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NOTE

Policy Department B
Structural and Cohesion Policies

STRATEGIC RESEARCH PRIORITIES TO THE COMMON FISHERY POLICY (CFP) WITH REGARD TO GLOBAL COMMITMENTS (MSY, EAF, MSFD)

FISHERIES

2008

EN

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Directorate General for Internal Policies of the Union

Policy Department B: Structural and Cohesion Policies

FISHERIES

STRATEGIC RESEARCH PRIORITIES TO THE COMMON FISHERY POLICY (CFP) WITH REGARD TO GLOBAL COMMITMENTS (MSY, EAF, MSFD)

NOTE

Content:

The report is focused on the research priorities pertaining to the implementation of the ‘maximum sustainable yield’ (MSY) and of the ‘ecosystem approach to fisheries’ (EAF). The MSY is first examined, taking account of its relevance as a management objective, of its link with maximum economic yield (MEY), and of its close relationship with ecosystem productivity and fishing capacity. Related research priorities are identified. In the second part, emphasis is put on EAF, a very challenge for fishery scientists. The extension of fisheries science towards an ecosystem dimension (including human activities) and the integration of uncertainty have opened up large fields of research. Priorities are presented by domain. Five principal areas of knowledge and related societal issues are identified: ecosystem, resources, exploitation, governance, methodology, the latter encompassing data collection.

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Executive summary

The objectives for the management and the restoration of resources and marine ecosystems require an evolution in the modes of governance, exploitation and also in fisheries research. The prevailing fisheries management system is based on conservation measures, i.e. on measures aimed at preserving the productive and reproductive capacity of the stocks, particularly the TACs (Total Allowable Catch), generally in association with technical measures (e.g., improvement of gear selectivity). The fisheries management systems are in fact based on a set of complementary tools, either for the preservation of resources and of the biodiversity (e.g., networks of marine areas), or for the access regulation to fisheries. The present report is focused on the research priorities pertaining to the implementation of the ‘maximum sustainable yield’ (MSY) and of the ‘ecosystem approach to fisheries’ (EAF), two management tools –the former ‘classic’, the latter ‘emergent’– both integrated to international commitments.

The MSY is defined as the highest theoretical equilibrium yield that can be continuously taken (on average) from a stock under existing (average) environmental conditions without affecting significantly the reproduction process. Referred to in the Convention on the Law of the Sea, it is an essential fisheries management benchmark. MSY is also considered as an international minimum standard for stock rebuilding strategies. Indeed, according to the Plan of implementation of the World Summit on Sustainable Development (2002), fish stocks should be rebuilt to the MSY by 2015.

In a dynamical acceptation, e.g., when dealing with fish stocks rebuilding, MSY provides a relevant target direction for the definition of restoration measures. In spite of that MSY is a monospecific management goal, MSY-oriented strategies will likely be a substantial progress towards restoring harvested fish communities and ecosystems. Furthermore, targeting MSY smoothes the way to the maximization of economic rent on a safe biological basis.

Considering research guidance, it is worth remembering that the ultimate ‘sizing factor’ of MSY is the productivity of ecosystem. At the eco-regional scale, significant progress are therefore needed in food webs dynamics knowledge, in the tracking of ecosystem ‘regime shifts’, and in deepening our understanding of fish recruitment process. At the ecosystem and fishery scales, a prime prerequisite is the precise knowledge of effective fishing capacity dynamics, and of strategy and tactics of fishing effort deployment.

The second part of the report put the emphasis on research needs with regard to ecosystem approach to fisheries (EAF). In its standard form, the EAF seeks to balance various socio-economical objectives, taking into account best available knowledge as well as current uncertainties on the biotic, abiotic and human components of ecosystems and their interactions, and to implement an integrated approach to fisheries management within a healthy ecological framework. Insofar as human activity is considered to be an ecosystem component rather than a source of exogenous disruption, all the social, economic and political factors that affect human behaviour towards fisheries and more broadly marine ecosystems have to be taken into account. Thus, governance is *de facto* a structuring research theme that supports EAF.

The international institutional framework within which the EAF has developed is comprised principally of three United Nations (UN) bodies: UNCLOS (UN Convention on the Law of the Sea, 1982), UNCED (UN Conference on Environment and Development, 1992), and the Committee on fisheries of FAO (United Nations Organisation for Food and Agriculture, 1965).The CBD (Convention on Biological Diversity) and Agenda 21, signed at the time of the Rio summit in 1992, complete the foundation stones.

Compared with the classic fisheries paradigm, the EAF greatly expands the field of research and expertise in several directions; (i) from the exploited population (stock) *stricto sensu* to the whole ecosystem; (ii) from the ternary system ‘fisheries-administration-science’ to the quaternary system ‘fisheries-administration-science-civil society’; (iii) from the operational short-term to the strategic long-term planning (including environmental constraints, particularly climate change); (iv) from a sectorial approach to an intersectorial and spatial approach; (v) from sectorial sustainability to the contribution of this sector to the sustainable development of coastal communities.

The scientific challenge is therefore considerable and the success of the EAF will depend on our capacity to turn the general objectives of EAF into operational management objectives and reliable and efficient evaluation methods. In practice, it seems that research and expertise develop in stages, depending on the available tools and the improvement in knowledge. The first stage focuses on the direct impacts of fishing on non-commercial species (by-catches) and habitats (impact of gear towed over the seabed for example). A second stage is to take into consideration biological interactions between the species on which fishing has direct and indirect impacts. This second dimension of the EAF implies sufficient understanding of marine ecosystem functioning so that operational lessons for fisheries management can be learned. The ultimate stage of EAF would be to include all the interactions between fisheries and other anthropogenic activities, by integrating all impacted marine ecosystem components (biotic and abiotic). But the current attractiveness of this idea does not guarantee that it will become operationally effective. In addition to the ecological and environmental uncertainties already mentioned, there is the difficulty of defining the interactions between uses, which are potentially numerous, often diffuse and whose ecological basis is often poorly known.

Pragmatically, the report categorizes research priorities by domains: the areas of knowledge and related societal issues have been divided into five principal groups: ecosystem, resources, exploitation, governance, methodology.

In close connection with Marine Framework Strategy Directive (MFSD), it is worth underlining that collecting and managing data will probably be a key issue within the EAF given the considerable expansion in the area of research and expertise. Taking into account anthropogenic effects in the medium and long term supposes that reference situations are available on a continuous basis over several decades and for various locations. Without such monitoring, it would have been (and still would be) impossible to describe, understand and speculate about the effects of climate variations and global warming on populations and marine ecosystems. Our understanding of the long-term changes that different uses (e.g. exploitation, regional development) cause in some biological and ecological processes (e.g. reproduction, migration) of the exploited populations or in ecosystem biodiversity has also been facilitated by the availability of long-term series and biological archives. In coordination with MFSD, the EAF will thus have to combine the classic approach (i.e., collecting data according to defined objectives) with a perennial system of marine ecosystem observatories.

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Introduction

Based on a rapid development of harvesting techniques and fishing capacities, an expanding geographical exploitation and an increase in the international trade of fish products, the global production of marine fisheries increased rapidly from the 1950s to reach its maximum at the end of the 1980s [1, 2]. Apart from the fact that the volumes landed have remained practically unchanged for about two decades, reports of the overexploitation of commercially-important stocks have multiplied [3]. This raises the question of the viability of exploitation systems, from the viewpoint of the resources and the human communities, and also of the capacity of marine ecosystems to sustain present levels of harvesting.

The issue is all the more urgent in that fish represent a significant protein source for humans. The global consumption of fish products has doubled since the beginning of the 1970s because of factors such as population growth, rising incomes and developing urban centres and is expected to continue to grow [4–6]. Furthermore, an increasing proportion of fisheries production is used to produce feed for aquaculture [7–9], which is growing rapidly at international level in response to the widening gap between fish production and the demand for fish products [2, 4, 6, 9–11].

The diagnosis of the causes of fish resource overexploitation is today widely agreed upon at international level: it is based on the acknowledgement of the *common pool* nature of these resources which leads to reciprocal negative externalities between operators(1) and to the development of phenomena such as ‘the race for fish’. In practice, these phenomena lead to the use of harvesting capacities exceeding those needed for optimal and sustainable fish production. Besides being a waste of resources for society, this overcapacity is the source of increasing conflicts between operators and promotes excessive harvesting levels compared to the potential for renewal and growth of the exploited species. Despite the crises and conflicts caused by these dynamics, and efforts made to regulate the sector’s activity, today’s production capacities considerably exceed requirements [12–15]. This is true in Europe, despite a reduction in the fleet and in employment since at least the middle of the 1940s [16].

Other activities (industries exploiting energy and mineral marine resources, maritime transport, waste products from land-based activities, coastal urbanisation, aquaculture, recreational activities) also put pressure on marine ecosystems. This pressure can have a direct impact on fishing through the competition created for access to resources and/or coastal areas, and an indirect impact through its effects on the structure and the functioning of marine ecosystems and also on water quality [17]. Thus it is recognised that there are increasing risks of degradation in fish product sanitary quality [18], due to chemical and microbiological contamination from various sources.

The present objectives for the management and the restoration of resources and marine ecosystems therefore require an evolution in the modes of governance, exploitation and also in fisheries research. The prevailing fisheries management system is based on measures aimed at preserving the productive and reproductive capacity of the stocks, particularly the TACs (Total Allowable Catch), generally in association with technical measures. Unfortunately, this type of management has failed in numerous cases, particularly because governance regimes have failed

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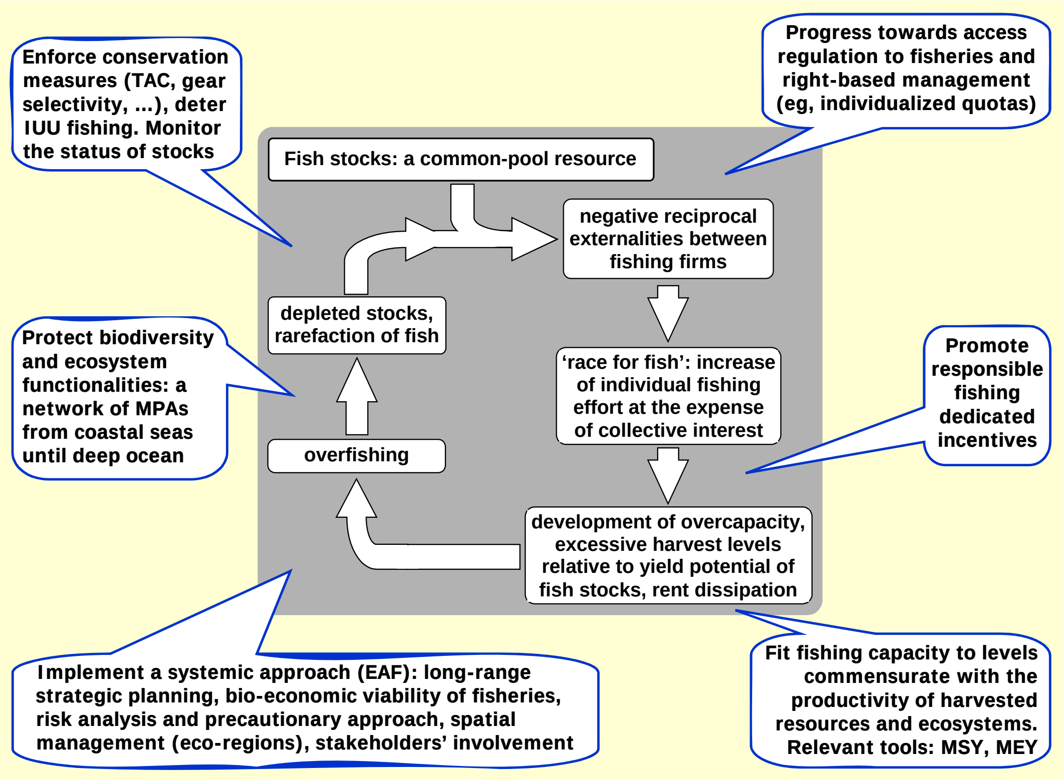
(1) Externalities mean any situation when the well-being of a person or the production of a company depends on real variables (non monetary) which are affected (even decided) by other agents (persons, companies, governments) without any particular attention given to the potential effects on the person or the company affected. The term ‘external’ refers to the fact that the effect happens outside the relationships voluntarily established between the economic agents on the markets. Interactions between fish resource operators represent reciprocal external negative effects, that is to say that the agents who cause the effects also suffer the consequences. These externalities arise from the specific nature of the resources. Because of their ‘fugitive’ nature, fish stocks are technically difficult to allocate to individual users beforehand; the use made by some reduces the availability of the resource for others.

to effectively regulate access to living marine resources. Indeed, conservation measures such as TACs cannot on their own contain the dynamics leading to the development of overcapacity(2). Furthermore, overcapacity creates social pressures which promote the adoption of insufficient conservation norms and inadequate implementation or control of the management recommendations advocated by independent scientific authorities.

The consensus on environmental issues, the involvement of civil society and the poor performance of conventional governance systems therefore create a driving force for an evolution of fisheries management, as broadly outlined in figure 1.

Figure 1. Diagram of the 'race for fish' process in a weakly-regulated access fishery (centre of the figure, grey outlined box), and of the main remediation management tools, either 'classical' (e.g., TAC) or at various developmental stage according to country (e.g., networks of marine protected areas – MPA, fishing rights).



It is worth emphasizing that the efficiency of each management measure depicted in figure 1 is highly dependent of the effectiveness of the other ones, let alone its social acceptance.

The research priorities pertaining to the implementation of the 'maximum sustainable yield' (MSY; cf. figure 1, bottom right) and of the 'ecosystem approach to fisheries' (EAF, bottom left) are discussed in the present report.

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(2) *Fishing capacity:* the maximum amount of fish over a period of time (year, season) that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology. The "fishing fleet" designates inputs (*i.e.*, physical capital and human capital). The term "fully-utilized" means "a 100% capacity utilization" (availability of variable factors of production not restricted). The usual proxies of fishing capacity of a fleet involve both the number of vessels and some measure of vessel size – such as gross tonnage, hold capacity, horsepower – and provide in general an underestimate of the true fishing capacity. *Overcapacity:* Long-term phenomenon when the potential output under normal operating conditions is higher than the maximum sustainable yield of the resource. In the long-term, fishing capacity that exceeds the level required to ensuring the sustainability of the stock and the fishery at the desired level. Fishing capacity in excess of what is required to reach the agreed catch or effort objectives materialised by agreed target reference points (http://www.fao.org/fi/glossary/default.asp).

1. The Maximum Sustainable Yield (MSY)

1.1. Definitions – back to basics

Box 1: Maximum sustainable yield (MSY)

MSY: 'the highest theoretical equilibrium yield that can be continuously taken (on average) from a stock under existing (average) environmental conditions without affecting significantly the reproduction process' (http://www.fao.org/fi/glossary/).

Referred to in UNCLOS, it is an essential fisheries management benchmark, but it is only one of the possible management reference points. MSY is also considered as an international minimum standard for stock rebuilding strategies (i.e. stocks should be rebuilt to a level of biomass which could produce at least MSY).

1.1.1. The first operational steps

The concept of MSY was laid down in the 1930s by several authors, but the onset of its popularity in fishery science took place two decades later with the advent of the so-called 'surplus-production models'. Basically, a surplus-production model describes the temporal dynamics of the total biomass of a given fish stock considered as an homogeneous population of identical individuals. The model takes both the net population growth rate (the population size being limited by the 'carrying capacity' of the ecosystem) and the biomass loss due to harvest into account, and allows a straightforward calculation of MSY (cf. Annex 1).

The advantages as well as the drawbacks of the surplus-production model ensue from its simplicity. The main advantage is that model parameters may be estimated with basic data: time series of total catch on the one hand, and, on the other hand, time series of a related index of biomass abundance, the classical index being a well-standardized set of CPUE (catch per unit of effort) data. The main drawback is due to the high-level of aggregation of the modelled variable (the total biomass) – therefore it is impossible to assess, for instance, the effects of a change in fishing gear selectivity. Furthermore, in a less intuitive way, the recruitment process is implicitly confounded with the net growth rate of the total biomass, this rate itself being in the model only influenced by the intensity of harvest. In other words, the impacts of environmentally-driven fluctuations of recruitment are out of reach in that frame.

Surplus-production models have continued to be applied in some relevant contexts (long-lived species, apparent stability of environmental conditions for given time and space scales, poor data), but they are today almost replaced by more complex age-structured models (Annex 1).

1.1.2. The advent of structured population dynamics models

An age-structured model describes the dynamics of the age distribution of individuals in the population. Unlike the 'global' surplus-production models –based on a total biomass growth rate–, the 'structured' models are based on individual rates of biological processes (growth, fecundity and mortality, including mortality due to fishing) expressed as a function of age. One practical output of an age-structured model is, for example, the representation of the temporal evolution of the number of individuals in the different age-classes of the whole population, and the changes of age distribution under different assumptions (e.g., modification of individual mortality rate due to fishing, environmental impacts on individual growth rate, etc.). It is worth emphasizing that the first age-class corresponds to the recruitment in the population of newborn individuals ([3]).

In the present case, the result of interest is the MSY estimate, also provided by age-structured models at the expense of more detailed data. The first step is to characterize the relationship between 'yield-per-recruit' (Y/R) and fishing pressure. The quantity of biomass Y/R is the expected contribution of a recruit to the total catches from the population([4]). The trade-off between individual growth and mortality determines the shape of the curve Y/R vs. mortality due to fishing: typically, Y/R increases from low fishing pressure values until it attains a maximum, and then decreases with fishing intensity. Another important property of Y/R is its dependence upon the 'fishing pattern', i.e., upon the main features of the exploitation (e.g. fishing mortality at age, size at first capture, seasons and/or areas of closure). From a management point of view, attempts to maximize Y/R could therefore be performed by different ways.

The previous development rests on an assumption of constant recruitment, i.e., it neglects the natural between-year variability of the number of young fish entering the fishery, neither does it consider how the reproductive capacity of the harvested population is impaired by high fishing pressure. The prerequisite to the estimation of MSY is thus to identify the relationship between the yield of the population and the yield-per-recruit, while taking –as far as possible– the variability of recruitment into account. The classical approach is a statistical one: an empirical relationship (the 'stock-recruitment relationship') is fitted to paired observations of parental biomass and of subsequent abundance of recruits, and the resulting stock-recruitment (S-R) curve summarizes the variation of the average number of recruits in response to change in SSB, the spawning stock biomass ([5]).

The observations are in most cases –indeed all– widely scattered around the fitted curve in the R-SSB plane: in fact, a lot of regulatory mechanisms of various nature (biological, physical, etc.) act at multiple spatial and time scales, and the number of recruits appears at best poorly related to the parent stock size over the range of observed SSB. Although blurred by environmental noise, the S-R relationship is an useful tool for analysing the sustainability of alternative harvesting regimes, and particularly those likely to produce the MSY.

1.1.3. Computing the MSY estimate

Assuming stable fishing pattern and environmental conditions, an age-structured model allows to compute:

- SSB_{Eq}, the equilibrium value of the parental population biomass. The S-R relationship provides the 'equilibrium recruitment' R_{Eq} corresponding to SSB_{Eq}.
- $(Y/R)_{Eq}$, the yield-per-recruit at equilibrium.

By definition, MSY is the maximum of the product $(Y/R)_{Eq} \times R_{Eq}$.

([3]) The same definition applies *mutatis mutandis* to size-structured models, the 'structuring criterion' being the individual size in that case. Fishery scientists apply size-structured models to crustacean populations, whose age of individuals may hardly be identified, if not.

([4]) The yield-per-recruit Y/R is the expected lifetime yield per fish recruited in the stock at a specific age. It depends on the exploitation pattern (fishing mortality at age) or fishing regime (effort, size at first capture) and natural mortality.The quantity of biomass Y/R is estimated assuming the stock and the fishery are at equilibrium (http://www.fao.org/fi/glossary/).

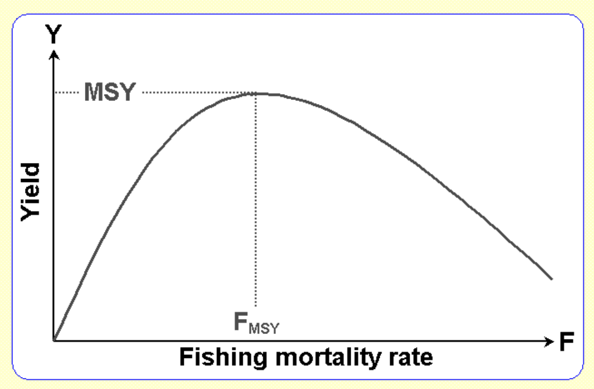
([5]) In all models, the average number of recruits first increases rapidly as the SSB increases from zero. As the SSB increases further, the average number of recruits either approaches an asymptote corresponding to a constant average recruitment regime (e.g., Beverton & Holt model), or it attains a maximum and then decreases under influence of density-dependent effects (e.g., Ricker model). Notwithstanding the variety of models that have been proposed to describe the S-R relationship, they remain almost undistinguishable in terms of how well they fit available SSB and recruitment data. A dimensionless parameter (the 'steepness') has thus been proposed to characterize the S-R relationship at low stock size. Let R_0 and SSB_0 correspond to the unexploited state of the stock; the steepness is the average recruitment (scaled to R_0) that results when SSB is 20% of SSB_0.

The MSY acronym is the usual one. But according to the previous definition, one should notice that the acronym MSY_{Eq} would have been better appropriate for avoiding some misinterpretations (cf. next paragraph).

1.2. Yield vs. fishing pressure relationship – some caveats

As previously recalled, the prime interest of MSY is to provide guidance to fishery managers. It is therefore logical to focus attention on the long-term yield variations of the harvested population in response to modifications of the fishing pattern. In this case, the 'control parameter' under consideration is F, the mortality rate due to fishing ([6]). Figure 2 portrays the generic shape of the Y vs. F curve.

Figure 2. Generic picture of the dependence of the yield of a stock (Y, ordinates) upon the rate of mortality due to fishing (F, abscissa). The curve depicts an equilibrium state: the MSY level expected from changing the current fishing pattern from F to F_{MSY}, and by maintaining F at F_{MSY}, will be reached after decay of transients (see text).



In spite of its simplicity, the concept of MSY is liable to be misinterpreted; it is thus useful to recall that:

(i) MSY-oriented harvesting strategies aim at maximizing the long-term productivity – not the abundance– of the stock. Figure 2 shows that for F values greater than F_{MSY}, a lowering in F will entail an increase of the catches. This is obviously not true in the short term: the immediate effect of a decrease in F is a decrease in catches. While fitting to the new fishing pattern, the stock dynamics enters a transient regime. Then, as the new equilibrium state is approached, the further effective becomes the gain of yield due to F decrease.

(ii) The MSY of a given population depends on the fishing pattern. In practice, more selective fishing practices and/or gears lead to higher MSY values. It is also worth remembering that 'yield' is not restricted to official landings, but that it includes also discards and illegal, unreported and unregulated (IUU) fishing landings.

(iii) MSY and F_{MSY} are not only 'fishing pattern dependent', their estimates are also conditional to given environmental conditions; MSY and F_{MSY} need therefore to be revisited after a 'regime shift' has occurred in the ecosystem dynamics.

([6]) In the 'global model' frame, only one F parameter summarizes the fishing mortality rate of the population. In the 'age-structured model' frame, a 'mortality-at-age' F_a parameter is linked with each age-class (as a quite general rule, F_a should be zero for age-classes of immature individuals).

1.3. Data requirements and proxies

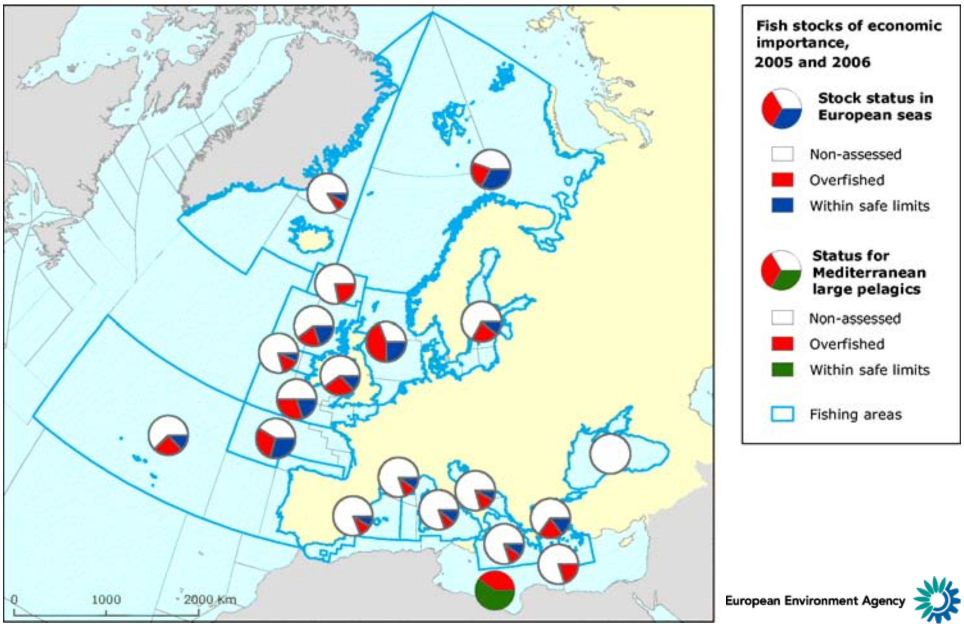
In order to estimate MSY and F_{MSY} by using an age-structured population dynamics model, several types of data are required:

- individual growth (size and weight at age), fecundity at age;
- natural mortality rate at age (7), a sensitive parameter in general poorly known;
- paired observations of abundance of spawners and consecutive number of recruits (including discards of juveniles) for different and well-characterized environmental conditions; besides the necessary availability of these data in the S-R relationship identification process, such multivariate time-series are also useful for performing re-analyses of the long-term harvested populations and ecosystems dynamics.

Since the mid 1970s, the Food and Agriculture Organization of the United Nations (FAO) evenly publishes diagnostics and syntheses about the state of world marine fishery resources. In the 2005 report [19], the FAO global assessment was based on 584 monitored stocks or species groups on which at least general catch trends were reported; information allowing some estimate of their state was available on 441 stocks (having produced ca. 80% of world marine official landings in 2002); no reliable information was available for the 143 remaining stocks (ca. 20% of 2002 world landings). In some fishing areas of the world (e.g., western Indian ocean, western central Atlantic), the state of exploitation of a large number of stocks is undetermined or unknown.

With regard to pan-European waters, the 2007 fourth assessment report [16] of the European Environment Agency (EEA) depicts the situation summarized in figure 3.

Figure 3. Status of the level of knowledge of fish stocks in pan-European waters; the figure emphasizes the need for an improved assessment of the state of commercial fish stocks. For example, 81% of Arctic, 67% of Baltic Sea and 54% of north-eastern Atlantic commercial fish stocks remained non assessed in 2006.



Source: European Environment Agency, *Europe's environment – The fourth assessment*, 2007

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(7) In population dynamics models applied to harvested fish stocks, the total mortality rate (Z) is defined as the sum of mortality rate due to fishing (F) and of natural mortality rate (M), i.e., Z = F + M. 'Natural mortality' encompasses various causes of death: predation, unfavourable environmental conditions (lack of food, poor temperature and/or oxygen conditions, habitat degradation, pollutants, etc.), illness, parasites, *inter alia*.

Clearly, even in rather well-studied marine areas, the characterization of many fish stocks condition is hampered by a lack of basic information. Owing to the fact that MSY is a management objective *inter alia* in many Regional Fishery Bodies (RFB) –for instance since 1949 in IATTC and ICNAF, since 1966 in ICCAT (8)–, proxies tailored to the context of sparse data were early developed. Four amongst the several recognizable types of MSY or F_{MSY} proxies are mentioned below.

(i) *Proxies using life-history parameters*, i.a. the parameters related to the individual growth, the length at first capture, the natural mortality rate. General conclusions have been drawn from theoretical considerations and from experience, e.g.: the potential yield is higher for higher individual growth rate (at fixed natural mortality rate) as for higher age or size at first capture. Some dimensionless parameters, such as size at sexual maturity to maximum size ratio, have also been related to potential yield. Examples of reviews are found in [20, 21].

(ii) *Proxies using the 'critical age'*. In the absence of immigration or emigration, the total number of fish of a non harvested age-class decreases at the rate M (the natural mortality rate). At the same time, individual growth raises the total biomass of the same age-class. Therefore, there exists a 'critical age' at which the loss of biomass due to natural mortality and the gain of biomass due to individual growth in weight are in balance: the biomass of the age-class is maximum at critical age. In many fish species, the critical age is close to the age of maturity, e.g. of the order of 2 years for small pelagic species, and of ca. 5 to 9 years (depending upon latitude) for gadoid species. Maunder [22, 23] underlines that the maximum achievable MSY for a population whose recruitment is independent of stock size is Y/R multiplied by the number of recruits, provided that all the fish are captured at the critical age. To our knowledge, actual examples of such sorely realizable fishing pattern are lacking.

(iii) *Proxies using the yield-per-recruit* Y/R. A relevant proxy of F_{MSY} has been defined as follows: the current marginal yield resulting of an increase in fishing pressure is compared to the marginal yield that would have resulted from the same increase in fishing pressure at the very beginning of the exploitation of the stock. In that sense, $F_{0.1}$ is the fishing mortality rate at which the marginal yield-per-recruit (i.e. the increase in Y/R for an increase in one unit of fishing mortality F) is only 10% of the marginal Y/R of the unexploited stock. Equivalently stated, $F_{0.1}$ is the fishing mortality rate at which the slope of the Y/R vs. F curve is only one-tenth the slope of the curve at its origin. To date, there is a general agreement on the suitability of the use of $F_{0.1}$ as a proxy of F_{MSY}, together with a monitoring of fishing impacts on spawning biomass.

It must otherwise be emphasized that F_{max} (the fishing mortality rate that maximizes equilibrium Y/R) is not a proxy of F_{MSY}. In fact, F_{max} is by definition greater than $F_{0.1}$, and is the F level often used to define growth overfishing. It has been established that F_{max} is greater than F_{MSY}, except in special cases of strong density-dependence in the S-R relationship (e.g., high cannibalism of adults on juveniles). For the majority of stocks, F_{max} provides at best an upper bound of the acceptable domain containing F_{MSY}.

(iv) *Proxies using the spawning biomass-per-recruit*. Spawning biomass-per-recruit and $F_{X\%}$ are respectively defined in the same way as Y/R and $F_{0.1}$. All these biological reference points are often used as proxies when data are lacking, in particular when the S-R relationship is unknown or hardly identifiable. The spawning biomass-per-recruit is the expected contribution to the reproductive potential of the population. The fishing mortality rate $F_{X\%}$ will reduce the equilibrium spawning biomass-per-recruit to X% of what it would be without any fishing; $F_{X\%}$ denotes thus a family of biological reference points. Based on simulation studies for groundfish

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(8) Cf. http://www.fao.org/fishery/rfb/search/en. IATTC: Inter-American Tropical Tuna Commission; ICNAF: International Commission for the Northwest Atlantic Fisheries (in 1979, the NAFO, Northwest Atlantic Fisheries Organization, succeeded to ICNAF); ICCAT: International Commission for the Conservation of Atlantic Tunas.

stocks, $F_{20\%}$ has been recommended as a default proxy for the level of fishing mortality at and beyond which recruitment overfishing occurs. Similarly, $F_{40\%}$ has been recommended as a proxy for F_{MSY}.

1.4. Applications

> ‘*The estimation of potential yield is not an abstract problem of interest only to fisheries scientists and biologists; it is arguably the most important problem for fisheries management* […] *Once an estimate of potential yield can be made, the key management information on the capacity of the fishery can be deduced*’.
>
> –J.R. Beddington & G.P. Kirkwood (2005)

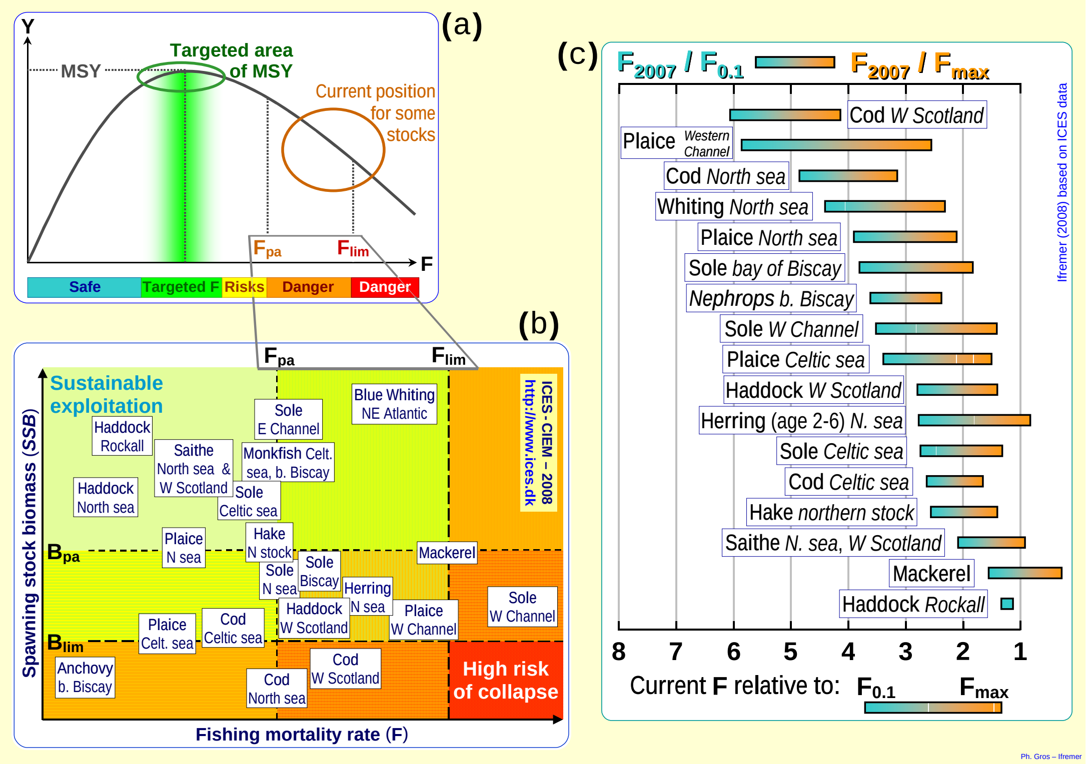
Two examples will be presented:

- the first one concerns the biological state of some European fish stocks of North sea, Channel, Celtic sea and Bay of Biscay, whose management is based i.a. on TAC and quotas [24]; the study provides a preliminary estimate of the difference between current F ($F_{current}$) and F_{MSY}, the first aim being to give prominence to the main lines of forthcoming management measures;

- the second example is the *Nephrops* fishery of the Bay of Biscay [25]. The study highlights significant dimensions of MSY-oriented management strategy, by taking into account: (i) the economic rent, (ii) the transition phase between fishing regimes –in short, from ‘$F_{current}$’ to ‘F_{MSY}’–, (iii) the effects of improving gear selectivity.

The $F_{current}$:F_{MSY} ratio, a relevant guidance for a long-term management objective

Figure 4(a): Y vs. F equilibrium relationship, with biological reference points (F_{lim}, F_{pa}) and target fishing mortality F_{MSY} also indicated; the subscript ‘pa’ stands for ‘precautionary approach’. (b): 2007 situation of 21 TAC-managed stocks in the domains of the F-SSB plane defined by the ICES biological reference points (F > F_{lim}: overfishing; B < B_{lim}: overfished; F_{pa} < F < F_{lim} and/or B_{pa} > B > B_{lim}: at risk; F < F_{pa} and B > B_{pa}: safe). (c): 2007 harvest rate (F_{2007}) of 17 of these stocks compared to $F_{0.1}$, a proxy of F_{MSY}. The ‘F_{MSY} target area’ is in fact represented by an interval whose left (blue) bound is $F_{0.1}$, and whose right (orange) bound is F_{max}. The horizontal axis shows the value by which F_{2007} should be divided (and maintained to) in order to match the equilibrium MSY target area.



Adapted from: Biseau, A., Ifremer (2008, unpublished)

Results presented in figure 4 are based on ICES data; the biological condition of the 18 stocks (10 species) under consideration is depicted on figure 4(b), which pinpoints their positions relative to the 'biological reference points'. It is worth emphasizing that a stock whose level of biomass produces the MSY is also a stock within 'safe biological limits' (i.e., SSB bigger than B_{pa} and F less than F_{pa}); as recalled by figure 4(a), the reverse is not always true. This is exemplified in figure 4(c), where $F_{0.1}$ is used as a proxy of F_{MSY}, and F_{max} as an upper bound of the likely values of F_{MSY}. Notice for instance that the $F_{current}$:F_{MSY} ratio of the hake northern stock shows that this stock is not harvested at the MSY level, albeit situated in the safe area.

As recalled by Mace [26], there has been comprehensive account written of the uses and misuses of MSY, all the more so as it was integrated in the important UN Convention on the Law of the Sea (1982), thus paving the way for integration into national fisheries acts and laws (cf. Annex 2). Figure 4 highlights the usefulness of MSY regarded as being a robust indicator of the required direction of change in fishing mortality rate when attempting to achieve a biologically optimal exploitation; in spite of its drawbacks, MSY is a readily understood and operational concept. Furthermore, without omitting counterexamples, several 'success stories' of substantial increase in biomass of fish and shellfish stocks following significant reduction in fishing pressure have been related [27]. In order to help matching the European Marine Strategy directive goals, it would be wise to generalize this approach to all harvested European fish stocks– whether yet assessed or not.

In terms of social acceptance, much attention must be paid to the transition periods: when fishing mortality rate exceeds F_{MSY}, the possible short-term negative outcomes following fishing mortality reduction have to be anticipated and facilitation measures planned. The simulation of transition phases applied to selectivity changes in a shellfish fishery is presented in the following paragraph.

From $F_{current}$ to F_{MSY} – economic rent variations during the transition phase

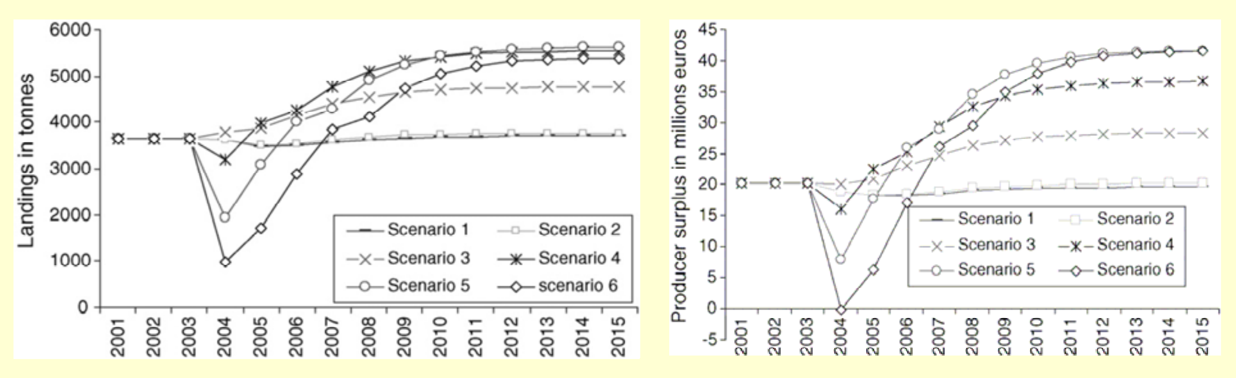
About 230 french bottom trawlers target the *Nephrops* in the Bay of Biscay (ICES divisions VIII a, b). The total allowable catch (TAC) is at 94% allocated to France (french quota: ca. 3000 tonnes in 2004), the remainder to Spain. The *Nephrops* trawl fishery management is chiefly based on conservation measures (a TAC together with a minimum landing size and minimum trawl mesh size).

These measures have failed to prevent high discard levels: 10% of the first two age groups are caught and 90% of those catches are discarded. According to ICES assessment, 1900 tonnes of *Nephrops* were discarded in 2004, i.e. 60% of *Nephrops* caught in number and 30% in weight (ICES, 2006). The main reason for discarding *Nephrops* is the minimum landing size. The current fishing mortality is well above F_{max} –especially for young age groups caught below the minimum landing size–, i.e., F is too high to yield the maximum level of production.

Based on a bio-economic simulation model, a synthesis of the results of six scenarios of selectivity improvement has been performed [25]. The status quo (scenario 1, the reference scenario) does not change the fishing pattern of the fleet. Scenarios from 2 to 6 assume that there is no catch (therefore no discard) of *Nephrops* under age 2-6, respectively. Notice that the size limit between *Nephrops* of age 2 and 3 corresponds to the minimum landing size, making scenario 3 equivalent to a scenario without any catch or discard of *Nephrops* below minimum landing size.

Under assumptions of the biological age-structured model (particularly constant recruitment hypothesis), together with the assumption that fishing effort remains constant throughout the simulation period, equilibrium is reached after a period of 5 to 7 years, as shown in figure 5. Despite long-term benefits of selectivity, it is generally objected that the fleets has to cope with economic losses during the transition phases towards equilibrium. According to figure 5, this should not always be the case (cf. scenario 3).

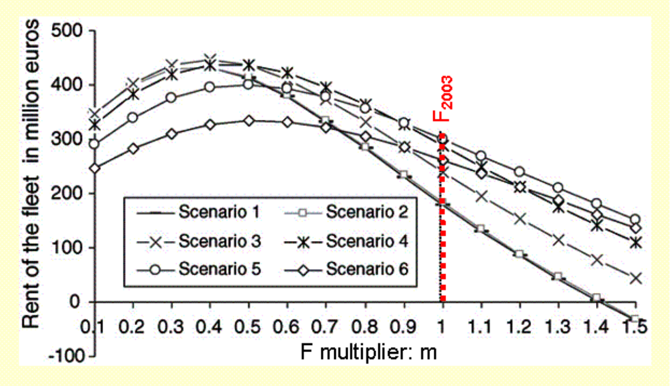
Figure 5. *Left*: evolution of the *Nephrops* landings. Notice that reducing discards does not necessarily entail a decrease in landings. Indeed, the 'scenario 3 selectivity' only affects the discarded fraction of the catches, landings are therefore unchanged at first and then increase. *Right*: evolution of the rent (or producer surplus: labour surplus + capital surplus). The largest short- and long-term revenues changes are observed for the most selective scenarios 5 and 6.



Source: Macher, C., et al., *Fish. Res.* (2008)

Beyond the transition phase summarized by figure 5, It is worth depicting the long term outcome (in terms of economic rent) of the six scenarios. The net present value of producer surplus over the 2004-2015 period –assuming a 4% discount rate– has been calculated for the six scenarios according to different fishing pressures.

Figure 6. Net present values of producer surplus (rent) over the 2004-2015 period assuming a 4% discount rate for all scenarios; abscissa scale: m, multiplying factor of the fishing mortality F; m varies between 0.1 and 1.5; the m = 1 value corresponds to the reference fishing pattern (F_{2003}, red dotted line).



Source: Macher, C., et al., *Fish. Res.* (2008)

The results relate to the 'Maximum economic yield' (MEY) concept linking total revenues from fishing to total fishing effort in a surplus production model [28] (cf. Annex 1). The MEY is obtained when marginal costs of fishing effort are equal to marginal revenues. It is equal to the maximum (sustainable) rent obtainable from the fishery.

Figure 6 displays curves of rent vs. fishing pressure for different selectivity scenarios. The results shown takes both transition phases and equilibrium state periods into account, thus they do not exactly correspond to the equilibrium MEY. Nevertheless, two salient features are highlighted :

- except in the case of ‘extreme’ scenario 6, an improvement of gear selectivity raises the resultant rent value;

- figure 6 also shows the dissipation of economic rent when increasing fishing pressure beyond current fishing mortality rate; as underlined in the introduction (cf. fig. 1), the gains expected from a better selectivity depend upon the whole set of the other management measures (the present case study stresses the relevance of access regulation measures).

1.5. Conclusions

Summing up:

- When dealing with fish stocks rebuilding, F_{MSY} and B_{MSY} provide **a relevant target direction for the definition of restoration measures**.
- It is worth remembering that **the precautionary biological reference points F_{pa} and B_{pa} are not management objectives**. Indeed, they are biomass and fishing mortality rate thresholds: when crossing these thresholds towards F_{lim} or B_{lim}, the stock is put at risk of overfishing.
- As a biological management objective, MSY relates to the state of the stock. In the broader frame of the fishery, and considering the producer standpoint, the prime concern is **the maximization of the economic rent on a ‘safe ecological basis’**. This leads *inter alia* to the concept of Maximum Economic Yield (MEY). **When targeting the equilibrium MEY, a fishing pressure lesser than the one achieving MSY is needed** (i.e., $F_{MEY} < F_{MSY}$). In the context of raising fuel costs, attention should be paid both to MSY and MEY.
- MSY is a monospecific management goal. Nevertheless, reducing fishing mortalities to or below the single-species F_{MSY} will likely be **a substantial progress towards restoring harvested fish communities and ecosystems**. Furthermore, a lesser variability in abundance is expected for stocks harvested close to the MSY level, thus facilitating the implementation of conservation measures such as multi-annual TACs.
- F_{MSY} and B_{MSY} values are defined for given environmental conditions. They call therefore for **tuning in case of ‘ecosystem regime shift’**, especially in a global change context. Notice that this is also true for biological reference points in general.
- F_{MSY} and B_{MSY} values are also defined for a given fishing pattern. In practice, **more selective fishing practices and/or gears lead to higher MSY values**.

Research priorities:

- MSY and MEY jointly encompass the three dimensions –and the related key issues– of the ‘fishery system’: ecosystem goods and services, exploitation and economic profitability, governance and management efficiency. The estimation and updating process of MSY and MEY are thus dependent on **a comprehensive gathering of multivariate time series of high quality data**.

- **The major ‘ecological sizing factor’ of MSY is biological productivity**. It is therefore essential to gauge the MSY-management scenarios at the relevant scale, i.e., **the scale of eco-regions**. Significant progress are needed (i) in the comprehension of the energy transfer processes from primary (phytoplankton) producers to higher trophic levels (zooplankton, young fish, large predators, etc.), (ii) in the identification of the ‘regime shifts’ driving variations in ecosystem productivity, (iii) in the deepening of our understanding of the recruitment process, and more broadly of the combined effects of fishing and climate. In the frame of an MSY-oriented strategy, it is indeed essential to be able to **assess the recovery capacities of fish populations**.

- **From the exploitation systems standpoint, the relevant scale is the fishery**. Besides the nominal capacity (number of vessels, kW, gross registered tonnage), an essential need is the **precise knowledge of effective fishing capacity dynamics**, taking account of technological progress. Strategy and tactics of **fishing effort deployment**, as well as knowledge pertaining to MEY, are complementary lines of investigation.

- Considering the practical outcomes of research (in terms of fishing fleets’ size and structure), all **uncertainties** have to be taken into account and explained. This is a key issue, regarding dissemination and communication with stakeholders (notably fishermen and public authorities).

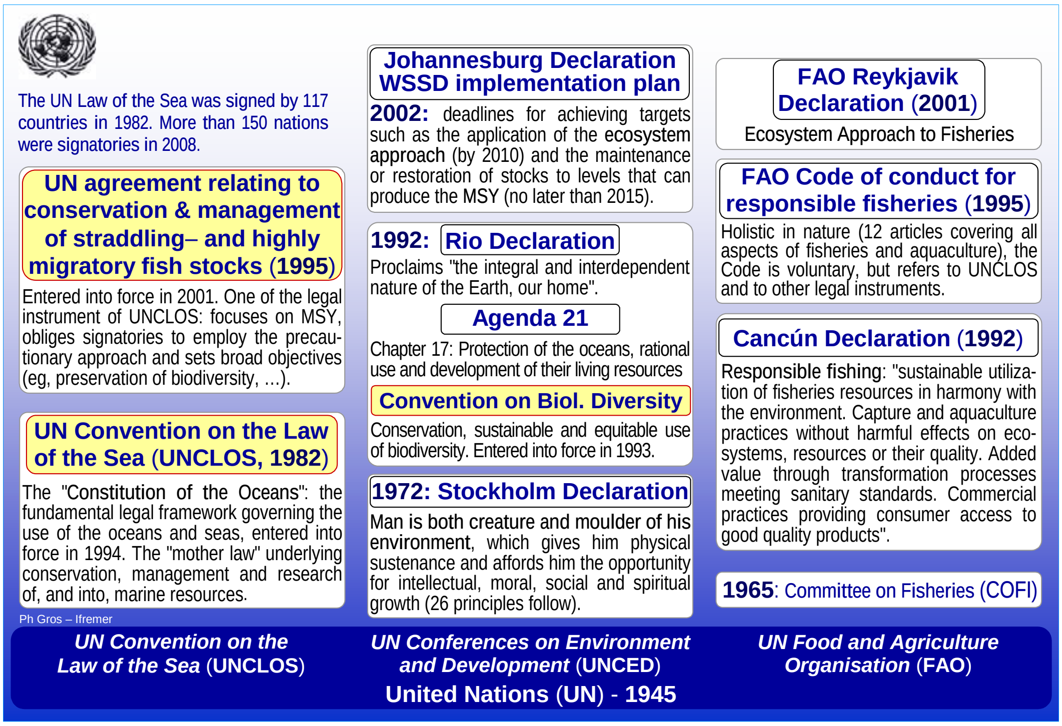
2. The Ecosystem Approach to Fisheries (EAF)

2.1. Institutional background

In its standard form, the EAF seeks to balance various socio-economical objectives, taking into account best available knowledge as well as current uncertainties on the biotic, abiotic and human components of ecosystems and their interactions, and to implement an integrated approach to fisheries management within a healthy ecological framework [29]. Insofar as human activity is considered to be an ecosystem component rather than a source of exogenous disruption, all the social, economic and political factors that affect human behaviour towards fisheries and more broadly marine ecosystems have to be taken into account [30–34].

The international institutional framework within which the EAF has developed is comprised principally of three United Nations (UN) bodies: UNCLOS (UN Convention on the Law of the Sea, 1982), UNCED (UN Conference on Environment and Development, 1992), and the Committee on fisheries of FAO (United Nations Organisation for Food and Agriculture, 1965). As depicted in figure 7, the CBD (Convention on Biological Diversity) and Agenda 21, signed at the time of the Rio summit in 1992, complete the foundation stones [35, 36]. At the European level, the new common fisheries policy of the EU explicitly adopts several themes from the EAF in its ‘green paper’ (e.g. overcapacity, governance or marine biodiversity) [37].

Figure 7. From Stockholm to Johannesburg: drawing up the governance of the world ocean (yellow outlined boxes: ‘hard law’; white: ‘soft law’).



The UN Law of the Sea was signed by 117 countries in 1982. More than 150 nations were signatories in 2008.

UN agreement relating to conservation & management of straddling– and highly migratory fish stocks (1995)

Entered into force in 2001. One of the legal instrument of UNCLOS: focuses on MSY, obliges signatories to employ the precautionary approach and sets broad objectives (eg, preservation of biodiversity, …).

UN Convention on the Law of the Sea (UNCLOS, 1982)

The "Constitution of the Oceans": the fundamental legal framework governing the use of the oceans and seas, entered into force in 1994. The "mother law" underlying conservation, management and research of, and into, marine resources.

Johannesburg Declaration WSSD implementation plan

2002: deadlines for achieving targets such as the application of the ecosystem approach (by 2010) and the maintenance or restoration of stocks to levels that can produce the MSY (no later than 2015).

1992: Rio Declaration

Proclaims "the integral and interdependent nature of the Earth, our home".

Agenda 21

Chapter 17: Protection of the oceans, rational use and development of their living resources

Convention on Biol. Diversity

Conservation, sustainable and equitable use of biodiversity. Entered into force in 1993.

1972: Stockholm Declaration

Man is both creature and moulder of his environment, which gives him physical sustenance and affords him the opportunity for intellectual, moral, social and spiritual growth (26 principles follow).

FAO Reykjavik Declaration (2001)

Ecosystem Approach to Fisheries

FAO Code of conduct for responsible fisheries (1995)

Holistic in nature (12 articles covering all aspects of fisheries and aquaculture), the Code is voluntary, but refers to UNCLOS and to other legal instruments.

Cancún Declaration (1992)

Responsible fishing: "sustainable utilization of fisheries resources in harmony with the environment. Capture and aquaculture practices without harmful effects on ecosystems, resources or their quality. Added value through transformation processes meeting sanitary standards. Commercial practices providing consumer access to good quality products".

1965: Committee on Fisheries (COFI)

Ph Gros – Ifremer

UN Convention on the Law of the Sea (UNCLOS)

UN Conferences on Environment and Development (UNCED)

UN Food and Agriculture Organisation (FAO)

United Nations (UN) - 1945

More specifically, several commitments related to the EAF were signed at the Johannesburg summit, relating in particular to:

- the application of the 1995 FAO Code of conduct for responsible fisheries(9) [38],

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(9) The FAO Code of Conduct for Responsible Fisheries FAO is an optional tool, of global scope, which defines principles and standards for the conservation, the management and the development of bioaquatic resources, which acknowledges the importance of the nutritional, economic, social, environmental and cultural value aspects of fisheries, and which integrates all the components of the fishery and aquaculture systems from management and fishing operations to fisheries research,

- reducing significantly the rate of biodiversity loss by 2010,
- creating a network of marine protected areas which is representative of marine ecosystem biodiversity by 2012,
- reversing the trend towards the degradation of living resources,
- restoring fisheries to their maximum sustainable yield (MSY) by 2015 and eliminating illegal, unregulated and unreported fishing (IUU fishing) in 2004,
- implementing a global action programme for the protection of the marine environment against land-based pollution sources.

These general or specific commitments made by numerous States, including France, mean that scientific research supporting the EAF must be maintained and developed. Such research must aim to produce the knowledge necessary for EAF implementation and to assess the transition stages to achieve the desired states in marine ecosystems and fisheries. At the European level, the EAF is already considered to be one of the elements of a broader environmental policy aimed at the protection of the marine environment [39]. Some countries, particularly Australia, Canada, the United States and New Zealand, have started to integrate the EAF into the research and management programmes of their coastal ecosystems. The EAF is also explicitly integrated into the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).

2.2. Scientific background

Research undertaken during the last few decades has modified fisheries themes *stricto sensu* (monospecific and geographically-limited studies) towards a more integrative approach to the various components of the marine ecosystems. This change was made possible by the progressive opening of fisheries science to the ideas of other disciplines such as ecology, biology, oceanography, economics and other social sciences [30, 33]. This opening is the result of the will to improve understanding of marine resource exploitation dynamics, in order to improve diagnoses and management recommendations, thereby increasing the chances of sustainable exploitation, and also to raise awareness of the importance and the impact of fishing on habitats, food webs and indirectly on the other uses of living marine resources [40–42]. The importance of the impact of fishing on ecosystems compared to other anthropogenic disturbances must also be assessed.

Research must now move towards improved understanding of the impact of fishing on all components of marine ecosystems, in particular concerning: (i) ecosystem diversity, (ii) biodiversity within each ecosystem, (iii) intra-specific genetic diversity, (iv) direct effects of exploitation on target species and indirect effects on non-target species, and (v) effects of exploitation on food webs and habitats [43, 44]. The human dimension will have to be better understood in areas as diverse as the analysis of marine ecosystem exploitation dynamics, the evaluation of externalities between uses, the study of methods to regulate individual access to resources and marine areas, or the analysis of collective processes in decision-making. Furthermore, social science research can play a key role in the integration process between research and collective decision-making processes. Thus the EAF raises the issue of the efficiency of truly inter-disciplinary research and therefore implies structural changes in the way research is organised, and its results disseminated.

The possible consequences of global climate change [45] add to the complexity of the research programmes which are currently being developed. The inclusion of uncertainty factors [46] also represents a major change in the way the state of resources and ecosystems is assessed and in the

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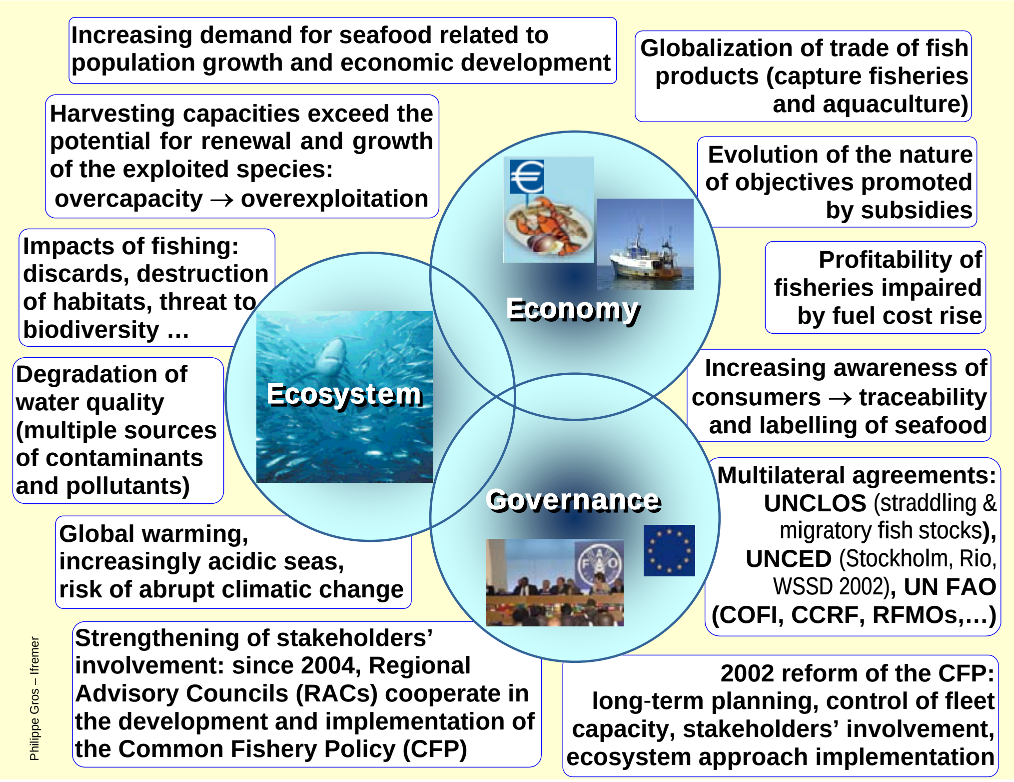
without forgetting the integrated management of coastal areas, the processing of products and trade. It is coherent with the rules of international law.

way this information is communicated to management bodies and more broadly to civil society. In the field of fisheries expertise, this process led to the adoption of the precautionary approach in the mid-1990s, which is also a key driving force in the EAF. This approach must now be extended in order to respond to the demand for expertise; for example, by applying risk analyses to compare the outcomes of various scenarios, which differ in terms of management strategies, the climatic and physical environment, the evolution in the commercial and non-commercial demand for ecosystem goods and services, or the population dynamics.

Acknowledging some weaknesses of fisheries governance also leads to work that focuses on a better understanding of the exploitation dynamics in response to changes in the ecological, economic and institutional contexts and forecasting their impact in terms of collective benefits [47]. This research focuses in particular on turning the now classic analyses of the origins of fisheries overcapacity into operational bio-economic approaches [15]. They progressively encompass interactions between fisheries uses and other uses of living marine resources and this signals a broadening approach which is an objective of the EAF.

The extension of fisheries science towards an ecosystem dimension and the integration of uncertainty have therefore opened up large fields of research. This is exemplified by figure 8, which portrays the fishery system and its key drivers.

Figure 8. The three components of the 'fishery system' and their related key issues: ecosystem goods and services, exploitation and economic profitability, governance and management efficiency. The main drivers of the system dynamics are also indicated.



Increasing demand for seafood related to population growth and economic development

Globalization of trade of fish products (capture fisheries and aquaculture)

Harvesting capacities exceed the potential for renewal and growth of the exploited species: overcapacity → overexploitation

Evolution of the nature of objectives promoted by subsidies

Impacts of fishing: discards, destruction of habitats, threat to biodiversity …

Profitability of fisheries impaired by fuel cost rise

Degradation of water quality (multiple sources of contaminants and pollutants)

Increasing awareness of consumers → traceability and labelling of seafood

Multilateral agreements: **UNCLOS** (straddling & migratory fish stocks), **UNCED** (Stockholm, Rio, WSSD 2002), **UN FAO (COFI, CCRF, RFMOs,…)**

Global warming, increasingly acidic seas, risk of abrupt climatic change

Strengthening of stakeholders' involvement: since 2004, Regional Advisory Councils (RACs) cooperate in the development and implementation of the Common Fishery Policy (CFP)

2002 reform of the CFP: long-term planning, control of fleet capacity, stakeholders' involvement, ecosystem approach implementation

Philippe Gros – Ifremer

The scientific challenge is considerable. Operational evaluation and management tools exist at stock level. But ecosystem management tools are still being developed and remain unproven within the EAF framework. Opinions vary within the scientific community concerning the extent to which exploited marine ecosystems are degraded and on directions to take in the near future. The community as a whole, nonetheless, agrees on some key-points, e.g. the need to reduce fishing mortality and overcapacity and to improve governance systems (in particular the relationships between operators, managers, scientists and civil society). Key issues remain concerning the evaluation of the economic and social impacts of these measures, the choice of how to implement them with the various stakeholders concerned and the introduction of compensation mechanisms so as to facilitate the transition process.

2.3. Strategic research priorities

Compared with the classic fisheries paradigm, the EAF greatly expands the field of research and expertise in several directions:

- from the exploited population (stock) *stricto sensu* to the whole ecosystem;
- from the ternary system ‘fisheries-administration-science’ to the quaternary system ‘fisheries-administration-science-civil society’; in fact, the subsystem depicted in figure 8 are implicitly embedded in the socio-sphere;
- from the operational short-term to the strategic long-term planning (including environmental constraints, particularly climate change);
- from a sectoral approach to an intersectoral and spatial approach;
- from sectoral sustainability to the contribution of this sector to the sustainable development of coastal communities.

The principal direct consequence of such an expansion is to increase considerably the number of dimensions (variables) that have to be taken into account during the evaluation and management process, *inter alia* the impact of fisheries and other anthropogenic activities on non-target species, trophic interactions within the ecosystem, habitat degradation or the influence of climate change on the resilience of exploited stocks.

This poses problems given the current state of knowledge and the limitations of observation and investigation systems for marine ecosystems. Two risks must be avoided: (i) to ‘oversell’ an expertise and management capacity which is not yet based on knowledge and understanding of the key-processes; and (ii) to develop ‘alibi research’ to postpone indefinitely dealing with issues for which we already have sufficient information to act efficiently [27, 48].

The challenge is therefore considerable and the success of the EAF will depend on our capacity to turn the general objectives of EAF into operational management objectives and reliable and efficient evaluation methods [49]. In practice, it seems that research and expertise develop in stages, depending on the available tools and the improvement in knowledge. The first stage focuses on the direct impacts of fishing on non-commercial species (by-catches) and habitats (impact of gear towed over the seabed for example). This is certainly the least ambitious vision for EAF, this expansion in the field of research is however substantial and poses key-questions which are rarely dealt with (e.g. the evaluation of the loss in social welfare through the impact of fishing on non-target species or on fragile habitats).

A second stage is to take into consideration biological interactions between the species on which fishing has direct and indirect impacts. This more ambitious second dimension of the EAF implies sufficient understanding of marine ecosystem functioning so that the interactions can be quantified and operational lessons for fisheries management can be learned. This raises the issue of our capacity to monitor the abundance of the many and varied components of a population and to provide tools for maintaining or restoring the desired characteristics. At present, this capacity is limited but it could increase with the development of new research [50].

The ultimate stage of EAF would be to include all the interactions between fisheries and other anthropogenic activities, by integrating all impacted marine ecosystem components (biotic and abiotic). As regards the coastal areas, where a large part of global fishing activity is concentrated, fisheries management would be integrated into a broader integrated coastal zone management. But the current attractiveness of this idea does not guarantee that it will become operationally effective. In addition to the ecological and environmental uncertainties already mentioned, there is the difficulty of defining the interactions between uses, which are potentially numerous, often diffuse and whose ecological basis is often poorly known.

Research priorities are presented below by domain, keeping with a pragmatic approach. The areas of knowledge and related societal issues have been divided into five principal groups: ecosystem, resources, exploitation, governance, methodology.

• **Ecosystem**.

Societal issue: how to reduce the impact of anthropogenic disruptions (e.g. fishing, climate change, pollution) on marine ecosystem, and what is the capacity of marine ecosystems to withstand these disruptions? For instance, in the case of non-target species (sharks, mammals, seabirds, etc.), and in the case of essential habitats.

Objective: to clarify the processes which govern the dynamics of marine ecosystems, define the response of these ecosystems to exploitation and other disruptions, and identify the consequences of their evolution for society. Components other than the populations targeted by fishing are studied here. Main research areas:

- Description and study of the dynamics of populations, habitats, communities, biodiversity, and of the food webs of exploited ecosystems;
- Description of the life-cycle and the spatio-temporal dynamics of non-target species (by-catch, discards and other affected species, invasive species) and qualitative and quantitative diagnosis of their vulnerability to exploitation;
- Resistance and resilience of ecosystems and/or of their components (e.g. stocks, habitats, biodiversity, food webs) to exploitation and other anthropogenic and natural disruptions;
- Cost-benefits analyses of different states of the exploited ecosystems.

• **Resources**

Societal issue: how to reduce waste and improve the use of exploited resources? With respect to discards and by-catches, catch value enhancement, public health standards. How to restore collapsed populations? How to ensure sustainable exploitation of resources?

Objective: to understand the dynamics of the populations targeted by fishing in response to anthropogenic and natural forcings. Main research areas:

- Description of the life-cycle and of the spatio-temporal dynamics of targeted species (e.g. defining essential habitats, seasonal cycles and inter-annual variations);
- Structuring the populations into local sub-populations / meta-populations; biological basis of stock identification;
- Adaptation mechanisms of individuals and populations to the environment and to exploitation;
- Analysis of the respective influence of: (i) environmental changes, (ii) exploitation and (iii) other alterations of anthropogenic origin (organic, chemical, radioactive and noise pollution, habitat modification), on the genetic, demographic, behavioural and spatial structure of the exploited populations (prioritisation and interaction of the effects).

• Exploitation

Societal issue: How to ensure sustainable exploitation of resources? To avoid collapse of overexploited stocks, to enable their renewal, to maintain/adapt exploitation systems.

Objective: to understand the dynamics of fisheries exploitation systems in relation to their ecological, economic and institutional contexts.

- Description of the spatio-temporal dynamics of effective fishing capacity and its interactions with other uses of marine ecosystems;
- Analysis of the relationships between methods / intensity of exploitation, state of the resources and ecosystems, and operators' social and economic performances;
- Analysis of the drivers in the seafood product markets (e.g. production, market value, consumption, international trade, traceability, eco-labelling, public health standards of the products);
- Analysis of the response of exploitation systems (the whole sector) to technological, economic and institutional developments as well as to changes in resource availability.

• Governance

Societal issue: what policies are possible for the management of marine resources? In terms of structures and mechanisms, in terms of performance (costs and benefits, etc.). Governance is in fact a structuring research theme that supports the EAF.

Objective: to understand fisheries governance systems, their functioning and their performance. Main research areas:

- Description and analysis of collective decision-making systems: stakeholders (e.g. local and regional professional organisations, national and international commissions, administrations, research institutes) and decision-making processes (e.g. annual decision on TACs and quotas within the EU);
- Description and analysis of management measures (e.g. biological and technical conservation measures, methods for the regulation of access to resources, etc.);
- Description of stakeholder behaviour (particularly fishers) when faced with management measures (perception, understanding, values, norms, legitimacy, social pressure);
- Measurement of the performance of existing governance systems;
- Exploration of scenarios of possible evolutions of governance systems in line with EAF objectives (including the development of participatory approaches and efficient decision-making processes).

- **Tools:**

surveys, observation, experimentation, individual markers, statistical and dynamics modelling, risk analysis, EAF indicators, dissemination and transfer tools.

Objective: to promote the collection and the management of information gathered in a systematic way as well as the development of new technologies for observation, experimentation, analysis, modelling and diagnosis. Main research areas:

- Methods and observation tools (innovative or not), information management (e.g. dynamic databases);
- Experimentation in a controlled environment (e.g. mesocosm) and *in situ*;
- Natural individual markers (e.g. genetic, chemical, parasitic) and manufactured individual markers (conventional and electronic);
- "Data-based" statistical modelling (e.g. regression models, survival models, Bayesian models) and multivariate modelling (e.g. simple and multi-table ordering);
- Dynamic modelling (e.g. analytical models, numerical simulation models or multi-agent systems applied at different scales);
- Risk analysis (identifying dangers, evaluating effects and consequences, comparing contrasted scenarios);
- Population, ecosystem and performance indicators for diagnosis and for management support.

Very close links will have to be established between governance, exploitation, resource and ecosystem, particularly through the development of tools which promote a scientific strategy to integrate knowledge. For example, work will have to be undertaken in the field of bioeconomic modelling, in the broad sense of developing representations coupling ecological and exploitation dynamics under the influence of various forcing factors. This work will produce medium and long-term scenarios for fisheries management (or, in the field of fisheries ecology, simulate global climate change). Diagnostic indicators must also be developed taking into account the various facets of ecosystem-based fisheries management, and including the development of risk evaluation tools. Although significant progress can be expected from these approaches, it remains difficult to find a proper balance between, on the one hand, the number of processes and their interactions and, on the other hand, the necessary simplification for all modelling and the quantity/quality of available information. In addition to these difficulties, there are also: (i) those arising from the law and from the capacity (in particular financial) to undertake experimentation, especially to be able to test some 'life size' hypotheses or scenarios, for example as regards the restoration of environments and populations or governance, and (ii) those linked to perpetuating observation systems of interest to EAF.

Issues linked to governance are intrinsically included in the EAF because, first, the EAF includes new and numerous stakeholders (different users and representatives of civil society) and, second, the international community acknowledges governance as a key-element in the EAF. Governance is in fact a structuring research theme that supports the EAF.

In close connection to the Marine Strategy Directive Framework (MSFD), collecting and managing data will probably be a key issue within the EAF given the considerable expansion in the area of research and expertise. The scientific approach tends to promote the collection of data in relation to a particular issue. However, this approach has limitations that cannot be reconciled with some of the EAF's objectives. Thus, taking into account anthropogenic effects in the medium and long term supposes that reference situations are available on a continuous basis over several decades and for various points in space. Without such monitoring, it would have been (and still would be) impossible to describe, understand and speculate about the effects of climate variations and global warming on populations and marine ecosystems [51–55]. Our understanding of the long-term changes that different uses (e.g. exploitation, regional development) cause in some biological and ecological processes (e.g. reproduction, migration) of the exploited populations or in ecosystem biodiversity has also been facilitated by the availability of long-term series and biological archives [56]. In coordination with MSFD, the EAF will thus have to combine the classic approach (i.e., collecting data according to defined objectives) with a perennial system of marine ecosystem observatories.

EU Integrated Maritime Policy; COM(2007)575 final

↕ Environmental pillar

Marine Strategy Framework Directive (MSFD); 2008/56/EC
'*to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest*' (Art . 1, subject matter)

the general basis for implementing cross-sectoral ecosystem approach to the marine environment

↕ recitals (9), (39), (40), (44), (45), Annexes III & V

Common Fisheries Policy (CFP); Council reg. (EC) 2371/2002
'*ensure exploitation of living aquatic resources that provides sustainable economic, environmental and social conditions* […] *apply the precautionary approach* […] *aim at a progressive implementation of an ecosystem-based approach to fisheries management*' (Article 2)

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Annexes

Annex 1: basic models of harvested populations dynamics

1. ‘Surplus-production’ model

Let B(t) be the total biomass of a finite population at time t.

The population is closed (neither immigration nor emigration).

Let r denote the intrinsic growth rate of the population biomass B(t), and let K be the maximum biomass that the population biotope can sustain (the parameter K is called the ‘carrying capacity’). With these two parameters r and K only, the simplest continuous-time model of the population relating the rate of change of the population biomass both to its current size and to its environment is the so-called logistic equation:

$$\mathrm{dB(t)}/\mathrm{dt} \;=\; \mathrm{rB(t)}[1-\mathrm{B(t)}/\mathrm{K}]$$

In shorthand notation:

$$\mathrm{dB}/\mathrm{dt} \;=\; G(\mathrm{B})$$

• ***Local stability analysis of equilibriums***

The equilibriums B^* are the values of B(t) which make its rate of change $G(\mathrm{B})$ equal to zero; hence they must satisfy:

$$G(\mathrm{B}^*) = 0$$

The logistic equation has two obvious equilibriums: $\mathrm{B}^* = 0$, and $\mathrm{B}^* = \mathrm{K}$

We represent small deviations from equilibrium by $\Delta\mathrm{B}$:

$$\Delta\mathrm{B(t)} = \mathrm{B(t)} - \mathrm{B}^* \qquad \Rightarrow \qquad G(\mathrm{B}) = G(\mathrm{B}^* + \Delta\mathrm{B})$$

The dynamics of the deviation $\Delta\mathrm{B}$ may be linearly approximated:

$$G(\mathrm{B}) \approx G(\mathrm{B}^*) + \Delta\mathrm{B}\left.\frac{\mathrm{d}G}{\mathrm{dB}}\right|_{\mathrm{B}=\mathrm{B}^*}$$

Noticing that $\mathrm{d}(\Delta\mathrm{B})/\mathrm{dt} = G(\mathrm{B})$, and remembering that $G(\mathrm{B}^*) = 0$,

$$\mathrm{d}(\Delta\mathrm{B})/\mathrm{dt} \;\approx\; \lambda(\Delta\mathrm{B})\text{, where: } \lambda = \left.\frac{\mathrm{d}G}{\mathrm{dB}}\right|_{\mathrm{B}=\mathrm{B}^*}$$

the dynamics of the deviation thus follows exponential growth or decline whose solution is:

$\Delta\mathrm{B(t)} \propto \exp(\lambda\mathrm{t})$ where the symbol $\propto$ means ‘proportional to’,

i.e., the amplitude of a perturbation of the equilibrium will change of a factor of e ≈ 2.718… after a time of the order $1/|\lambda|$, the ‘characteristic response time’ of the population.

In the logistic model, $G(\mathrm{B}) = \mathrm{rB}(1 - \mathrm{B/K})$; therefore: $\lambda = \mathrm{r}(1 - 2\,\mathrm{B}^*/\mathrm{K})$.

The value of λ associated to the equilibrium $\mathrm{B}^* = 0$ is positive, and any small perturbation of this equilibrium will thus grow exponentially. The equilibrium $\mathrm{B}^* = 0$ is unstable. In the same way, it is easy to verify that the equilibrium $\mathrm{B}^* = \mathrm{K}$ is stable.

- ***Combining harvesting with logistic growth: an elementary 'surplus production model'***

Let Y(t) be the yield resulting from harvesting the biomass B(t) at catch rate E:

$$dB(t)/dt = rB(t)[1 - B(t)/K] - EB(t) \text{ where: } \quad Y(t) = EB(t)$$

The non-zero equilibrium is: $B^*(E) = K(1 - E/r)$

Notice that: $B^*(E) > 0 \quad \Rightarrow \quad E < r$ (population crashes if $E > r$)

Let $E < r$

Therefore: $d(\Delta B)/dt \approx (E - r)\,\Delta B \quad \Rightarrow$ the equilibrium $B^*(E)$ is stable

- ***Maximum sustainable yield***

The yield at equilibrium is:

$$Y^*(E) = E\,B^*(E) = EK(1 - E/r)$$

The maximum of $Y^*(E)$ is by definition the 'maximum sustainable yield'.

In the present case:

$$MSY^* = \max_E\{Y^*(E)\} \qquad \Rightarrow \qquad MSY^* = rK/4 \quad \text{when } E = r/2$$

Obviously, this result is model-dependent.

- ***Recovery time***

(i) Let E = 0; ΔB denotes a little perturbation of the non-zero equilibrium B^*.

The 'characteristic response time', or 'recovery time' T_R is defined as follows: the magnitude of the perturbation ΔB changes of a factor $e \approx 2.718\ldots$ after a time T_R, i.e.,

$$\left.\begin{array}{r} \Delta B(t) \propto \exp(-rt) \\ \frac{1}{e}\Delta B(t) = \Delta B(t+T_R) \propto \exp(-r(t+T_R)) \end{array}\right\} \Rightarrow \quad T_R\big|_{E=0} \sim \frac{1}{r}$$

(ii) Let $0 < E < r$. In the same way, it can be shown that: $T_R\big|_{0<E<r} \sim 1/(r - E)$

From (i) and (ii), we conclude that harvest increases the time period of return to equilibrium after a small perturbation.

(iii) Instead of considering its dependence upon catch rate E, the order of magnitude of the recovery time may also be expressed as a function of the yield Y; it can be shown that (with obvious notations):

$$T_R(Y)/T_R(0) = 2/(1 \pm \sqrt{1 - Y/MSY^*})$$

Analysis of the above equation shows that, near the equilibrium MSY^*:

- approaching MSY^* with $Y < MSY^*$ (i.e., at catch rate $E < r/2$) has the following effect: an increase of Y, and little increase of T_R;

- effect of increasing Y beyond MSY^* by increasing $E > r/2$: decrease of Y, and risk of high increase of T_R.

2. Elementary bio-economics

The definition of fishery includes i.a. the biological resource –the stock– and the harvesting system; in order to link formally the latter with the former, we define the ‘economic rent’:

$$R(B, E) = pY - cE = (pB - c)E$$

$R(B, E)$ denotes the net revenue flow to the fishery, i.e. sales revenues pY less fishing costs cE (here, variable costs only).

Notice that: $R(B, E) > 0 \quad \Leftrightarrow \quad B(t) > c/p$

We could thus expect that the catch rate E will remain positive as long as $B(t) > c/p$, i.e., as long as fishing is profitable. But if entry to the fishery is unrestricted, E will continue to increase as long as the economic rent remains positive, leading to the so-called ‘bio-economic equilibrium’ of the unregulated open-access fishery, where $R(c/p, E) = 0$. In other words, all economic rents are dissipated.

It has thus been proposed to define an economically optimal fishing regime, whose aim is to maximize sustained economic rent. In the present frame, this becomes:

$$\max_B\{R(B, E)\} \text{ subject to } dB/dt = 0, \quad \text{where: } dB/dt = G(B) - EB$$

This can be written as:

$$\max_B\{ (p - c/B)\, G(B) \}$$

Write $c(B) = c/B$ (the unit cost of fishing); the stock biomass B_{opt} at optimum is solution of:

$$(p - c(B_{opt}))\ \left.\frac{dG}{dB}\right|_{B=B_{opt}} - \ G(B_{opt})\ \left.\frac{dc}{dB}\right|_{B=B_{opt}} = 0$$

Remembering that $G(B) = rB(1 - B/K)$, then B_{opt} is easily calculated:

$$B_{opt} = \frac{1}{2}\left(K + \frac{c}{p}\right)$$

This result shows that:

- economically optimal (static) fishing maintains the stock biomass above c/p, i.e., at a biomass level B_{opt} that is higher than the ‘bio-economic equilibrium’;

- notice also that $B_{opt} > B_{MSY}$; indeed, with logistic biomass dynamics, $B_{MSY} = K/2$.

For severely depleted fish stocks, it may require several years of reduced catch before the stock recovers to B_{MSY}, let alone to B_{opt}. In order to consider both conservation target (stock rebuilding) and economic revenues, a dynamic optimisation model can be formulated:

$$\max_{\{E(t)\}} \int_t^T \exp(-\delta t) R(B,E)\, dt \qquad\qquad \delta\text{: discount rate}$$

Discount rate δ measures the time value of money for stakeholders involved in fishery management: by applying a discount rate, more weight is given to earlier costs and benefits than later ones. In the above formula, the future expected net income flows for the fleets (over the simulation period $t = 1, \ldots, T$) are converted to a present value amount.

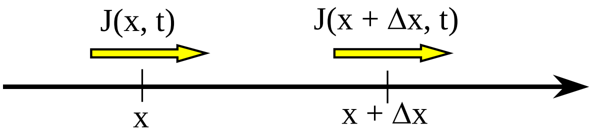
It can be shown that the dynamically optimal equilibrium B_{dopt} is again greater than c/p, but less than B_{opt}. The latter in fact corresponds to zero future discounting, by definition of δ.

3. 'Age-structured population' model

3.1. Structured models in continuous time

In many situations, it is essential to recognize the distinct contribution made by individuals according to a given characteristic attribute. In the following, age will be the individual specific feature of interest. Nevertheless, it is worth pinpointing that there are several other possible 'individual structuring criterions':

Let x denote the individual structuring criterion. The common ones are age (x = a), size (x = s), spatial coordinates x = (x, y). We shall first consider the generic attribute x, and then deal with individual age (x = a) only. To obtain a general description of the population dynamics, we focus our attention on the net rate of flow of individuals past the position x:



J(x, t), J(x + Δx, t):

population fluxes of individuals into,

and out of the segment [x, x + Δx]

The total rate of change of the 'segment population' [x, x + Δx] is the difference between the flow rates in (at the left end of the segment) and out (at its right end), added to the difference between recruitment and death rates.

Let:

η(x, t) be the density function, i.e.,

$$\eta(x, t)\Delta x \approx \text{ number of individuals in the 'segment population' } [x, x + \Delta x],$$

μ(x, t): per capita mortality rate, i.e.,

$$\mu(x, t)\eta(x, t)\Delta x \approx \text{ loss of individuals from the 'segment population' due to mortality,}$$

ρ(x, t): recruitment rate, i.e.,

$$\rho(x, t)\eta(x, t)\Delta x \approx \text{ appearance of recruits in } [x, x + \Delta x],$$

The instantaneous change in number of individuals in [x, x + Δx] is therefore:

$$\frac{\partial[\eta(x,t)\Delta x]}{\partial t} = \rho(x,t)\Delta x - \mu(x,t)\eta(x,t)\Delta x + J(x,t) - J(x+\Delta x,t)$$

And, provided the increment Δx is small:

$$\lim_{\Delta x \to 0} \frac{J(x+\Delta x,t) - J(x,t)}{\Delta x} = \frac{\partial J}{\partial x} \quad \Rightarrow \quad \boxed{\frac{\partial \eta}{\partial t} = \rho - \mu\eta - \frac{\partial J}{\partial x}}$$

This equation is completely general. Further model development involve making specific assumptions relating the processes governing recruitment and individual life history processes (growth, mortality).

The age-structured continuous-time population model is the classic von Foerster equation:

$$\partial\eta(a,t)/\partial t + \partial\eta(a,t)/\partial a = -\mu(a,t)\eta(a,t)$$

$$\text{subject to: } \eta(0, t) = \int_A \beta(\alpha, t)\eta(\alpha, t)d\alpha \text{ (boundary condition)}$$

Notice that the 'boundary condition' (density at age 0) is the mathematical formulation of recruitment of newborn individuals; β(a, t) is the per capita birth rate.

In a general way, the standard elementary structured models in continuous time may be summarized as follows:

Structuring criterion x	*Nature of the flux* J	*Model*
$x = a$, $J(a, t) \equiv (da/dt)\eta(a, t) = \eta(a, t)$	J: *ageing* (a: *chronological age*)	$\partial\eta/\partial t + \partial\eta/\partial a = \rho - \mu\eta$
$x = s$, $J(s, t) \equiv \gamma\, \eta(a, t)$, $\gamma = ds/dt$	J: *growth in size*	$\partial\eta/\partial t + \partial(\gamma\eta)/\partial s = \rho - \mu\eta$
x *spatial coord.*, $J(x, t) \equiv v\, \eta(x, t)$	J: *advective flux*; v: *speed*	*advection model*
x *spatial coord.*, $J(x, t) \equiv - D\, \partial\eta/\partial x$	J: *diffusive flux*; D: *diffusion coef.*	*diffusion model*

3.2. Age-structured harvested population model in discrete time

Most of population models applied to fish stock assessment are discrete-time models. Time is represented by consecutive increments ΔT (the usual choice is $\Delta T = 1$ year). In the same way, the ‘width’ of the age-classes is $\Delta A = 1$ year (in general). The model variable and parameters are indexed by subscript ‘a’ and/or ‘y’ when they depend upon age or time, respectively.

Thus, $N_{a,y}$ is the abundance of age-class a at year y. In the same manner are defined the catches $C_{a,y}$ and the total mortality rate $Z_{a,y}$. The latter is the sum of the mortality rate due to fishing ($F_{a,y}$) and of the ‘natural’ mortality rate ($M_{a,y}$). In discrete-time form, the relationship between catches and abundance is the so-called Baranov equation:

$$C_{a,y} = \frac{F_{a,y}}{F_{a,y} + M_{a,y}} (N_{a-1,y-1} - N_{a,y})$$

The Baranov equation relates catches-at-age to stock abundance of age classes for a given fishing pattern. Classical textbooks (e.g., see supplementary references) provide the many developments and analytical results necessary for stock assessment, *inter alia* the Y/R relationship, the MSY estimation methods, etc.

Supplemetary references:

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Ricker, W.E., *Computation and interpretation of biological statistics of fish populations*, Environnement Canada, Fisheries and Marine Service, Bulletin 191, 382 p., Ottawa (1975).

Annex 2: MSY within different policy instruments related to fisheries management

1966

ICCAT Convention – Annex I (5th revised and updated version, September 2007).

After a ratification process, the ICCAT Convention entered formally into force in 1969.

'The Governments […], considering their mutual interest in the populations of tuna and tuna-like fishes found in the Atlantic Ocean, and desiring to co-operate in maintaining the populations of these fishes at levels which will permit **the maximum sustainable catch** for food and other purposes, […]'. (Preambule).

Article IV, § 2: 'The carrying out of the provisions in paragraph 1 of this Article shall include:

(a) […];

(b) studying and appraising information concerning measures and methods to ensure maintenance of the populations of tuna and tuna-like fishes in the Convention area at levels which will permit **the maximum sustainable catch** and which will ensure the effective exploitation of these fishes in a manner consistent with this catch;

[…]'.

http://www.iccat.int/

1982

United Nations **Convention on the Law of the Sea** (UNCLOS)

Part V: Exclusive Economic Zone.

Article 61: Conservation of the living resources.

§ 3: 'Such measures shall also be designed to maintain or restore populations of harvested species at levels which can produce **the maximum sustainable yield**, as qualified by relevant environmental and economic factors, including the economic needs of coastal fishing communities and the special requirements of developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global'.

See also: Part VII (High seas), Section 2 (Conservation and management of the living resources of the high seas), Article 119 (Conservation of the living resources of the high seas), § 1(a).

http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm

1992

Agenda 21: Chapter 17

Protection of the oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources

C. Sustainable use and conservation of marine living resources of the high seas

Basis for action

Objectives

17.46. 'States commit themselves to the conservation and sustainable use of marine living resources on the high seas. To this end, it is necessary to:

(a) […];

(b) Maintain or restore populations of marine species at levels that can produce **the maximum sustainable yield** as qualified by relevant environmental and economic factors, taking into consideration relationships among species;

[…]'.

D. Sustainable use and conservation of marine living resources under national jurisdiction

Basis for action

Objectives

17.74. 'States commit themselves to the conservation and sustainable use of marine living resources under national jurisdiction. To this end, it is necessary to:

[…]

(c) Maintain or restore populations of marine species at levels that can produce **the maximum sustainable yield** as qualified by relevant environmental and economic factors, taking into consideration relationships among species;

[…]'.

http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21chapter17.htm

1995

United Nations Conference on straddling fish stocks and highly migratory fish stocks. Sixth session, New York, 24 July-4August 1995.

AGREEMENT FOR THE IMPLEMENTATION OF THE PROVISIONS OF THE UNCLOS OF 10 DECEMBER 1982 RELATING TO THE **CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS**

PART II: CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

Article 5 (General principles).

'In order to conserve and manage straddling fish stocks and highly migratory fish stocks, coastal States and States fishing on the high seas shall, […]:

(a) adopt measures to ensure long-term sustainability of straddling fish stocks and highly migratory fish stocks and promote the objective of their optimum utilization;

(b) ensure that such measures […] are designed to maintain or restore stocks at levels capable of producing **maximum sustainable yield**, as qualified by relevant environmental and economic factors […], and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global;

(c) apply the precautionary approach in accordance with article 6;

[…]'.

ANNEX II: GUIDELINES FOR THE APPLICATION OF PRECAUTIONARY REFERENCE POINTS IN CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS

'[…]

7. **The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points**. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that the biomass does not fall below a predefined threshold. For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target'.

http://www.un.org/Depts/los/convention_agreements/texts/fish_stocks_agreement/CONF164_37.htm

1995

The FAO Code of Conduct for Responsible Fisheries

Article 7 – Fisheries management

§ 7.2. Management objectives

7.2.1 'Recognizing that long-term sustainable use of fisheries resources is the overriding objective of conservation and management, States […] should, *inter alia*, adopt appropriate measures, based on the best scientific evidence available, which are designed to maintain or restore stocks at levels capable of producing **maximum sustainable yield**, as qualified by relevant environmental and economic factors, including the special requirements of developing countries'.

Article 12 – Fisheries research

§ 12.1 'States should recognize that responsible fisheries requires the availability of a sound scientific basis to assist fisheries managers and other interested parties in making decisions. Therefore, **States should ensure that appropriate research is conducted into all aspects of fisheries including biology, ecology, technology, environmental science, economics, social science, aquaculture and nutritional science** […]'.

ftp://ftp.fao.org/docrep/fao/005/v9878e/V9878E00.pdf

2002

Plan of implementation of the World Summit on Sustainable Development (WSSD 2002)

§ 30(d): 'Encourage the application by 2010 of the ecosystem approach, noting the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem and decision V/6 of the Conference of Parties to the Convention on Biological Diversity;'.

§ 31(a):'Maintain or restore stocks to levels that can produce **the maximum sustainable yield (MSY)** with the aim of achieving these goals for depleted stocks on an urgent basis and where possible no later than 2015'.

§ 32(c): 'Develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012 and time/area closures for the protection of nursery grounds and periods, proper coastal land use and watershed planning and the integration of marine and coastal areas management into key sectors'.

§ 44: ' […] the achievement by 2010 of a significant reduction in the current rate of loss of biological diversity'.

http://www.un.org/esa/sustdev/documents/WSSD_POI_PD/English/POIChapter4.htm

2006

Ministère de l'Agriculture et de la Pêche. ***Plan d'Avenir pour la Pêche***, chapitre 1.

'Le **RMS**, en cohérence avec la Politique commune de la pêche (PCP), constitue un objectif important. […] Une partie des stocks se trouveraient exploités au-delà de ce point de référence. Une feuille de route devrait ainsi être élaborée qui fixera, pêcherie par pêcherie, les objectifs quantitatifs en termes de niveau d'exploitation (captures, effort de pêche), mais aussi en termes de sélectivité (tailles des captures). […] La réflexion sur le format de la flotte correspondant au **RMS** doit être accompagnée d'une réflexion sur les réductions des coûts énergétiques et sur une valorisation optimale des produits. […] L'échelle pertinente pour mener à bien cette réflexion est bien celle de la pêcherie ou de la façade, qui doit être le lieu d'une réflexion menée par la profession en étroite liaison avec les pouvoirs publics et la recherche'.

RMS : « *rendement maximal soutenable* », a french translation of MSY. Other translations are RMD, « *rendement maximal durable* », or PME, « *production maximale à l'équilibre* ».

http://www.agriculture.gouv.fr/IMG/pdf/060613planavenirpeche.pdf