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# *The tragedy of our legacy: how do global management discourses affect small-scale fisheries in the South?*

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**Abstract:** Modern fisheries management discourse is supported by two fundamental narratives that have global impacts. One is the fear of open access regimes, and the other is the condemnation of catching under-sized and immature fish. These narratives have existed for more than half a century and originate from the Common Property Theory (Gordon 1954) and the Maximum Yield per Recruit theory (Beverton and Holt 1957). Our aim is to critically discuss and evaluate these narratives which have been developed within the context of scientific management of single-species industrial fisheries. We will show that the underlying assumptions can be seriously wrong and particularly absurd in fluctuating multi-species, multi-gear artisanal fisheries. Fishing effort in small scale fisheries is often largely regulated by natural production, like other top predators, and many targeted fish stocks and fish communities display a high degree of resilience. Furthermore, in spite of common belief, small scale unregulated, non-selective, adaptive fishing patterns could be healthier and far more ecosystem conserving than the current imposed single species management strategies. Many of these fisheries are serving as a 'social security system' - a common good and thereby function as a 'last resort' for economic mishap. Limiting open access will undermine the role of small-scale fisheries to provide insurance, particularly for the poorest and least advantaged. The immense pressure to adapt to modern fisheries management thinking and economic theory is based on flawed assumptions and will not only have negative social effects, but also negative biological effects.

## Background

For more than 600 years the fear and cry of stock depletion and overfishing has been part of fisheries lore. Consequently, in the beginning of the 20th century, fisheries advice and management institutions were established in the Northern hemisphere in order to understand how fish populations respond to exploitation and to regulate the way we harvest them. The philosophies and principles developed in these institutions have since turned into universal models that permeate the epistemology of fisheries management. Some of these fundamental tenets, however, are based on theoretical and hypothetical, relationships for which there is limited empirical evidence. Two of these ideas, which are omnipresent in fisheries management, are the general condemnation of unselective gears and of open access to the resources. In the first two parts of this essay we will critically examine the origin of these notions. Then we will examine their general validity in relation to small-scale fisheries. We will argue that there are situations, notably in small scale multi-species and multi-gear fisheries, where the implementation of management regulations to address these two issues are ecologically, and possibly also economically and socially, unjustified and may even be harmful to the functioning and structure of exploited ecosystems.

Fisheries management involves numerous social and economic concerns, but there are only two biological considerations: *how much* can be caught and *how* should it be caught? “How much” refers to the quantity, the total yield, that can be taken from a fish stock relative to its productivity and this amount is largely determined by the fishing effort (e.g. numbers of fishers). “How” refers to the specific fishing methods used to obtain the targeted amount. All fishing methods are species and size selective to varying degrees, and the construction, deployment and combination of gears used determine the so-called ‘fishing pattern’ which is the specific species and/or size selective harvesting schedule of any fishery operation in a particular space.

## Part 1. Selective fishing

The issue of how to catch fish sustainably dates back long before modern fisheries theory was developed. Already in 1376 a petition was forwarded to Edward III, King of England, complaining about a newly introduced beam trawl, or ‘*wondy choun*’, with mesh sizes so small that *”no manner of fish, however small, entering within it can pass out”* while its beam *“destroys the spawn and brood of the fish beneath the said water, and also destroys the spat of oysters, mussels and other fish by which large fish are accustomed to live and be supported (….) to the great damage of the commons of the kingdom and the destruction of the fisheries in like places”* (cited by Collins 1887). A commission of inquiry was installed to investigate the matter of which we do not know the outcome, but no legal action was taken. 200 years later Elisabeth I passed the first act of Parliament which introduced mesh size limits of “*two inches and a half broad*” and minimum landing size limits on pike, salmon and barbels. In 1605 the legislation was extended to marine fisheries by James I, which, except for pelagic species, was set to 1.5 inch knot to knot. Hundred years later, in 1714, another act was passed stating that *“..as the breed and fry of sea fish has been of late years (....) destroyed by the using of too small size of mesh (....) no one shall use (....) any trawl-net, drag-net, or set-net (.....) which has any mesh size less than three and a half inch* [90 mm] *from knot to knot (...)”* (cited by Burd, 1986).

Size selectivity is therefore deeply rooted in fisheries legislation, and regulations to control it are almost mandatory around the world. There are two theoretical biological reasons – as well as several economic – for concentrating on size in fisheries management. The biological reasons are 1) a normative argument, known as the ‘propagation theory’, that fish should be given at least one chance to reproduce before being caught, and 2) the ‘growth theory’ that fish should not be fished too young before they have utilized their growth potential (Petersen 1894, Cushing 1976).

The origin of the propagation theory can be traced to the above historical accounts and that “a fish should have a chance of spawning before it is killed” was first formulated in scientific literature by Fulton (1890) and Holt (1895). But the argument also has parallels in the historic legislation of game hunting (e.g. Hayden 1942), where the Anglo-Saxon notions of “fair chance” and “protection of young” to the hunting of game have had considerable impact on the formulation of fisheries regulations (Malasha 2003). The theory also intuitively appeals to most people with limited knowledge of the life history pattern and potential fecundity of most fish species, which have survivorship completely different from mammals (Fig. 1). The tacit assumption often made is that all fish that escape being caught when young will contribute to future catches of mature fish. This is certainly not the case with fish that are expected to die predominantly young – but we are mammals, surrounded by mammals, and see the world through mammal eyes.

Although already formulated by Petersen (1894), the growth overfishing argument was not really adopted until the pioneering theoretical treatise of Beverton and Holt (1957), which became the genesis of modern age-structured approach for fisheries sciences. In their so-called Yield-per-Recruit (Y/R) model, which is purely theoretical,  they showed that for long-lived species, with a low natural mortality, one can maximize the theoretical potential yield by delaying the age-at-capture to a certain optimum. This so-called 'eumetric fishing' principle invoking minimum mesh and/or fish sizes is simply done by adjusting the size selectivity of the gear. Ever since, the 'growth-overfishing' concept has permeated the global management discourse. Recently it was succinctly formulated by two fisheries economists, incidentally showing their mammal bias:
*' (…)  a fishery will yield its maximum physical returns if all fish are allowed to grow to the point where the rate of increase in weight just ceases to outstrip losses due to natural mortality and then harvested, sparing a breeding stock if the existing stock has not bred sufficiently prolifically. (This is logical, and is how a farmer would produce meat, bearing in mind that he must leave a breeding stock.)'* (Hillis and Arnason 1995)

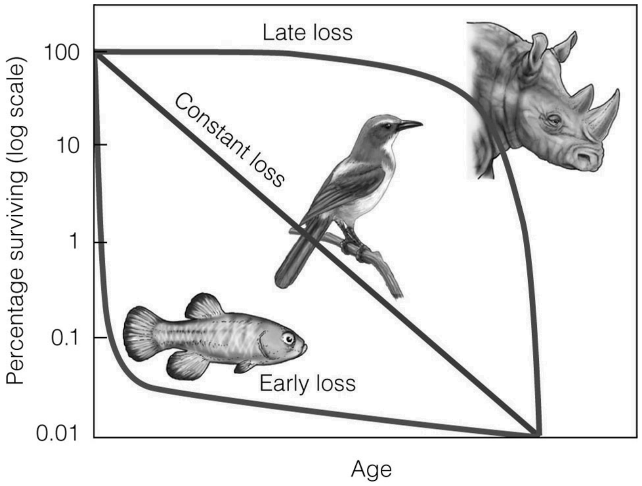


Figure 1 Dying is more certain than giving birth. Generalised survivorship curves of different animal categories (mammals, birds, and bony fish). The prevailing mortality pattern – i.e. when does death commonly occur to individuals in a population? – will shape the adapted life history strategy. Fish have a very high fecundity, often millions of eggs, but the vast majority of juveniles will die long before reaching adulthood (Larkin 1978). After Miller (2007).

Under the 'growth-overfishing' concept, old large mature individuals are the legitimate target for harvest, albeit a healthy biomass of mature individuals, the so-called 'spawning stock biomass', is also needed to safeguard the future of the stock against the risk of reducing its reproductive capacity, or 'recruitment overfishing' as it is known among fisheries scientists (Larkin 1978, King and McFarlane 2003). The assumption often made is that spawners in their first year of maturity make a major contribution to reproduction and then can be captured safely afterwards. We know, however, that the youngest spawners have the lowest relative fecundity and the poorest egg quality and larval survival (Rijnsdorp 1993, Solemdal 1997, Marteinsdottir and Begg 2002).

Yet, generations of fisheries biologist have been taught the Yield-per-Recruit models to the point that unselective or, with a term often used in small-scale fisheries literature; 'indiscriminate' fishing methods are by default synonymous with destructive fishing practices. In small-scale fisheries the normative argument that killing juveniles is depleting the stocks has become so dogmatic that it doesn't even warrant verification. In addition, with the increasing focus on discarded bycatch problems in single species industrial fisheries (Alverson et al. 1994; Kelleher 2005; Lewison et al. 2009) the issue of selectivity has been further highlighted, and much research is devoted to develop increasingly selective fishing methods or exclusion devices. The topic is also closely connected to the modern western management modus based on single species quota regulations (TAC or ITQs), with their economic optimisation incentives of targeting the right species and sizes with the highest value. The result of all this is that the modern objective for industrial fisheries has become a highly selective kill on targeted species and sizes.

An important additional factor is that mesh size- and gear restrictions are among the cheapest, most easily applied and therefore most widely used management regulations; much cheaper than 'how much' regulation such as catch quotas or effort restrictions, which require biological monitoring and the associated costly information and enforcement requirements. Consequently most nations have imposed legislation banning certain gears and mesh-sizes with the aim of protecting the resources. Although these regulations are originating from the theoretical optimisation problems associated with the large scale single species fisheries, they are uniformly applied and mostly without any form of empirical research for their configuration or justification. Despite that numerous authors have already pointed to the problems of defining the "right" mesh-size in a multi-species fishery (e.g. Sainsbury 1984, Murawski 1991, Gobert 1994, Caddy 1999), the paradigmatic notion of a need for regulations on selectivity still persists. Selective fishing gears are continuously advocated among the universal solutions to prevent overfishing and rebuild collapsed fisheries among conservation biologists (Worm et al. 2009), and even highlighted in the FAO Ecosystem Approach to Fisheries and Code of Conduct framework (Bianchi 2008).

## *Life history effects of selective fishing*

Vital population parameters (or life history traits), typically consist of growth, survival, recruitment, and reproduction (age-at-maturity, fecundity, egg size, investment in parental care etc.). The combination of these attributes largely determines the life history strategies (roughly the adaptations) to which different species have evolved. Nearly all life history parameters have a strong relationship with size and age. Changes in these parameters therefore indicate changes in external selective pressures, particularly the probability of mortality as a function of age (Fig. 1). Life history parameters are also used for classifying the resilience and the potential productivity of fish stocks. Some of them, such as growth and mortality, form the basic inputs in all fisheries stock-assessment models.

For most fish species, unprotected by parental care, the *natural* rate of mortality decreases almost exponentially with age (size). So, the bigger you get the less chance there is that you are eaten by predators. For exploited populations, however, the *fishing* mortality generally increases with age in accordance with the ruling 'growth overfishing' theory. The result is an almost exact opposite mortality pattern from natural predation and thus opposite selective pressures (Fig. 2). We know from theoretical and empirical studies that there is a strong inverse correlation between the age at which a fish matures and mortality (or life expectancy) (Adams 1980, Hoenig 1983, Roff 1984, Law 2000). Consequently, as populations experience increased mortality on adult stages under fisheries that select for large sizes, maturing at an earlier age (or smaller size) becomes evolutionary advantageous to increase the chance of reproducing before dying. This indeed has been observed in several heavily exploited fish stocks (Jørgensen et al. 2007, Fig 3).

Whether this stunting effect is a short term response to pressures (compare stunting in human populations during famines) and is easily reversible, or whether selective fishing has longer term genetic consequences that are much less reversible has only recently been addressed (Sutherland 1990, Law 2000, Swain et al. 2007, Conover et al. 2009). Controlled experiments performed to illustrate the effects of size selective mortality, have largely confirmed the earlier predictions from life history theory, and have shown genetic effects. Populations experimentally harvested on small sizes produced after only four generations nearly twice as much yield than the populations where only large specimens were harvested. (Conover and Munch 2002, Conover et al. 2005). This is clearly in contrast to what the Yield-per-Recruit model predicts. There were also genetic effects: the populations that were harvested on small fish remained having faster growth rates even when the harvesting stopped (Walsh et al. 2006, Conover et al. 2009)

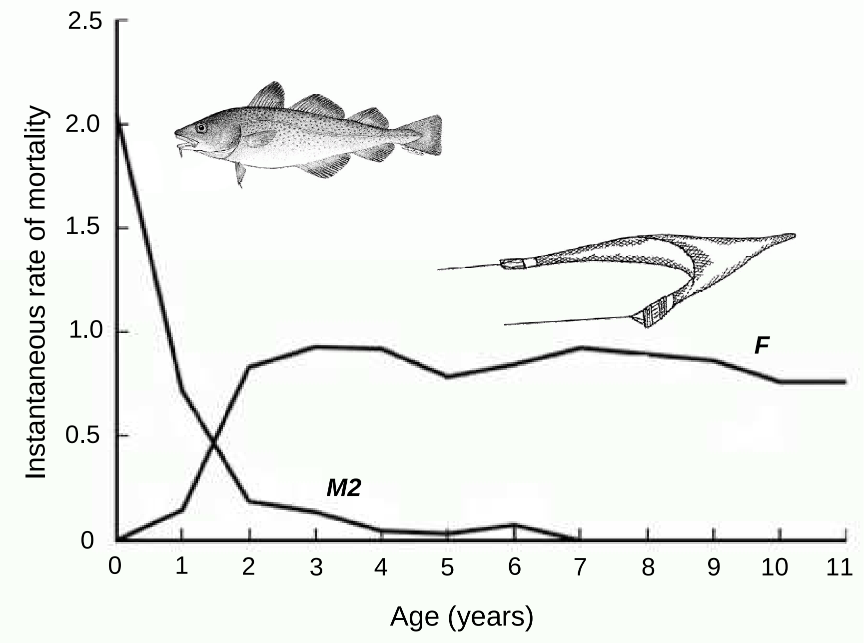


Figure 2. Age specific mortality rates due to fishing (F) and predation (M2) on Atlantic cod in the North Sea. Data averaged over 1987-1994. After ICES (1997).

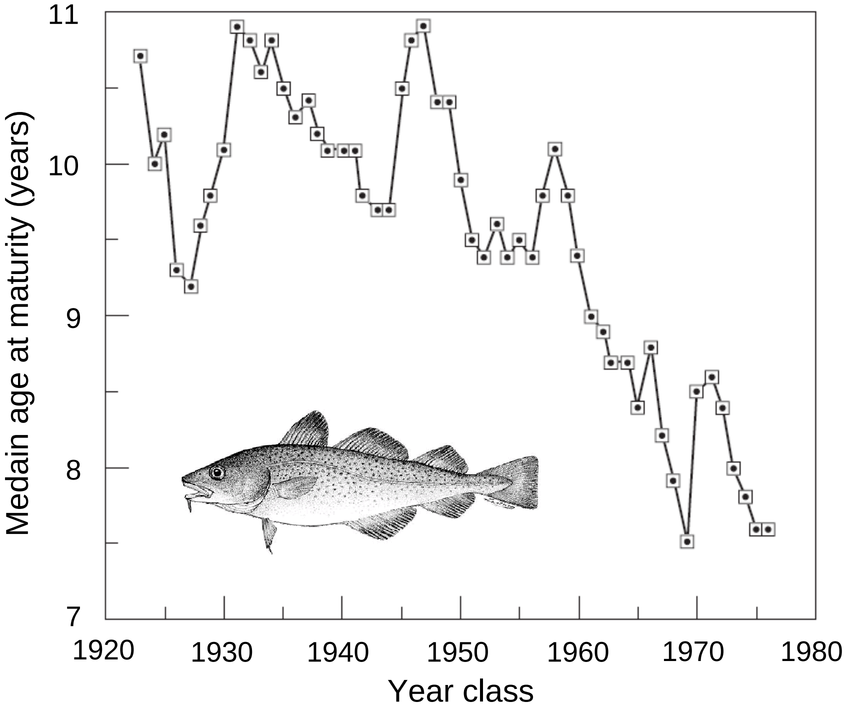


Figure 3 Median age-at-maturation (sexes combined) of Northeast Arctic cod based on spawning zones in otoliths (after Jørgensen 1990).

Some biologists claim that the laboratory selection regimes imposed in experiments do not resemble what happens in nature. They point to a vast body of literature that shows that fish grow large faster, not slower, when fishing pressure is high due to decreased competition for food (Hilborn 2006), Others claim that there are no genetic effects from fishing (Beverton, 1998). Nevertheless, the experiments have shown that growth is a heritable trait and provided testable hypothesis on how fisheries actually operate.

Fisheries scientific advice to management, however, is largely oblivious to these evolutionary and ecological studies and continues to reiterate the standard recipe from Yield-per-Recruit models. In the North Sea and surrounding waters, during the past two decades, the minimum mesh sizes in the demersal trawl fishery has been increased in several steps from 90 to 120 mm, in combination with many other management measures (Suuronen and Sardà 2007). The expected benefits, however, have not materialised and the only rationale for regulation of size at first capture might be a prevention of wastage through discards (Halliday and Pinhorn, 2002). Interestingly, already two decades ago, the ICES multispecies working group, in a less well known study discovered that increasing mesh sizes in the North Sea fishery in a multispecies situation would in the long term result in lower yields due to greater predation rates (and thus competition) from large predatory fish (cod, whiting, haddock, saithe) released by the larger mesh sizes contrary to the predictions from from single species Yield-per-Recruit models (ICES 1989, Fig 4).

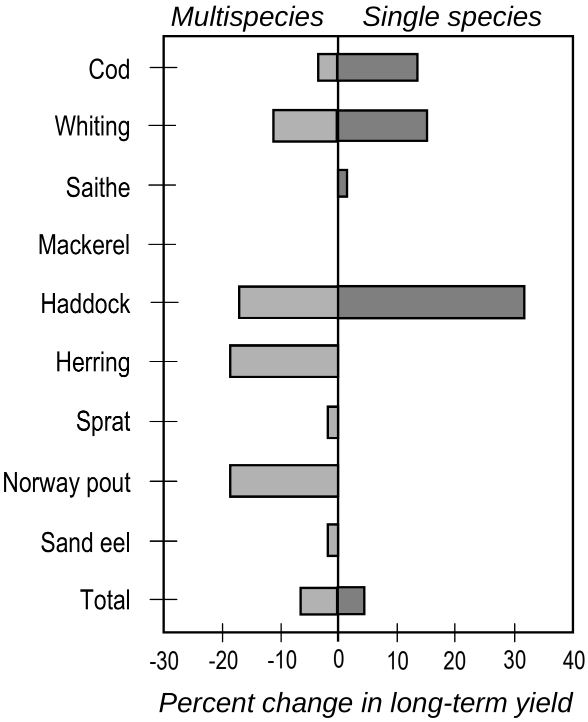


Figure 4. Percent changes in the long term fishery yields for North Sea multispecies system resulting from an increase in trawl mesh size from 85 to 120 mm for the directed fishery for cod. Results are presented for single species (but multi-fleet) Yield-per-Recruit assessment (dark bars) and multi-species virtual population analyses (MSVPA) including interspecies predation (light bars). Lower yields in the multispecies analysis are due to greater predation rates from large predatory fish (cod, whiting, haddock, saithe) released by the larger mesh sizes. After ICES (1989).

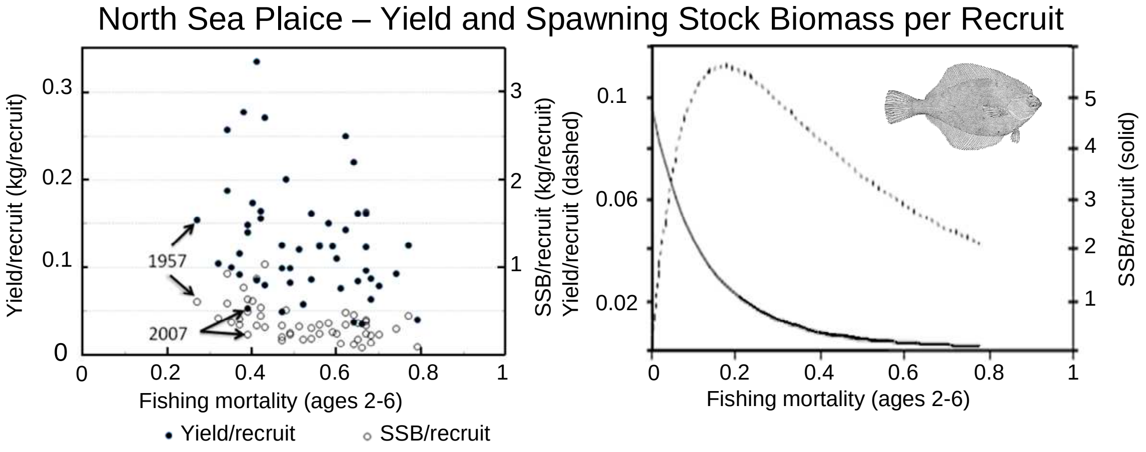
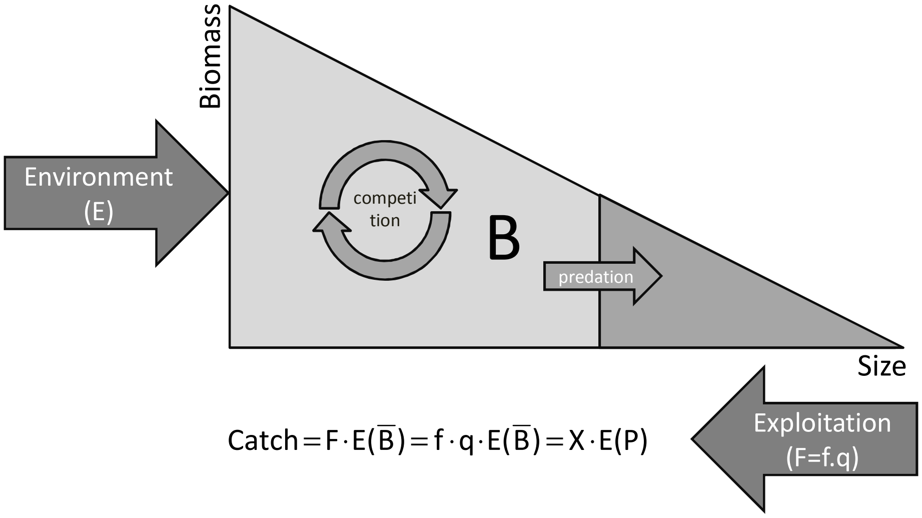


Figure 5. Observations (left) and model (right). (Left) Actual annual estimates of relative yield (black dots) and spawning stock biomass (open dots) from 1957 to 2007 for plaice caught in the North Sea versus the annual average fishing mortality rate of plaice of 2 to 6 years old. Landings of plaice (including discards) and the estimated spawning stock biomass are made relative by dividing them by the estimated number of recruits (one year old fish).(Right) Modelled relative yield and spawning biomass per recruit over corresponding fishing mortality.This diagram is the result of a classical yield-per-recruit model analysis used by ICES, simulating the positions of the black dots (Yield/recruit) and open dost (SSB/recruit) in the left diagram. All data as well as the model result are from the ICES advice of 2008 (ICES 2008).

Thus empirical experiments, historical experience (Fig 3), and multispecies models are basically invalidating the theoretical foundation for size selective fisheries management regulations. The old single species Yield-per-Recruit models, upon which decades of management advice, and volumes of simulation studies have been performed are basically not reflecting reality (Fig 5). They are 100% synthetic (there is no fitting of model to data), and they are ecologically vacuous being density independent, steady state models that contain no genetic responses and have no trophic interactions.

## *Fish community effects of selective fishing*

Fish communities are regulated by both bottom-up and top-down processes (Fig. 6). Bottom up processes are controlled by the energy flow through the food-web starting from input of nutrients, temperature and light controlling the primary productivity (algae). Energy (food) is then partitioned up the food-web between populations of different fish species in a fish community through competition and predation. As there generally is a larger biomass of small fish, consisting of small prey species and juveniles of large species, compared to large predatory adult fish, the overall shape of a biomass-size distribution is a descending curve over size (Sheldon et al. 1972). Variations in the shape of this curve, both its slope and intercept with the vertical axis, indicate systematic changes in the abundance and size structure of fish communities. The descending slope represents the decrease in numbers over size and is therefore related to the mortality pattern (see Fig. 1). Changes over time in the intercept are an indication of the changes



$$\text{Catch} = F \cdot E(\overline{B}) = f \cdot q \cdot E(\overline{B}) = X \cdot E(P)$$

Figure 6. A fish community represented as a biomass-size distribution forms a framework that illustrates the various components consisting of environmental drivers (E), resource states (B) and exploitation pressures (F). The basic relations are that Catch is a fraction (F=f·q) of stock biomass (B) and a fraction (X) of biological production (P). " How much" is fished is expressed by f = nominal fishing effort, while "how" is being fished, or the efficiency of a unit of effort is expressed by q = catchability coefficient. Stock abundance and the amount of biological production are expressed as a function of the environment (E). Arrows indicate main processes affecting fish communities, both internal (competition, predation) and external (fishing and environmental drivers). The descending slope of the curve is represented here as straight line on a logarithmic scale, while on an arithmetic scale it would be an exponential downward curve as for the fish survivorship-curve in Fig.1 (modified from Jul-Larsen et al. 2003).

in biomass and should reflect changes in productivity (bottom-up changes or *how much*), while changes in the slope indicate changes in the size structure of the fish community which can be related to changes in the mortality patterns (top-down processes or *how*). Increasing selective fishing pressure generally results in a decrease in biomass of large fish and an increase of smaller fish (a.o. through less predation and competition), and thus a steepening of the slope. Rice and Gislason (1996) tested the biomass-size theory on the North Sea demersal fish community over the period 1977-1993 (Fig 7). They found that the annual slopes became significantly more negative over the years, which was attributed to increased selective exploitation on large sized fish.

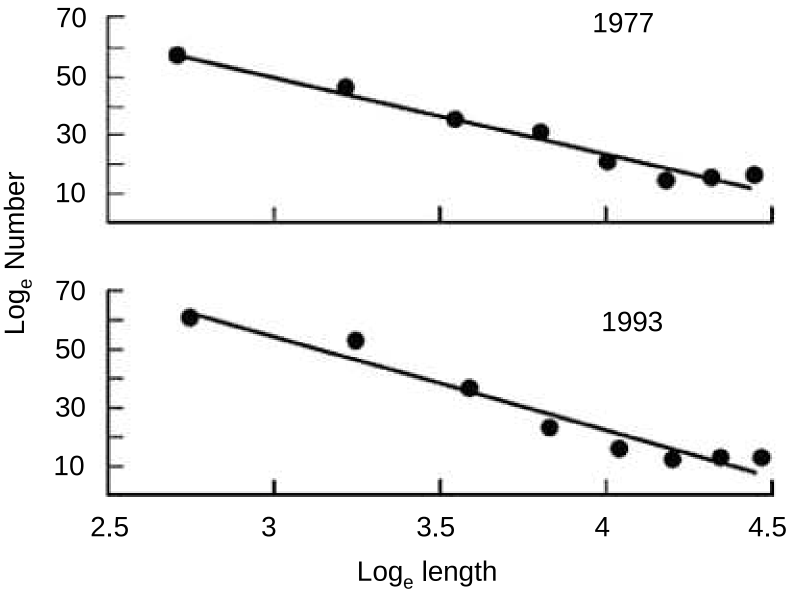


Figure 7. Example of size spectrum for the North Sea demersal fish community from experimental trawl surveys in 1977 and 1993. The numbers of fish per 10cm size class are shown on a log$_e$ scale. Note the steeper slope and higher intercept of the fitted relationship in 1993. After Rice and Gislason (1996).

The selective removal of large – mostly predatory – fish was also documented by Pauly et al (1998) in the widely cited “fishing down marine food web” process. This process reflects a gradual transition in landings - used as an indicator of the availability of fish in the sea - from large, long-lived, fish eating bottom fish high in the food-chain toward smaller, short-lived, invertebrates and plankton eating pelagic fish low in the food-chain. The disappearance of large (predatory) fish and the consequent alteration of the foodweb is now being recognised as a symptom of overfishing, the so-called ecosystem overfishing (NRC 1999, Murawski 2000, Coll et al. 2010).

In conclusion, the selective removal of large fish does not only affect life history traits of individual fish populations in the long run, but also the overall fish community structure, and thereby the internal food-web processes that represent a major part of ecosystem functioning. So far we have described the history, development and consequences of the ‘how’ question (gear selectivity) in fisheries management. We will now turn to the epistemology and outcomes of the ‘how much’ question before we relate these two to the situation in small-scale fisheries.

## Part 2: Open access - the origin of the common property theory (CPT) and need for management

The idea of restricting the entrance into a fishery (nominal fishing effort, fig 6) is much younger than size and gear limitations. In fact, up until the First World War, there was a great debate on whether man was actually capable of exhausting the fish resources. The influential Darwinian biologist T.H. Huxley in 1884 argued strongly against all restrictive measures as he considered that fish resources are inexhaustible and man's capacity to harvest was limited (Smith 1994), though he pronounced that with the important qualifier "*in relation to our present mode of fishing*". This view changed rapidly in the following decades of technological development as many fisheries showed signs of reduced catch rates and possibly depletion. Huxley himself helped form the Fishery Board of Scotland to prevent overfishing. Concerns about overfishing led to the creation of the International Council for the Exploration of the Sea (ICES) in 1902 and one of its first standing committees addressed overfishing (Rozwadowski 2002). From the mid-1960s it became increasingly clear to the various North Atlantic fisheries commissions that mesh and fish size regulations alone were not enough to provide for rational exploitation. Fishing power or intensity became central to the theory of fishing, and control on the amount of the so-called 'fishing effort' became an essential element of management (Caddy 1999, Halliday and Pinhorn 2002).

The control of effort, or "management belief" discourse (Jul-Larsen et al. 2003), is based on the long reigning image among ecologists that ecosystems are closed entities in equilibrium, or at least in a process towards equilibrium, with limited resources. Humans are generally not considered part of the natural, pristine environments, and human interventions, such as fishing, are therefore regarded as an external disturbance with significant effects that affect the productivity of the system. There is a long historical tradition for this view in resource management, and it totally dominates the abstract mathematical modeling framework that characterizes fisheries science (Rose 1997, Angelini and Moloney 2007).

One of the first models to be used in population dynamics was by reverend Thomas Malthus (1798) addressing the fear of unlimited human population growth. Malthus exponential growth rule was later modified by Verhulst (1838) who introduced the concept of the dependency of a population's growth on its own density under limited resources or so-called "carrying capacity", and thereby transformed the exponential "J-curve" into the logistic "S-curve" of a population growth trajectory in a constant environment. Verhulst's logistic curve, predicting the highest growth rate at a population size midway to the carrying capacity, was introduced to ecology by Raymond Pearl (1924) and soon explored by fisheries biologists (Hjort et al. 1933, Graham 1935, Schaefer 1954, 1957) for determining optimum yield. The biological foundation of fisheries resources management was shortly after extended with economic theory in the seminal paper on common property problems by Gordon (1954). Gordon argued that a common property resource, with uncontrolled competitive exploitation under diminishing returns (decreased catch per unit effort, CPUE), would lead to poverty because the harvesting would end yielding no economic profit (value of landings minus costs is zero, Fig. 8), or as Gordon wrote "*Wealth that is free for all is valued by none...the fish in the sea are valueless to the fisherman, because there is no assurance that they will be there for him tomorrow if they are left behind today*" (Gordon 1954:135).

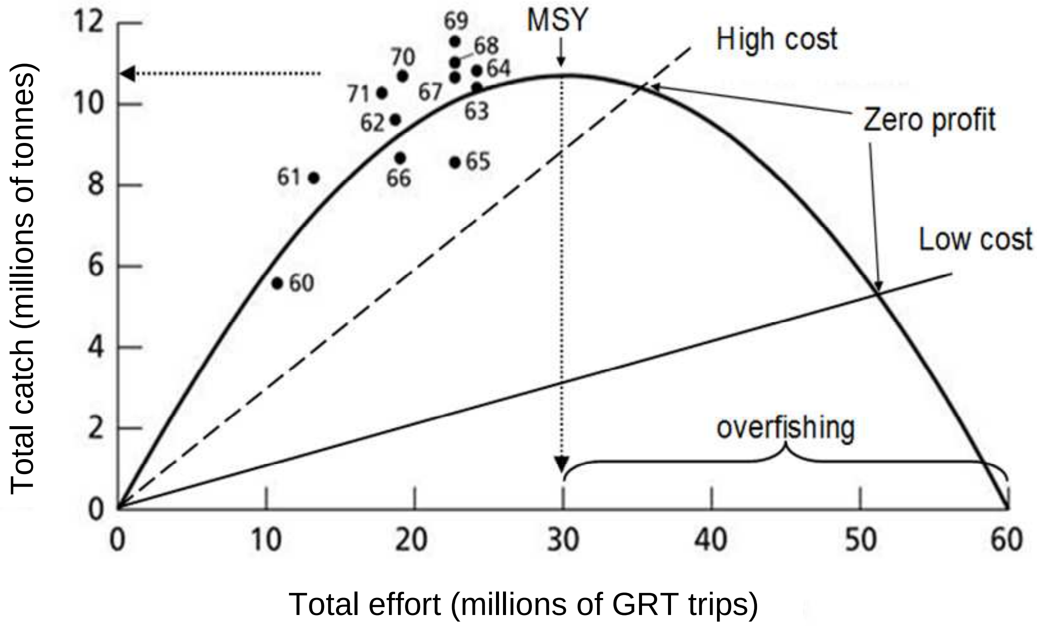


Figure 8. Example of a derivative of the logistic growth curve and the Common Property Theory. A Schaefer surplus production model (parabola) fitted to catch per unit effort data (black dots) for the biggest single species fishery in the world, the Peruvian Anchovy fishery, in the 1960s (after Boerema and Gulland 1973). The dome shaped hypothetical production curve (note that there are no observations on the right side) assumes the total catch entirely as a function of total effort (Gross registered tonnage trips). Maximum sustainable yield (MSY) is around 11 million tonnes obtained with 30 million GRT trips. Any effort level above this will theoretically result in overfishing with predicted reduced productivity (descending arm). Superimposed is a theoretical Gordon economic model, which assumes the cost of the fishery is a linear function of effort. The solid low cost line illustrates a technically poor developed fishery (e.g. a small scale fishery), while the dotted high cost line illustrates a high investment industrial fishery. If the production (tonnes) is scaled to the value of the fishery, then CPT predicts that effort will develop to the points of zero profit under open access (where cost and value intersects). Theoretically this means that low cost fisheries will tend to overexploit their resources to a higher degree than high cost fisheries, and thus are in most need of management.

In 1968 Garett Hardin, without reference to Gordon, used the same rationale to develop his "Tragedy of the Commons" (TOC) doctrine where "*freedom in a commons brings ruin to all*" (Hardin 1968: 1244). In contrast to Gordon, however, who merely saw human poverty as the result of open access, Hardin changed the ultimate result to also include the destruction of the biological resources. Although his essay was originally meant as another motivation for controlling the human population growth ("*freedom to breed brings ruin to all*"), this aspect has later been totally overshadowed by the focus on private property rights in later references on resource management (Feeny et al. 1990). The "Common property Theory" (CPT), and particularly its resource destructive alias "The Tragedy of the Commons" (TOC), which occurs when property rights are absent and access to a resource is open has since become one of the most influential theories guiding contemporary natural resources management. At present, the dominant doctrinal view is that private property is clearly superior to common property (Ostrom and Hess 2007). Fisheries in particular are considered the classic examples of the "Tragedy of the Commons" (Berkes 1985, Benjamin 2001), and many economists since Gordon (1954) have argued that overfishing problems could only be overcome if we somehow privatize the commons (e.g. Leal 2005). Recently, pseudo-ownership, in the form of Individually Transferable Quotas (ITQs), is rapidly spreading in many industrial fisheries as the management tool of choice. Likewise, conservation biologists have embraced the TOC idea and open access fisheries are practically synonymous with the apocalyptic road to overexploitation and destruction.

The supposition behind CPT and TOC, that private property was superior to common property, was soon to be challenged by social anthropologists and human ecologists (e.g. J.M. Acheson, B. McCay and F. Berkes) using empirical evidence to demonstrate that many common production systems contain various local institutional mechanisms that regulate people's access to the resources (e.g. Feeny et al 1990). These scholars argued that by taking for granted that a common property regime implies free access to the resources, the CPT fails to understand the social institutions that often are critical in the management of resources in local communities. This empirical emphasis on local management regimes as "community-based" represented an alternative to the state-centred solutions advocated by the protagonists of CPT (Jul-Larsen et al. 2003). During the 1980s, management studies were influenced by a new interest in economics and social sciences for institutional analysis (Ostrom 1990). Though these scholars were inspired by anthropological studies of local rules for the management of common resources, the "new institutionalism" viewed natural resource management from a slightly different angle. Instead of the strong emphasis on local communities that many anthropologists had advocated, management became more of a question to be resolved in the interface between the state, the civil society and the market. The term "co-management" thus came to substitute that of "community-based" management, even if the critique of the CPT thinking in many ways remained the same. Common to all the theories, however, is the fundamental assumption that "property rights", whether private, joint or communal, are necessary for the long-term sustainable use of local resources. In practically all the disciplines discussing resource management, whether economic, political, anthropological or ecological, then open and free access is considered unsustainable. The management/co-management debate has therefore mostly focused on *who should* manage rather than on *what should* be managed. Whether decisions on objectives and regulations or the enforcement of management rules are put in the hands of the state, the local community or as a co-operation between these, all approaches are based on the assumption that fisheries always can and should have regulated access to a limited resource or else it will be overexploited. However, from both a natural science and a social science point of view this "management belief" assumption is not self-evident (Jul-Larsen et al. 2003).

## Internal versus external drivers of productivity

If management in terms of property rights, effort control, or access limitations to the resources is to be effective, then there must be a clear relationship between human activities and the regenerating ability of the ecosystem. Management models based upon CPT represent a density dependent equilibrium approach and consider human intervention as the only significant external variable while any natural variability is "noise" or "process uncertainty". The dome-shaped relationship between effort and production and the concept of 'maximum sustainable yield' (MSY), are in fact based upon the assumption that a close correlation exists between human intervention (fishing) and the regenerating capacity of the system. (Fig. 8). However, if other external variables are more than just minor ‘disturbances’, but actually are significant drivers that may alter the dynamics of the ecosystem and keep it in a persistent state of non-equilibrium, the picture becomes far more complicated (Fig. 6). One can then not *a priori* say how changes in effort will affect the system (as assumed in Figures 5 (right) and 8), since the effect of effort must be expected to vary according to the magnitude of the external abiotic variables (E in Fig. 6) that drives the system and determines the size of the resources.

This discourse relates to what has been termed outside ecological science as the *'new ecology'* or ‘*dynamic ecology*’ (Zimmerer 1994). This ‘new ecology’ questions the image of ecosystems without human intervention and as closed entities in equilibrium or in a process towards homeostasis. Instead it regards local ecosystems in most cases to be in a constant and ever changing state of disequilibrium, density independent instability, and even chaotic fluctuations due to external variables such as climatic variation (e.g. in rainfall, temperature, wind and evaporation) or human interventions (habitat change, eutrophication). The discussion between internal and external drivers, or between density dependent equilibrium and density independent fluctuations is in fact not new to fisheries and can be traced all the way back to the beginning of the science (Hjort 1914, Skud 1975). Actually, it seems to reappear every time a fishery has unexpectedly collapsed or recovered. Incidentally, the increasing occurrence of the widely heralded fishery ‘collapses’ is almost identical with the increasing occurrence of less advertised recoveries (Fig. 9), which could be an indication that natural fluctuations are much more prevalent than the equilibrium theory assumes.

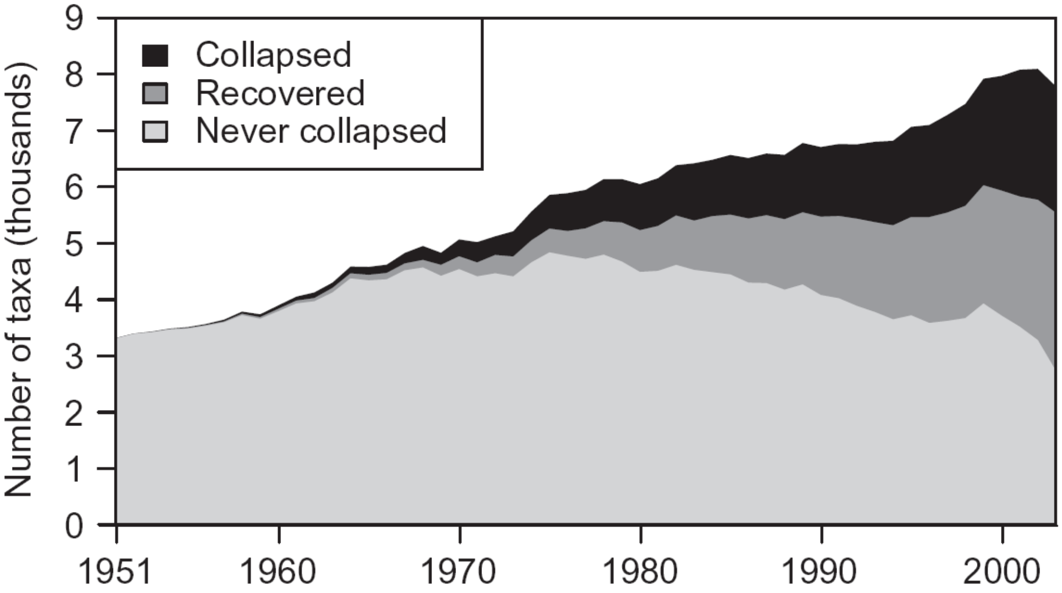


Figure 9. Total global fishery taxa grouped into categories of never collapsed, recovered, and collapsed using the criteria of Worm et al. (2006). While an increasing percentage of fisheries are in a collapsed state, the total number of fisheries has grown and counterbalances this effect. Simultaneously an almost identical increasing number of taxa have recovered, and the ratio collapsed/recovered is steadily around 1 (actually slightly decreasing in favor of recovered). This development could therefore just as well indicate long term climatic driven fluctuations as failed/successful management interventions. E.g. both the North Sea herring stocks and the Peruvian anchovy stocks (Fig. 8) have repeatedly collapsed and recovered again. After Branch (2008).

Although climate-related variability of fish populations is now recognized to be the rule rather than the exception (Klyashtorin 2001, Lehodey et al. 2006), the theoretical biological and economic models used to inform fisheries management are still inherently dependent on equilibrium assumptions and/or predictable top-down drivers, and therefore these assumptions continue to be silently transmitted into management considerations. We only can manage fisheries by regulating effort and gears, and this also means that we must believe in the models that describe the utility of these measures while disregarding the generally overriding effects of nature. The standard assumption of fisheries theorist is that density dependence is present but hard to see, therefore *"faith plays an accordingly large part in fisheries science"* (Larkin 1978:63).

## Natural predators and open access

The 'management belief' discourse considers human actions subject to other rules than natural interactions between populations. Humans are not part of the ecosystem they exploit, and since they allegedly will tend to harvest the system to the point of zero profit (CPT), or even degradation and collapse (TOC), they must be managed (i.e. somehow restricted). All other predators in the system are natural components even though they also harvest a common resource (their prey). The density of predators is basically regulated by the amount of prey (Fig. 6). Thus the carrying capacity of a predator population is equal to the maximum productivity of the prey, which theoretically is at a density around half their own carrying capacity. If a predator overshoots its carrying capacity, i.e. when it "overharvests", the prey productivity will decline, and the predators must respond by reducing their abundance – leading to oscillating cycles in density of predator and prey - or switch prey. Although these principles are derived from exactly the same ecological reasoning and models as CPT and TOC, there seems to be a fundamental epistemological distinction between human and natural predators although they both essentially are doing the same, i.e. harvesting other populations. The basic argument is that humans always have the technological prowess to maintain pressure on the resource while utilizing additional resources to sustain themselves and therefore are different than other predators. The question however is why would they do this if there is no profit and even diminishing returns? A question that nobody seems to ask is why does CPT not apply to natural predators? They are also harvesting a commons. Why are they usually (!) not overexploiting and destroying their prey? Does human harvesting *always* differ from other predators? Barring institutional arguments, there seems to be no logical reason, why fishers, at least those with limited technology, should behave fundamentally different than other predators: thus their density should be regulated by the productivity of the fish. In other words, when the individual catch rate of a fisherman becomes too low for him to sustain a livelihood, he must leave, switch resources or increase his efficiency. The latter is achieved by higher investments in industrialized fisheries, and the last two by changing the selectivity (smaller mesh sizes, gear diversification) in small-scale fisheries. It appears that most African inland fisheries, with their yet relatively low technological level, behave largely as natural predators, i.e. the density of fishers to a large extent seems regulated by the environmentally driven natural productivity of the ecosystem as will be shown in the next section.

## Part 3 - Small scale fisheries and the narratives on selectivity and open access

Small scale fisheries (SSF) are estimated to contribute more than half of the total global landings, more than 2/3 of the catch for domestic human consumption, and employ more than 90% of the world's fishers (BNP 2009). Compared to the industrial fisheries, however, the research on SSF is insignificant, and there are big gaps in our knowledge on their functioning. Due to the increased marginalization of small-scale fisheries in the industrial world, or their conversion into semi-industrial or recreational activities, artisanal fisheries are more and more associated with developing countries. They are often perceived as traditional, poorly equipped subsistence fisheries subject to Malthusian overexploitation (Pauly 1994). Informally organised they are habitually looked upon as unruly members of a society that are difficult to manage (Misund et al. 2002). Small-scale fisheries are mostly low cost, low-tech multi-species fisheries that use a variety of gears. Many of these gears and particularly the traditional ones such as seines, small mesh-sizes, drive- or beat fishing, barriers and weirs are often classified as illegal under the pretext of being non-selective with assumed negative impacts on the fish populations. However, in line with the scarcity of studies on the effect of size selective fishing on fish populations and communities in industrial fisheries, very few studies have actually investigated the effects of using the illegal fishing methods in multi-species and multi-gear fisheries. In the few instances where the actual impact of non-selective illegal gear used in small-scale fisheries have been studied, it is an open question how "detrimental" these fishing methods in fact are (Misund et al 2002, Kolding et al. 2003a,b).

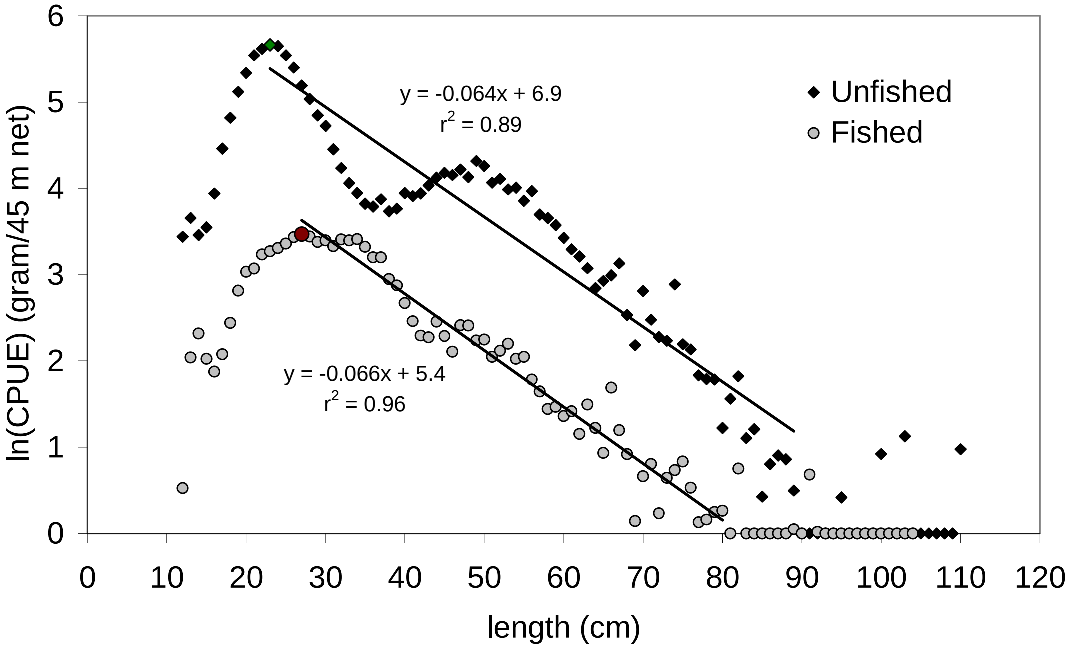


Figure 10. Relative biomass-size distribution with linear regression from Zimbabwe (Unfished area) and Zambia (Fished area) experimental fisheries during the period 1980-1994 for all fish caught in mesh sizes 50-152 mm. Linear regressions on ln-transformed standardised mean catch rates (gram/45 m net set) were made from length range 23-89 cm (Zimbabwe) and 25-78 cm (Zambia) (from the highest value to first 0-observation). The slopes are not significantly different at 95% confidence level. (After Kolding et al. 2003a).

The inland fisheries in Africa are among the best studied SSF from a fisheries perspective. The majority of these are open access but have gear and mesh regulations that are almost universally ignored. Man-made Lake Kariba for example, is an interesting case study because the two sides of the lake, Zambia and Zimbabwe, have had very different management regimes since its creation in 1969. While the Zimbabwean side has had strict enforcement of licensed effort, gears and mesh sizes, the Zambian side has experienced open access with ensuing high fishing pressure and changing fishing patterns in terms of an increased use of small mesh sizes and customary use of traditional, but illegal, fishing methods such as drive (beat) fishing. The results (Kolding et al. 2003a) after 40 years of different management regimes show that the Zambian production is approximately six times higher than on the Zimbabwean side, but with no symptoms of overfishing. While catch-rates of individual fishers in Zambia are lower, there are no significant differences in the mean size of the individual fish species or in the species landings, community composition, or diversity indices between the two sides of the lake. In fact, the overall size structure of the fish community was largely intact compared with a non exploited section of the lake (Fig. 10): this can be attributed to the more unselective fishing pattern from small mesh sizes targeting all species at different trophic levels in the 15-40 cm length range.  Thus, in contrast to the intensively exploited industrial fisheries, such as the North Sea, with clear symptoms of size selective effects (Fig. 7), the only discernable effect from the ‘unselective’ fishery on the Zambian side of Lake Kariba is an overall decrease in the standing biomass. Thus the fish community is largely intact although all components are less abundant.

## *The optimum fishing pattern?*

A fishery that harvests all species at all trophic levels and sizes at rates proportional to their natural productivity will be overall non-selective and has been labelled the “utopian” but optimal exploitation pattern (Caddy and Sharp, 1986). The question is how can this be achieved?

The Zambian side of Lake Kariba (Fig. 10) and the fishery in Lake Volta (Fig. 11) illustrate a process that can be found in most open access small scale artisanal fisheries, and which result in minimal selectivity. The constant trial and error in a strongly competitive fishery, where all fish can be utilised, generates through an ingenious diversification and combination of gears and through rapidly changing fishing practices, an overall species, abundance and size composition in the catch that may closely match the size and species structure of a fish community as well as the productivity of its various components. Therefore, as all fishing gears are more or less species and/or size selective, the “utopian” non-selective exploitation patterns can only be achieved by employing a multitude of gears simultaneously. Floodplain fisheries in the large Asian rivers, for example the Mekong River (Coates, 2001) are examples of highly complex fisheries in which a large number of species are targeted by an enormous diversity in gears, without evidence for any of the species disappearing from the system. The Bangweulu, Lake Mweru and Lake Volta fisheries are similar examples of how the different gear types, many of which are illegal, are targeting different parts of the fish community (Kolding *et al*. 2003b, Van Zwieten at al. 2003, van Zwieten et al. in press).

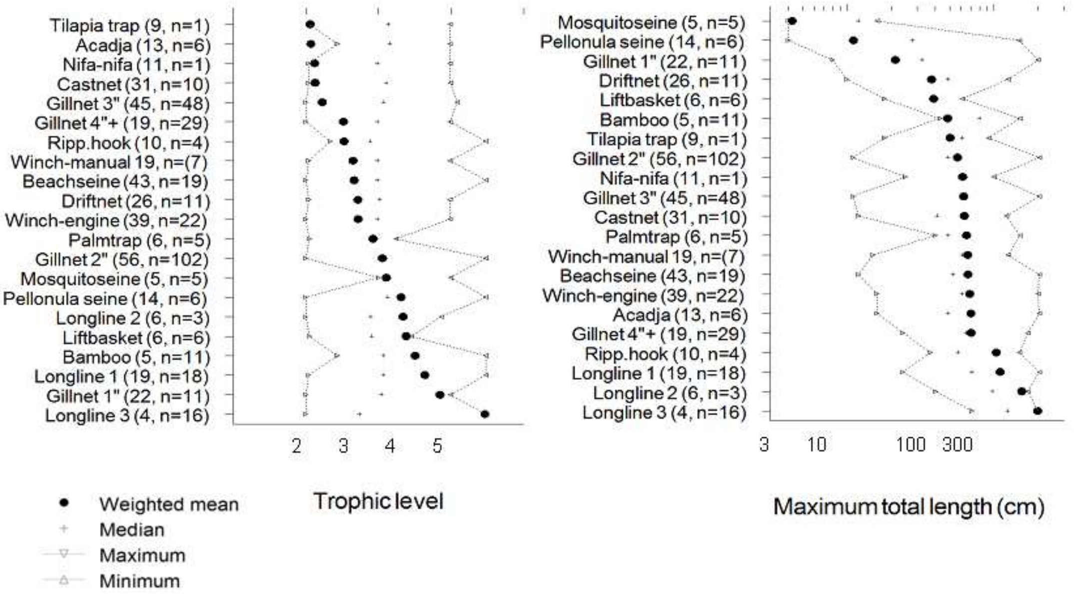


Figure 11. Left: The trophic signature of fishing gears: mean trophic level of the catch in 21 gears operated in Lake Volta, Ghana. Right: The average of the maximum size that individual species can attain caught in 21 gears operated in Lake Volta. Shown in brackets is the number of species caught by a gear, followed by the number of samples (n) on which the proportion is calculated. Both graphs combined give an indication that the Lake Volta multi-species and multi-gear fisheries target all trophic levels and a large size range of species: in total 74 species are utilised over 27 fishing methods (21 are shown). On average each gear catches around 25 kg per day and the fishermen adapt their gear constellation (fishing pattern) according to season and space. After van Zwieten et al, (in press).

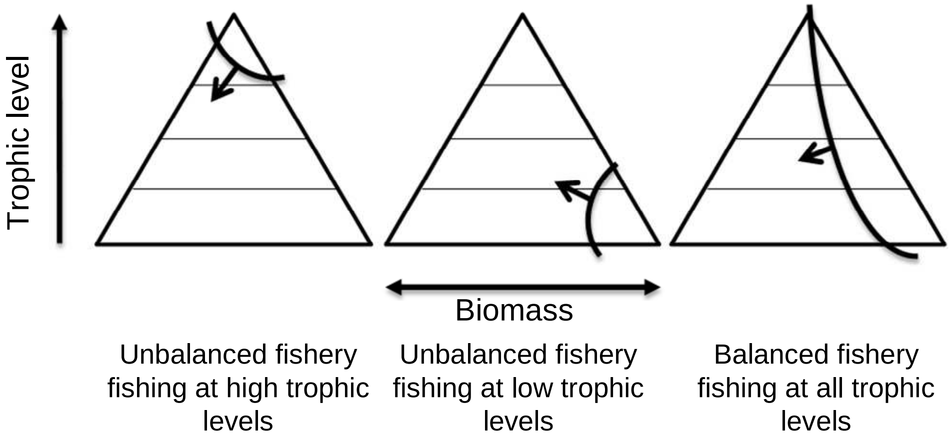


Figure 12. How a fishery intervenes on a community. Lindeman thropic pyramids with fish predators at the top and phytoplankon and detritus eaters at the bottom. The width of the triangle represents relative biomass. Black curves represent selective exploitation patterns, arrows the direction of increased fishing pressure (Adapted from Jul-Larsen et al 2003).

In other words, the multi-gear (overall nearly unselective) fishing pattern employed in many small-scale fisheries, combined with the ability of fishermen to adapt to abundance changes and change their target species even within a single trip (Misund et al. 2002, Jul-Larsen et al. 2003, van Zwieten et al. in press), is the closest example of the optimal exploitation pattern that exists. Thus, the conceived negative image of “indiscriminate fishing methods” or “fishing down the food webs” is actually not (always) ecologically evil but often represents a fishing pattern where the fishery exploits all trophic levels in proportion to the natural production. A non-selective harvesting pattern is not only optimal, but also in principle ecosystem conserving. While everything is less abundant, the relative fish community structure remains largely unchanged (Fig. 12).

### *The optimum fishing pressure?*

The primordial notion of unmanaged fisheries is that they will result in tragedies, poverty and destroyed ecosystems, if not from destructive gears, then at least from too many people (Cunningham et al. 2009). Many small scale fisheries, however, are often serving as a social security net for the riparian human populations (Panayotou 1982, Jul-Larsen et al. 2003, Béné 2004) and function as a safety valve when other economic opportunities are failing. The solution in the management literature is simply to establish alternative livelihoods and income activities, but the fact remains that fishing still remains an important alternative when other livelihood strategies fail. While economic theory is the primary justification for closing open access at the local scale, no economic analyses, with the exception of a rough calculation in Béné et al. (2010) has ever examined the costs of closing the natural social safety nets at national, regional or even global scales. The past 15 years has seen a strong push for introducing co-management and user rights in small scale fisheries, under the default, albeit largely undocumented, assumption of ‘tragedy’ scenarios. Often, however, an ‘instrumental approach’ (Nielsen et al. 2004) to co-management is adopted through a simple shift in ‘responsibility’ of management from the state to the users but with no changes in existing regulations. This new management paradigm based on rather fuzzy user rights is mainly voiced by social scientists (e.g. Normann et al. 1997, Geheb and Sarch 2002, Wilson et al. 2003), and its wide promotion poses a strange paradox as their disciplines were the first to challenge the presumption behind CPT and TOC. It appears that the criticism is limited to the *social* assumptions of the CPT theory, while the social scientists have acutely ignored, or failed to understand, the problematic underlying *biological* assumptions of internal equilibrium and steady state, which is actually a prerequisite for seeing effects from effort control. The question is if effort is controlling productivity or whether productivity is controlling effort?

### *Lake level changes and their relation with natural productivity*

The fluctuating externally climate controlled hydrological regime is very important in stimulating fish production in tropical lakes and reservoirs (Kolding and van Zwieten 2006). When lake level rises terrestrial vegetation is submerged and nutrients leaching from decomposing organic matter (dung, terrestrial grass, shrubs and trees) and nutrients from outside brought by rivers or rain, result in increased plankton and fish production. These effects result in better spawning conditions and excellent conditions for growth and survival of juveniles of fish species. For most tropical freshwater fish the dominant breeding peak coincides with the local rains, monsoons, or floods. African fishers are well aware of the close relationship between rain and fish, and "Fish come with the rain" is a common expression. While this relationship has long been recognised in river and floodplain fisheries (Welcomme 1976) its validity for also lakes and reservoirs is more recent (Kolding 1992, Karenge and Kolding 1995, Jul-Larsen et al. 2003, Kolding and van Zwieten 2006).

Thus, by examining different scales of hydrological variability, we can make a general classification of lakes in terms of the externally controlled system stability and productivity. As fluctuating environments are dominated by short-lived species and shorter food chains there is a general positive relationship between the degree of environmental fluctuations, and the productivity level. This general relationship can be used to compare different African lakes, which can be grouped according to a fluctuation, or productivity pulse, index (Jul-Larsen et al. 2003, Kolding and van Zwieten 2006) called the Relative Lake Level Fluctuation (RLLF) index. Standardized catch (annual yield per $km^2$) as well as the standardized effort (number of fishers per $km^2$) appears to increase significantly the more pulsed a systems is (higher seasonal RLLF) (Jul-Larsen et al. 2003). Interestingly, the standardized catch rates (ton/fisher/year) have no correlation with RLLF. This strongly indicates that effort to a large degree may be self-regulating in open access African inland fisheries by the productivity (yield) instead of vice versa as usually assumed.

In addition, in the range of *de facto* open access African freshwater fisheries, each fisher catches on average 3 ton/yr (range 1-5 ton/yr) irrespective of the system where he fishes, indicating a linear relationship between ‘production’ and ‘effort’ (Fig 13). The most fluctuating, and thereby resilient and productive systems in African inland fisheries are also the most intensely exploited, while the stable, species rich, and therefore most vulnerable systems are also the relatively least exploited. For Lake Victoria, where fish production has increased due to increased eutrophication (Kolding et al. 2008), the effort has increased accordingly. Lake Kainji, on the other hand – one of the most productive lakes in Africa - has since 1996 experienced a 60% reduction in effort due to imposed ‘co-management’ regulations in the form of effectively banning beach seines, small mesh sizes, and mandatory licensing (Abiodun 2003, Alamu et al. 2003). The only visible result (Fig 13), is a corresponding 60% decrease in yield and no positive response in the individual catch rates as the models assume. In this case the donor driven ‘management project’ has only turned a high biologically productive into a less productive system while generating an exodus of mainly non-gear owning fishermen (assistants, crew) who based their livelihood on this fishery. On closer examination none of these systems have showed any signs of biological overexploitation (Jul-Larsen et al. 2003, Van Zwieten et al. *in press*) and for many – except Kainji - the exoduses from the fishery may be as prevalent as the entry, thus confirming their role as temporary stations to earn a living (Jul-Larsen et al. 2003). These rather surprising results do not conform to the ruling idea of open access fisheries as victims to the ‘tragedy’ scenario. On the contrary, the results strongly suggests that the overall fishing effort (density of fishers) exerted on these systems is limited by the productivity of the ecosystem through individual catch rates, rather than following the “Tragedy” assumption where productivity would be degraded by an unlimited growing effort. In other words, the open access, low technology African inland fisheries appear to behave like a predator-prey system which fluctuates, but where the predators are ultimately limited by the productivity and abundance of prey.

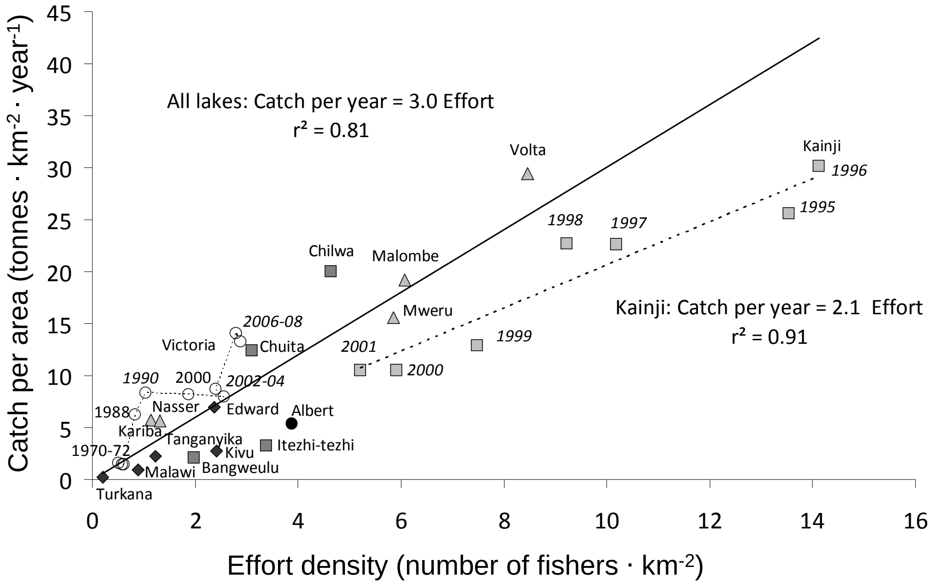


Figure13. Catch rates plotted versus effort density in 18 African lakes, of which 16 with data from the period 1989-92 (excluding Lake Victoria and Kainji) are used for the "All lakes" regression (solid line). The regression shows an average yield of about 3 tons per fisher per year irrespective of water body and country. The symbols show diamonds = low, triangles = intermediate and squares = high Relative Lake Level Fluctuation (RLLF). Superimposed (dashed line, open circles) is the development in Lake Victoria between 1970 and 2008 that shows how productivity has increased over time concurrently with the increase in effort and eutrophication. Three periods can be distinguished: after an initial boom in production in the late 1980's and early 1990s following the start of the Nile perch fishery the catch rates approached the overall mean. Since 2004 the catch of the Lake became dominated by Dagaa (*Rastrineobola argentea*). Naturally productive Lake Kainji (dotted regression line on light garys squares) shows an opposite downward trend between 1995 to 2001, where effort reductions since 1996 following donor driven management actions has resulted in a much reduced yield, but unchanged average catch rates of 2.15 tonnes per fisher per year. Fishers are all people actually involved in catching fish (i.e. gear and boat owners and crew). Updated after Kolding and van Zwieten (2006) and Kolding et al. (2008).

This situation is not unique to African inland fisheries. Myers (2001) showed that the individual catch per man in the Newfoundland inshore cod fishery appears to have been constant around 10 tonnes per year over the past four centuries. Furthermore, in accordance with the self-regulating principle, when the catch rate was above this level, the fisher populations in the settlements increased, while when it was below this level fisher populations decreased. Myers concluded the results from the Newfoundland fishing settlements as consistent with the behaviour predicted by Gordon's (1954) bio-economic model.

## Conclusions

We also believe that Gordon's model on common property has its merits, but with an essential qualifier. Effort in an open access fishery without subsidies will tend to fluctuate according to the catch rates (productivity of the system), and these catch rates will represent the average minimum economic profit that a fishermen can accept. This will not necessarily be unprofitable or lead to a situation where fishers will be locked in poverty, as Gordon assumed. Thus fishers are not inherently poor in an open access system, even if their density is too a large extent determined by the catch rates. Fishing has always been a dangerous and risky occupation, and the fishing settlements of Newfoundland would not have persisted over centuries, if the 10 tonnes per man per year had not been profitable and acceptable. The African fishers appear to accept a lower level around 3 tonnes per man per year, but they are also not always poor (Béné et al. 2006, 2009). If the acceptance level for staying becomes so low that there really is no economic profit left, then the ambient socio-economic conditions will most likely be so detrimental that exclusion and effort control would be hard to justify on simply humanitarian grounds. The Malthusian poverty trap then is probably more often a consequence of institutional failures or economic marginalization than a result of resource degradation (Béné et al. 2010).

Furthermore, there is no direct inevitable link between Gordon's prediction (poverty) and Hardin's prediction (tragedy). The level of acceptable catch rates alone will tell nothing about the actual state of the resource. It is unfortunately a common misunderstanding among resource managers that a decrease in catch rates is a sign of overfishing – but seen in isolation it is only a sign of fishing. In steady state systems, catch rates will start decreasing from the very first fisher that enters the system and continue to decrease gradually with increased effort, also in multispecies fisheries (Worm et al. 2009). Biological overfishing will first occur when total catches (not individual) start to decrease (Fig. 8), but that point is not easily determined (Hilborn and Walters 1992) and will change according to changes in productivity. Thus individual catch rates, i.e. the fisher's revenue, may be low, high or alternating without the overall productivity having reached its maximum, but this cannot be judged based on catch rates alone. The inshore Newfoundland cod fishery was, although fluctuating, sustainable for four centuries, and it is still debated whether the notorious collapse, despite high catch rates to the end, was mainly due to the massive overfishing of the offshore industrial trawl fleet, species interactions, poor science or climatic changes. And it is even less understood why the northern cod stocks have not yet recovered despite two decades of moratorium (Rose 2007).

The global discourse on fisheries management was developed within the modern rationality of industrialised societies based on abstract bio-economic models with strong underlying assumptions of constant environments and top-down control (Nielsen et al. 2004) in an attempt to answer the biological questions on how much catch and how to catch it. The first question has almost unanimously been combined with the economic assumption that open access would lead to poverty and destruction –or at least would be vastly inefficient - under the premise that the state of the resources was controlled by effort instead of vice versa. Consequently, this has lead to a universal paradigmatic belief that effort control is indispensable whether by enforcement (state control and policing) or user-rights (various derivatives of co-management). The alternative option that a dynamic balance may be reached between productivity of the resources and the individual gain, by a bottom-up control of the harvesting rate, appears almost inconceivable although there is empirical evidence around from small-scale fisheries. The other question, how to harvest (selectivity), has apparently been dominated more by economic and normative considerations, than on a full understanding of the life history of fish (Fig. 1). A pig farmer would slaughter his sow and let the piglets grow up; while an apple farmer would harvest the fruits, but never cut down the tree. We inherently treat – and model - fish like livestock, although the biggest obstacle in fisheries science has been the consistent lack of relationship between adults and recruitment, strongly indicating that the life history of fish is closer to insects and plants. Our common fear of unselective harvesting is based on a synthetic mathematical model without empirical evidence of populations behaving accordingly. On the contrary, there is increasing evidence that only show negative ecological effects of adult size selectivity. Lastly, our theoretical models are still single species considerations as we have not yet developed a uniform theory on how to harvest a multi-species community without causing structural changes (Larkin 1996). Everything else being equal, however, we can safely deduce that the less we select on species and sizes, the more the original composition and structure of a fish community will remain the same.

Thus modern rational fisheries management perhaps is not so rational as we wish to believe when compared with the ‘unregulated’ open access small scale fisheries that are inherently controlled by the shifting productivity and changing constellation of the ecosystems they live off, and that have developed an overall unselective harvesting pattern to cull all components of this unpredictable mosaic. Although this ‘indiscriminate’ feature is exactly what has earned them an overall negative reputation, it appears that it is much closer to sound ecological principles, and conserve the structure of the ecosystem (Figs. 10 and 11). Lastly, we question the rationale for systematically and effectively excluding open access to small scale fisheries, the last remaining common property resource, and thereby often the last remaining option when other income generating activities fail. Many African inland waters fisheries function as a social security institution and restricting access, even under co-management, will create inequity and social injustice. When right-based principles are invoked, the question always is who shall be given rights and who shall be excluded? Furthermore, the investment opportunities for obtaining highly efficient destructive fishing technologies in open access artisanal fisheries is mostly so low that the sustainability of the resource is generally not threatened. In other words, when effort and development is more demographic than technological (Jul-Larsen et al. 2003) then efficiency in catch rates will remain too low to effectively destroy the resources. In contrast, the continued effort reduction and synchronous increased efficiency in industrialised fisheries over the past 50 years has generally not lead to better stock status or more catch from particular ecosystems, only less fishermen (Hersoug 2007). Fish are generally much more resilient than mammals, and by uncritically promoting and implementing mesh size, gear and effort regulations in small scale fisheries management we may create more transmitted tragedies than those we try to prevent.

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