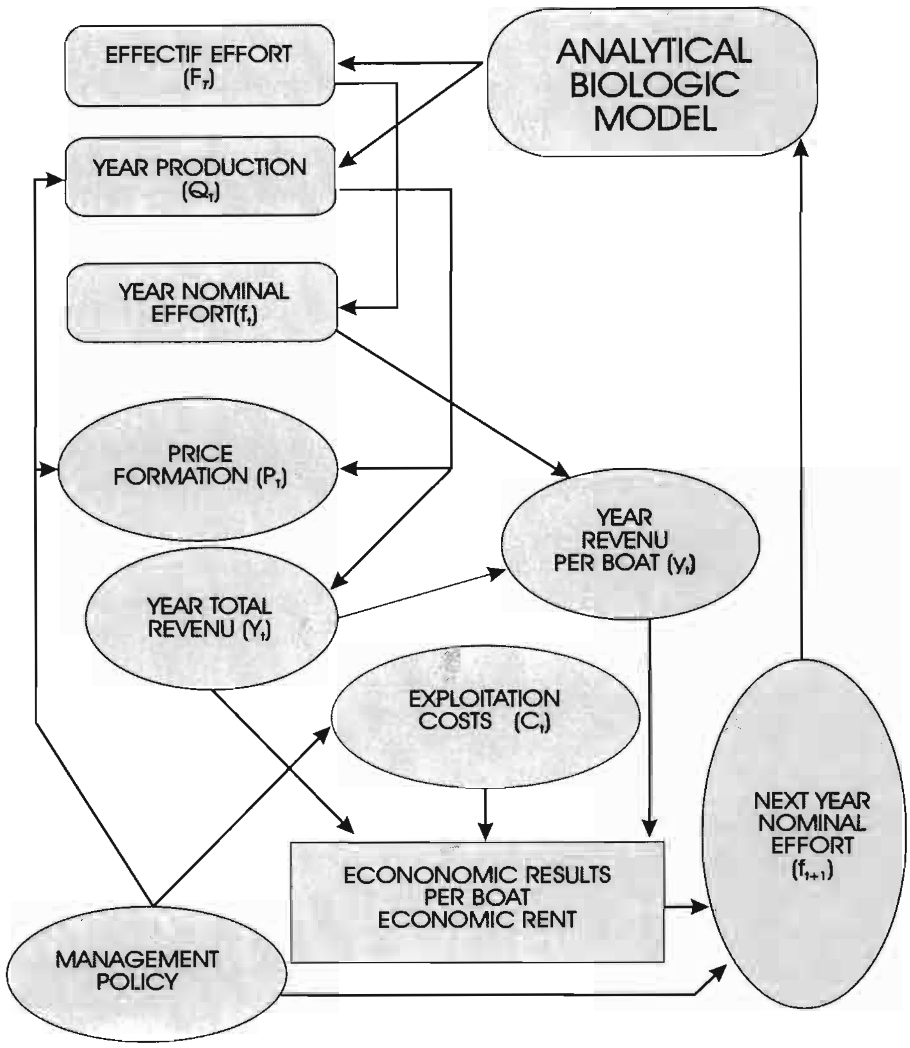

Figure 1 : Principal relations in a year simulation cycle
Hubungan-hubungan utama dalam kurun simulasi setahun

2- An analytical biological model which includes :

- the growth function (Von Bertalanfy equation);
- the total and fishing mortality equations (with a constant M per age);
- the catch equation;
- the recruitment equations : two types of relationships are available. The first is the Ricker (1980) equation which supposes a relation between fecund biomass and recruitment. The second possibility is constant recruitment (indendance between fecund biomass in year t and recruitment in year t+1);
- the evolution of the age structure of the fish stock from year to year.

3- A management module including the following tools :

- taxes/subsidies which may be proportional to fishing effort or proportional to catch;
- fleet size (maximum fleet size or fixed fleet size);
- annual total quota;
- price intervention (minimum price level);
- gear control (mesh size control).

This model has been developed in a personal computer software where different menus allow to define simulation parameters and to choose management decisions for every year of simulation.

DETERMINISTIC AND STOCHASTIC APPROACHES

Most fisheries are characterised by risks and uncertainties, related to the natural environment (which, for instance, contributes to recruitment success and then to resource abundance for the following years) as well as to socio-economic conditions (input prices and availability, market conditions). Management oriented simulation models have to introduce risk and uncertainty, especially for small pelagic fisheries, characterised by high levels on instabilities, especially when recruitment success is related to upwelling conditions (Cury and Roy, 1991).

The model has been developed in a deterministic way. In that case, simulation produces outputs (for non critical values of parameters) similar to the « classical » results of standard models. Open access fisheries are characterised by a convergence to the open access equilibrium and economic rent dissipation. For critical values of some economic parameters, deterministic simulations may lead to non equilibrium dynamics (limits cycles, chaotic behaviour). Chaotic behaviour may come from price formation or from the sensibility of fishing effort to past economic results.

Stochastic simulations are obtained by introducing white noise disturbances in some important relations in the model : demand or cost functions, recruitment equation. The method used to introduce stochastic elements (frequency and magnitude of stochastic events) is presented in Annex. The parameters used to calibrate the stochastic terms can be tuned as to obtain statistical distribution close to observed data.

SIMULATION OBJECTIVES

This model can be used for many goals :

• It allows to represent the fishery dynamics (on its economic and biologic sides) in relation with the initial values of the simulation parameters. It is possible to obtain the « classical » curves of the standard bio-economic theory and exploited population dynamics. It is then possible to determine the range of parameters which may lead to stable equilibrium but also to limit cycles, divergent cycles, chaotic unpredictable behaviour. The simulation outputs give a precise view of the evolution of economic variables (catch, revenues, private profit, economic rent, number of boats, transfers between private agents and state) and stock dynamics variables (number of individuals by age class, recruitment, fecund biomass, total biomass).

• It allows to evaluate the effects of many different management decisions, implying the following tools : taxes/subsidies, control of fleet size, age at first capture trough gear control, price intervention. One of the advantages of this model is to show the time lag between management decisions and their consequences. It permits also to see the different consequences between short and long term. For instance conservative decision (mesh size control) for long life species (for instance cod or bluefin tuna) have an immediate negative effect on private profits but positive effects on stock and economic results may only arise after many years.

• It allows also to analyse the consequences of different types of variability (economic or environmental). Efficiency of different management tools facing uncertainty can then be assessed, in relation with the values of biological and economic simulation parameters. The method used to determine the frequency and range of stochastic events is exposed in Annex .

CALIBRATION OF MODELS AND DATA NEEDS

The calibration of the model with observations from a real fishery is not still realised. Data needs on fish biology and stocks dynamics are quite important. A good biological research has to be done before implementing such a model. Analytical models need not only fishery data (on catch and effort), but also information about growth, stock-recruitment relation and other biological aspects. That kind of model is more data consuming than surplus production models. Concerning the economic side of the model, data needs are similar to those of classical bio-economical models. Cost and earning surveys have to the done to calibrate the cost function. Market analysis is necessary to evaluate price elasticity and demand functions. The dynamics of investment in the fishery, in response to past economic results has also to be analysed to evaluate the sensibility coefficient of the entry/exit functions and possible lag effects. Such models can then be only used for the real management of very well known fisheries. In the case of poor data quality or lack of information on some important economic or biologic component of the fishery, a sensibility approach can be used to analyse the response of the fishery dynamics

SIMULATIONS EXAMPLES

We propose here two simulations. The first is a deterministic simulation of a small pelagic fishery (semi-industrial seiners fishing for sardinellas). The second is an industrial tuna fishery with variability in resource abundance due to a stochastic component in annual recruitment.

A deterministic example

The first example shows the impact of different management policies, in a deterministic context, on the evolution of a small pelagic fish coastal fishery. Figure 2 presents the dynamics of three state variables (catch, stock biomass and fleet) over a 100 years simulation. Figure 3 presents the results of same simulation for the stock recruitment relationship, the demand and supply (long run average cost) plot, the relationship between fecund biomass and fishing fleet.

The consequences of two types of management tools are shown :

- Conservation measures through mesh size control : in year 35, an increase of mesh size permits the age of first capture (t_c) to increase from 1.5 to 2 years. t_c goes back to 1.5 at simulation period 77.
- Increase in price (public intervention of fish market) to improve fishermen incomes, especially for fisheries exploiting abundant species and when market structures are highly sensible to catch increases. For instance intervention prices are used in EU countries for the most common low price species. A minimum price level equal to 150 is used at year 61.

The consequences of the two types of management decisions are in conformity with the classical results of bio-economic theory. An increase of age of first capture (t_c) from 1.5 to 2 leads to a new bio-economic (from E_1 to E_2 on Figure 3) equilibrium with a small increase of the catch but also a substantial improvement in the resource biomass. The introduction of a minimum price of 150 in year 61 leads to a new shift of equilibrium from E_2 to E_3 (very small increase of the catch, quite important increase of effort and then of average cost, small decrease of resource abundance). The last decision which consists in lowering t_c to its initial value (1.5) leads to a new equilibrium E_4 close to E_1. The observed differences for biomass and fishing effort between E_1 and E_4 are due to the difference in price (150 vs. 120).

A more interesting aspect underlined in this simulation is the time lag between a decision and the achievement of a more desirable equilibrium. For instance the increase in t_c in year 35 has a full effect (improvement in biomass level) only 15 years later. The immediate effect is a drastic decrease of total catch and the consequent exit of many fishing units from the fishery. This result underlines an important aspect often ignored in static management models : the importance of time lags and the difference between long term decision effects and immediate consequences. In developing countries, fishery managers and fishermen are characterised by myopic behaviours and thus are more concerned with short term impacts than with long term consequences.

A stochastic example

The second example is the dynamics of an industrial tropical tuna fishery. Uncertainty in the dynamics of the natural resource is due to the existence of a « white noise » in the stock-recruitment relationship (SSR). The simulated SSR is shown in Figure 6.

This example is mainly oriented to analyse the impact of this type of stochastic effects on the endogenous fishery dynamics than to assess the impact of management decisions.

The dynamics of total catch over 200 years is shown in Figure 4. The histogram on the same Figure shows the statistical distribution of total catch.

If we ignore the simulation of the 30 first years (which can be considered as the development and stabilisation stages of the fishery dynamics), it can be seen that total catch varies between 130,000 and 250,000 MT. Such a result can be used for explanatory risk analysis, in relation with the simulated economic results of the fishery (not shown here). The statistical distribution for recruitment and fecund biomass (Fig. 5) are also important elements to take in account for risk analysis if conservation objectives are considered relevant by policy makers.

Figure 6 shows the size and age structure of each year cohort during the first twenty simulation years. It helps to understand how recruitement variability does influence the level and structure of exploited population over many years. It shows also how resource age structure is modified during the development stage of the fishery. The number of old fishes (more than four years old) is rapidly decreasing.

CONCLUSION

This presentation of this bio-economic simulation model is aimed to underline its general characteristics and main outputs. Despite the frequent critics against bio-economic models, we consider they still are interesting ways to analyse fisheries dynamics (not only to optimise fisheries). The availability of powerful softwares allows to produce simulation models related to specific hypothesis about fisheries structures and functioning. Such type of modelling can help to obtain and evaluate new tools to help decision-making in fisheries. The importance of precautionary approach in fishery management gives more importance to risk analysis. Stochastic simulation is then a very useful tool to more explicitly include risk and uncertainty in the dialogue between decision makers and researchers.

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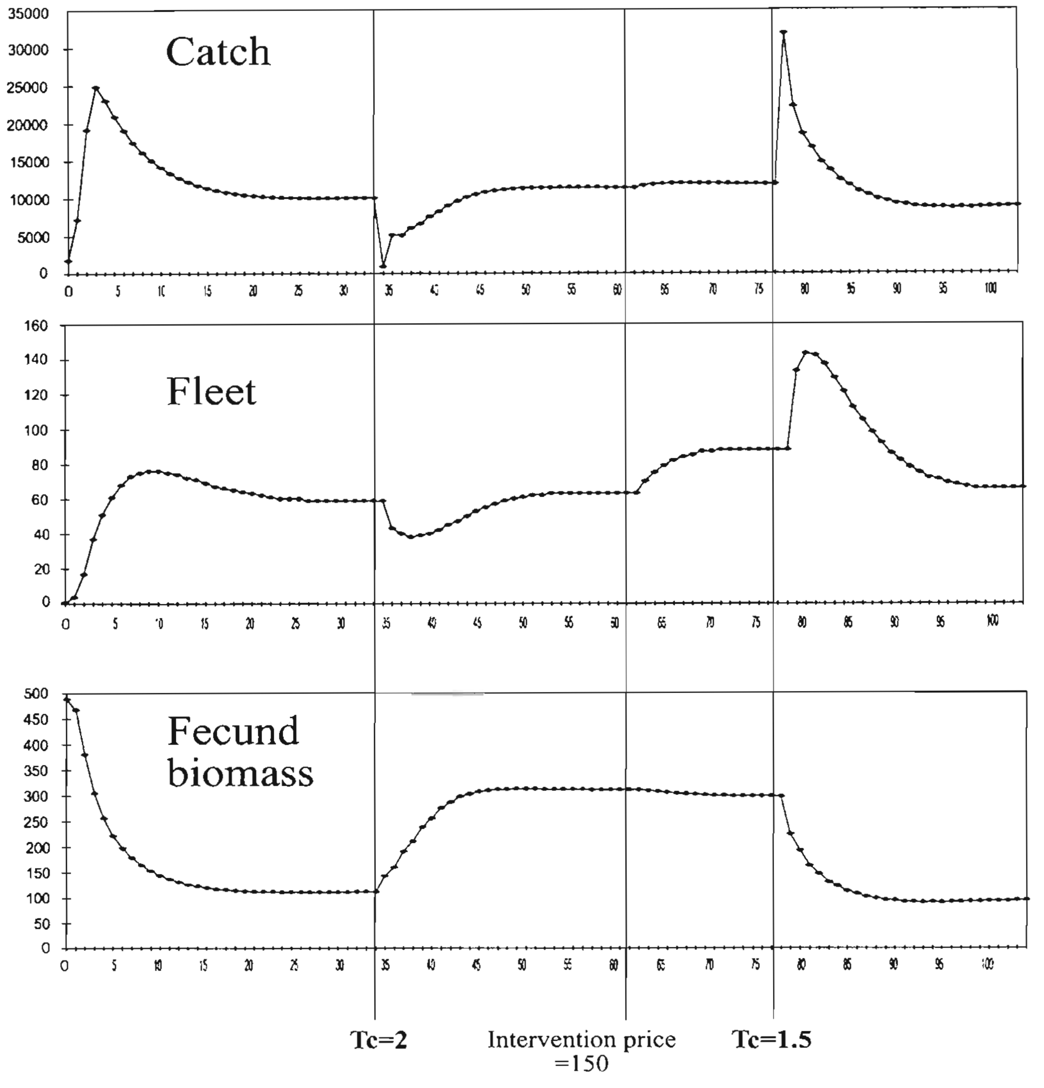


Figure 2 : Deterministic simulation of a small pelagic fishery : catch, fleet and fecund biomass dynamics over 100 time periods

Simulasi deterministik dari suatu perikanan pelagis kecil : armada, kelimpahan biomassa yang berubah lebih dari 100 periode waktu

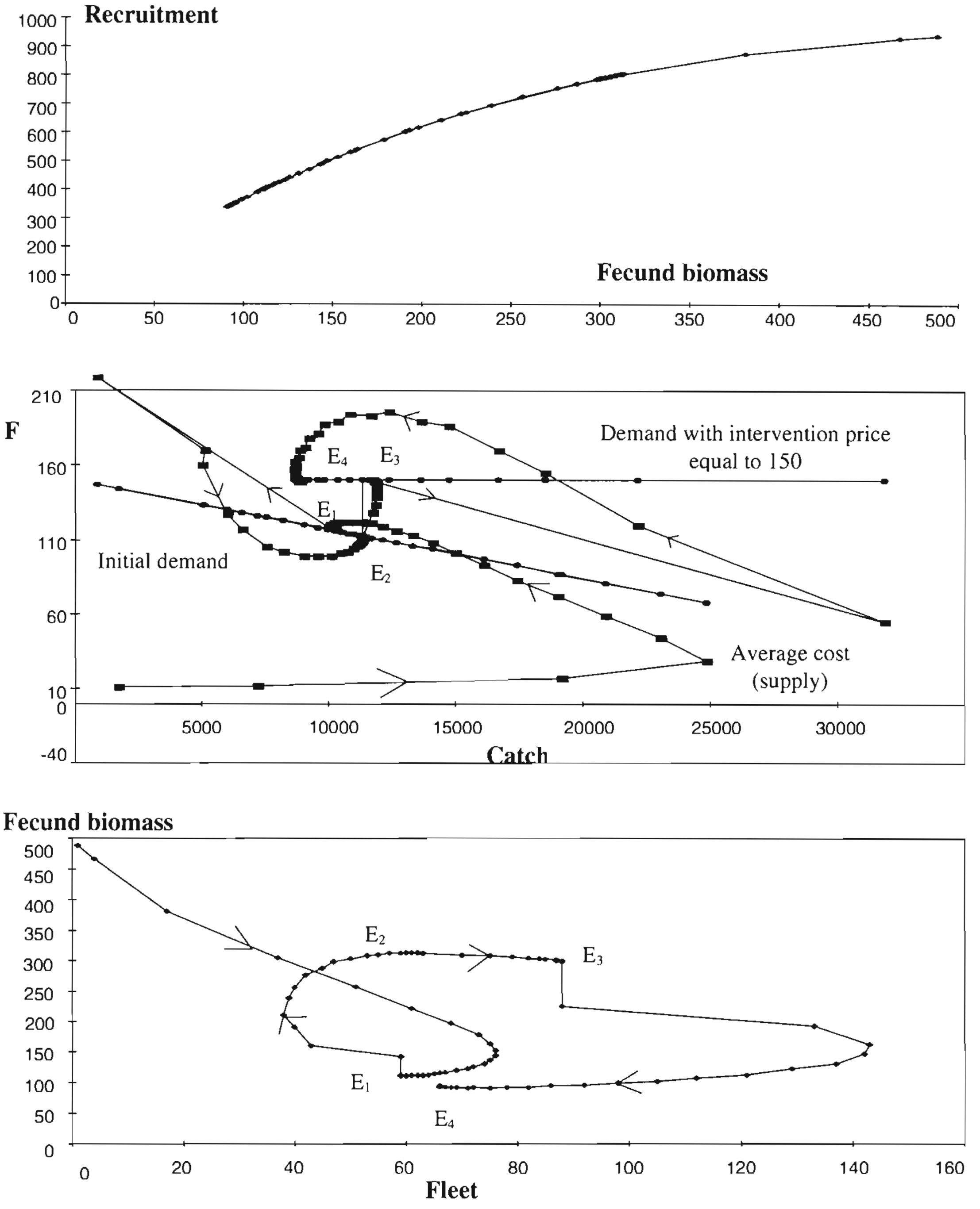


Figure 3 : Deterministic simulation of a small pelagic fishery : bi-plots of some important relationships : (1) S/R relation, (2) supply and demand, (3) biomass and effort.
Simulasi deterministik dari suatu perikanan pelagis kecil : bi-plot beberapa hubungan penting : (1) hubungan S/R, (2) penawaran dan permintaan,(3) biomassa dan upaya penangkapan

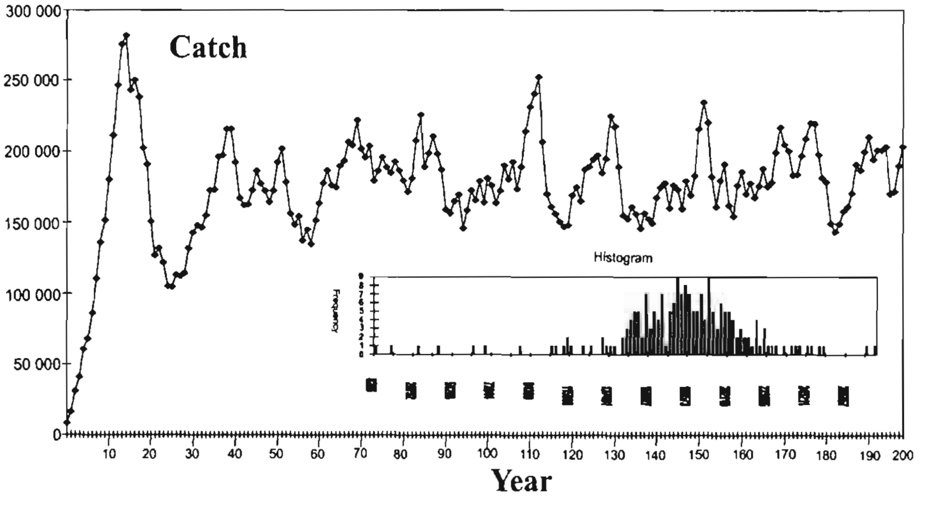


Figure 4 : Stochastic simulation of a tuna fishery : catch time plot and histogram
Simulasi stokastik dari suatu perikanan tuna : plot waktu penangkapan dan histogram

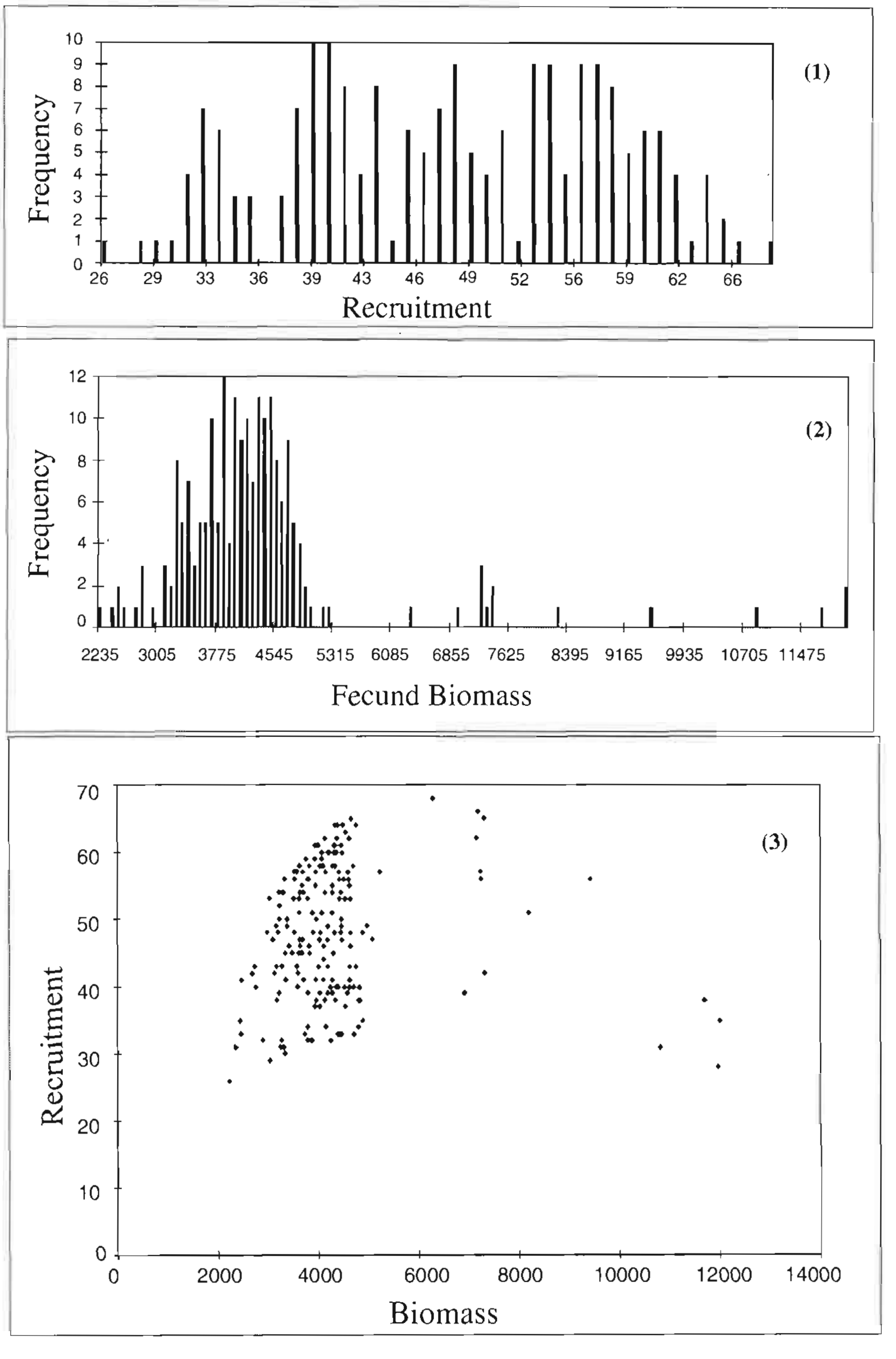


Figure 5 : Stochastic simulation of a tuna fishery : histograms of recruitment (1) and biomass (2), S/R relation (3)
Simulasi stokastik dari suatu perikanan tuna : histogram rekrutmen (1) dan biomassa (2), hubungan S/R (3)

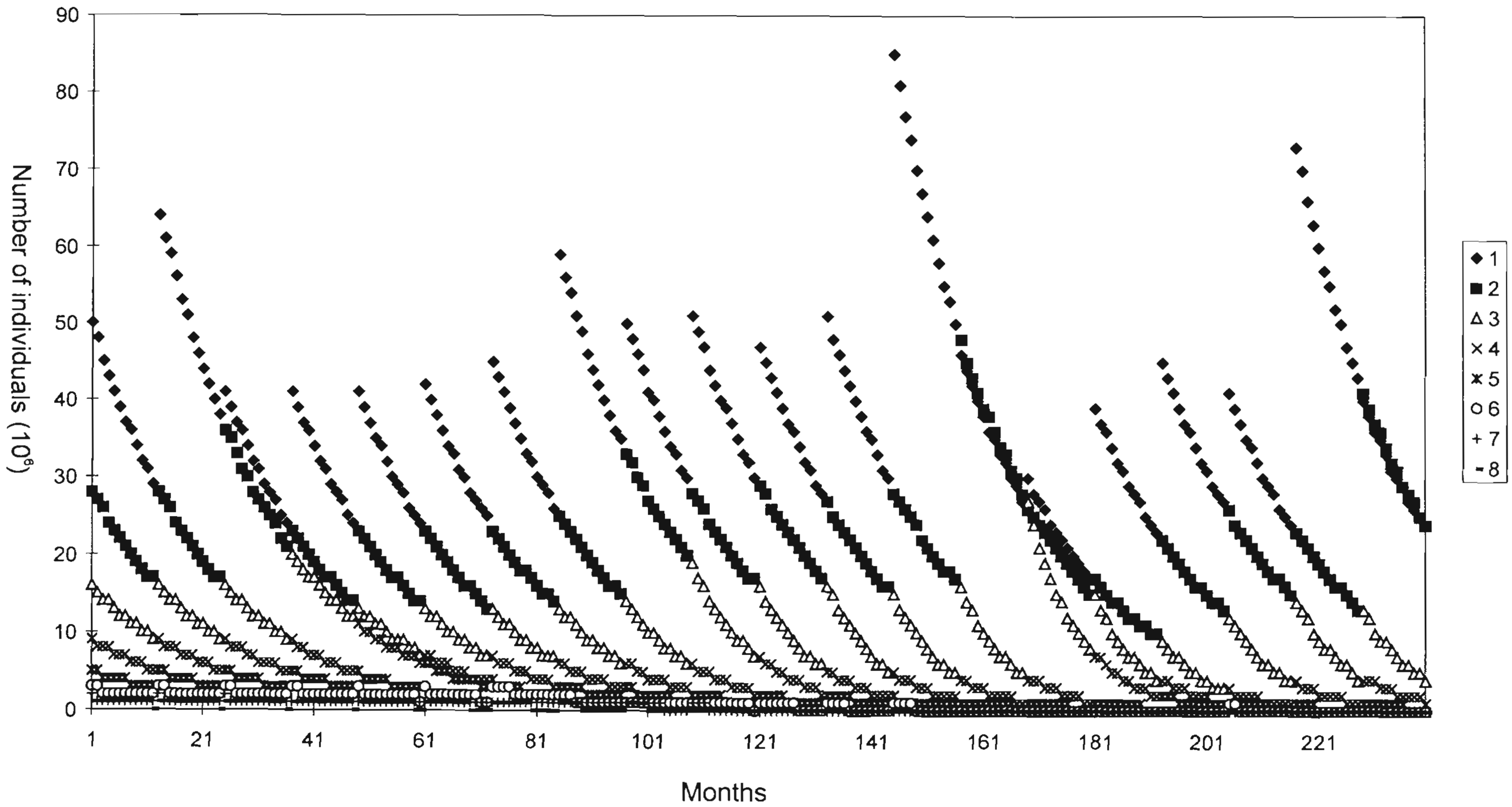


Figure 6 : Stochastic simulation of a tuna fishery : cohort-sizes during the first twenty simulation years

Simulasi stokastik dari suatu perikanan tuna : ukuran kelas umur selama 20 tahun pertama masa simulasi

ANNEX

INTRODUCTION OF STOCHASTIC PARAMETERS IN THE MODEL.

Time occurrence of stochastic events during simulation is determined by a parameter $B \in [1,10]$. For each time period t, a random number $a_t \in [0,1]$ is obtained from a uniform statistical distribution. The solution used to determine if there is a stochastic event during year t is the following :

- if $a_t < 1/B$, there is a stochastic event in year t.
- If B is equal to 10, the probability of occurrence of a stochastic event is 1/10, and 1/5 if B = 5.

The average range of the stochastic terms is determined by a parameter $C \in [1,10]$. During each simulation period a random number $b_t \in [0,1]$ is obtained from a uniform distribution. b_t is then multiplied by a number with can take one of the two values 1 or -1 with equal probabilities 0.5.

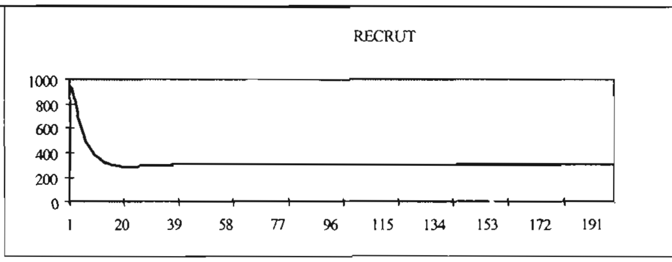
The stochastic factor A_t is then obtained using the formula : $A_t = 1 + b_t / C$

A_t has a uniform distribution, with mean 1.Application to recruitment

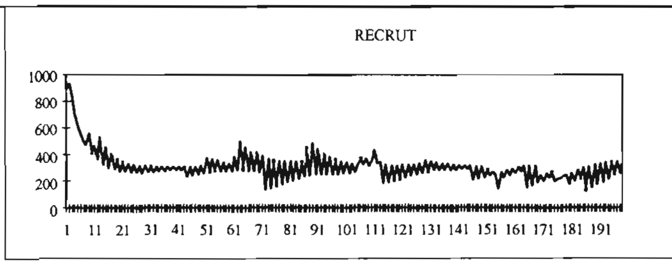
At the beginning of each simulation period the deterministic recruitment R_t, obtained form fecund biomass at the previous period, is introduced in the model. The effective recruitment R_t taken in account in year t will then be equal to $R_t.A_t$.

The dynamics of recruitment over time for different simulations characterised by different values of B and C parameters is shown below :

Non stochastic component



$B = 5$
$C = 2$



$B = 1$
$C = 1$