10. Prototype of an integrated model of the worldwide system of small pelagic fisheries

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INTRODUCTION: THE WORLDWIDE SYSTEM OF SMALL PELAGIC FISHERIES

We consider the 'worldwide system of pelagic fisheries' as the main pelagic fish resources, the main pelagic fisheries, the main markets for the products (canned fish, fishmeal, fish oil and fresh fish), the human factors (fishers, managers, fishery biologists, conservationists, and so on) and the bioeconomic and political interactions of these components (Figure 10.1). Marine fisheries exploiting small pelagic fish (for example anchovy, sardine, herring) produced some 34 million tonnes per year over the period 2000–2003, 53 per cent of the world's marine fish catch (excluding molluscs, crustaceans and elasmobranches). Pelagic fisheries are found in all oceans, mainly on the East coasts of continents and often related to upwelling processes (Table 10.1). The catch is used to produce fishmeal, canned fish, fish oil, fresh fish and smoked fish (Table 10.2). Important changes are anticipated for the fishmeal and oil markets during the present decade (Table 10.3).

Catches of anchovy and sardine (local, regional and global) are highly variable and prone to massive peaks and troughs (Csirke, 1988; Fréon and Misund, 1999; Schwartzlose *et al.*, 1999). Recent analyses of small pelagic fisheries have generally concluded that neither fishing pressure nor demand for fish products should increase (FAO, 2002), and have highlighted the inherent instability of the pelagic system. More specifically, small pelagic fisheries worldwide have been characterized by (i) overcapacity in many fleets, one of the major issues in world fisheries management (Gréboval, 1999; Lindebo, 1999), (ii) changes in the destination of catch product, particularly following the development of aquaculture and its demand for fishmeal (Holmes, 1996; Durand, 1998; Rosamond *et al.*, 2000), (iii) lack of knowledge of the effects of climate change on the dynamics of the populations (DeAngelis and Cushman, 1990; Bakun and Weeks, 2004), and

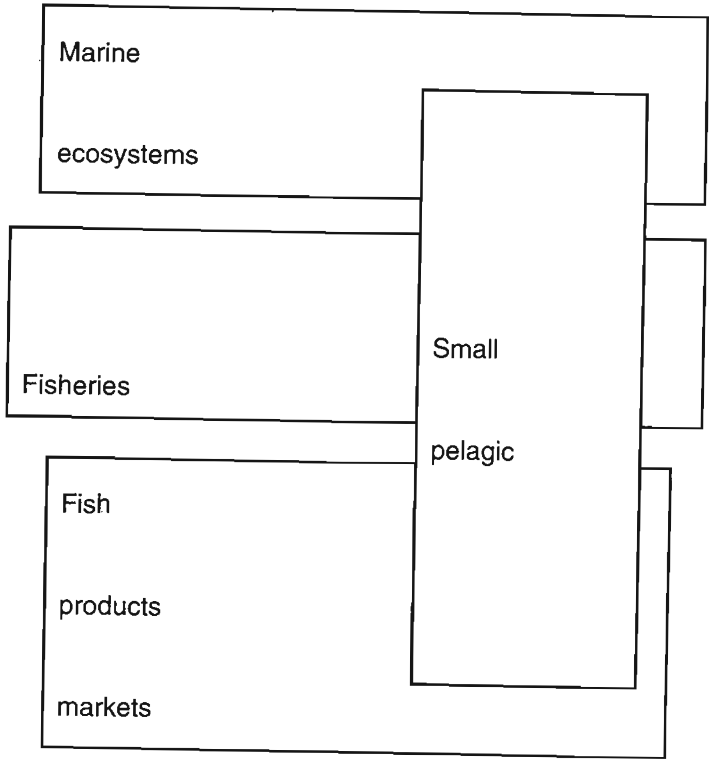


Figure 10.1 The system of small pelagic fisheries as it interacts with other ecological and economic systems

(iv) great discrepancies, mainly in management systems, between developed countries and developing countries, mainly at the level of small-scale fisheries (Garcia and de Leiva Moreno, 2003). Particular and urgent attention needs to be given to Chinese fisheries, which are important, growing fast (Figure 10.2), and poorly known (Watson and Pauly, 2001). The future of pelagic fisheries is clearly difficult to predict, though certain events or cascades of events can be foreseen.

Owing to the effects of global climate change, the dynamics of exploited marine ecosystems are becoming more unstable, some stocks are collapsing, supply to the markets that rely on them are drying up, and there is increasing pressure on other stocks, making them in turn less resilient. Such a scenario was observed when Californian sardine collapsed, pelagic fishing pressure being removed first to the Mexican ecosystem, then to the Peruvian ecosystem, both of which weakened as a result (Troadec *et al.*, 1980; Cisneros-Mata *et al.*, 1995).

Table 10.1 World catches of small pelagic fish in 2000

Country	Production (1000 tons)	(%)
Peru	7637	39.28
Chile	2317	11.92
Japan	1441	7.41
United States of America	1036	5.33
China	828	4.26
Norway	648	3.33
Russian Federation	605	3.11
Indonesia	475	2.44
Morocco	465	2.39
Denmark	397	2.04
Philippines	355	1.83
Thailand	348	1.79
Mexico	334	1.72
South Africa	325	1.67
India	322	1.66
Turkey	281	1.45
Sweden	279	1.43
Korea, Republic of	259	1.33
Canada	232	1.19
Spain	232	1.19
Senegal	230	1.18
Iceland	217	1.12
Ghana	181	0.93

Source: FISHSTAT (FAO, 2002).

Table 10.2 Use of small pelagic fish catches in 2000

	Production	(%)
Canned fish	411 491	24
Dried, salted or smoked fish	149 368	8
Fresh, chilled or frozen fish	447 542	26
Fishmeals	396 580	23
Fish oils	327 269	19
Total	1 732 250	100

Note: Percentages add up to more than 100% due to rounding.

Source: FISHSTAT (FAO, 2002).

Table 10.3 Destination of fishmeal and fish oil in 2002 and projection for 2010

	Fish meal 2002 (%)	Fish meal 2010 (%)
Aquaculture	34	48
Poultry	27	15
Pigs	29	22
Ruminants	1	0
Others	9	15
	Fish oil 2002 (%)	Fish oil 2010 (%)
Aquaculture feed industry	56	79
Industrial	12	5
Edible	30	14
Pharmaceutical	2	2

Source: International Fishmeal and Fish Oil Organization (IFFO).

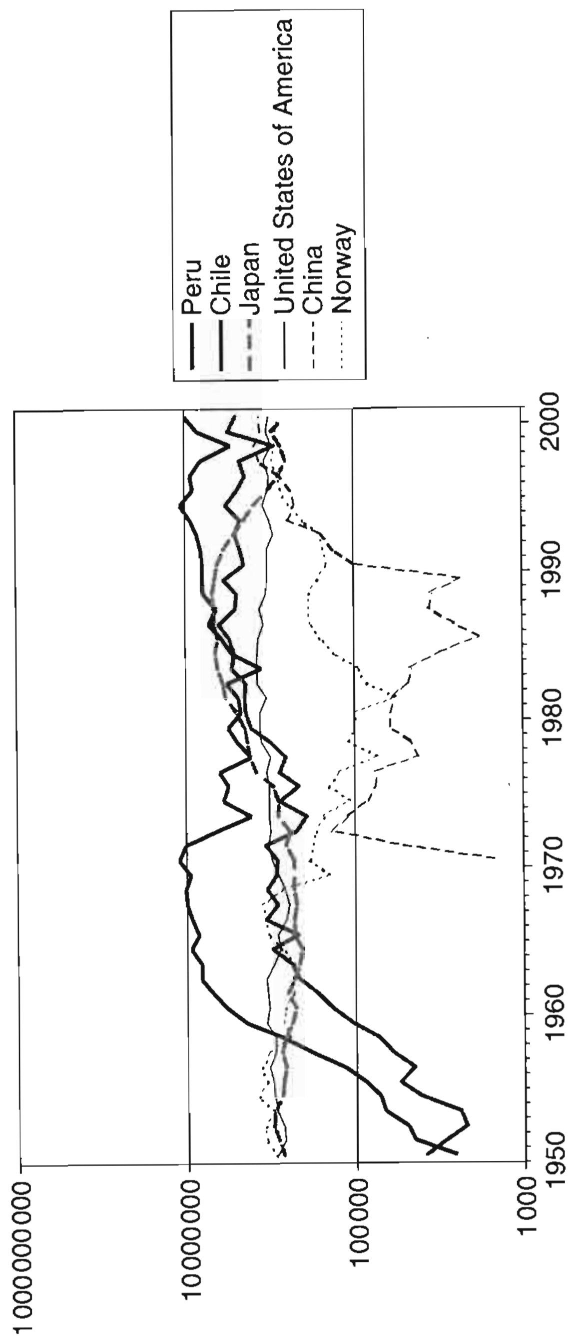
Global climate change results in a latitudinal shift in ocean temperature (Bakun, 1990; Mendelssohn and Schwing, 2002; Mote and Mantua, 2002; Snyder *et al.*, 2003; Diffenbaugh *et al.*, 2004), then in a corresponding latitudinal drift of the stocks, and consequently in fishing rights failing to adapt to the new biological situation. Some developed countries manage to reduce their national fishing effort as required to enhance the principle of sustainability, but exert increased political pressure for fishing rights in developing countries. At the same time, the development of fishing capacity in emerging countries can proceed uncontrolled.

The development of aquaculture resulted in a huge increase in the demand for fishmeal, while consumer preference for feeding poultry on soya meal rather than fishmeal resulted in a virtual collapse of the market for fishmeal in the poultry industry.

Developing demand for some pelagic fish product (for example for fish oil Omega 3) competes with demand for fishmeal; in contrast, development of new demand (for example for surimi) can result in the development of a specific fishery to feed the demand (Alaska pollock).

The globalization of trade resulted in the uncontrolled opening of the world's fisheries; perhaps now the globalization process has ended, resulting in curtailment of fishing rights given to foreign fleets by developing countries.

These uncertainties have led and will continue to lead to increasing negotiations and conflict, and highlight the need for tools to be applied to consensus building. Collectively, we must find a way to predict the effects of the



Note: This figure shows the distribution of yields, with one fishery (Peru) producing half the world's catch (Note the log scale for the y-axis), the high variability of pelagic catches, and the emergence of Chinese fisheries during the past 10 years.

Figure 10.2 World production of anchovies and sardines in the most important national fisheries

variability in small pelagic fish stocks attributable to climate change, within the current context of the economic globalization that makes the fisheries of the world interdependent. Tools are required to unify the views of stakeholders and decision makers (fisheries, fish product consumers, politicians, conservationists, scientists), to open dialogue (to address specific questions and to develop appropriate concepts), and to develop relevant hypotheses (from the knowledge of all the stakeholders). These needs are key to the sustainable management of fisheries (World Bank, 2004).

MODELLING PRINCIPLES

With the objective of providing such tools and concepts, and dedicated to the global management of small pelagic fisheries, an integrated model of the worldwide system of small pelagic fisheries is being designed. Of course, building a fully predictive model of such a complicated and open system is not possible. To support discussion and negotiation, mainly through role-playing game sessions, the model has to be (i) realistic, (ii) able to reproduce typical past events and (iii) sensitive to parameterization. It should also allow consideration of the consequences of various hypotheses, at least in terms of trends and directions.

The approach to building the model is participative and step-by-step, and aims to involve stakeholders at every step: definitions of goals, entities and processes, assessment of results, and ideas for improvements. The first step has been to build a prototype of the model that runs with approximate data. This has allowed us to make explicit the components of the model, to explore which databases can support the model (in terms also of parameterization and validation), to show its technical feasibility from a computing point of view, and to discuss the theoretical background.

Pauly *et al.* (2000) and Watson *et al.* (2004) made the point that 'mapping marine fisheries onto marine ecosystems' represents possibly the most efficient tool for consensus building. Therefore, the computer interface of the model is designed to produce 'kinetic maps' as a representation of the dynamics of a system, specifically of changes or shifts. An advantage of this 'geographic' approach is that it implies explicit definition of entities represented as (1) a trade-off between extension and resolution: only few ecosystems or fisheries or markets can be mapped together on a global map, (2) a trade-off between appropriateness of the model structure and the availability of data: existing data are based on specific typologies, defining entities, so are not the most adequate to represent the dynamics.

We have selected national or regional fisheries, FAO marine areas (rather than Large Marine Ecosystems), and national or regional markets for fish products. Because it allows us to stress the process of communicating scientific results to stakeholders, the model is designed to support role-playing game sessions (Kagel and Roth, 1995; Duffy, 2001; Barreteau *et al.*, 2003) that group together several stakeholders involved in the management of a complex marine area with students attending courses in environmental management. Model simulations are used to provide the framework of the play and to make explicit the consequences of players' decisions. Role-playing games efficiently reveal the behaviour and the motivational drivers of stakeholders.

Bioeconomic models provide a simple and efficient way to display the dynamics of renewable resources (Clark, 1990). They relate biological variables, such as productivity or carrying capacity, to economic variables, such as the social rate of discount. Practically, they lead to aggregated models, which are currently not particularly relevant within the context of the global management of fisheries. In contrast, disaggregated supply-demand models focus on how equilibrium occurs in several interlinked markets, where economic agents maximize profits; see, for example, Dey *et al.* (2003) and Briones *et al.* (2005) for applications in the context of fisheries, and the FISH2020 model, which provides projections of the state of world fisheries until 2020 (Delgado *et al.*, 2002). These models work as follows:

- quantitative characteristics of supply (for ecosystems) and demand (for markets) functions are assessed from time-series of data;
- general hypotheses are set about the evolution of supply (for example, changes in the productivity of ecosystems) and demand (for example, increasing or decreasing pressure on specific markets);
- finally, for each simulated year, a global equilibrium is computed on the ecosystems and the markets, to yield detailed projections of fishing effort, production, prices and income.

These are models of behaviour, not of strategy. This approach allows us to consider non-individual entities, such as national fisheries, as agents, and to adapt them to help us describe a complex dynamic system.

Supply-demand models are mostly static; they do not address the ecological, economic and bioeconomic feedbacks of the systems. They therefore cannot show the impact of any resulting equilibrium (fishing effort, production or prices) on the evolution of stocks or markets. With a similar disaggregated approach, computable equilibrium models (Shoven and Whalley, 1992; Floros and Failler, 2004) close the macroeconomic loop, relating production, consumption, investment and savings in a dynamic perspective. However, their relevance to modelling a specific subsystem such as that of small pelagic fisheries is not obvious; being quite complicated, they can easily lead to neglecting characteristics that are perhaps specific to pelagic fisheries systems, for example their instability.

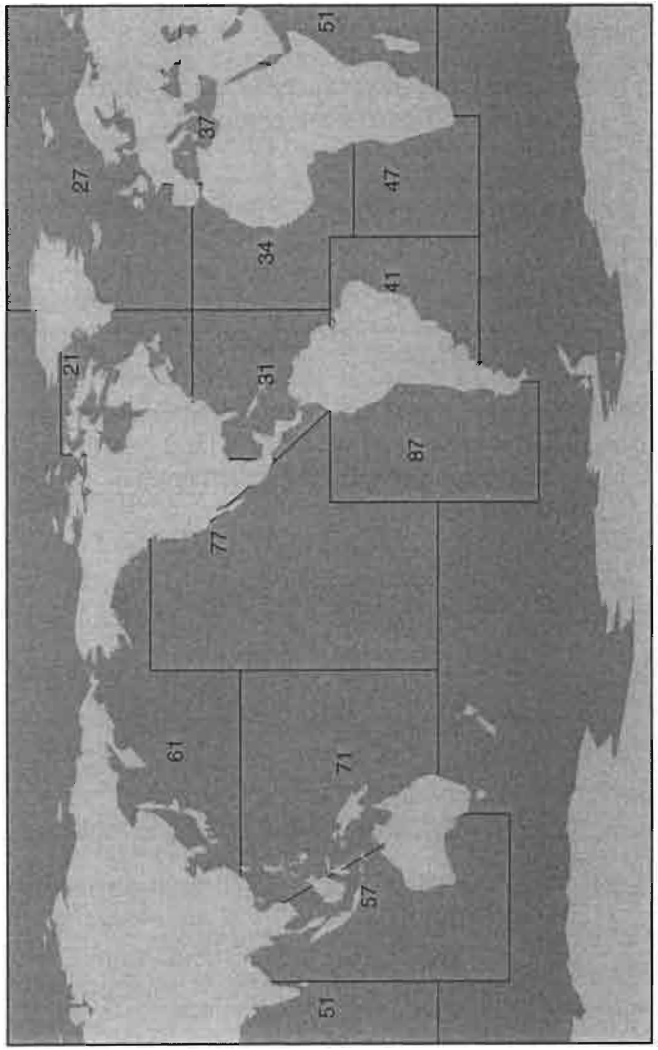
To take into account biological and economic feedback, our model of the worldwide system of pelagic fisheries is one of supply and demand, integrating worldwide pelagic stocks, small pelagic fisheries and markets for fish products. Inter-temporal dynamics are represented by simple deterministic equations that describe how pelagic stocks evolve, the behaviour of fisheries and the demand on the markets for fish product.

MODELLING CHOICES

Entities, Scales and Mechanisms

On one hand, the model must be spatially disaggregated; on the other hand a coherent set of data is needed to calibrate and validate the model; as a resulted of taking this dilemma into account, a model of intermediate complexity has been designed, involving less than 100 entities. The prototype integrates the behaviour of the following entities, all defined in the FAO database, FISHSTAT (FAO, 2004):

- 13 marine areas: Eastern Central Atlantic, Northeast Atlantic, Northwest Atlantic, Southeast Atlantic, Southwest Atlantic, Western Central Atlantic, East Indian Ocean, West Indian Ocean, Mediterranean Sea, Eastern Central Pacific, Northwest Pacific, Southeast Pacific, Western Central Pacific (Figure 10.3);
- 15 national and regional fisheries: Central America, China, Mediterranean, North Africa, North America, Northeast Asia, North Europe, Russia, Southeast Africa, Southeast America, Southeast Asia, South Europe, Southwest America, Southwest Asia, West Central Africa;
- 40 markets for fish products: Central America (canned, fresh), China (fresh, meal, other), Mediterranean (canned, fresh), North Africa (canned, fresh), Northeast Asia (canned, other), North Europe (canned, fresh, meal, oil), North America (meal, other), Russia (canned, fresh), Southeast Africa (canned, fresh, meal, other), Southeast America (canned, meal, oil, other), Southeast Asia (canned, other), South Europe (canned, fresh), Southwest America (canned), Southwest Asia (canned, meal, other), West Central Africa (fresh, other). Here, Fresh depicts fresh, chilled or frozen fish, and Other depicts dried, salted or smoked fish.



Notes: The marine areas are Eastern Central Atlantic (34), Northeast Atlantic (27), Northwest Atlantic (21) Southeast Atlantic (47), Southwest Atlantic (41), Western Central Atlantic (31), East Indian Ocean (57), West Indian Ocean (51), Mediterranean Sea (37), Eastern Central Pacific (77), Northwest Pacific (61), Southeast Pacific (87) and Western Central Pacific (71). Those not defined are not used in the model.

Source: ftp://ftp.fao.org/fi/stat/by_FishArea/Default.htm.

Figure 10.3 FAO marine areas used in the model

Table 10.4 The mean annual production of FAO marine areas during 1991–2000

Area	Mean production of small pelagic fish	%
Atlantic EC	1 504 606	9.45
Atlantic NE	722 684	4.54
Atlantic SE	394 924	2.48
Atlantic SW	89 527	0.56
Atlantic WC	123 192	0.77
Indian E	245 382	1.54
Indian W	287 989	1.81
Mediterranean	659 309	4.14
Pacific EC	441 884	2.77
Pacific NW	2 480 930	15.58
Pacific SE	7 981 059	50.11
Pacific WC	997 019	6.26

Source: FISHSTAT (FAO, 2002).

- One super-species grouping of pelagic species, that is, the species aggregated in the category 'Herrings, Sardines and Anchovies' of FISHSTAT.

The model simulations provide results every year for 15 years. This duration may be debated from a biological or an economic point of view, but from a management perspective, it is straightforward and allows simplification at all levels. Catches by area are listed in Table 10.4.

General Principles

The model integrates (i) the dynamic processes, that is, biological (population dynamics) and economic (evolution of investment, activity, demand), and (ii) behavioural processes, that is, fisheries behaviour (distribution of effort in several marine areas and the yield in several markets). At each time-step:

- The states of marine areas, fisheries and markets evolve according to deterministic rules;
- The behaviour of fisheries is related to how they select marine areas in which to fish and markets in which to sell. The result of the equilibrium between supply and demand is a consequence of their competition;

Table 10.5 Variables of the model

Variable	Denomination	Unit
X_e	Stock	Tons
q_e	Fishing efficiency	1/(Boat × Ton)
P_{ef}	Access costs to marine areas	Euro/Boat
Q_{fm}	Access costs to market	Euro/Ton
E_f	Number of boats	Boat
A_m	Demand price (intercept)	Euro/Ton
B_m	Demand price (slope)	Euro/(Ton × Ton)
τ_{ef}	Repartition of effort	No unit
μ_{fm}	Distribution of product	No unit
R_f	Income	Euro
Y_f	Yield	Ton

- Biological dynamics are governed by a conventional production function, whose parameters may depend on climate.

The resulting model is quite simple; all variables are defined in Table 10.5.

Representation of Marine Areas

Marine area dynamics are represented through the conventional formalism of production models (Beverton and Holt, 1957; Hilborn and Walters, 1992). A marine area e is characterized by a stock X_e and a fishing efficiency q_e. A fishery f applying effort E_f on this marine area obtains a yield $Y_{ef} = E_f q_e X_e$. The total production from this marine area is therefore $Y_e = \Sigma_f Y_{ef}$. A stock of a marine area evolves according to a conventional production model:

$$X_e(t+1) = X_e(t) + R_e(X_e(t)) - Y_e(t) \tag{10.1}$$

Production functions are logistic:

$$R_e(X) = r_e X\left[1 - \frac{X}{K_e}\right]$$

where K_e is the carrying capacity and r_e the natural rate of renewal.

Representation of the Markets for Fish Products

There are many approaches, both theoretical and practical, to show the behaviour of fish product markets, focusing on both elasticity of prices/quantities and the supply/demand relationship (Asche and Bjørndal, 1999; Tacon, 2001; Tvetaras *et al.*, 2002). In the model, markets for fish products are represented by a simple demand function. Let Y_{fm} be the product sent by fishery f to market m. Then, at market m, the supply is $Y_m = \Sigma_f Y_{fm}$. Prices are related to supply by the functional equation $P_m = V_m(Y_m)$. Currently this equation is linear: $V_m(Y_m) = A_m - C_m Y_m$, where A_m and C_m are the parameters intercept and slope respectively, intercept being related to the demand, and slope to elasticity. The evolution of the demand function of a fishery depends on global economic trends, and is expressed through time-dependent functions: $A_m(t)$, $C_m(t)$.

Representation of Fisheries

A fishery f is determined by (i) its fishing capacity (the number of 'standardized' boats), E_f, (ii) its access costs (per 'standardized' boat) to the different marine areas, P_{ef}, and (iii) its access costs (per unit sold) to the different markets for fish products, Q_{fm}. Access costs to ecosystems are the sum of transport costs (fuel) and royalties, and to markets the sum of transport costs and importation taxes.

Each year, fishery f selects its own strategy $S_f = \{\tau_{ef}, \mu_{fm}\}$, where τ_{ef} is the distribution of its effort among the marine areas it is permitted to access and μ_{fm} is the distribution of its yield among markets for fish products (of course, $\Sigma_e \tau_{ef} = 1$ and $\Sigma_m \mu_{fm} = 1$). Its yield from marine area e is $Y_{ef} = E_{ef} q_e X_e = E_f \tau_{ef} q_e X_e$, and its total yield is

$$Y_f = \sum_e Y_{ef} = E_f \sum_e \tau_{ef} q_e X_e.$$

To market m, fishery f sends

$$Y_{fm} = \mu_{fm} Y_f = \mu_{fm} E_f \sum_e \tau_{ef} q_e X_e,$$

and it receives $Y_{fm} V_m(Y_m)$. The income of a fishery f with strategy $S_f = \{\tau_{ef}, \mu_{fm}\}$ is equal to its sales $\Sigma_m Y_{fm} V_m(Y_m)$ minus its transportation $\Sigma_m Q_{fm} Y_{fm}$ and exploitation costs $\Sigma_e E_f \tau_{ef} P_{ef}$, that is:

$$R_f = \sum_m Y_{fm} V_m(Y_m) - \sum_m Q_{fm} Y_{fm} - \sum_e E_f \tau_{ef} P_{ef} \tag{10.2}$$

If $\tilde{Y}_{fm} = Y_m - Y_{fm}$ represents the sales of other fisheries at market m, this results in:

$$R_f = \sum_{me} \left[V_m \left(E_f \sum_e \mu_{fm} \tau_{ef} q_e X_e + \tilde{Y}_{fm} \right) - Q_{fm} \right] \mu_{fm} \tau_{ef} q_e X_e E_f - \sum_e E_f \tau_{ef} P_{ef} \tag{10.3}$$

Modelling fisheries investment behaviour assumes a relationship between fishing capacity and income. For the current implementation, this is: $E_f(t+1) = \kappa E_f(t) + \lambda R_f(t)$, where κ and λ are parameters that reflect the depreciation of capital and the portion of income reinvested, respectively. Coefficient κ is set at 0.95, but λ can be set by the user.

Obtaining the Competitive Equilibrium

The income generated by a fishery depends on both its own strategy as well as the strategies of other fisheries. The system is therefore a competitive game (for example Mueller, 1997) in which one may be interested in its non-cooperative or Nash's equilibrium, that is, the sets of choices by all fisheries and strategies, in such a manner that a given fishery cannot change its strategy unilaterally without diminishing its income.

There are theoretical and computing difficulties in the equilibrium model. The author will supply on request an algorithm which results in a Nash's equilibrium for the above income functions. The other, deterministic, part is simple and can easily be implemented with such tools as Stella, or even Excel.

PARAMETERS

The model has been designed to simulate scenarios that result from various hypotheses concerning the future of marine areas (for example their productivity, in relationship to climate change), the future of fisheries (for example their investment behaviour), and the future of the markets for fish products (for example demand). In the present implementation of the model, simulations are based on the parameters listed in the following sections.

Marine Areas

- Changes in carrying capacity. Coefficient υ represents a continuous (constant rate) increase or decrease in carrying capacity for all marine areas: $K_e(t+1) = [1 + \upsilon_e(t)]K_e(t)$.

- Changes in renewal rate. Coefficient η represents a continuous (constant rate) increase or decrease in renewal rate for all marine areas: $r_e(t+1) = [1 + \eta_e(t)]r_e(t)$.
- Fishing efficiency changes. Coefficient ϑ represents a continuous (constant rate of) increase in fishing efficiency for all marine areas attributable to technological improvements: $q_e(t+1) = [1 + \vartheta_e(t)]q_e(t)$.
- Latitudinal climate change. Coefficient ω represents how the carrying capacity of marine areas changes according to latitude: $K_e(t+1) = [1 + \omega_e(t)][lat - 30°]K_e(t)$.
- Recruitment variability. Coefficient σ represents the randomness of the recruitment function. All stocks of marine areas evolve according to the formulation

$$X_e(t+1) = [X_e(t+1) + R_e(X_e(t+1)) - Y_e(t)][1 + \theta_e(t)],$$

where θ is a random number normally distributed with mean 0 and variance σ^2.

Fisheries

- Changes in fishing capacity. This is the portion of income that is reinvested, coefficient λ in the formula $E_f(t+1) = \mu E_f(t) + \lambda_f(t)R_f(t)$. Coefficient μ, representing depreciation of capital, is set to 0.95.
- Compliance. This takes into account how quotas are respected. Compliance by fisheries is one of the principal issues in management of any fisheries sector, so it is specially important to reflect the differences in means of enforcement between developing, emerging and developed countries.
- Changes in flexibility. A differential parameter that represents how fisheries adapt to new strategies.

Markets

- Demand function changes (intercept). In the formula $V_m(Y_m) = A_m - C_m Y_m$, this shows how parameter A_m evolves over time: $A_m(t+1) = [1 + \alpha_m(t)]A_m(t)$.
- Demand function changes (slope). In the formula $V_m(Y_m) = A_m - C_m Y_m$, this shows how parameter C_m evolves over time: $C_m(t+1) = [1 + \chi_m(t)]C_m(t)$.
- Growth of fish meal markets. In the formula $V_m(Y_m) = A_m - C_m Y_m$, this shows how parameter A_m evolves over time, in order to represent a specific increase (or decrease) in the demand for fishmeal in the market: $A_m(t+1) = [1 + \alpha_m(t)]\,[1 + \psi_m(t)]A_m(t)$.

Access to Marine Areas

- Changes in fishing rights. This parameter quantifies a uniform increase (or decrease) in exploitation costs: $P_{ef}(t+1)=[1+\zeta_{ef}(t)]P_{ef}(t)$, and is used to take into account the trend in fuel prices or the evolution of royalties.

Access to Markets

- Changes of importation taxes. This parameter quantifies uniform increase (or decrease) of access costs: $Q_{fm}(t+1)=[1+\zeta_{fm}(t)]Q_{fm}(t)$, and is used to take into account the effects of globalization.

SCENARIOS

A scenario involves setting the above parameters to given values. These values are the same for all steps of a given simulation, and are the same for all entities.

SENSITIVITY ANALYSIS

The model allows sensitivity analysis. Conventionally, such analysis consists of:

- Choosing a sensitivity parameter among those listed above;
- Fixing a minimum and a maximum value for that parameter;
- Fixing single values for all other parameters;
- Running the simulations for 11 values of the parameter between minimum and maximum values;
- Generating global views of the resulting dynamics.

ROLE-PLAYING GAME

A role-playing game needs a set of 12–20 players gathered around a table, with several computers between them, and a game leader to guide them. Players are:

- Representatives of fishing industries for a given economic area, that is, West Asia, East Asia, North America, South America, North Atlantic and South Atlantic, who set an investment behaviour for their principals, accepting or refusing quotas. Their goal is to ensure a positive annual income from the fisheries they represent;
- Representatives of fish product industries, for example canned fish, fishmeal, fish oil and transformed fish. They reorientate the demand function in the markets, so modifying the cost of access to markets. Their goal is to generate a sufficient supply of fish product from the markets each year;
- Representatives of conservation societies for the extended marine areas North Pacific, South Pacific, North Atlantic, South Atlantic and Indian Ocean. They pressurize governments to implement appropriate quotas and ensure that stock levels remain above sustainability thresholds;
- Representatives of governments, in the political zones Europe, America, East Asia, Asian developing countries and so on. They implement quotas and define taxes. Their goal is to ensure sufficient income and supply, and to avoid stock collapses in the region they manage.

The players are not directly the agents (that is the fisheries) involved in the model. Overall there are two levels: the level of the role-playing game itself (the agents are the players), and the level of the model (the agents are the fisheries).

Play proceeds as follows. First the game leader randomly selects a scenario with climate, investment and demand components. Then he or she distributes roles to the players, that is, the representatives of fishing and fish product industries, conservation societies and governments. A game has nine rounds. For every normal round (10 minutes, one year), (i) the game leader presents a specific context, (ii) each player determines his or her own strategy (which results in setting the values of scenario parameters for that time-step), (iii) the simulation is run according to these strategies, and (iv) each player is given the results and asked to analyse them. For special rounds (third and sixth rounds, 30 minutes), meetings are set up to coordinate strategies and to allow alliances to be forged. At the end of play, a meeting is organized so that feedback on what happened during the game can be given. This process is easily implemented as a functionality of the above model. Players have access to the parameters for the entities they represent: in any round, the representative of Asian fisheries gives a value to the parameters Adaptation of fishing capacity and Compliance for fisheries in China, Northeast Asia, Southeast Asia and Southwest Asia. Concomitantly, the representative of fishmeal industries in Europe gives values to the parameters of demand (slope and intercept) for the corresponding markets for fish products.

DATA COLLECTION

A rough but testing data set is constructed with existing data when they are easily available, and with reconstructed data from very general hypotheses when this is not the case.

Marine Areas

To characterize a marine area in the model, it is necessary to quantify the renewal rate r_e, the carrying capacity K_e and the fishing efficiency q_e. Most of these characteristics can be reconstructed from FISHSTAT, the FAO Fishing Effort database, and some modelling with a production model such as CLIMPROD (Fréon *et al.*, 1991).

Fisheries

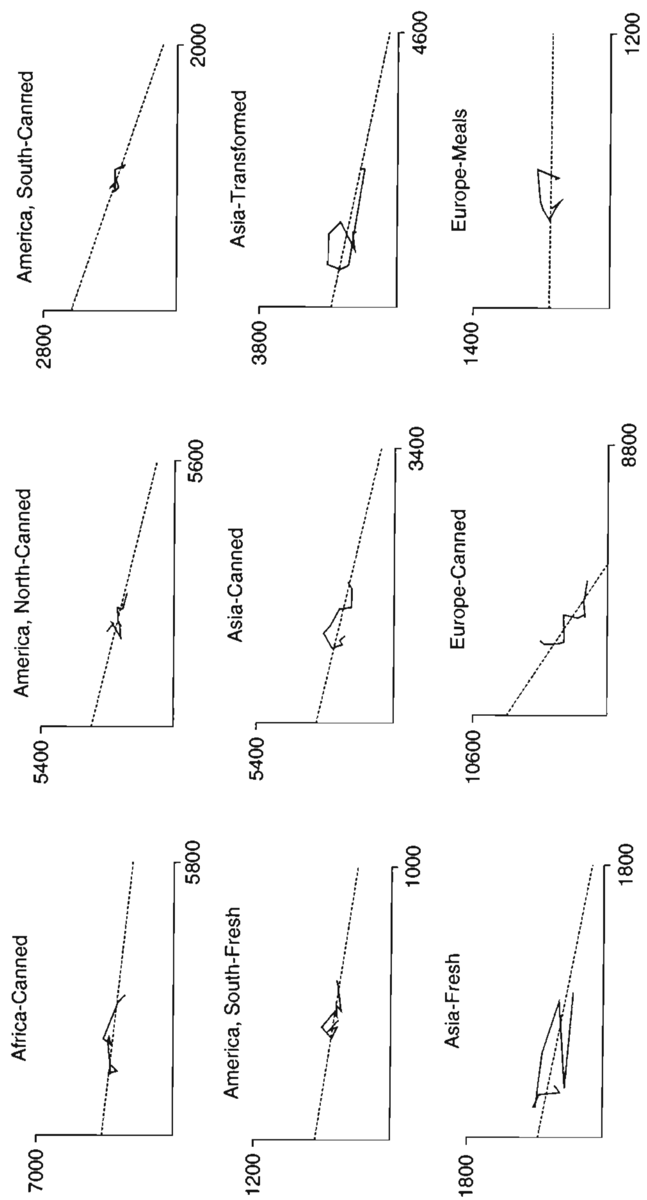
To characterize a national or a regional fishery in the model, it is necessary to quantify the fishing capacity, E_f. It can also be extracted from the FAO Fishing Effort database. In this version of the model, a proportional relationship between fishing capacity and average yield is assumed at the start of any simulation. A standardized boat is defined as producing on average 200 tons per year over the period 1990–2000.

Markets

To characterize a market for fish products in the model, one must quantify the parameters of the demand function (slope and intercept), A_m and C_m. These too can be extracted from FISHSTAT, which gives the volumes of exchanges, expressed either in tonnes or in a currency unit for recent years and for many markets for fish products. Prices and, by linear regression, coefficients A_m and C_m, can then be calculated (Figure 10.4). For several series, one knows only the mean price, mean quantities and the price/quantity elasticity, $\bar{P}, \bar{Q}$ and e, so one must use the formulation $A = \bar{P}(e+1)$ and $C = e(\bar{P}/\bar{Q})$.

Access to Marine Areas and to Markets

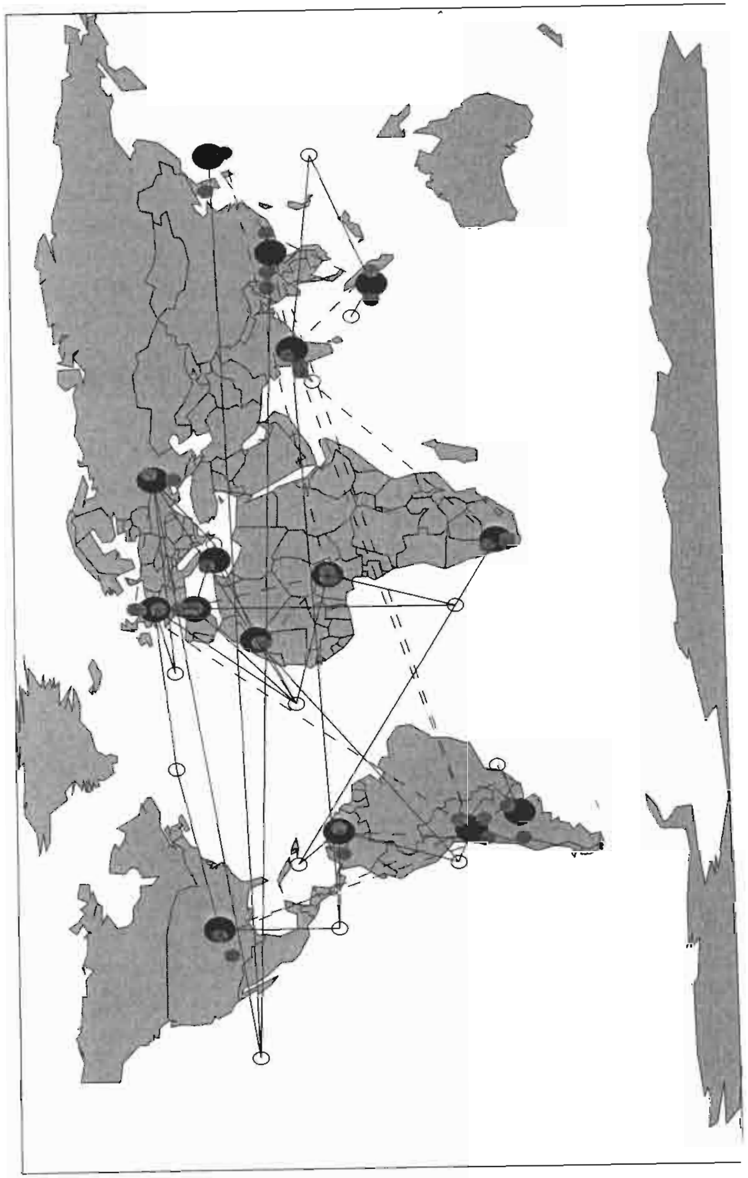
It is assumed that transportation costs from marine areas to fisheries and from fisheries to markets were proportional to the geographic distance used in the past (Figure 10.5).



Note: Price/quantities relationships for several fish products markets: Prices (abscissa) are expressed in dollars. Quantities (ordinates) are expressed in tons.

Source: After FISHTAT (FAO, 2004).

Figure 10.4 Relationships between prices (y-axis) and quantities (x-axis) during the past 15 years for several fish product markets, and the related demand functions



Note: Marine areas are represented by circles, fisheries by grey discs, fish product markets by black discs, usual routes from fisheries to marine areas by lines, and usual routes from fisheries to markets by dashed lines.

Figure 10.5 Network structure of the small pelagic fisheries system

MODELLING RESULTS

The model allows scenarios to be simulated and quantitative views of the resulting dynamics of pelagic fisheries to be generated. Here we present the results of two contrasting scenarios and a sensitivity analysis. However, in the model's current state, with non-validated data and with an algorithm that has not been fully checked, the results are simply indicative and caution must be applied to their interpretation. However, they do provide information on the model's dynamic behaviour, its plasticity and its sensitivity. The resultant individual dynamics (of marine areas, fisheries and markets) have to be interpreted in a speculative context: for instance, where we refer to the behaviour of the North European fishery, we have defined that entity with some properties of the real one simply to give some realism to the approach.

Scenarios

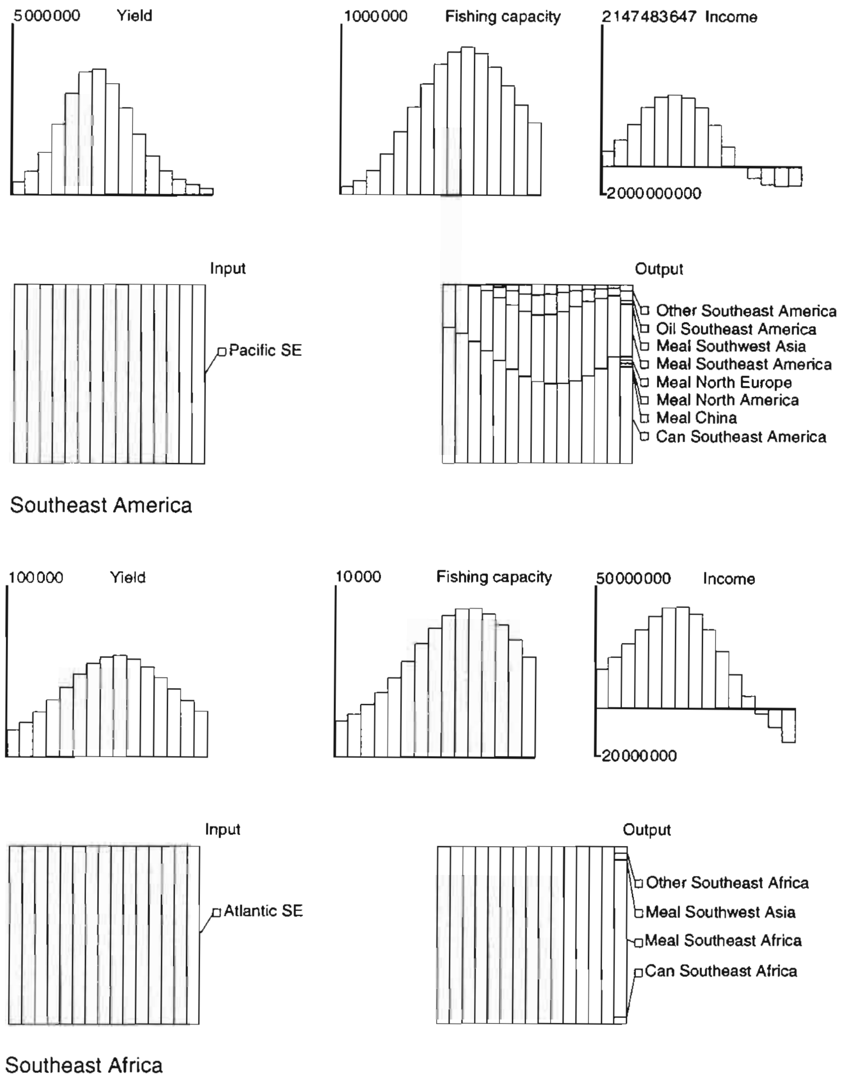
Black scenario

The black scenario is based on the following assumptions:

- Climate change results in an increasing productivity of the marine areas. This is represented by setting for all areas the parameters Changes in renewal rates and Changes in carrying capacity to −6 per cent.
- Globally, fisheries are quite rigid; they do not immediately adapt their fishing capacity to be in line with their income. This situation is represented by setting for all fisheries the parameter Adaptation of fishing capacity to + 3 per cent.
- There will always be some pressure on fisheries from fluctuations in the price of fuel. This situation is represented, for all routes to marine areas, by setting the parameter Changes of access costs to + 5 per cent.

Simulating the consequences of these hypotheses with the integrated model provides detailed results for marine areas, fisheries and markets. For all marine areas, stock biomasses decrease (not shown), as expected. Fisheries (Figure 10.6) increase their fishing capacity until they overexploit their resources. Incomes in each area mirror their yield, except at the end of the simulation for the Southwest Asian fishery, which recovers from losses at the start because it reorientates its production exclusively towards fresh fish for China. Moreover, the same fishery shifted its effort from the Western Central Pacific to the Western Indian Ocean then back to Western Central Pacific.

As a result of the simulation, one can obtain views of the network structure of the system, through kinetic maps. Figure 10.7 represents two



Notes:
The input figure represents how fishing effort is distributed, the output figure how the sales of fishing products are distributed.
Yields are expressed in tons; fishing capacities are expressed in normalized boats; incomes are expressed in dollars; input and output are expressed in percentages.

Figure 10.6 Black scenario. Results of simulations for Southeast American, North European, Southeast African and Southwest Asian fisheries

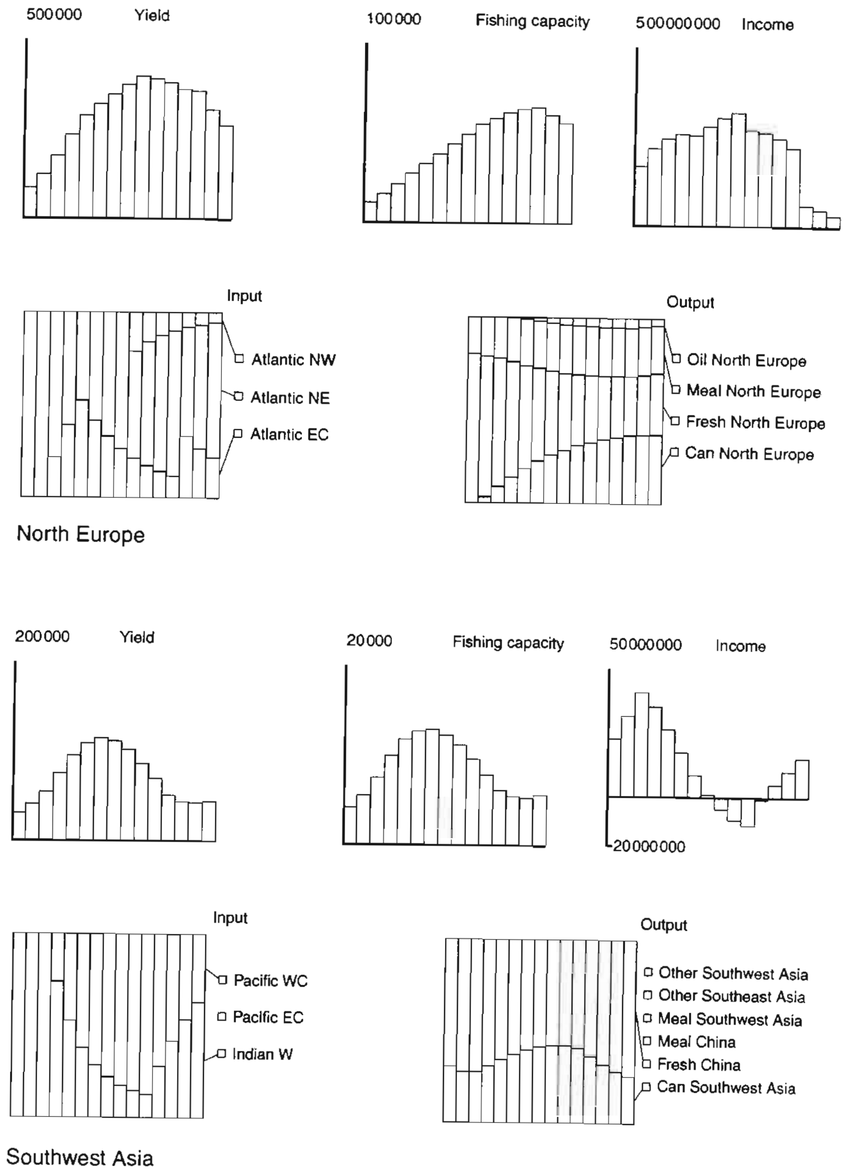


Figure 10.6 (continued)

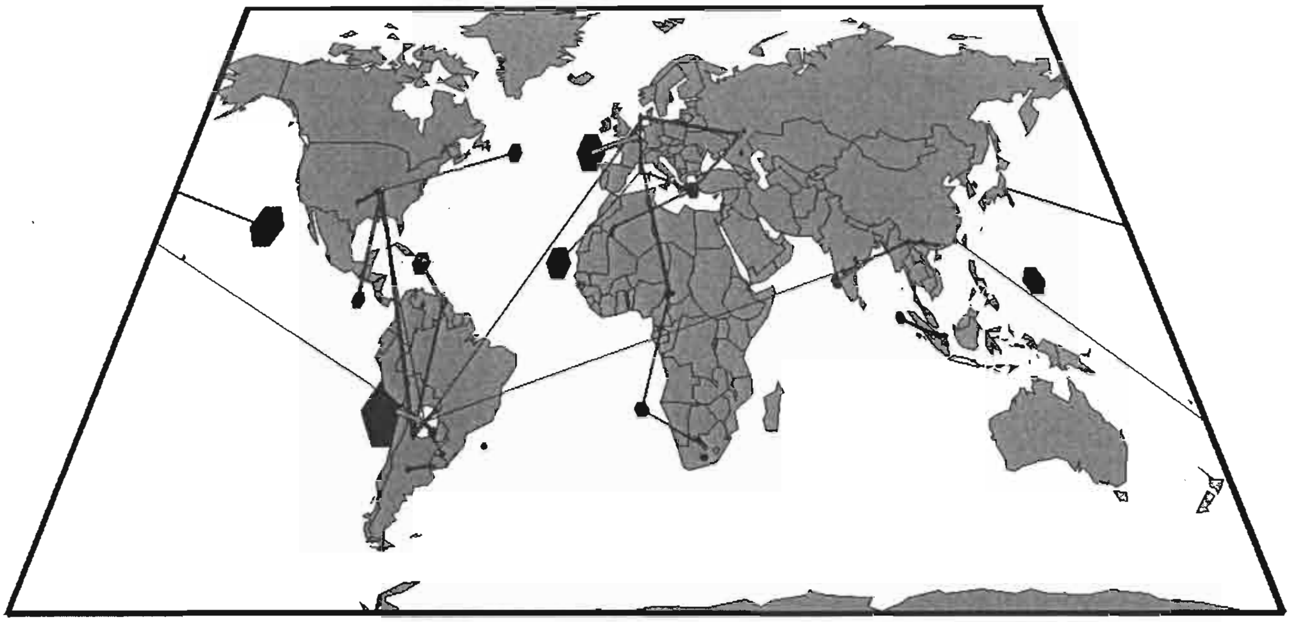


Figure 10.7a   Black scenario: map of production and flow in 2006

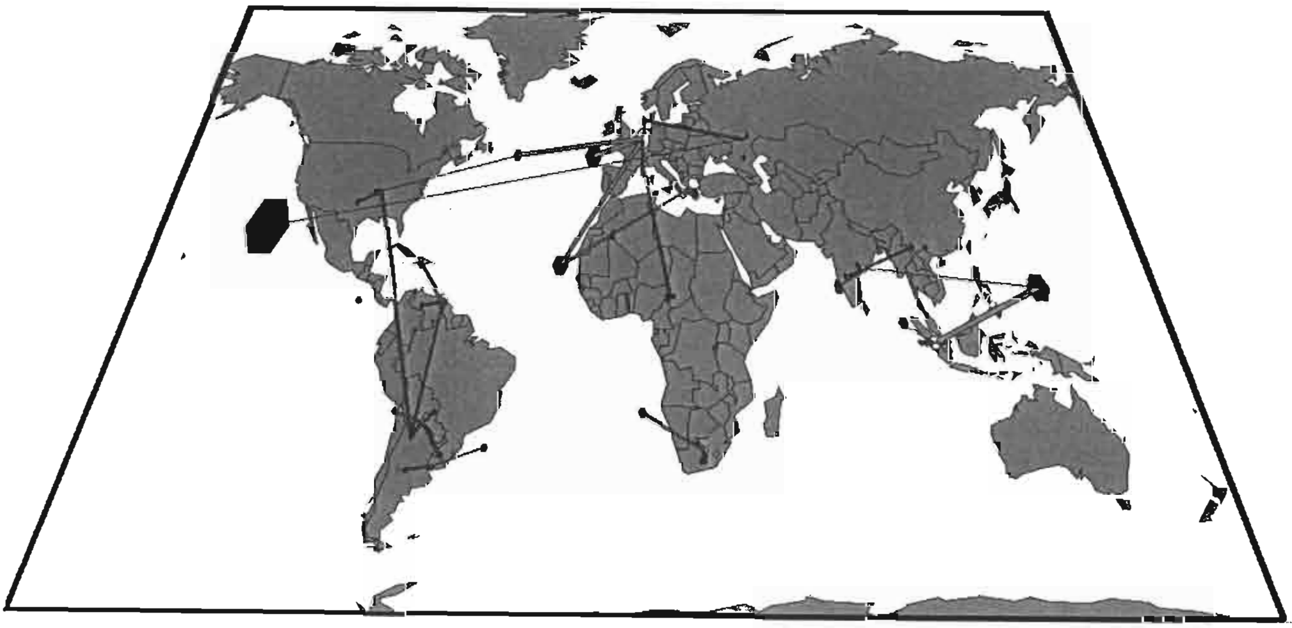


Figure 10.7b   Black scenario: map of production and flow in 2019

snapshots of the animations: for the years 2006 (start of simulation) and 2019 (end of simulation). These maps allow identification of structural patterns, for example some changes in the North Atlantic, which are attributable to the collapse of the North European fishery and the subsequent supply of corresponding markets from other fisheries.

Pink scenario

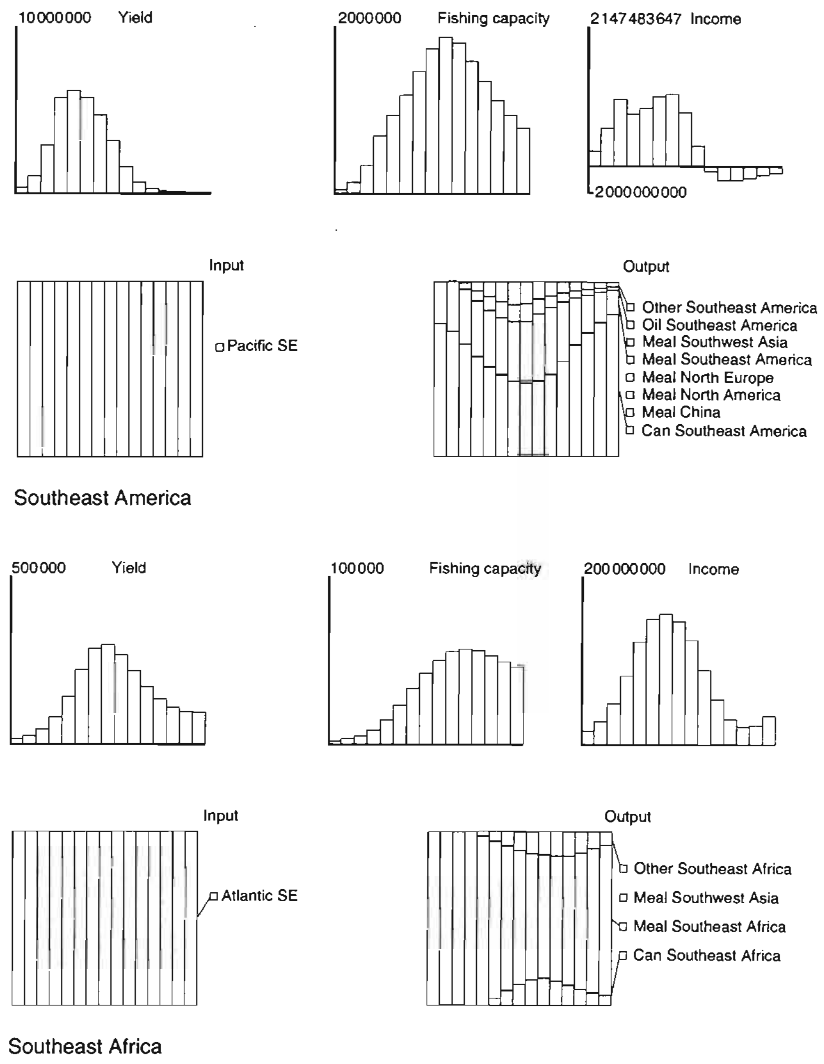
The pink scenario is based on the following assumptions:

- Climate change is beneficial for the productivity of marine areas. This is represented by setting for all areas the parameters Changes in renewal rates and Changes in carrying capacity to +6 per cent.
- Globally, fisheries are reactive; they adapt their fishing capacity in line with their income. This situation is represented by setting for all fisheries the parameter Adaptation of fishing capacity to +8 per cent.
- There will be some relaxation in the fuel price. This situation is represented, for all routes to marine areas, by setting the parameter Changes of access costs to −5 per cent.

With this scenario, predictions are variable (Figure 10.8) and not all positive. Several fisheries (Southeast America, Southeast Africa) collapse owing to their high reactivity; their fishing capacity increases too much and the stocks they exploit weaken. At the opposite end of the spectrum, the North European fishery, with low income at the start of the simulation, immediately reduced its fishing capacity, and moved its fleet within the Atlantic Ocean to generate sustainable income. Its yields increased, and it was able to sell its output on different markets in a dynamic manner, without interference from other fisheries that had collapsed. In this scenario, the Southwest Asian fishery shows patterns of sustainability that are comparable to the ones of the North European fishery.

Sensitivity Analysis

The results thus far highlight the adaptation of fishing capacity to generated income as an important factor in determining the dynamic behaviour of the small pelagic fisheries system. Therefore, a sensitivity analysis was performed with this parameter, allowing it to vary from 0 to 8 per cent. Low levels of adaptation are conservative for the stocks (Figure 10.9); they favour maximum yield at the end of simulation. In contrast, high levels favour adaptation at the start of the simulation. High production with a high level of adaptation is offset by lower prices, resulting in smaller incomes.



Notes:
The input figure represents how fishing effort is distributed, the output figure how the sales of fishing products are distributed.
Yields are expressed in tons; fishing capacities are expressed in normalized boats; incomes are expressed in dollars; input and output are expressed in percentages.

Figure 10.8 Pink scenario. Results of simulations for Southeast American, North European, Southeast African and Southwest Asian fisheries

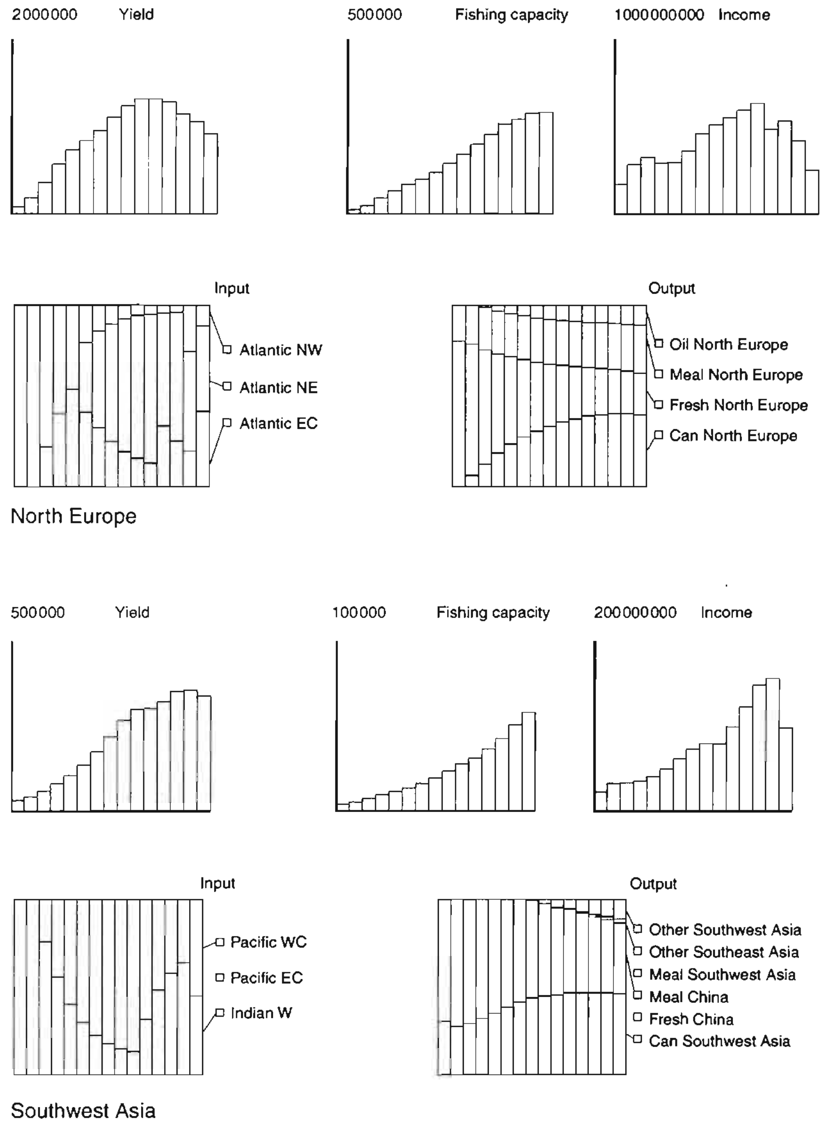
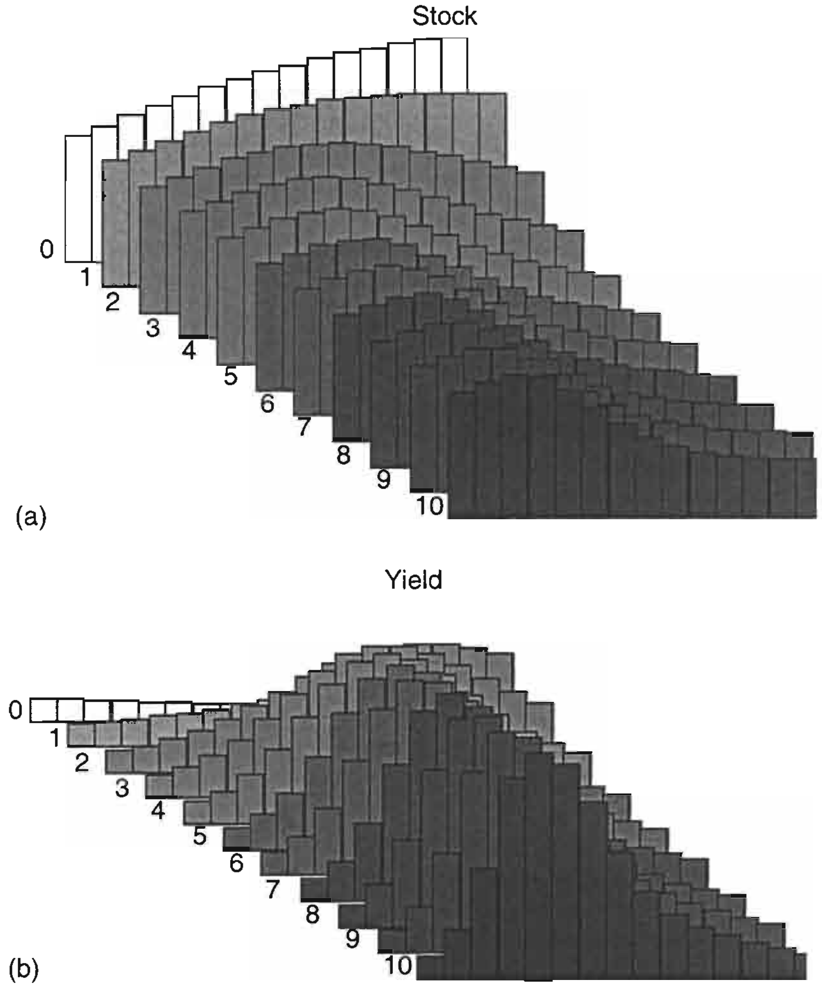


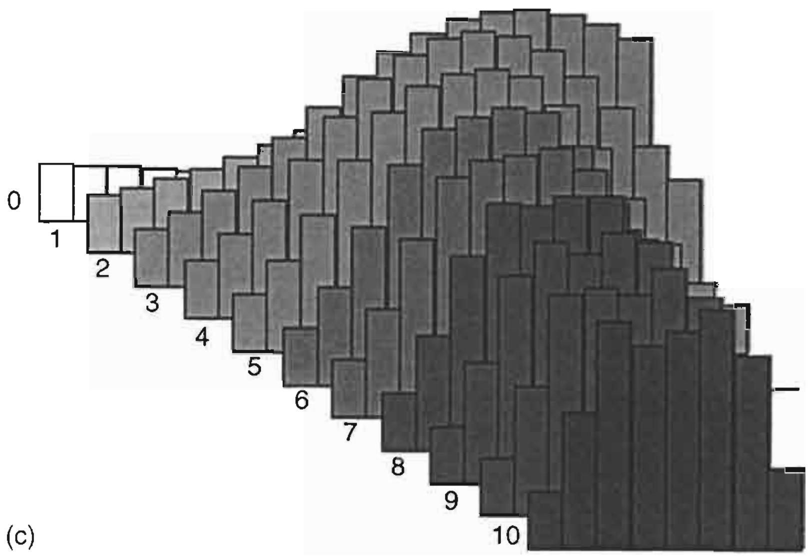
Figure 10.8 (continued)



Note: Simulation 0 corresponds to 0 per cent, simulation 1 to 0.8 per cent, 2 to 1.6 per cent, and so on.

Figure 10.9 Sensitivity analysis on a 15-year (x-axis) simulation: global results (stock, yield, income, effort, price) of 11 simulations for values of parameter Adaptation of fishing capacity varying from 0–8 per cent

Total income



Total effort

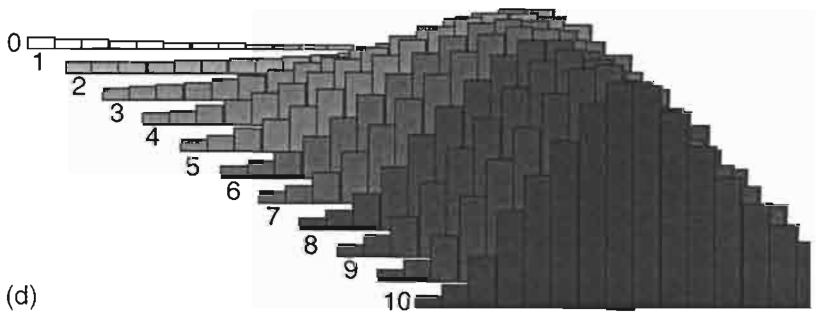


Figure 10.9 (continued)

DISCUSSION

One may ask whether the objectives of this preliminary step towards developing an integrated model of the worldwide system of small pelagic fisheries have been reached. The prototype has defined the components of the

Mean Prices

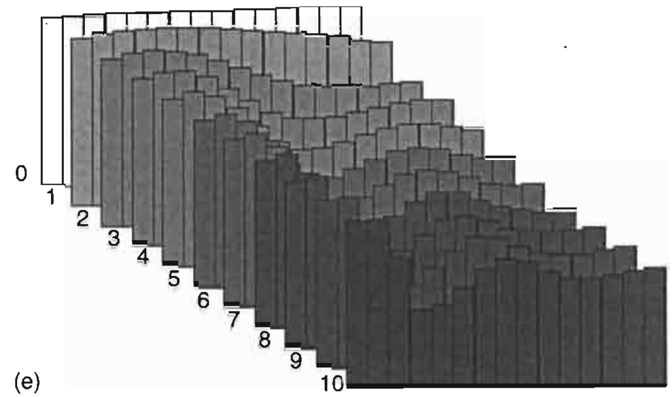


Figure 10.9 (continued)

integrated model. The selected resolution (disaggregation) allows dynamic patterns to be reproduced; more complicated modelling of the economic behaviour (macroeconomic looping) seems to be unnecessary.

The databases necessary to support the model (in terms of parameterization and validation) have been defined. Even if entities are not exactly those needed by a dynamic model, the FAO databases can provide most of the required data; complementary data can be provided by the International Fishmeal and Fish Oil Organization (IFFO) and the International Food Policy Research Institute.

The technical feasibility of the model has been evaluated: computing algorithms are fast enough to provide an interacting framework for the modelling itself. Several issues have, however, been raised by the preliminary results:

- Discussion of the main assumptions of the model are crucial: (i) the worldwide small pelagic fisheries as a system, (ii) the fisheries as active entities of the dynamics of that system, (iii) the dynamics of that system as the results of a coupling between deterministic processes and a competitive equilibrium.
- The model must be made more realistic, that is (i) tuning the definition of entities (marine areas, national or regional fisheries, markets for fish products), considering several groups of pelagic species instead of just one, (ii) improving the estimation of access costs, and (iii) using more appropriate data sets.
- Role-playing game sessions must be organized better and their progress more effectively analysed.

- The mathematical formulation should be improved. The whole formulation of the model could be rephrased in the framework of network economics (Nagurney, 1999), which allows general hypotheses, such as considering non-linear price functions, to be relaxed. A similar approach could be applied to different marine systems, at a different scale and in different contexts. For example, it may be of value to refine the dynamics of the system by focusing on one area, for example the Southeast Pacific, where fleets and species can be further disaggregated and parameterization improved.
- The main assumption of this modelling approach (the worldwide small pelagic fisheries as a system), needs in-depth discussion: do the worldwide pelagic fisheries constitute a single system? Would it not be of greater value to focus on the interactions between upwelling ecosystems, small pelagic fisheries and markets of small pelagic products rather than on the interactions between coastal upwelling ecosystems and deep-sea ecosystems, or on the targeting behaviour of fisheries switching between small pelagic resources and other fish resources, or on the interactions between all fish products, or between fish products and substitutes (for example soya meal versus fish meal)? Our preliminary modelling experiments may contribute to resolving this question. Although they are very unstable at all levels of organization, climate, biology and economics, but still highly viable (Fréon *et al.*, 2005), the system of small pelagic fisheries provides a good case study of collective management of a shifting resource. For example, it can help to address the question of overcapacity as a structural adaptation to fish variability.

According to FAO (2002), one of the most important challenges facing the world's fisheries management lies in improving the data systems. Such a model relating very different components of the system, and providing a global overview of it, can be used to reveal and minimize incoherencies between data sets. This is a similar approach to one that recently showed that Chinese catches were overestimated in the past (Watson and Pauly, 2001). A global model can be used in a systematic way with the same purpose.

The probable increase in conflicts in the worldwide system of small pelagic fisheries attributable to globalization and climate change underlines the urgent need for tools of consensus building to be developed. The present prototype of the model is a step in this direction, because it should allow discussion between the different stakeholders and favour unifying points of view within the context of an ecosystem approach to fisheries management.

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