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The Obligation of Sustainable Fisheries Management: Review of Endured Failures and Challenges in Exploitation of the Living Sea

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1. Introduction

Fishing is defined as a specific use of our living environment, the extensive or intensive activity to hunt or collect aquatic species for a huge variety of motivations related to leisure, nutrition or profit. More generally interpreted, the term can also be applied as a metaphor for any passive and active advantage taking from our surroundings, from "fishing" for monetary values to compliments. So we (creatures) and many of our actions are concerned.

The world's confined biosphere is composed of living and non-living constituents, which are interlinked by a complex web of relations at different levels and with different intensities. We subdivide the various constituents and their effects into ecosystems. Their common and main feature appears to be a dynamic change at all scales in time and space, which provokes the vital evolution through everlasting mutation and adaptation (Pickett *et al.*, 2007). We need to realize that the non-equilibrium is a major feature of ecology and widely accepted as paradigm (Lévêque, 2003). Humanity, as highly developed constituent, intensively exploits living and non-living resources with high impacts (footprints), and thus highly depends on stability and resilience when optimizing its exploitation strategies over short or medium term, i.e. periods of generations or beyond with increasing ethical concerns. The initiation of the concept of sustainability in the 20th century reflects the increasing global awareness of the threat posed by the human-induced effects and thus can be interpreted as a logical consequence by defining limits to achieve a stable and optimized use of any sort of common or private goods.

While such conceptual thinking is not new and appears easily comprehendible, the reality largely differs regarding both common property (Hardin, 1968) as well as private property (common experiences, I guess). Despite sufficient knowledge leading to various definitions and requests of precautionary approaches, principles and time frames towards sustainability, human management normally fails and results in crisis management to minimize damages at all levels, from personal to international dimensions. The desperate try to constrain climate changes and mitigate their consequences are an impressive example. Fisheries do not represent an exemption (Cochrane *et al.*, 2009), and different arguments are used driven by multifaceted objectives of various interest groups, such as non-governmental organizations, stakeholders, politicians and their international frameworks, and even scientists.

2. Overfishing as ecological footprint: The facts and definitions

Historically, hunting of whales was among the first human activities which proved that marine resources are limited. Commercial bowhead (*Balaena mysticetus*) whaling began in the 1840s, and within two decades caught over 60 percent of the bowheads (Braham, 1984). It's noteworthy that the populations appear still not fully recovered as the International Union for Conservation of Nature (IUCN) assigns their status still as 'lower risk' to 'critically endangered'. More than 100 years ago, Garstang (1900) demonstrated that increased fishing could reduce fish abundance, which is seen as the basis for Graham's (1943) fishing law (Hart & Reynolds, 2002). Schaefer (1954) formulated the first general production model to be applied to fisheries data for the quantification of the surplus, which is still interpreted as the sustainable yield from a given living resource. Further milestones with increased understanding and precision were the growth modeling (v. Bertalanffy, 1938) and the development of age structured dynamic pool models (Gulland, 1965; Pope, 1972) to estimate the past and future stock production (Beverton & Holt, 1957; Ricker, 1975).

The drastic short term changes in the ecosystems and their components is reflected in the relative high amount of energy many marine species invest for reproduction, i.e. the amount of eggs and prolonged reproductive seasons in tropical, boreal and polar regions. The species are classified based on the number and quality of offsprings (MacArthur & Wilson, 1967) into the so-called r-strategists (high number of eggs and short lived) versus the k-strategists (low number of eggs and long lived). Higher variability is expected and can be seen in the fisheries targeting the r-strategists of the pelagic habitats. Taking this into account, the recent scientific challenge is characterized by the move from the individual stocks to the ecosystem approach (Jennings, 2001) to fisheries management, which shall provide a wider understanding of the human impact through exploitation of living marine resources. Hilborn (2010) defines the most important elements of ecosystem based fisheries management as keeping fishing mortality rates low enough to prevent ecosystem-wide overfishing, reducing or eliminating by-catch and avoiding habitat-destroying fishing methods.

The recent state of the marine ecosystems has been continuously assessed by many authors and institutions. The largely biased general public opinion is that the sea is empty, the food webs are fished down to small species and there is a general loss in biodiversity impairing the oceans' capacity to provide food, maintain water quality, and recover from perturbations (Pauly *et al.*, 1998; Pauly & Palomares, 2005; Worm *et al.*, 2006). But the facts prove that the oceans are surprisingly resistant, despite the destructive and ongoing illegal, unreported and unregulated fishing practices (IUU fishing), which are officially condemned and combated as a serious global problem regarding habitat destruction and fish stock depletion. The destructive and incidental catch of sharks, seabirds, turtles and marine mammals has to be avoided by selective devices (FAO, 2008). However, the latest assessment of the Food and Agriculture Organization of the United Nations (FAO, 2010 a) concludes that global production of marine capture fisheries reached a peak of 86.3 million tons in 1996 and then declined slightly to 79.5 million tons in 2008, with high annual fluctuations and changes in contributions of the major species. While there are severe concerns regarding the human impacts through capture fisheries on marine ecosystems, we may realize that 63% of assessed fish stocks worldwide still require rebuilding to optimize the productivity, and even lower exploitation rates are needed to reverse the collapse of vulnerable species (Worm *et al*., 2009). In summary, overfishing is an ecological footprint of our recent society but we are far from the apocalypse of collapsed world's fisheries (Hilborn, 2011).

After having assessed the world's fishing resource situation, we now need to define sustainability and then review the development of recent management reference points consistent with sustainability. In accordance with the definition by Costanza & Patten (1995) sustainability is generally interpreted as the capacity of ecological, economic or social systems to endure under stress, e.g. exploitation. However, it appears clearer when sustainability is compared with resilience (Ludwig *et al*., 1997). Sustainability encompasses resilience but also requires a predefined goal in addition. Sustainable goals or reference points are commonly set at high or optimized levels. However, in order for sustainability to be a useful criterion for guiding changes, its characterization should be literal, system-oriented, quantitative, predictive, stochastic and diagnostic (Hansen, 1996).

The international requirement for marine protection is stipulated in the Treaty on the Convention on the Law of the Sea (UN, 1982), where all States enjoy the traditional freedoms of navigation, overflight, scientific research and fishing on the high seas and they are obliged to adopt, or cooperate with other States in adopting, measures to manage and conserve living resources. Coastal States are granted sovereign rights in a 200-nautical mile exclusive economic zone (EEZ) with respect to natural resources and certain economic activities, and exercise jurisdiction over marine science research and environmental protection.

During the Earth Summit held in Rio de Janerio, Brazil, 3 to 14 June 1992, the Agenda 21, the Rio Declaration on Environment and Development, and the Statement of principles for the Sustainable Management of Forests were adopted by more than 178 governments. The "Rio Principles" represent the international guidelines calling specifically for the reduction of unsustainable patterns of production and consumption and capacity building for sustainable development (UN, 1992). In 1995, the United Nations agreed upon the implementation of the provisions of the convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks. The implementation of limit reference points was requested, which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield (MSY), while target reference points are intended to meet management objectives (UN, 1995). Assigning the maximum yield a long term perspective immediately turns the underlying intention towards maximum conservation, as only well protected stocks can produce high yields over a long time. However, any stock size status indicator shall gain less weight in comparison with the exploitation indicator in the decision making progress as the actual stock size underlies and is considered the outcome of many ecological effects in addition to the human impacts through fishing. In the same year the idea of such reference levels for the fisheries management was more widely applied in the Code of Conduct for Responsible Fisheries by the FAO (1995). The sustainability goal for fisheries management was re-confirmed during the Sustainability Summit in Johannesburg (UN, 2002), interpreted as the core publication. The MSY of all exploited stocks has now to be implemented by the specific date of the year 2015, a clear ecological target. Undoubtedly such ratified political design, which is based on the principle of short term losses in the view of long term gains, requires major and continued efforts towards transparent information and protection against the unsustainable solution of short term gains versus long term losses.

The internationally agreed fishing mortality F_{MSY} that produces MSY is defined as

$$F_{MSY} = r/2 , \qquad (1)$$

where *r* is intrinsic rate of population growth in the logistic population growth model (Prager, 1994),

$$dB_t/dt = rB_t - (r/K)B_t^2, \qquad (2)$$

in which the change in stock biomass over time (dB_t/dt) is a quadratic function of biomass (B) and K is defined as the carrying capacity.

After all these considerations we are in the position to defend the conclusion that the world fisheries do unsustainably exploit many of the living marine resources, and have a long history and prominent examples to do so with disastrous socio-economic consequences. In particular, the hardly or non-reversible damages caused by fishery effects in the deep sea or hard substrate habitats (coral reefs) have to be avoided by all means (FAO, 2008). Discarding, throwing back into the sea the whole or selected parts of the unwanted catch, appears an unacceptable performance, recognizing the ethical concerns regarding the waste if biological resources through discards in the magnitude of 7 million tons in the world's fisheries (FAO, 2010 a). In addition, unknown and thus unaccounted discarding implies increased uncertainty in assessments of exploited stocks, scientific advice and fisheries management. However, a discard ban or landing obligation is already implemented in national fisheries regimes but unsurprisingly appears difficult to control after all. While the best practice is to avoid discarding by not catching the potentially unwanted fish, a discard ban might incentivize improved technical selection through appropriate gear specifications or closing of sensitive areas.

Probably the most impressive relation between humans and fish is the story of Atantic cod (*Gadus morhua*) fisheries which spans a thousand years and four continents (Kurlansky, 1997). Before the 1970s, the annual capture production exceeded 3 million tons and rapidly fell below 1 million tons at the beginning of the millennium 30 years later. We could continue with many examples, e.g. collapsed and recovered herring (*Clupea harengus*) fisheries or the recent annual bluefin tuna (*Thunnus thynnus*) battles heavily debated in the international press.

Europe ranges among the poor regions when it comes to the status of its common fishery resources as the great majority of the European fish stocks (88%) remain overexploited with regard to high long term yields (EU, 2009). The deep-rooted problem of overcapacity and imprecise policy objectives and will are identified as the main structural failings, in particular at the operative level of individual fishermen and their fishing strategies. The joint exploitation of fish and shell fish stocks in European marine waters underlie the

Common Fisheries Policy (CFP; EU, 2002), which apparently lacks a specific definition of the sustainability. The European Parliament acts as co-legislator under the Lisbon Treaty (EU, 2007a), with the exception of measures on fixing prices, levies, aid and quantitative limitations and on the fixing and allocation of fishing opportunities, that will remain as in the EC Treaty, where they have to be adopted by the European Council on a proposal from the European Commission. However, the CFP is due to a reform by 2012, after a standard 10 years interval. The management goals of the reformed CFP requires consistency with the European Marine Strategy Framework Directive (MSFD; EU, 2008a) and its focus on good environmental status of all exploited fish and shellfish stocks in all European regions including the EEZs and territorial waters by 2020 (Rätz *et al.*, 2010). The complementary decision by the European Commission (EU, 2010) identified the so-called fishing mortality F to generate MSY as primary indicator of sustainability. F is defined as the famous coefficient of the annual rate of dead or removed fish caused by fishing as a function of the annual rate of dead fish caused by natural reasons (see following section). Such stock specific level of exploitation needs to be identified and set considering all ecological effects, as the sustainable production differs not only among species but also among stocks. Rätz & Lloret (2003) demonstrated that the cod stocks in the warm regions of the Northeast Atlantic are more productive in terms of growth and recruitment and can sustain higher fishing rates as compared with the stocks inhabiting the colder Northwest Atlantic, which appear more vulnerable through lower productivity.

3. Less is more: We know enough to move towards it!

The major challenge of the modern fisheries management is not any longer to define sustainable exploitation levels and to best approach them but to correct the errors made in the past decades, mainly related to the reduction of fishing power accounting for increased efficiency and technological creep, which can reach 2% per year (Rijnsdorp *et al.*, 2006). Whatever kind of regulations are chosen, ranging from the suite of technical measures (e.g. closures, gear configurations) and direct fishing restrictions (total allowable catches TAC or total allowable fishing effort TAE), they shall effectively control the fisheries induced mortality and shall consider of potential future effects based on experience.

By fishing less the expected yields from an overexploited resource will be increasing as can be seen from the classical yield curve of the prominent and continuously overfished North Sea cod stock (including Skagerrak and Eastern Channel, Fig. 1). It must be acknowledged that there exists no experience in stock dynamics during sustainable exploitation at the maximum sustainable term yield or below it, even after 50 years of data. Therefore, the estimation of the maximum sustainable yield of 700,000 tons per year at a stock weight of all spawning fish around 800,000 tons is a result of an extrapolation and thus appears quite hypothetical. These high values can be considered overestimated if under such favorable conditions the ecological processes gain a more dominant role, i.e. intra-specific (cannibalism) and inter-specific consumption (predation by other species).

In the cases of heavy overfishing and depleted stocks it may be advisable to search agreement among interested parties by designing multi-annual plans considering an adaptive stepwise mitigation process rather than the short term solution with drastic consequences for all involved parties. However, the mitigation process should be significant enough to ensure a transparent monitoring in order to justify the measures taken. This can

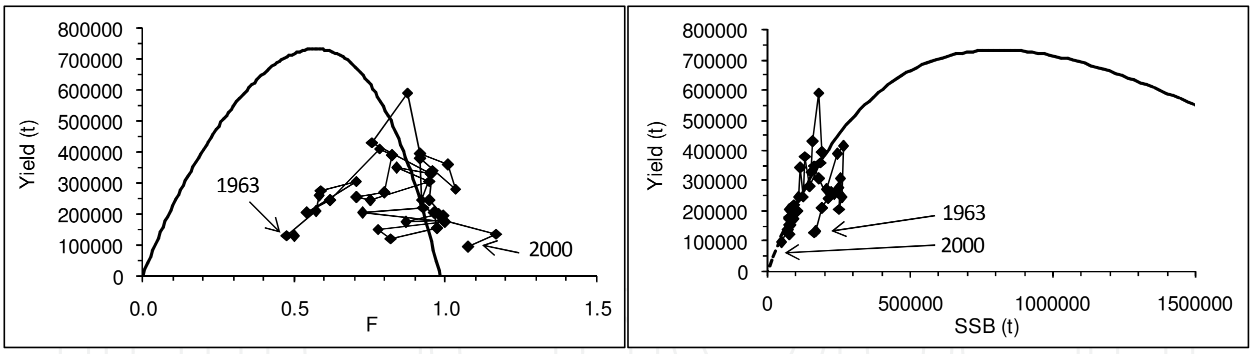

Fig. 1. North Sea cod stock. Potential annual yield as a function of fishing induced mortality F and the weight of all spawning fish (spawning stock size SSB) as estimated by means of a non-equilibrium model using data 1963-2000 from ICES North Sea working group (ICES, 2010).

be achieved even if the scientific advice regarding the final goal is imprecise but clearly quantifies the problem and the direction to solve it (Patterson *et al.*, 2001).

Single stock fisheries, the easy case: Sustainable fisheries management requires the pre-agreed biological limit exploitation level based on the above outlined policies. Given that the stock of a target species can be fished without significant by-catch of other species and impact on its habitat, a simple TAC including potential discards of the target species can be used to effectively control the single species fishery induced mortality and keep it below the a-priori set limit accounting for stock specific conservation requirements. This recommendation applies to both passive gears, i.e. longlines, nets and traps, as well as actively moved gears such as seines and trawls. However, fully implemented and effective scientific monitoring and advisory as well as fishery control and enforcement systems must be in place. If the exploited stock is considered a shared resource among nations and their various fisheries, a complex framework of political commissions will be active to decide on access rights, probably to the level of individual fishermen, defined as individually transferable quotas (ITQ) and recently favored to strengthen stakeholder involvement through increased responsibility (Hauge & Wilson, 2009). Often the access rights are based on historic records on contributions of each fishery and nation to the overall exploitation. However, the prominent example of the Mediterranean blue fin tuna fisheries already demonstrates the many potential management failures starting from biased scientific knowledge and advice based on wrong catch records due to ineffective control. The simplicity of single stock/species fisheries management through catch constraints to achieve sustainable levels is enough reason to incentivize fishing industries to conduct so-called "clean" fisheries without by-catches where- and whenever possible. The incentives should force fisherman to stop effectively fishing once their allowance is exhausted. In particular, this recommendation regards fisheries for pelagic stocks/species, such as the tunas, herring, mackerel, anchovy and sardine fisheries. The pronounced schooling and migratory behavior of pelagic species over continued periods prevents relatively small areal closures or direct effort limitations being effective and safe. "Clean" catches can also be achieved by advanced selective trawl devices (Valentinsson & Ulmestrand, 2008).

Mixed fisheries, the difficult cases: We have to realize that sustainable fisheries management can be much more complex and difficult. The great majority of stocks are exploited by multi-species (mixed) fisheries, particularly the near bottom and bottom dwelling species due to their coexistence in diverse communities (Caddy & Seijo, 2005) and the poor selectivity of many gears used. Fisheries using bottom trawls and seines might severely impact the structure of the sea bottom (Kaiser & Spencer, 1996). Still, the variety of exploited stocks in mixed fisheries requires specific conservation needs based on the specific ecological role and stock status. In addition, the selection of the various mixed fisheries involved in the exploitation of certain stocks varies significantly with the gears and the fishing strategies. It is argued that the mixed fisheries are best managed by fishing effort (Kell *et al.*, 2005; Schwach *et al.*, 2007), if they deploy trawled (active) gears. This can be done by settings of effort constraints (TAE) in units of days at sea or the product of kilo Watt times days at sea to account for engine power (Cotter, 2010). It's noteworthy that such effort measure can be easily controlled. However, the effectiveness of such effort measures regarding passive gears has still to be proven. Fishing grounds with high stratification, e.g. along continental shelves, may force certain stocks or parts of them to occur highly aggregated and thus make pure effort measures ineffective to control fishing mortality, like in the example of pelagic fisheries (see above). However, catch constraints (TAC) estimated and set consistently with effort constraints (TAE) will help to communicate foreseen fishing possibilities to the involved stakeholders.

Now, since we've learnt that many stocks are exploited simultaneously by various mixed fisheries, we may understand that, under such circumstances, fisheries management can be very complex. While the agreed stock specific conservation requirements can be defined as F_{MSY} (1), the way towards it appears less clear when simultaneously considering all jointly exploited stocks by a variety of fisheries characterized by different selection patterns. A stochastic medium term forecast model for North Sea demersal fisheries (7 stocks, 9 fisheries) based on data from ICES (2010) and STECF (2011) provides some robust conclusions on future catch and biomass trends under various management scenarios. The major underlying dynamic concept is defined as

$$N_{y+1,a+1} = N_{y,a} \exp(-(M_{y,a} + F_{y,a})), \quad (3)$$

where N denotes stock size in numbers in given year y at age a, M equals natural mortality and F fishing mortality (Beverton & Holt, 1957).

The most important stock productivity parameter is the recruitment to the stock expressed as

$$R = \alpha S \exp(-\beta S), \quad (4)$$

where R denotes the recruitment to the stock, S the parental stock size with α and β as stock specific parameters (Ricker, 1975).

Finally, the catch equation links the observed catches taken from a given stock with the stock size and the two components of mortality, i.e. the natural and the fishing mortality as

$$C_{y,a} = F_{y,a} N_{y,a} ((1-\exp(-(F_{y,a} + M_{y,a}))) / (F_{y,a} + M_{y,a})) \quad (5)$$

where C denotes catch in numbers in a given year y at age a (Beverton & Holt, 1957).

Stock specific production parameters required and the limit reference levels of exploitation of seven stocks are listed in Table 1 defining all stock areas as being consistent with the joint demersal fisheries management area of the Skagerrak, North Sea and Eastern Channel. It has to be noted that the stock dynamics of Norway lobster in the North Sea are largely unknown and they are assumed to be a short lived species with one age group only during its exploitation phase. The matrix of actual contributions in terms of fishing mortalities by stock for each of the nine fisheries is given in Table 2. The fisheries definitions are in accordance with the fleets defined in the cod management plans (EU, 2008b), one of the major concerns in European fisheries management. It can be taken from Table 2 that each of the nine defined fisheries contributes to the exploitation of each of the seven stocks with different intensity. While the trawlers are catching all gadoids, Norway lobster and flatfishes except sole, the beam trawlers are mainly targeting the flatfish plaice and sole. The major interest of the passive gillnets and trammel nets focuses on sole with some cod shares of gillnets as well. Longlines do not play an important role in the evaluated system at all and other fisheries catch a rather small share of cod and whiting.

	COD 3an47d	HAD 3an4	WHG 47d	POK 3a46	PLE 4	SOL 4	NEP 3a4
Ricker coefficient a	3.5	20	17	1.5	9	6	77
Ricker coefficient k (t)	1700000	300000	300000	300000	290000	50000	250000
first age group	1	1	1	3	1	1	1
last age group	7	7	8	8	9	9	1
recruitment relative variation CV	0.8	0.9	0.4	0.5	0.7	0.9	0.1
precautionary biomass Bpa (t)	150000	140000	200000	200000	230000	35000	150000
Fref range (fishing mortality)	age 2-4	age 2-4	age 2-6	age 3-6	age 2-6	age 2-6	age 1
F in 2010 (fishing mortality)	0.86	0.25	0.35	0.30	0.25	0.37	0.17
F limit or FMSY proxy (fishing mortality)	0.40	0.30	n.a.	0.30	0.20	0.22	n.a.
relative max. annual change Fref	0.1	0.1	0.1	0.1	0.1	0.1	0.1
relative max. annual change TAC +-	100	100	100	100	100	100	100

Table 1. Stock specific parameters of seven stocks as used in the stochastic medium term forecast model of catch and biomass under various management scenarios. Cod in ICES divisions 3an, 4 and 7d (*Gadus morhua*, COD 3an47d), haddock in ICES divisions 3an and 4 (*Melanogrammus aeglefinus*, HAD 3an4), whiting in ICES divisions 4 and 7d (*Merlangius merlangus* WHG 47d), saithe in ICES divisions 3a, 4 and 6 (*Pollachius virens*, POL 3a46), plaice in ICES division 4 (*Pleronectes platessa*, PLE 4), common sole in ICES division 4 (*Solea solea*, SOL 4) and Norway lobster in ICES divisions 3a and 4 (*Nephrops norvegicus*, NEP 3a4). Note that n.a. assigns not available.

As we start from an overexploited situation for some stocks, the overarching rule applied is an annual reduction in fishing mortality by 10% for each stock whenever the exploitation exceeds the pre-agreed reference point. This appears close to the existing multi-annual plans for the North Sea stocks (EU, 2007b; EU, 2008b). A limitation regarding the annual variation of TACs as often requested by the fishing industry and implemented in the stock specific multiannual plans is not considered in the following simulations as such rules imply conflicts among the plans in the likely case that the stock dynamics differ. Let's start with the current situation in European mixed fisheries management, i.e. only the exploitation status of one individual stock is decisive for the regulation of the fishing mortalities induced by multi-species fisheries. There is a good chance that any time one of the exploited stocks is in a good environmental status, and this becomes the decisive stock for the management and the fisheries continue until their last quota shares are exhausted. All other by-caught stocks, for which the limit exploitations and the respective TACs are exceeded through ongoing fisheries, have then to be discarded. Often such catches are black landed due to their economic value and ineffective control. In cases that discarding of marketable fish is not prohibited, high-grading of the landed catch proportions is a common response by the fishing industry. This strategy intends to maximize the economic value of the catches by means of discarding of low-priced catch components while keeping the landing and revenue option valid throughout the management periods.

Gear	Mesh size (mm)	Fishery code	COD 3an47d	HAD 3an4	WHG 47d	POK 3a46	PLE 4	SOL 4	NEP 3a4
Trawls other than beam trawls	≥100	TR1	0.496	0.15	0.173	0.253	0.031	0.002	0.002
Trawls other than beam trawls	≥70 <100	TR2	0.192	0.076	0.057	0.033	0.021	0.006	0.151
Trawls other than beam trawls	≥16 <32	TR3	0.001	0.002	0.002	0.002	0.002	0.002	0.002
Beam trawl	≥120	BT1	0.005	0.002	0.002	0.002	0.006	0.001	0.002
Beam trawl	≥80 <120	BT2	0.012	0.002	0.002	0.002	0.177	0.299	0.002
Gillnets	all	GN1	0.048	0.002	0.002	0.002	0.003	0.018	0.002
Trammel nets	all	GT1	0.01	0.002	0.002	0.002	0.004	0.033	0.002
Bottom longline	n.a.	LL1	0.003	0.002	0.002	0.002	0.002	0.002	0.002
OTHER	n.a.	OTHER	0.095	0.009	0.103	0.002	0.002	0.002	0.002

Table 2. Nine European fisheries active in the Skagerrak, North Sea and Eastern Channel and their contributions to the overall stock specific exploitation rates expressed as partial fishing mortalities. Data are adopted from ICES (2010) and STECF (2011).

The consequences of the management of mixed fisheries based on only one decisive stock are illustrated in Figure 2. While the exploitation of the most productive stock in the system, in this case the North Sea cod, is reduced stepwise towards the limit management reference with the logic and positive recovery of its stock size, the exploitation rates of the other stocks increase rapidly as their stock sizes diminish to very unproductive levels, in particular plaice and saithe. Only the stock size of Norway lobster remains without feedback to increased exploitation as the stock dynamics are specified as unknown in the model. As mentioned above, the simulated management scenario will allow major discarding of haddock, plaice and saithe while the discarding of cod is declining. All fleets except the trawlers with a mesh size of 70-99 mm will increase their efforts based on opportunistic catch possibilities. In summary, the effort management of mixed fisheries based on a single stock's reference point puts the goal of a sustainable exploitation at an unacceptable level of risk. The high amount of catches exceeding the TACs (overquota catches) contributes significantly to the management risk.

There will be immediate agreement among the conservative interests in the prescribed goal of the MSFD that not one but all exploited stocks shall be in a good environmental state, at least as far as the fisheries impact is concerned. Such conditioned simulations are illustrated in Figure 3, with the same annual reduction in fishing mortality by 10% if the exploitation exceeds the any of the limit reference points set. Under such circumstances all the stocks are quickly recovering to highly productive states and their exploitation rates are consistently reduced. Maintaining at and below or reaching such goals simultaneously for all exploited stocks implies renouncement of catches in short term from more productive stocks which are by-caught in the various fisheries. However, the previous overall catch reduction will be compensated after about 6 years with some changes in the contributions by the various stocks, there will be more cod and saithe while sole landings will remain unchanged.

Haddock and plaice landings will be significantly reduced. The projection of increased Norway lobster landings must be interpreted with care due to the largely unknown stock dynamics. Discarding will be largely reduced after a short period of few years, as all catches can be landed without further restrictions and minimum landing sizes will have a reduced effect on the amount discarded as higher individual survival will result in higher abundance of large fish. As such this management scenario supports the idea of a discard ban. The results of the management scenario suggest that all fisheries will reduce their effort proportionally by more than 60%. Although this reduction across the board offers a huge potential to economically safe investments and thus increase the economic viability of the fisheries, it equally requires the need to adequately cover the social consequences of such a drastic effort reduction. However, the winning argument for a similar management of mixed fisheries is the gain in stock size with the related high security against fisheries collapses.

Mixed fisheries management based on specific limit reference points of all stocks may require the option of disproportional weighing of specific fisheries, e.g. by favoring fisheries avoiding overfished stocks or selecting less stocks from the ecosystem (Rätz *et al.*, 2007). In this way fisheries management can adaptively benefit from stock specific fishing possibilities. Focusing exclusively on the exerted fleet specific impact expressed as the ratio between fishing mortality in relation to the sustainable management limit on a stock by stock basis one could assign the fisheries a specific relative factor according to the formula

$$fac_{fishery} = (P \,/\, \Sigma\, (F_{fishery} \,/\, F_{MSY})) \,/\, (\Sigma\, (P \,/\, \Sigma\, (F_{fishery} \,/\, F_{MSY})) \,/\, L), \qquad (6)$$

where $fac_{fishery}$ denotes a fisheries specific weighing factor, P the number of stocks caught by a given fishery and L the number of fisheries. $F_{fishery}$ quantifies the fishing mortality exerted by specific fishery, known as the partial fishing mortality. Such factor $fac_{fishery}$ would be relatively low if a given fishery contributes more to overfishing than other fisheries. Contrarily, fisheries contributing less to the risk of overfishing would be assigned a relatively high factor which could be then applied to allow for an increased impact of such fisheries, i.e. their partial fishing mortality determining the specific fishing possibilities of future years.

The fisheries specific management scenario applying the above outlined algorithm of a specific factor to consistently estimate landings, discards, fishing mortality and specific relative fishing effort is illustrated in Figure 4. In comparison with the proportional fisheries management scenario illustrated in the preceding Figure 3, the arbitrary choice to privilege certain fisheries at the expenses of more problematic ones results in almost unchanged stock dynamics but increased landings, which are still taken consistently with the sustainable management goals. The possibility of continued and incentivized fishing strategies if considered less problematic is demonstrated by their relative effort trends in Figure 4, i.e. constant or increasing trends. Such potential solutions for conflicting interests among various fisheries and the predefined regulatory frameworks shall be discussed and agreed among stakeholders and managers in advance and be implemented in multi-annual plans of the fisheries.

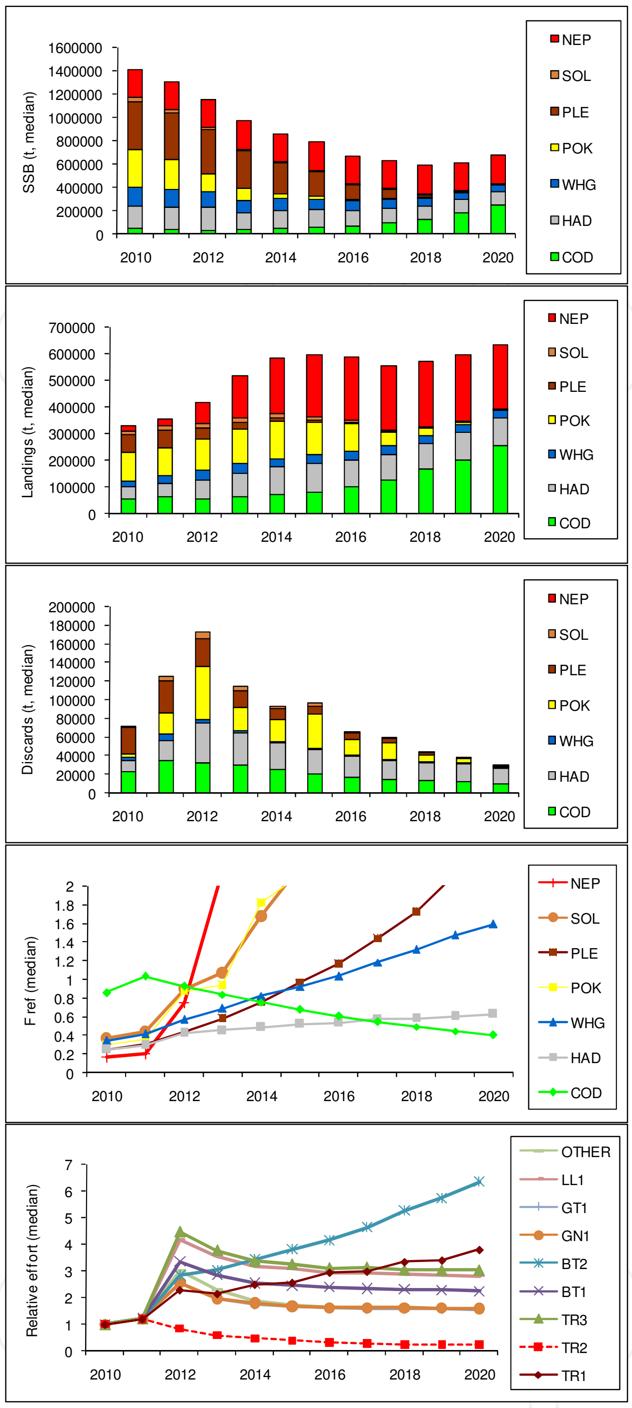

Fig. 2. Decadal trends of median stock (SSB=spawning stock biomass, Fref=fishing mortality) and fisheries parameters (landings, discards and relative fishing effort) based on 100 iterations obtained from a stochastic forecast model to simulate mixed fisheries effects for 7 stocks and 9 fisheries in the Skagerrak, North Sea and Eastern Channel. Stocks and fisheries are defined in Tables 1 and 2, respectively. A harvest control rule to reduce exploitation below or to maintain exploitation at the agreed limit reference point (Table 1) by means of an annual variation in fishing mortality constrained to a maximum of 10% is applied. Only one (the highest) stock specific and sustainable limit reference point is decisive for the control of fishing mortality.

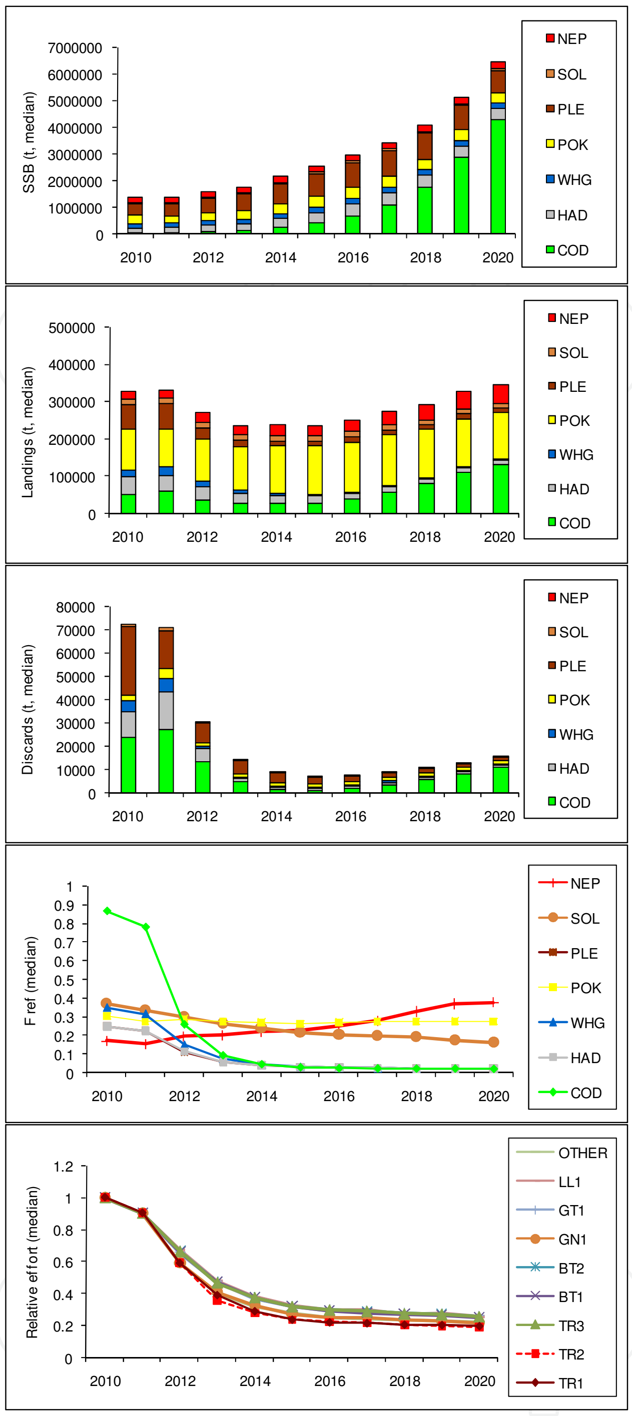

Fig. 3. Decadal trends of median stock (SSB=spawning stock biomass, Fref=fishing mortality) and fisheries parameters (landings, discards and relative fishing effort) based on 100 iterations obtained from a stochastic forecast model to simulate mixed fisheries effects for 7 stocks and 9 fisheries in the Skagerrak, North Sea and Eastern Channel. Stocks and fisheries are defined in Tables 1 and 2, respectively. A harvest control rule to reduce exploitation below or to maintain exploitation at the agreed limit reference point (Table 1) by means of an annual variation in fishing mortality constrained to a maximum of 10% is applied. All defined stock specific and sustainable limit reference points are simultaneously decisive for the control of fishing mortality.

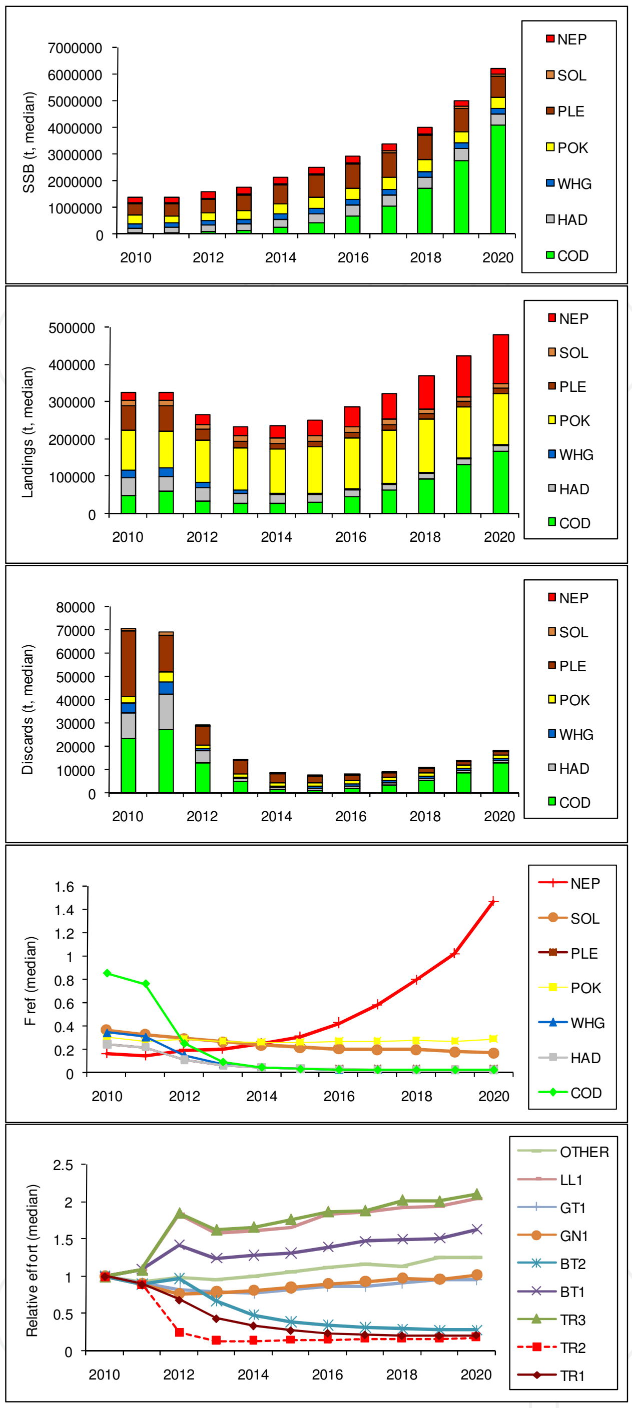

Fig. 4. Decadal trends of median stock (SSB=spawning stock biomass, Fref=fishing mortality) and fisheries parameters (landings, discards and relative fishing effort) based on 100 iterations obtained from a stochastic forecast model to simulate mixed fisheries effects for 7 stocks and 9 fisheries in the Skagerrak, North Sea and Eastern Channel. Stocks and fisheries are defined in Tables 1 and 2, respectively. A harvest control rule to reduce exploitation below or to maintain exploitation at the agreed limit reference point (Table 1) by means of an annual variation in fishing mortality constrained to a maximum of 10% is applied. All defined stock specific and sustainable limit reference points are simultaneously decisive for the control of fishing mortality with a non-proportional fisheries specific management scheme.

4. Money doesn't make the fisheries go-round: Sustainable nutrition and ethical responsibility to the benefits of all!

We have realized that the oceans are not empty but overfishing occurs frequently at an unacceptable level with significant disadvantages for the entire society including industry and consumers. While the objectives of sustainable fisheries management are internationally agreed (UN indicators for exploitation of marine stocks defined as F_{MSY}), the road to implement them remains long and bumpy, also because coastal nations of a marine region have to be consulted, come to an agreement, implement it to their national legislation, enforce and finally control it. Given the improved information available from scientific assessments of exploited stocks and their fisheries impacts and in line with the responsible fisheries management, there shall be no further reason to postpone necessary actions regarding evaluations, decisions and measures implemented to achieve high long term yields at reduced ecological and economic risk within a reasonable time (OECD, 2011). Unfortunately, slow decision-making and implementation has been identified to delay or even prevent a sustainable approach – once decided lately, many decisions appear outdated and their implementation often turn counterproductive. As a consequence, lost value through forgone future opportunities caused by depleted and non-rebuilt fisheries are seldom accurately accounted for in arguing to delay implementation of sustainable fisheries management (Shelton, 2009). The responsible parties shall immediately develop policies aimed at sustainable stewardship of the biosphere; in easy words: how our oceans shall look like in 50 years and how Neptune's garden shall be used. By doing this, the human role needs to be re-identified and respected; yet we are players in and not controlling managers of the ecosystems. Although the global modeling including climate and other ecological effects are rapidly improving and leading to a better understanding, the sustainable management of ecosystems appears rather ideological and shall be approached by adaptive regional steps while considering the existing gaps in knowledge and political power (Norton, 2005). Gladwin *et al*. (1995) were calling for re-integration of humanity into nature and truth to morality.

The policy makers already raised the need for economic information to assess and consider the socio-economic consequences and the potential conflict with confidentiality of individual data. Socio-economic consequences are commonly presented in so-called "impact assessments" to verify the social welfare. However, it is of vital importance that ecological and economic goals are harmonized as functional ecosystems are seen as the natural capital, i.e. there must first be something you can harvest, and secondly the economy deals with the strategy of the investments and revenues. The evolution of ecological economics as an extended "ecological regime" is both qualitatively and quantitatively dependent on an adequate understanding of the behavior of living systems (Jansson et *al*., 1994). Economists have long argued that a fishery that maximizes its economic potential usually will also satisfy its conservation objectives. To add, it is well acknowledged that subsidies to fisheries that contribute to overcapacity and overfishing will turn the effectively strong relation between ecology and economy to perversity (Meyers & Kent, 2001). Recently, maximum economic yield (MEY) has been identified as a primary management objective for Australian fisheries and is under consideration elsewhere. However, the avoidance of significant trade-offs is complex and to develop an implementable management strategy in an adaptive management framework, a set of assumptions must be agreed among scientists, economists, and industry and managers, indicating strong industry commitment and involvement

(Dichmont *et al.*, 2010). The optimum structure of regional decisive power and whether the fishing industry is willing and able to assume greater responsibility for its actions remain key questions (Lassen *et al.*, 2008). We conclude that fisheries management has to be fisheries specific to be acceptable and effective. Furthermore, it is obvious that smaller systems are easier to manage than starting top down on large and complex fisheries at a global or continental scale.

The mutual educational processes between scientists and decision makers, from scientific monitoring, modeling, understanding to the complementary advisory role of global political frameworks, is exemplarily documented for air quality targets by Hordijk & Amann (2007). However, such demanding process will certainly benefit if the various parties involved keep their cooperation strictly constrained towards exchange of relevant information and their mandates, i.e. scientists shall undertake accurate science and advice and policy makers shall undertake and defend the sustainable decisions. Given the global poor status of many exploited stocks and their fisheries, which appear depleted in many cases, the realization of the political goal towards sustainable fisheries would require stringent or even brutal management actions. For obvious reasons, multi-annual management plans accompanied by impact assessments offer preferable solutions to avoid irrational responses (Symes & Hoefnagel, 2010). Needless to emphasize that specific multi-annual management plans and their outcomes depend on a full implementation into the fisheries management schemes including monitoring, enforcement and control without any tolerance against violations. The vision is that once fishing capacity and deployed fishing effort are adapted to the production of the exploited marine stocks, the required investments into control and enforcement could be minimized.

Fisheries science is to support the achievement of the sustainable use of the oceans by sound scientific advice based on accurate data from monitoring, and in close relation with economy and social sciences (Symes & Hoefnagel, 2010). Nature is everything else but stable, instead high and increasing variability appears the normal under the climate changes we are recently facing (Walther *et al.*, 2002). Fish production is considered highly variable even without fishing. However, status classification of exploited marine stocks and ecosystems requires more consistent frameworks worldwide to further develop and review integrated scientific advice to sustainable fisheries management considering also economic impacts in the format of an integrated advice. Many of the regional fishery organizations need to consider such needs and their advisory bodies need to be reformed regarding their structure and mandate towards integrated advice.

In particular, sustainable fisheries shall support the food production from sustainable aqua- and agriculture. The aquaculture, as closest sector to fisheries, is boosting as it maintained an average annual growth rate of 8.3 percent worldwide between 1970 and 2008 (FAO, 2010 a), peaking at 52.5 million tons reported for 2008. In common with all other food production practices, aquaculture is facing challenges for sustainable development, including genetic conservation and environmental risk of genetically altered aquatic organisms (NACA/FAO, 2001). The continued efforts in optimizing production practices, including food supply and pollution, have to be assessed, regulated and controlled to avoid environmental problems. Like capture fisheries, aquaculture will contribute to food security only after full compliance with long term sustainability criteria.

But do we need all this fish and shellfish that can potentially be produced once we are fishing and rearing sustainably? Annual per capita fish consumption grew from an average of 9.9 kg in the 1960s to 11.5 kg in the 1970s, 12.6 kg in the 1980s, 14.4 kg in the 1990s and reached 17.0 kg in 2007. In 2007, fish accounted for 15.7 percent of the global population's intake of animal protein (FAO, 2010 a). There is of course significant regional variation in the dietary. Given the recent status of marine fisheries and resources, their relevance in protein supply has to be significantly improved, which is considered necessary to effectively increase food security and thus combat world's hunger. The world population is expected to grow from the present 6.8 billion people to about 9 billion by 2050. The growing need for nutritious and healthy food will increase the demand for fisheries products from marine sources, whose productivity is already highly stressed by excessive fishing pressure, growing organic pollution, toxic contamination, coastal degradation and climate change (Garcia & Rosenberg, 2010). The number and the proportion of undernourished people have declined, but they remain unacceptably high. Although the number and proportion of hungry people have declined in 2010 as the global economy recovers and food prices remain below their peak levels, hunger remains higher than before (FAO, 2010 b). Fisheries and their management shall adopt the challenge of sustainable food production and adjust their goals and actions at global as well as regional scales in accordance with the view to safeguard biodiversity, bio-production and thus increase livelihood of humanity.

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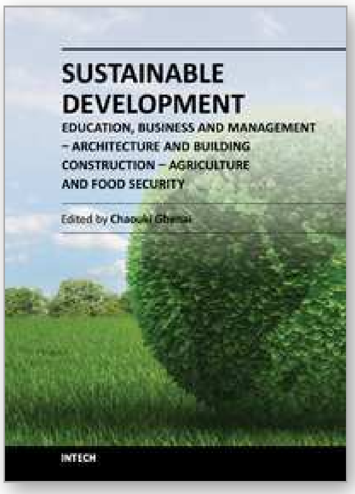

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Securing the future of the human race will require an improved understanding of the environment as well as of technological solutions, mindsets and behaviors in line with modes of development that the ecosphere of our planet can support. Some experts see the only solution in a global deflation of the currently unsustainable exploitation of resources. However, sustainable development offers an approach that would be practical to fuse with the managerial strategies and assessment tools for policy and decision makers at the regional planning level. Environmentalists, architects, engineers, policy makers and economists will have to work together in order to ensure that planning and development can meet our society's present needs without compromising the security of future generations. Better planning methods for urban and rural expansion could prevent environmental destruction and imminent crises. Energy, transport, water, environment and food production systems should aim for self-sufficiency and not the rapid depletion of natural resources. Planning for sustainable development must overcome many complex technical and social issues.