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BIOECONOMIC MODELLING OF ENGLISH CHANNEL FISHERIES AND THEIR TECHNICAL INTERACTIONS : PRESENTATION OF THE SIMULATION MODEL BECHAMEL (BioEconomic CHAnnel ModEL)

Clara ULRICH*, Bertrand LE GALLIC, Matthew R. DUNN*****

in association with: P.Berthou[1], J.Boncoeur[**], C.Dintheer[2], D.Gascuel[*], J.Guitton[*], S.Mardle[***] and S.Pascoe***

**: Laboratoire Halieutique, ENSAR, 65 rue de St Brieuc, 35042 Rennes Cedex, France.*
P : (+33) (0)2 99 28 54 56; F : (+33) (0)2 99 28 75 35, Email : ulrich, dgascuel@roazhon.inra.fr
*** : CEDEM, UBO, 12 rue de Kergoat. BP 816. 29285 Brest Cedex. France*
e-mail :bertrand.legallic@univ-brest.fr
**** : CEMARE, University of Portsmouth, Locksway Road, Southsea, UK Email : M.R.Dunn@cefas.co.uk*

Abstract :**This paper presents the structure and examples of results from a bioeconomic model that simulates the fisheries of the English Channel. The main purpose of the model is to study the consequences of various management alternatives on the economic situation of the UK, French and Belgian fleets fishing in the area, and on exploited resources.** Considering the large number of technical interactions, the whole Channel may be regarded as one large multi-country, multi-gear and multi-species fishery. The model describes this feature through the links between three entities : fleets, "métiers" and species caught. The empirical basis of the model is composed of UK, French and Belgian data concerning stocks, fleets and landings, and on two economic sample surveys of UK and French fleets. The different modules (effort module, biological module and economic module) are described. A simple simulation is run, and the model reliability is discussed. The model presented in this paper is part of the EU funded project "Bioeconomic modelling of the fisheries of the English Channel" (FAIR CT-96-1993).

Key words : bioeconomic modelling, English Channel fisheries, multispecies, multifleet, simulation

Résumé : Ce papier présente la structure et des exemples de résultats d'un modèle bioéconomique de simulation des pêcheries de la Manche. L'objectif principal du modèle est d'étudier les conséquences de différentes alternatives de gestion sur la situation économique des flottilles anglaises, françaises et belges pêchant dans cette zone, et sur les stocks exploités. En raison d'un grand nombre d'interactions techniques, la Manche peut être vue comme une unique pêcherie internationale, multimétiers et plurispécifique. Le modèle traduit cette complexité à travers les liens entre 3 entités : la flottille, le métier et le stock exploité. La base empirique du modèle est composée de données françaises, anglaises et belges de production et d'effort, et de 2 enquêtes économiques sur les flottilles anglaises et françaises. Les différents modules (module d'effort, de production/biologie et d'économie) sont décrits. Une simulation simple est analysée, et la validité du modèle est discutée. Le modèle présenté dans ce papier fait partie d'un projet européen de "modélisation bioéconomique des pêcheries de la Manche (FAIR CT-96-1993).

[1] IFREMER, Centre de Brest BP 70. 29280 Plouzané Cedex. France
[2] IFREMER, Centre de Boulogne/Mer BP 699. 62321 Boulogne/Mer. France

INTRODUCTION

Although bioeconomic models have been developed and used as management decision-making tools in many fisheries around the world, relatively few studies had been conducted on English Channel fisheries (Santarelli and Gros 1986, Meuriot *et al* 1987, Pascoe 1997). These studies largely focused on only one particular component of the fisheries, and did not take into account all the various and numerous technical interactions that exist among stocks, gears and fleets. As part of an EU funded project on bioeconomic modelling of the fisheries of the English Channel (FAIR CT96-1993), a simulation model, BECHAMEL (Bio-Economic CHAnnel ModEL), was developed. The model focuses mainly on these technical interactions, and allows a more detailed assessment of the impact of various management policies than the previous models[3].

This paper presents the structure of BECHAMEL. First, the specific modelling constraints due to particular characteristics of Channel fisheries are summarised. The general structure is then described, and the different components are explained. A few preliminary simulation results are also presented and discussed.

CHANNEL FISHERIES MAIN FEATURES, AND CONSEQUENCES ON MODELLING PROCESS.

The English Channel (ICES sub-divisions VIId and VIIe) is exploited commercially by fishers from several European states. The fleet consists of almost 4000 vessels, with 2200 from the UK and 1700 from France. Most of these are small, multi-purpose inshore boats. Because of interactions between species, these boats catch different combinations of species based on the area fished, the main species targeted and the gear used. These combinations of area, target species and gear define a series of distinct métiers (Laurec *et al*, 1991, Tétard, Boon *et al* 1995). The CFSG (Channel Fisheries Study Group) identified 74 different métiers (Tétard, Boon et al., 1995), targeting more than 50 commercial stocks. The large number of interactions among the three different components of the fishery (i.e. the fleets, métiers and species) results in considerable complexity. For example,

- A species may be targeted in many different métiers,
- Fishers may target several species in a single métier (and land others as bycatch);
- A fleet may operate in several different métiers during the year; and
- A métier may be exploited by several different fleets at any one time.

Because of this large number of interactions, the whole Channel may be regarded as one large multi-country, multi-gear and multi-species fishery, rather than a number of separate fisheries geographically co-located (with provision for some local activities targeting sedentary or semi-sedentary species). This implies that any change in a fleet's activity will have an impact on the catch and economic performance of other fleets, and this has to be measured and quantified some way for a relevant model. A map showing main Channel inshore activities is presented Fig. 1.

[3] An optimisation model of the fishery is also being developed This has similar structure to BECHAMEL, and is to be used to estimate the optimal levels of effort and catch rates taking into account the multi-objectives of management

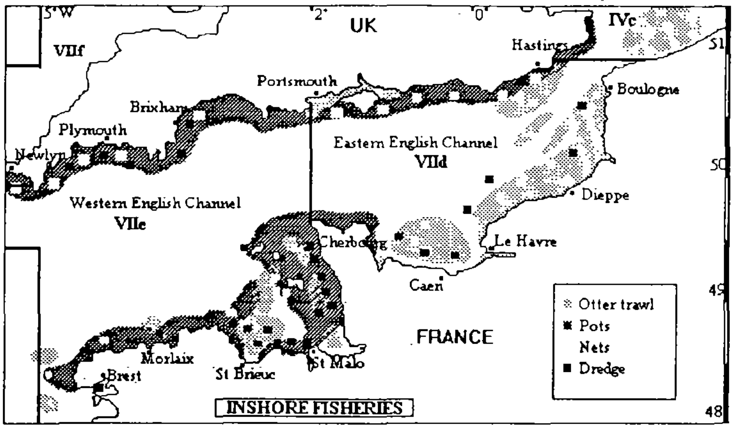


Fig. 1. English Channel inshore fisheries

The second main feature is the very heterogeneous levels of data and knowledge of various components of the fishery, and the necessity to find a common methodology to take them into account in a homogeneous way. This is the case in particular for the fleet typology, the stocks assessment and the model time step :

- **Fleets encompass boats with similar fishing strategies, and which therefore can be managed with similar policies. Because of a high level of polyvalence (each boat participates in 2.5 métiers on average in a year, Tétard *et al* 1995), and different levels of aggregation in the available databases, different methods were required. The boats were allocated to the different fleets based on the dominant métier. The completed typology is presented in appendix 1.**
- **Many métiers have very poor landings data. In many cases, most landings are not sold through auctions and are consequently not recorded in official statistics. A method has been implemented in order to estimate some of these landings through a measure of fishing effort (Le Pape and Vigneau 1998, Laurans 1998).For some other stocks, a rough estimation has been set.**
- The level of knowledge on exploited species is highly variable, depending on specific features of the life cycle, on the reliability of landings data, and/or on its value in the fishery. As a result, they can not be assessed and modelled with the same accuracy (methods are detailed in the part 2.2). For the same reasons, no trophic relationships have been included in the model. And as in most cases no stock-recruitment relationships have been clearly identified, species recruitment is considered to be an exogenous variable.
- Both biological parameters (e.g. mortality coefficients and catchability coefficients) and effort parameters (e.g. effort allocation of the different fleets over the year) are calculated on an annual average basis, calculated using 3 years of data (1993-1995).
- The Channel fishery is a relatively open system with some boats coming from outside of the Channel and fishing Channel species. In addition, some Channel fleets fish outside of the Channel. These both externalities need to be included in the model.
- Many stocks spatial limits lie well beyond the Channel boundaries. The impact of boats that operate outside the Channel on these stocks also needs to be taken into account (Ulrich *et al* 1998)
- Almost no economic data on costs and revenues were previously available. An economic survey with harmonised methodologies had first to be worked out on both sides of the Channel (Pascoe *et al* 1997, Boncoeur *et al* 1998)

The task of data collection and collation in order to harmonise the many various databases and to fit multi-country and multi-disciplinary needs was a major component of the project. All data are being gathered into one single database, BAHAMAS (Dintheer *et al* 1995), structured by métier, and implemented by the CFSG.

PRESENTATION OF THE MODEL

BECHAMEL is a static multi-species, multi-*métier* and multi-country bioeconomic simulation model of the fisheries of the English Channel. It is composed of three main components that interact with each other (Fig. 2).

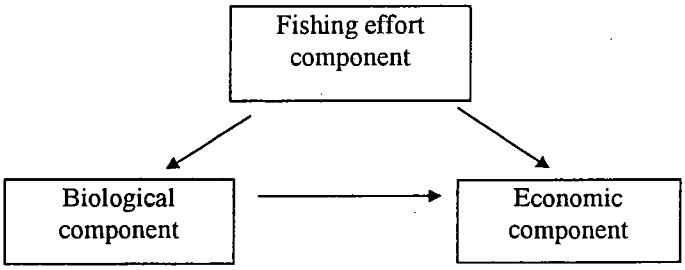


Fig. 2. basic structure of the bioeconomic model BECHAMEL

The fishing effort component estimates the level of fishing effort by fleet, boat length class and métier. It may be regarded as the cornerstone of the model, as it has a direct impact on both the economic and biological variables in the model. The majority of simulations will involve varying the assumptions about the effort allocation and level. For a given level of effort, the biological component of the model calculates catch of each species and each *métier*. The economic component transforms landings into revenues for each fleet and length class. It also calculates costs on the basis of fleet characteristics, effort levels and revenue. Economic performance indicators can then be calculated from the revenues and costs. The successive stages of calculation are presented in figure 3.

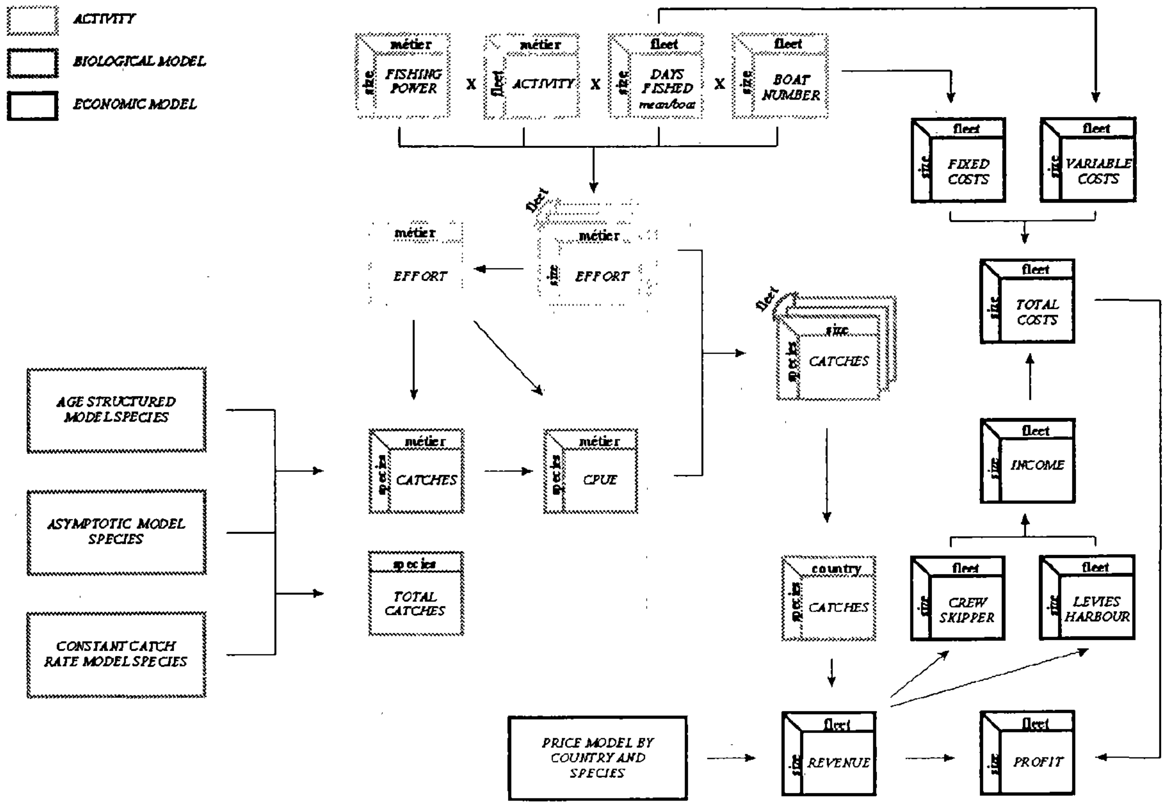


Fig. 3. Structure of the model

The simulation model is physically located on the server of the Fisheries laboratory of ENSAR, but may be run from any computer through an Internet interface. Access to the model is protected by a password. The model itself is composed of a succession of programs written in the PERL language (Practical Extend Report Language), which is specifically designed to interact through the Internet. Choosing this interface makes it possible to avoid multiplying the number of physical copies of the model, while allowing anyone to use it from any computer equipped with a standard Internet navigator. As a result, changes have to be made only on one copy of the program, and improvements in the model are immediately available to everybody (Ulrich & Guitton, in press). An example of the interface is presented in appendix 2.

Fishing effort component

The first component of the model is devoted to the determination of the levels of standardised fishing effort, and the allocation of this effort to the various fishing activities (métiers). This level of standardised effort depends on the number of boats in each fleet and length class, their relative fishing power, and their fishing time. The distribution of effort is fixed in the model through an activity matrix based on the observed distribution of effort.

In most fisheries bioeconomic models, the concept of fishing effort is the main link between the biological and economic components. Biologists use fishing effort in order to quantify the pressure exerted by fishing activity on fish stocks (fishing mortality). Differences in efficiency between boats requires the differentiation of "nominal" and "effective" effort (Gulland 1956, Beverton and Holt 1957, Laurec and Le Guen 1981). However, this differentiation raises problems, and the choice of a relevant unit of fishing effort may be difficult in practice. Similar problems exist for economists. The economic concept of fishing effort is a synthetic index representing the total inputs (including the anthropic inputs) of the production function in the fishing industry. Both indices are not always easily comparable.

For some métiers, the usual effort measure units are easy to compare (for example, between métiers using towed gears), but this is not always the case (for example, between métiers using towed and static gears). As is was difficult to make comparisons on the basis of the technical characteristics of gear used (for example, number of pots, time of immersion, trawl length), it was decided to use a measure of fishing effort based on the number of days at sea of the boats weighted by the relative fishing power. Fishing powers are an index of relative efficiency of the boats that, in theory, encapsulate the differences in technology and skill employed in the fishery. These are derived from observed differences in catch per unit of nominal effort. Applied to the measure of nominal effort (e.g. days fished), the product is a better indicator of the level of effective effort expended by the boat.

The multi-purpose nature of most of the boats was incorporated into the model by the use of an activity matrix. This apportioned the number of days fished to the various métiers in which the boats operated. On the French side, the activity matrix was calculated on the basis of the boat activity calendars established by IFREMER/DPMCM investigators (BAHAMAS database, table 3), and of a typology of fleets worked out by Patrick Berthou (IFREMER, Brest) and Christian Dintheer (IFREMER, Boulogne). For each fleet, the matrix gives the average percentages of time at sea dedicated to the various métiers. For the UK side, the activity matrix was calculated based on the observed allocation of effort in the logbook information compiled by CEFAS. The typology of the fleet was derived by CEMARE and CEFAS. For both the French and the UK fleet, an allowance is made for Channel boats operating part of the time outside the Channel.

The fishing power matrix is designed to standardise, within each métier, the fishing powers of boats belonging to different length classes. Within a given métier, the coefficient of relative fishing powers are the same for each species. It is estimated from the relative catch per unit of effort of individual vessels. The average catch per unit of effort was defined as the total catch each species in each métier divided by the total effort applied annually to the métier.

Therefore, fishing effort by fleet (*f*), length class (*l*) and métier (*m*), expressed in equivalent standard-days of the standard-class, is given by:

(1) $$E_{f,t,m} = N_{f,t} \cdot J_{f,t} \cdot a_{f,m} \cdot Pg_{t,m}$$

where $N_{f,t}$ is the number of boats in fleet *f* and length class *t*; $J_{f,t}$ is the average yearly number of days at sea of boats in fleet *f* and length class *t* (computed from economic surveys); $a_{f,m}$ is the proportion of total fishing time of fleet *f* spent in métier *m* (computed from the activity calendars);and $Pg_{t,m}$ is the relative fishing power of length class *t* in métier *m*, compared with the fishing power of the standard length class (see calculation below).

From the above expression it follows that:

(2) $$E_m = \sum_f \sum_t E_{f,t,m}$$

where E_m is the total yearly effort (expressed in standard boat-days) in métier *m*.

Biological component

The biological component of the model calculates the catches by species and by métier on the basis of the amount of standardised fishing effort in each métier. In order to have an homogeneous modelling methodology, although stocks modelling abilities are strongly heterogeneous, depending on their life cycle, data quantity and reliability, and commercial value in the fishery, stocks were classified in 2 sets, each set being itself divided into 2 sub-sets, according to the method used for assessment. Some species are sampled and measured, either routinely or sporadically, and an age-structured model can be applied. Many others, especially crustaceans, molluscs, and low-value by catch fishes (dogfish, conger eel etc.) are biologically poorly known in the Channel, and/or their official landings statistics are particularly bad (the estimated level of unreported catches may reach 90% for some crustaceans such as brown and pink shrimps). For the latter species, a surplus production model has been empirically set, with rough catches estimations and an *a priori* hypothesis on the shape of the curve, i.e. on the parameter m in the generalised Pella and Tomlinson 1969 form $CPUE(f) = (a + b.f)^{1/(m-1)}$. Production models, although less realistic than age-structured models, are still valuable when very little is known about age classes. The stock classification is presented appendix 3.

Age-structured model species

The age structured biological model general diagram is illustrated in Appendix 4. All age structured model stocks have been divided into 2 sub-sets, depending on their spatial distribution. Some stocks have been assessed at the Channel scale, assuming that stocks limits fit Channel boundaries. Only Channel catches are taken into account. Other stocks are considered to belong to a larger regional stock, distributed beyond Channel limits, in the North Sea (ICES divisions IV), or the Irish Sea - Celtic Sea - Bay of Biscay (ICES divisions VII and VIII). Channel catches often account for a small part of total catches (Anon., 1997a and b). For these species, an assessment method (the In/Out method) has been developed. This method is briefly summarised below.

Channel stocks

For most of these stocks, only one or two years of sampling data were available (Dunn *et al*, 1996). They have been assessed by using equilibrium pseudo-cohort method (Mesnil, 1980), on averaged catches over 1993-1995. The global assessment outputs recruitment and fishing mortality coefficients by age and stock, $F_{s,a93-95}$. A partial fishing mortality by métier can be derived from this coefficient :

(3) $$F_{m,s,a93-95} = F_{s,a93-95} \frac{Y_{m,s,a93-95}}{\sum_{m} Y_{m,s,a93-95}}$$

with $Y_{m,s,a,93-95}$ the mean yield by age, stock and métier during 93-95.

Given the estimates of the partial fishing mortalities, the observed effort levels by métier E_m for the reference years 1993-95 can be used to derive the average catchability coefficients $q_{m,s,a}$ by species s, age a and métier m, given by

(4) $$q_{m,s,a,93-95} = \frac{F_{m,s,a,93-95}}{E_{m,93-95}}.$$

Though it is possible to change these catchability coefficients in the course of a simulation (e.g. when simulating the consequences of a change in mesh size), they are generally regarded as fixed inputs of the model. Given the catchability coefficients calculated on the basis of real data, it is possible to estimate the consequences of changes in fishing effort on the fishing mortality of a given species, given by:

(5) $$F_{m,s,a} = q_{m,s,a,93-95} \cdot E_m$$

where E_m is the estimated effort by métier calculated in equation 2.

The long term equilibrium levels of yield per recruit are estimated as a function of the exogenously determined biological parameters (natural mortality by age $M_{s,a}$, average weight by age $W_{s,a}$,), and the rate of fishing mortality ($F_{m,s,a}$) by species, age and métier, given by:

(6) $$Y_{m,s} / R_s = \sum_{a=1}^{T-1} \left(\left(\prod_{i=1}^{a} e^{-(F_{m,s,i}+M_{s,i})} \right) \frac{F_{m,s,a} \cdot W_{s,a}}{\left(\sum_{m} F_{m,s,a} \right) + M_{s,a}} \left(1 - e^{-(F_{m,s,a}+M_{s,a})} \right) \right) + \left(\prod_{i=1}^{T-1} e^{-(F_{m,s,i}+M_{s,i})} \right) \frac{F_{m,s,T} \cdot W_{s,T}}{\left(\sum_{m} F_{m,s,T} \right) + M_{s,T}}$$

with T, the total number of age for the stock s

(7) $$Y_s / R_s = (\sum_{m} Y_{m,s}) / R_s$$

The long term catches for each species s by métier ($Y_{m,s}$)and in total (Y_s) are estimated by multiplying these estimates by an exogenous constant recruitment R_s.

In / Out stocks (Ulrich *et al*, 1998)

This method allows to take into account in Channel assessment the fact that some catches occur outside of the Channel, made by external fleets. Channel catches are considered to be made up of two components : a component coming from a local stock, only distributed within the Channel (In component), and a component coming from an external regional stock (Out component). The ratio between both component is determined by a single coefficient α, representing the probability for a fish caught in the Channel to belong to the global stock. The closer from 0 α is, the bigger the local stock is. Once α a priori set, catches by age and stock (local and global) are calculated, and both stocks are assessed with cohort analysis, and the total Channel yield can be calculated by summing both components yield :

(8)
$$Y_s = R_1 . \left(\sum_{i=1}^{T-1} \left(\left(\prod_{j=1}^{i} e^{-(F_{1,j}+M_{1,j})} \right) \frac{F_{1A,i} W_i}{F_{1,i} + M_{1,i}} \left(1 - e^{-(F_{1,i}+M_{1,i})}\right) \right) + \left(\prod_{j=1}^{T} e^{-(F_{1,T}+M_{1,T})} \right) \frac{F_{1A,T} W_T}{F_{1,T} + M_{1,T}} \right)$$
$$+ R_2 . \left(\sum_{i=1}^{T-1} \left(\left(\prod_{j=1}^{i} e^{-(F_{2,j}+M_{2,j})} \right) \frac{F_{2,i} W_i}{F_{2,i} + M_{2,i}} \left(1 - e^{-(F_{2,i}+M_{2,i})}\right) \right) + \left(\prod_{j=1}^{T} e^{-(F_{21,T}+M_{2,T})} \right) \frac{F_{2,T} W_T}{F_{2,T} + M_{2,T}} \right)$$

with R_1 and R_2, the recruitment values for the global and local stock respectively, T the total number of age, W the mean weight at age in the Channel, M_1 and M_2 the natural mortality at age for the global and local stock respectively F_1 and F_2 the total fishing mortality by age in the global and local stock respectively, and F_{1A}, the fishing mortality in the global stock coming from Channel catches.

The calculation of catches by métier is done with a similar methodology as for Channel age-structured model stocks, but all coefficients of catchability and fishing mortality have to be estimated for both components (In and Out).

This method has been applied to stocks currently assessed by ICES working groups (Anon. 1997a and b) (Ulrich *et al*, 1999), and to all migrating stocks. For some of them, the coefficient α has been set close to 0, assuming a preponderant local stock (2 plaice and sole stocks, western Channel cod stock), for others it has been set to 1, meaning a single global stock regionally distributed (megrim, mackerel, hake, eastern Channel cod, 2 whiting stocks).

Surplus production model stocks.

Surplus production model species have been also empirically classified into 2 sub-groups, depending on the shape of the production-effort curve. For some strongly overexploited and decreasing species, we fitted a Schaefer 1954 form : ($CPUE(mf) = a + bmf$). For others, a Fox 1970 model ($CPUE(mf) = ae^{bmf}$), assuming that current situation is close to the MSY, was adjusted.

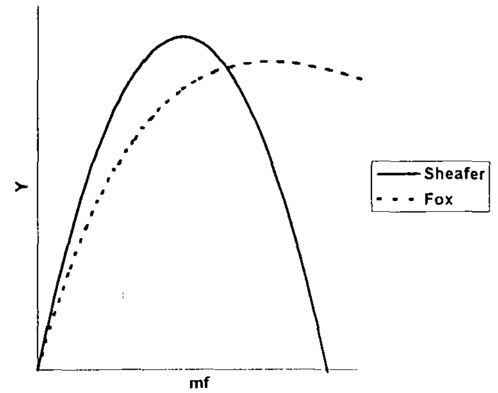


Fig. 4. Surplus production models yield curves

mf represent a multiplicator of total effort, and CPUE(mf) is the catch per unit of effort corresponding to the total multiplicator of effort. The multiplicator of effort during reference years 93-95 is set to 1 (current situation). Yet each level of effort can be defined by its multiplicator of effort :

(9) $mf = E / E_{93-95}$,

where E is the total yearly effort (expressed in standard boat-days), all métiers summed.

Each métier is defined by its catchability coefficient q_m. Then

(10) $Ys = mf.CPUE(mf)$, and

(11) $$mf = \sum_m q_m . E_m$$

By choosing a reference métier (the most catching métier for instance), we can write that for each métier

(12) $$\frac{q_m}{q_{ref}} = \frac{U_m}{U_{ref}} = r_m ,$$

with $U_m = \frac{Y_{m,93-95}}{E_{m,93-95}}$, the catch per unit of effort during reference years. Then

(13) $$mf_{93-95} = q_{ref} \sum_m r_m . E_m = 1$$

from (12) and (13), it is then possible to calculate a catchability coefficient by métier and stock, and then, an equilibrium yield for any level of effort.

Of course, the use of surplus production models is a strong assumption that has to be kept in mind when analysing simulation results. For some species, a better single-stock assessment could have been used (Dunn, 1999), but the use of dynamic equations with, for instance, different time steps, could not be incorporated into the BECHAMEL general methodology. For some other species, no quantitative assessments have been conducted in the English Channel (e.g. conger eel, shrimps, pilchard). As these species account for a non-negligible part in fishermen revenues, they have to be incorporated in the model as best as possible. It is worth noting that an exponential production model, fitted close to the MSY, will output near constant catches in a realistic range of effort, and can be compared with Cobb-Douglas and Spillman asymptotic production functions used by economists in bioeconomic models (Varian, 1993; Pascoe & Robinson, 1997).

Economic component

The economic component of the model is largely driven by the outputs from the effort and biological components. Just as the biological component transforms fishing effort into catches, the economic component transforms these catches into revenue and fishing effort into costs[4]. This transformation relies on estimates of prices and costs, and allows for the estimation of economic performance indicators for the various fleet segments and the fishery as a whole.

Prices and revenues

For the purposes of the economic analysis, two types of species have been distinguished. The first group is composed of species for which landings from the fisheries of the English Channel display no noticeable influence on prices. In most cases, landings of these species from the Channel represent only a small part of a well integrated national or international market. Prices of landings are then treated as exogenous. This was the case for all UK species. Most of the high valued species landed in the Channel by UK boats are exported to France, Spain or the Netherlands. The prices for these species are more dependent on conditions in these markets rather than the quantity landed in the UK. For species consumed domestically, the Channel landings represented only a small proportion of the total landings.

[4] In this first version of the model, no distinction is made between catches and landings. Discards are therefore neglected, an assumption which in various cases is not realistic, both from a biological point of view - see Morizur, Pouvreau and Guénolé, 1996 - and from an economic point of view - see Boncoeur, Fifas and Le Gallic, 1998.

The second group is composed of species (sometimes differentiated according to origin) for which the flexibility of prices to landings from the Channel is significantly different from zero. For species in this group, landings from the Channel represent a major part of the national market (e.g. scallops and spider-crabs on the French side) and the prices are treated as endogenous variables. The relations used to simulate these prices are based on simple log-linear regressions of the type :

$$\ln(P_s) = \alpha_s \ln(C_s) + \beta_s \tag{14}$$

where P_s is the annual average first sale price of fish of species s, and C_s the total corresponding landings (assumed equivalent to catches in the first version of the model). Possible substitution effects between various species were not considered at this stage of the building of the model. Studies on this topic are still in progress. In a future version of the model, it will also be possible to differentiate the prices according to the type of fishing (bass caught by liners and bass caught by pelagic trawlers for instance).

Revenues, or gross sales, are estimated by multiplying landings (or catches in the present version of the model) by prices. For each métier m and each species s, the revenue is given by:

$$GS_{m,s} = P_s . C_{m,s} \tag{15}$$

where $GS_{m,s}$ is the gross value of sales of species s caught in métier m. For each métier m and species s, the catches and thus revenues per fleet f and length class t are assumed to be proportional to their standardised effort, such that

$$GS_{f,t,m,s} = P_s . C_{f,t,m,s} = P_s . C_{m,s} \frac{E_{f,t,m}}{E_m} \tag{16}$$

where $GS_{f,t,m,s}$ is the gross value of sales of species caught by boats of length class t in fleet f in métier m. The total yearly revenue of length class t in fleet f ($GS_{f,t}$) may therefore be expressed as

$$GS_{f,t} = \sum_m \sum_s GS_{f,t,m,s} = \sum_m \left(\frac{E_{f,t,m}}{E_m} \sum_s P_s . C_{m,s} \right) \tag{17}$$

Hence, the revenue of boats in the length class t of fleet f is assumed to depend on the:

- relative standardised fishing effort in each *métier m* (activity component of the model);
- an element relying on the number of boats, fishing time and relative fishing power of each set of boats involved in métier m (see equation 1 above);
- total catches by métier and species $C_{m,s}$ (biological component of the model); and
- price of each species P_s

Costs

Costs have been estimated on the basis of two sample surveys undertaken on both sides of the English Channel using a harmonised methodologies (Pascoe, Robinson and Coglan 1996, Boncoeur and Le Gallic 1998, Boncoeur, Le Gallic and Pascoe 1998, Pascoe and Coglan 1999).

In the long run, all costs depend on the level of effort, and therefore may be regarded as variable. In the short run however, a distinction has to be made between variable and fixed costs[5]. The variable costs are themselves of different types, according to the factor upon which they depend. Four types of costs were distinguished :

1. *Fixed costs* depend on the characteristics of the boat (fleet and length class), irrespective of its level of activity and distribution of total activity between various métiers.
2. *Métier variable costs* of a boat belonging to a given length class depend on its activity (number of days at sea) in each métier.
3. *Landing taxes and other marketing costs* depend on revenue (gross sales)
4. *Labour costs.* In the English Channel, as in most small scale or "artisanal" fisheries, crew members are rewarded through a "share-system"[6]. Crew members get a share of the balance produced by deducting the "common costs" (the costs that are shared between the owner and the crew, the definition of which is not uniform) and the value of net sales (revenue minus landing taxes). The share system encourages and rewards harvesting efficiency and cost effectiveness, which makes the "crew-share" somewhat different from a standard wage cost.

In the development of the model, the following distribution of costs between *métier* variable costs and fixed costs was adopted (Table 2)

Table 2. Métier variable costs and boat fixed costs

Métier variable costs	cash costs	Fuel and lubricant Bait Ice Food Gear renewal and maintenance (France only)
Fixed costs	cash economic costs	Boat maintenance Gear renewal and maintenance (UK only) Insurance Management Licenses Miscellaneous
	non cash costs	Fixed capital depreciation Opportunity cost of capital

The distribution between fixed and variable costs is not straightforward, and the allocation of costs displayed in Table 2 is subject to debate. For example, boat maintenance costs are likely to be affected by the level of effort expended. In the UK, gear costs were considered fixed costs while in France they were considered variable costs. While gear costs are affected by effort levels, in the UK it was considered that regular maintenance and replacement costs outweighed the variable component. In contrast, the converse was found in France. The choices that were made rely on practicability considerations (availability of data), and are not necessarily optimal from a theoretical point of view.

The way different types of costs are calculated in the model is not fully presented here. For further details, see Le Gallic & Ulrich, 1999.

[5] Although BECHAMEL is a long term equilibrium model for biologists, it is essentially a short term model for economists.
[6] This system includes employed skippers. As regards skippers-owners (by far the most frequent case in the Channel fisheries), the situation is different in the UK and France. In the UK, skippers-owners are rewarded only through the "owner-share". In France, they get their personal income from two sources - as fishermen working onboard they are rewarded through the crew-share, and as boat-owners and entrepreneurs they are rewarded through the owner share For the sake of homogeneity in the calculation of labour-costs, an imputed wage was estimated in the case of UK skippers-owners, and added to the wage costs.

Economic performance indicators

Three main types of economic performance indicators are calculated by the model:

Gross margin
The gross margin is the difference between net sales and total variable costs (including labour costs). In the short term when capital is fixed, profit maximising fishers will aim to maximise gross margins. In doing so, profits will also be maximised.

Rate of return on capital
The rate of return on capital, or rate of profit, is a classic indicator of economic profitability that is sometimes used for the analysis of economic performance in the fishing industry (Davidse *et al* 1997). It is calculated by dividing full equity profit by the value of capital invested in the firm. Full equity profit is what the owner of the firm would get if the activity of his firm was fully self-financed. It is equal to gross margin, less fixed cash economic costs and fixed capital depreciation allowances.

Income of the skipper-owner
Due to the peculiarities of the share-system for the rewarding of the crew, the economic significance of full equity profit is not perfectly clear in the case of "artisanal" fisheries like those of the English Channel. The rate of profit does not look like a reliable economic performance indicator if one compares the relative profit rates by length class to the actual dynamics of the fleet over the last decade (Boncoeur, Le Gallic and Pascoe 1998). Therefore, it was decided to calculate another performance indicator, representing the personal income of the skipper-owner. This indicator is equal to the actual income of the skipper-owner only if the opportunity cost of capital employed in his firm is equal to its net financial costs :
On the basis of both UK and French sample surveys of the fishing activity in the English Channel, it was concluded that the net activity income of the skipper-owner was an economic performance indicator consistent with the actual dynamics of the fleets operating the English Channel fisheries, unlike the rate of return on capital (Boncoeur, Le Gallic and Pascoe, 1998).

APPLICATIONS AND RESULTS

The objective of this section is to discuss the range and the reliability of simulations that may be run. A simple example will be presented that illustrates the potential of the model.

Range of simulations

The majority of simulations will involve varying the assumptions about the effort allocation and level. These include changes in boats number by fleet (such as might occur under a decommissioning scheme), limitations of days at sea (a policy that has already been suggested by the UK Government to meet effort reduction targets) or changes in the activity matrix. The effects of varying quotas will be approached by considering that over-quota catches are discarded (what is often the case in English Channel, due to the joint-catch problem)[7]. The effects of changes in mesh size can be estimated by varying the catchability coefficients for particular size classes. However, at this stage, lack of data on gear selectivity prevents any reliable estimates being generated.

[7] This approach was adopted by Pascoe (1997) in the model of the UK portion of the fishery.

The biological component of the model can also be used in ecological simulations. By considering the Channel exploited species ecosystem as the emerging combination of single species assessment, the model allows estimation of the impact of fishing activities on populations under different levels of fishing effort. Various synthetic ecological indicators can be derived from production functions and may be used into multispecies assessment studies (Ulrich *et al*, 1999).

The sensitivity of the model results to the biological parameters can be estimated by varying the key biological exogenous parameters. These include the catchability coefficients, variations in recruitment and influence of the assumption of existence of Channel endemic local stocks, which may have large effects on the production function (Ulrich *at al* 1998). Similarly, the sensitivity of the model to the economic parameters can be analysed by examining the effects of changes in prices, changes in the different costs components, and variations in the "share-system" rates.

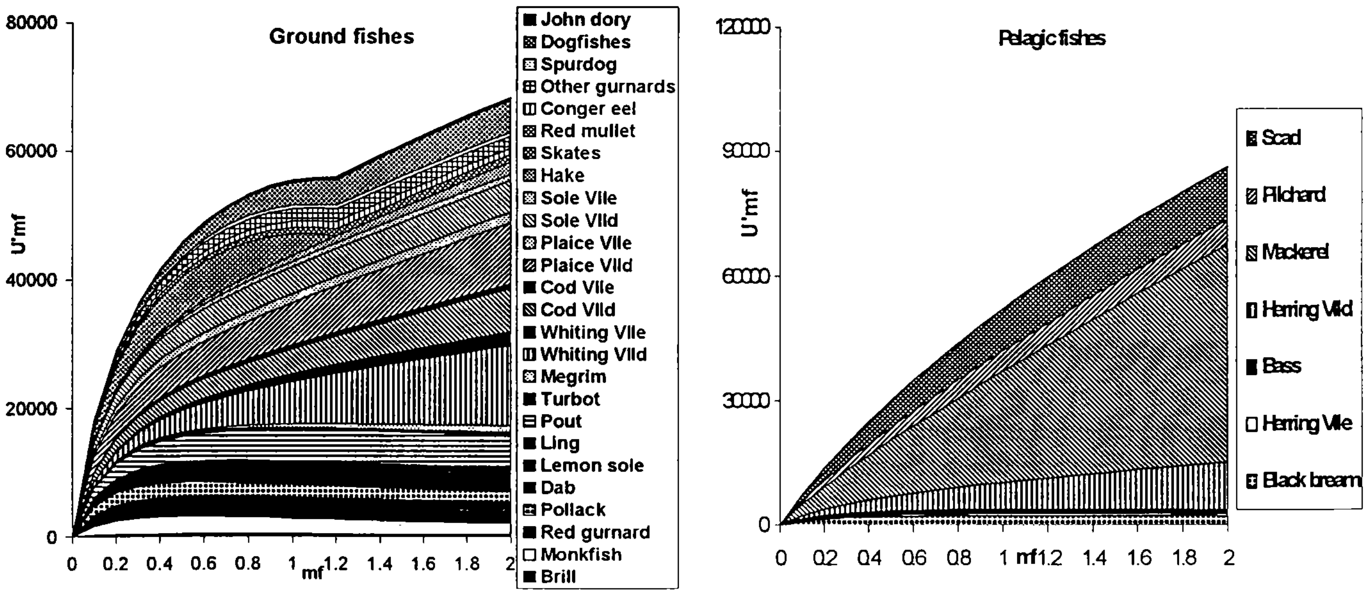
Main outputs are catches per species, métier, fleet and countries, as well as a number of economic indicators (Appendix 5). All results are expressed in terms of mean and total values.

Multispecies assessment

A multispecies production function can be calculated by combining the single-species assessments on different levels of effort, as did Gascuel & Ménard (1997). The model being fitted on the nominal value of effort E_{93-95}, each level of effort can be characterised by its effort factor *mf*, defined as :

(18) $$mf = \frac{E}{E_{93-95}}.$$

The estimated yield for mf ranging from 0 to 2 is presented fig. 5, by groups of species and for all groups together.



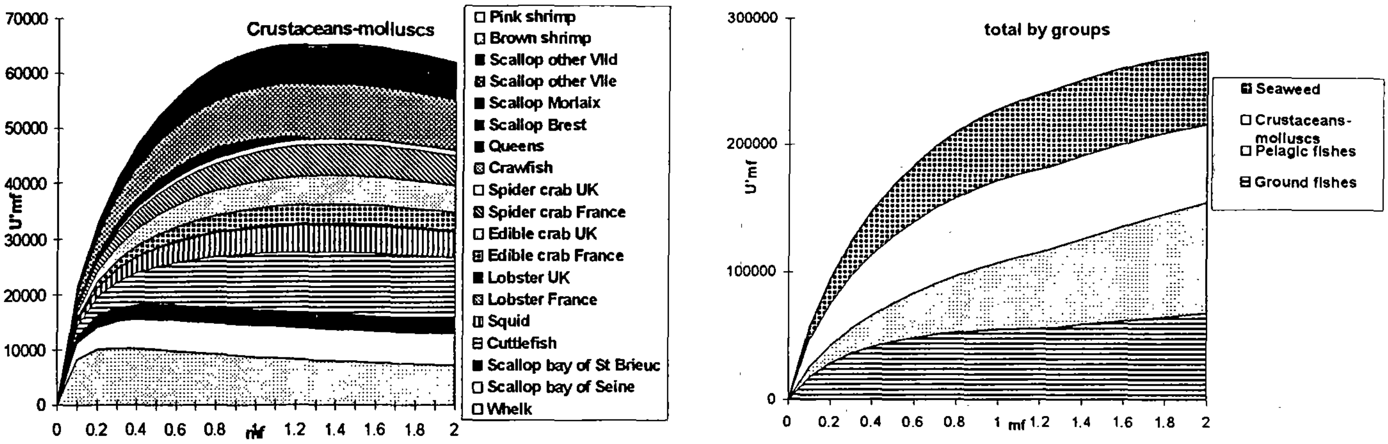


Fig. 5. multispecies production functions

As we see from figure 5, the multispecies assessment is rather optimistic in the Channel. At a level of effort double than the current situation, total catches would increase by 20%. This result appears rather inconsistent with many overexploited assessments made on Channel stocks.

This result is of course strongly dependant of model used. In fact, this unrealistic increase is mostly due to 2 stocks : mackerel and whiting VIId. As said previously, these stocks are considered as belonging only an external large stock, and Channel catches account for only a very small part of total catches (4.9 % for mackerel, 14.8% for whiting VIId). At the global stock scale, fishing mortality due to Channel fleets is very low, and increasing Channel effort increases related catches without significantly affecting the stock. In this case, a non-spatialised age-structured model gives similar results to those that would have been obtained with a constant CPUE coefficient. This is also the case for other external stocks such as megrim or hake, but total catches for these species are much less important. These production functions could be empirically limited by decreasing the α coefficient in the In/Out model.

Most groundfish stocks are decreasing, except underexploited species such as dab and pout. Molluscs, crustaceans and seaweed have constant catches over a large range of effort. Thus no or only a slight increase would be expected when increasing fishing effort.

Two simple simulations

The following simulations illustrate the general use of the model, but results are at this stage preliminary and minor changes may occur after further testing and validation of the model.

Effects of reduction of one single fleet segment

To illustrate the potential of the model, the number of French boats in the over 20 metres Otter Trawlers fleet from the western half of the Channel (FW_Ot) were reduced by 20 %. The estimated effects of this on their exploited stocks, on total revenue for all fleets, and on mean revenue for some fleets operating in the same (or similar) métiers, or targeting same species are presented in Figure 6. These include French otter trawlers from the eastern half of the Channel (FE_Ot), UK Otter trawlers (UC_Ot), and French netters from the western Channel (FW_Nt)

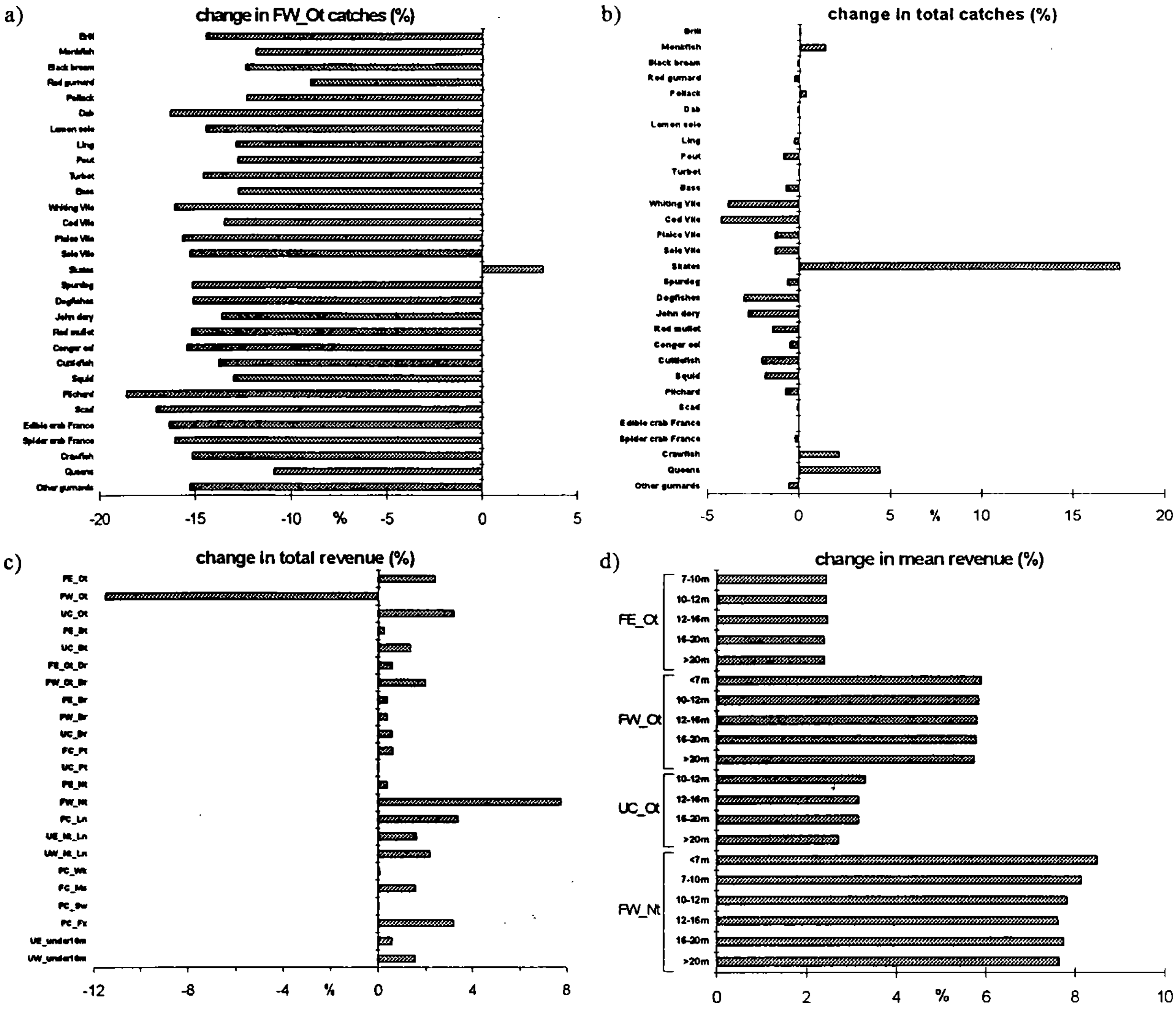


Fig. 6. consequences of a 20% decrease in >20m french west otter trawlers
F: France. U : UK. W : west. E : east. C : whole Channel. Ot : otter trawlers. Bt : beam trawlers. Dr : dredgers. Pt : potters. Nt : netters. Ln : liners. Wk : whelkers. Ms : Miscellaneous. Sw : Seaweeders. Fx : other fixed gears.

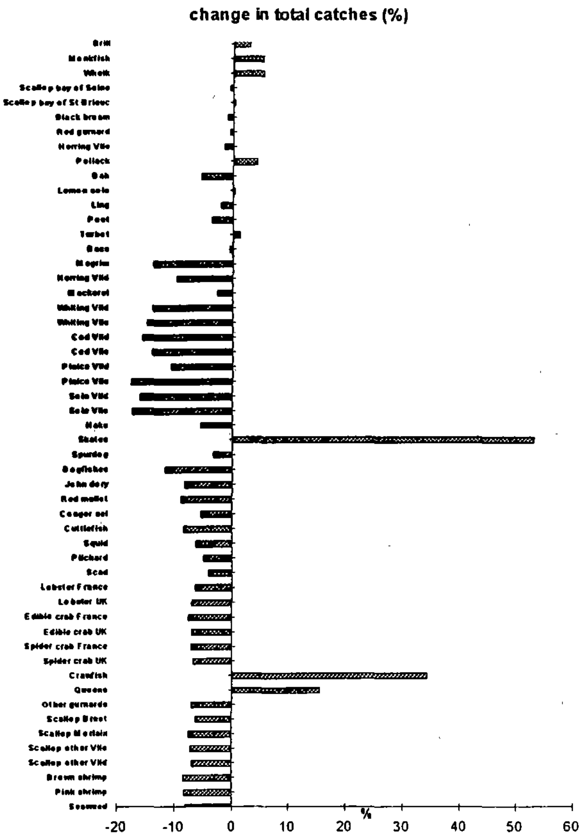
French west otter trawl is an important fleet in the English Channel fisheries. It consists of only 51 boats (1.2% of total number of Channel boats), but 44 of them are relatively large at over 16m in length. They exploit more than 38 different stocks, and account for 6.5% of the total landings weight, and 11.8% of the total landings revenue.

A 20% decrease in the effort of the boats over 20m in length decreases the total FW_Ot fleet by 13.7%. We see in Figure 6a that this change reduces the landings of all species made by this fleet except for skates and rays, which are so strongly overexploited that the decrease in effort results in a significant increase in catches. At the whole fishery scale the decline in catches by the FW_Ot fleet is compensated by the positive effect on the catch per unit effort made by other fleets, and thus catches increase. This may even lead to a net positive effect on total catches of some species such as monkfish, crawfish and queens (Fig. 6b).

From the economic point of view, the revenue from French west otter trawlers decreases significantly, as would be expected. Conversely almost all other fleets increased their revenues, with the exception of the fleets which have little or no interaction with trawlers (for example boats exploiting whelks and seaweed). This increase was greatest for the French west netters (8%), which target many same species as trawlers (Fig. 6c). Although the total revenue decreases, the mean revenue of the remaining boats in the French west trawlers increased, as did the mean revenue of boats in other size classes in the same fleet, and in other fleets. (Fig 6.d).

Multi-Annual Guidance Programme

The Multi-Annual Guidance Programme (MAGP) of the Common Fisheries Policy of the European Community calls for effort reductions in certain sectors of the European fleet. The next of these (MAGP IV) is due at the end of December 2001. As a prelude to this type of restriction, it is possible to simulate the effects of a reduction in effort by 20% across all Channel fleets, and view the changes to species catches and economic performance measures. (fig 7).



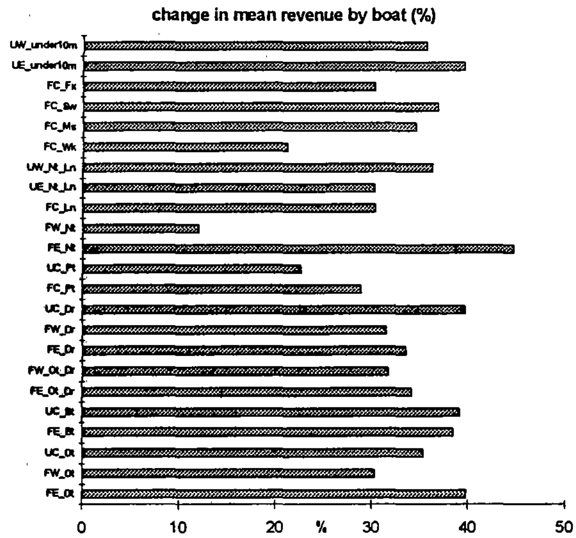


Fig. 7. Change in total catches and mean revenue for a 20% decrease in effort by all fleets

Figure 7 shows that the effects of a global 20% decrease in effort would not have similar effects across all species and fleets. On the whole landings will decrease for both age-structured and surplus yield species. The exceptions are surplus yield species that were considered to be severely overexploited (skates and rays, crawfish and queen scallops). Given that many surplus production models have been adjusted assuming that current situation was close to the MSY, decreasing total effort will not result in an increase in overall catches.

However, from the economic point of view, the increase in catch rates per unit effort will result in a significant increase in the mean revenue by boat. Depending on their target species, this increase will range from 12% to 44%. There is therefore a relatively large reward to be potentially made (in terms of increased economic performance) following such a decrease in effort.

DISCUSSION

Taking the interactions between fishing activities into account is necessary for the management of any complex fishery. The bioeconomic simulation model of the English Channel fisheries, BECHAMEL, was built in response to that need. It is a multi-species, multi-gear, multi-country model which encapsulates the key interactions between the biological, effort production and economic components that exist in the fishery. As such, it is a potentially powerful management tool that can be used to estimate the effects of changes in management on the economic performance of different fleets in the fishery.

The preliminary results presented in this paper demonstrate how interactions among fleets were taken into account. Further they demonstrate that, in fisheries with large numbers of technical interactions, the consequences of management changes will often be experienced by fleets that were not originally subjected to this change (externalities). In the example above these effects were positive, however the model will also enable the identification of any negative externalities that may arise from changes in management. This information will be invaluable to fishery managers when evaluating potential new policies..

However, as outlined previously, the results are subject to discussion. The model, whilst functioning, is in the process of development. For example, there is evidence that the prices of some species (particularly in France) may be endogenous. An allowance for endogenous prices has been built into the model, although the price flexibility has still to be finalised for some species. As a result, the prices are currently considered only as exogenous.

Major assumptions also exist in the biological component. Many production functions are very simplified, mostly due to very unreliable data or because of incomplete knowledge of the species. Age-structured production functions also assume an exogenous recruitment, without any stock-recruitment relationship. A mean recruitment for the period 1993-95 is assumed, which remains constant despite potential fluctuations in the spawning stock biomass.

Another limit of the current model is the fact that the level and allocation of fishing effort is regarded as an exogenous variable. An attempt to develop fleet dynamics, at least from an inter-annual perspective, will be undertaken at a later date. Such an analysis requires an estimation of the short-term biological production, which has be done only for a few species.

The model presented above is one of two models being developed in the project. The second model is an optimisation model based on the same data and underlying structure. This will enable the estimation of the optimal level and allocation of fishing effort in the long run from a multi-objective perspective. A key feature of the optimisation model is that effort allocation is endogenous, so that the effects of changes in management on the reallocation of effort can be estimated using the optimisation model. This can provide information for the development of the effort dynamics in the simulation model that could not otherwise be observed or collected in reality.

Whatever the further development and improvements of the structure of the model, the quality of the model is strongly dependant upon the level of available information. BECHAMEL, as is any model, is only able to give an idea of what should happen under given circumstances, and for a given level of knowledge. This, however, is a vast improvement over the previous situation where the effects of management changes could only be speculated rather than estimated.

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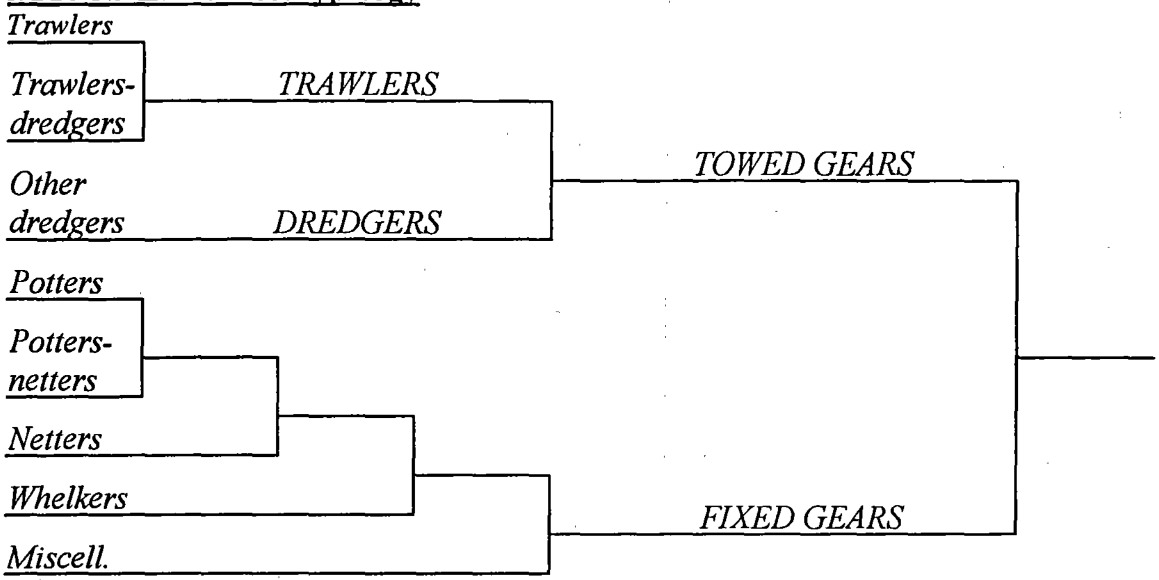
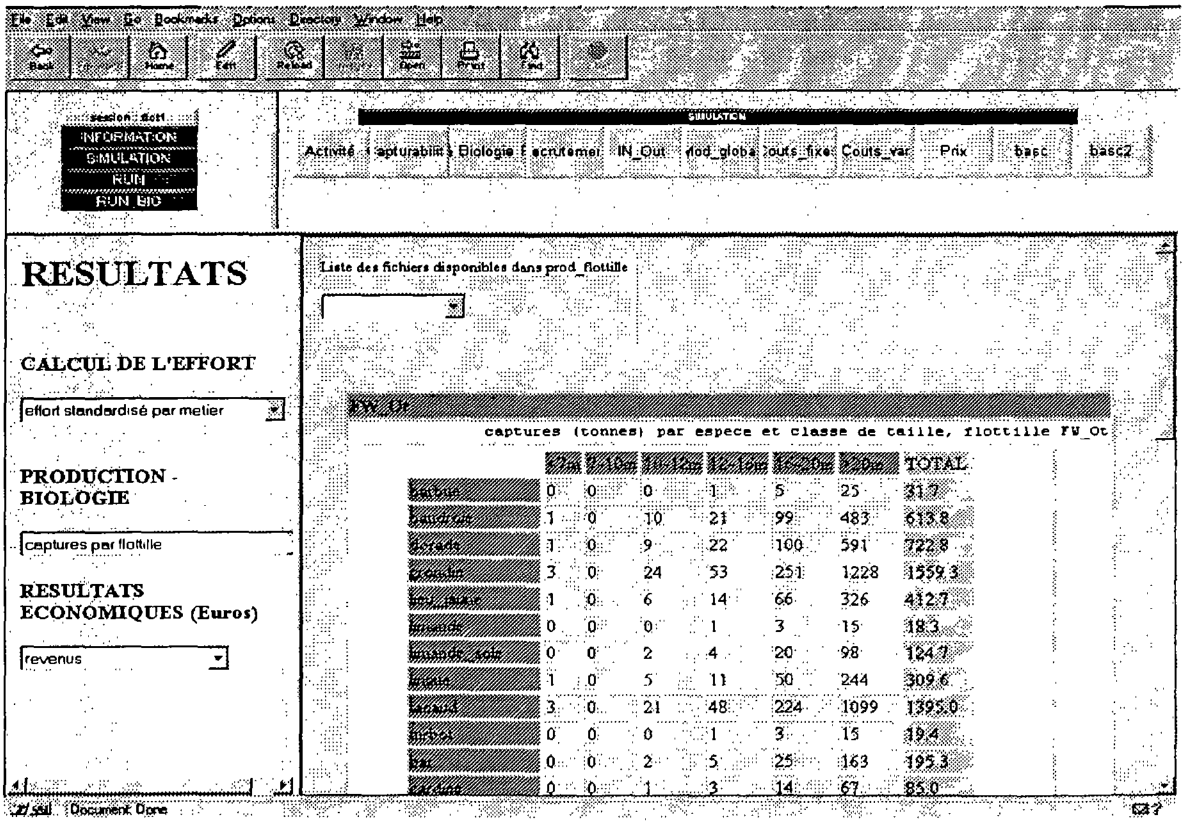
APPENDIX 1 : Fleet typology



APPENDIX 2 : The BECHAMEL Netscape interface.



APPENDIX 3: Stock classification and mean annual landings (tonnes)

APPENDIX 3: Stock classification and mean annual landings (tonnes)

Age structured model stocks				Surplus production model stocks			
Channel stocks (15)		In/Out stocks (12)		Fox model (23)s		Schaefer model (3)	
Bass	915	Cod VIId	3 667	Brown shrimp	245	Crawfish	25
Brill	384	Cod VIIe	629	Conger eel	1 020	Queens	1 459
Black bream	2 223	Hake	818	Cuttlefish	10 139	Skates spp	3 307
Dab	1 038	Herring VIId	6 510	Dogfish spp	3 480		
Herring VIIe	590	Mackerel	25 580	Edible crab France	3 188		
Lemon sole	1 496	Megrim	527	Edible crab UK	4 858		
Lingue	1 233	Plaice VIId	5 988	John Dory	396		
Monkfish	2 462	Plaice VIIe	1 420	Lobster France	212		
Pollack	1 895	Sole VIId	4 090	Lobster UK	218		
Pout	4 734	Sole VIIe	863	Pilchard	4 931		
Red gurnard	3 332	Whiting VIId	6 185	Pink shrimp	151		
Scallop bay of Seine	5 627	Whiting VIIe	1 285	Red mullet	987		
Scallop bay of St Brieuc	2 864			Scad	10 229		
Turbot	436			Scallop bay of Brest	35		
Whelk	10 000			Scallop bay of Morlaix	123		
				Scallop other VIId	9 095		
				Scallop other VIIe	6 534		
				Spider crab France	5 416		
				Spider crab UK	828		
				Spurdog	576		
				Squid	4 553		
				Other gurnards	1 872		
				Seaweeds	56 805		

APPENDIX 4: Age structured model diagram