

Impact of Fishing on the Abundance of Marine Species

Rainer Froese and Kathleen Kesner-Reyes

The Census of Marine Life program aims to document the existence, distribution and abundance of marine organisms using all suitable data sources. In this study we analysed time series of catch data published by ICES and FAO in respect to trends in the resilience of species towards fishing. For this purpose we classified the fishing status of over 900 exploited species into undeveloped, developing, fully exploited, overfished, and collapsed or closed, where the sequence of the last three stages usually corresponds to a decline in species abundance. In world fisheries the percentage of species being overfished within 10 years after start of full exploitation increased from 26% in the 1950ies to 35% in the 1980ies. In 1999 the status of 50% of the exploited species was overfished, collapsed or closed. The number of species with low or very low resilience to fishing has been increasing from 80 (26%) in 1950 to 155 (32%) in 1999. Of 24 species reaching full exploitation in 1998 or 1999 for the first time, 8 had low and 8 had very low resilience to fishing. Of 25 species that had sustained 30 or more years of full exploitation before 1989, 11 species reached overfished or collapsed status thereafter. An analysis of length-frequency studies of commercial landings showed that in most cases mean length was below length at first maturity. In the ICES area 46% of the species were overfished within 10 years after start of full exploitation and in 1999 the status of 60% of the species were overfished, collapsed or closed. We suggest an alternative management regime that would allow fish to spawn at least once before being caught. A census of marine life conducted in an exploited area will still largely be able to detect the evolutionary species composition, but will not be able to determine the evolutionary relative abundance of species and their respective roles in the ecosystem.

Keywords: overfishing, species abundance, resilience, census of marine life

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Introduction

It is well established that most capture fisheries extract more from the oceans than can be replaced by reproduction and growth of the exploited species (e.g., Grainger 1999, Pauly et al. 1998, Watson and Pauly 2001). This process is called overfishing and has been identified as the first human disturbance in a chronological sequence that typically includes pollution, eutrophication, physical destruction of habitats, outbreak of diseases, and introduction of invasive species (Jackson et al. 2001). Overfishing can lead to undesirable ecosystem shifts that are hard to reverse (Pitcher 2001). And overfishing usually results in catches well below those that could be derived from proper fisheries management (Grainger 1999). Most fisheries go through the following sequence of development stages: undeveloped, developing, fully exploited, overfished, and collapsed or closed. The Food and Agriculture Organization of the United Nations (FAO) published global fisheries statistics since 1950, documenting the landings of over 1000 aquatic species or aggregates of species as reported to them by member countries. Similarly, the International Council for the Exploration of the Seas (ICES) published landings for the Northeast Atlantic since 1973. Here we used these data to explore the dynamics of global and regional overfishing and we discuss the implications of fisheries for a 'Census of Marine Life' (Malakoff 2000).

Material and Methods

We used the FAO Fisheries Production time series 1950-1999 (available from www.fao.org/fi/statist) and focused on marine fisheries (ISSCAAP groups >23 and FAO Areas > 9), and excluded shells, plants, and sponges (ISSCAAP groups >=81) as well as non-cephalopod molluscs (ISSCAAP groups 52-56), because these are often reported from mariculture. That left 932 species items, which for the purpose of this study we considered to be global fisheries, and for which we calculated the total production per year. We then arbitrarily classified the status of these fisheries in any given year into one of the above mentioned development stages using the criteria given in Table 1.

Table 1. Criteria used to assign development stages to fisheries in FAO production data time series.

| Status of fishery | Criterion applied |
|-------------------|---|
| Undeveloped | Year before maximum production and production less than 10% of maximum value. |
| Developing | Year before maximum production and production 10-50% of maximum value. |
| Fully exploited | Production larger than 50% of maximum value. |
| Overfished | Year after maximum production and production 10-50% of maximum value. |
| Collapsed/Closed | Year after maximum production and production less than 10% of maximum value. |

We excluded the first (1950) and last (1999) year from the resulting graph (Fig. 1), because the 'after maximum year' and 'before maximum year' criteria, respectively, as specified in Table 1, could not be applied to them.

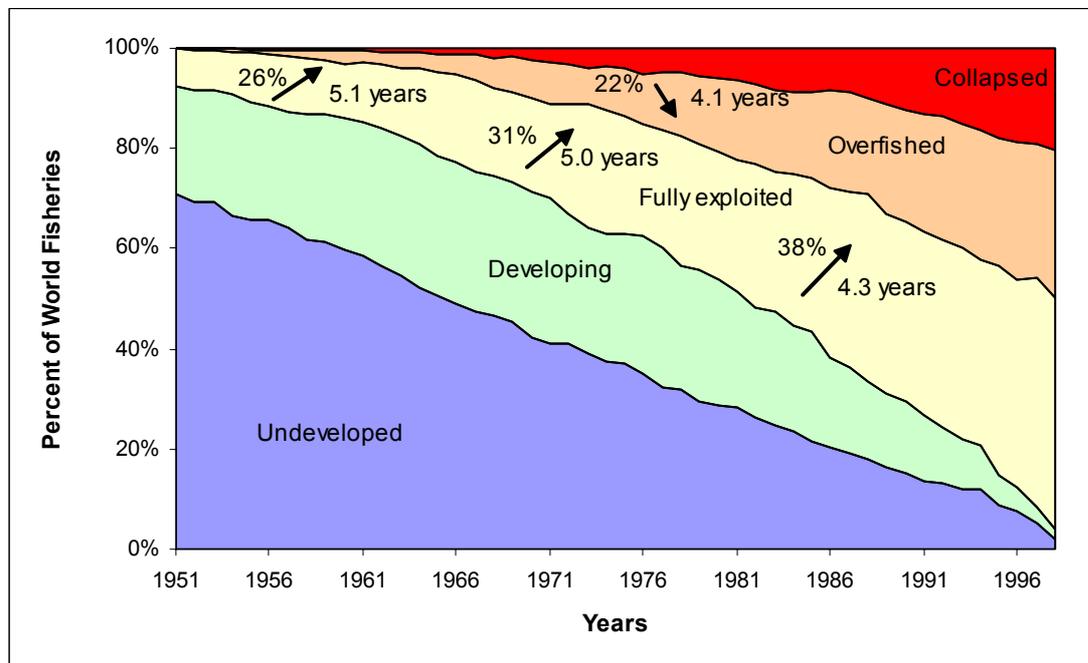


Figure 1. Trends in world fisheries as reflected in FAO Production Data 1950-1999. See text for explanation of methods used.

We used a similar approach for the ICES 1973-1999 catch data for the North East Atlantic (available from www.ices.dk), where we accepted all 362 species items and considered them as North East Atlantic fisheries, for the purpose of this study (see Fig. 2).

Results and Discussion

The resulting graphs show how global fisheries (Fig. 1) have passed through these development stages, with management apparently unable to maintain them at the 'Fully exploited' level, resulting in about half of the fisheries being overfished or collapsed, with respective losses to the global economy and to the livelihoods of millions of people depending on fisheries. Grainger (1999) estimated the global loss due to overfishing at US\$ 8-16 billion per year. The increase in overfished and collapsed fisheries is accelerating thus demonstrating the continuing or even increasing inability of existing approaches and institutions to manage fisheries. This is especially visible in the North East Atlantic (Fig. 2), which shows the same overall trends as Fig. 1, despite the fact that this is the best researched area in the world, with well equipped research institutions and fisheries departments, a well-respected advisory body (ICES), and a powerful coordinating institution (Fisheries Directorate General of the

European Commission), which is tasked to "implement [fisheries] management policy and monitor compliance" (taken from their web site, November 2001). Fig. 2 thus confirms the "consensus on the institutional origin of the failure [of fisheries management], with all other factors, including scientific uncertainty, being secondary" (Grainger 1999).

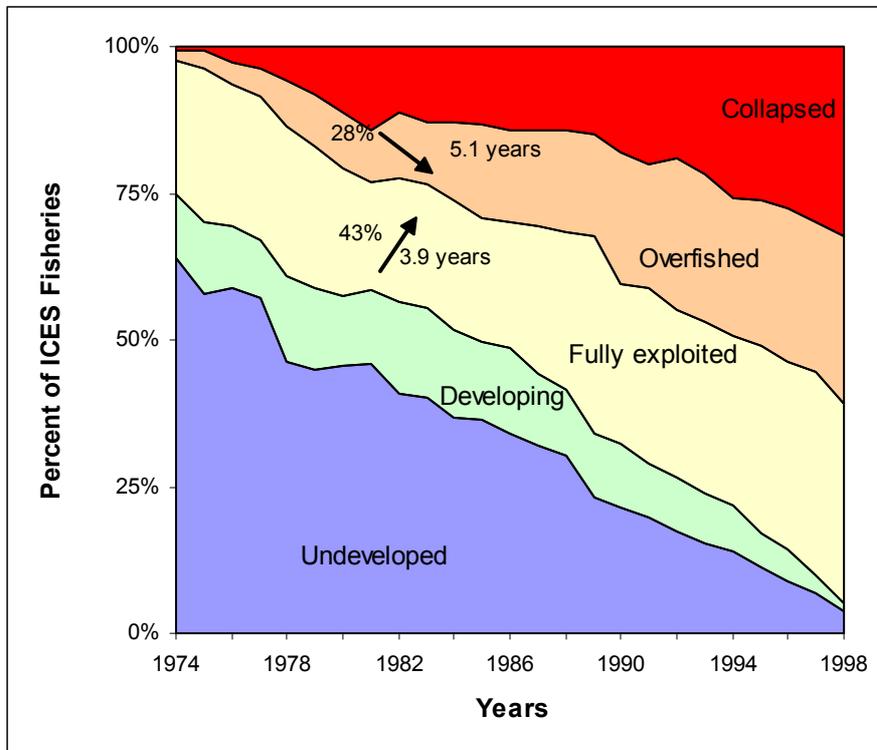


Figure 2. Trends in fisheries in the Northeast Atlantic, derived from ICES Catch data 1973-1999. 46% of the species items were overfished within less than 10 years, with an average duration of 3.9 (s.e. +/- 0.37) years. Only 28% of species items that had collapsed during this period recovered in less than 10 years, with an average duration of 5.1 years. See text for explanation of methods used.

Dynamics of Overfishing

We took a closer look at the accelerating increase in overexploited and collapsed fisheries, suspecting that this was caused by a shortening of the cycle from 'Fully exploited' to 'Overfished'. To test this hypothesis we counted for every year the fisheries that reached the 'Fully exploited' status for the first time, and determined the percentage of these that reached the 'Overexploited' status in less than ten years thereafter, which from 1951 - 1988 was 32 %. As Fig. 3 shows there was an increase in this figure from about 26 % in the 1950ies to 38 % in the 1980ies. The average time within the 'less than 10 years' group to pass from 'fully exploited' to 'overexploited' was 4.8 (s.e. +/- 0.19) years, with a decrease from 5.1 (s.e. +/- 0.41) years in the 1950ies to 4.3 (s.e. +/- 0.31) years in the 1980ies. In the northeast Atlantic, from 1974 to 1988, 46% of the species items were overfished within less than 10 years, with an average time of 3.9 (s.e. +/- 0.37) years.

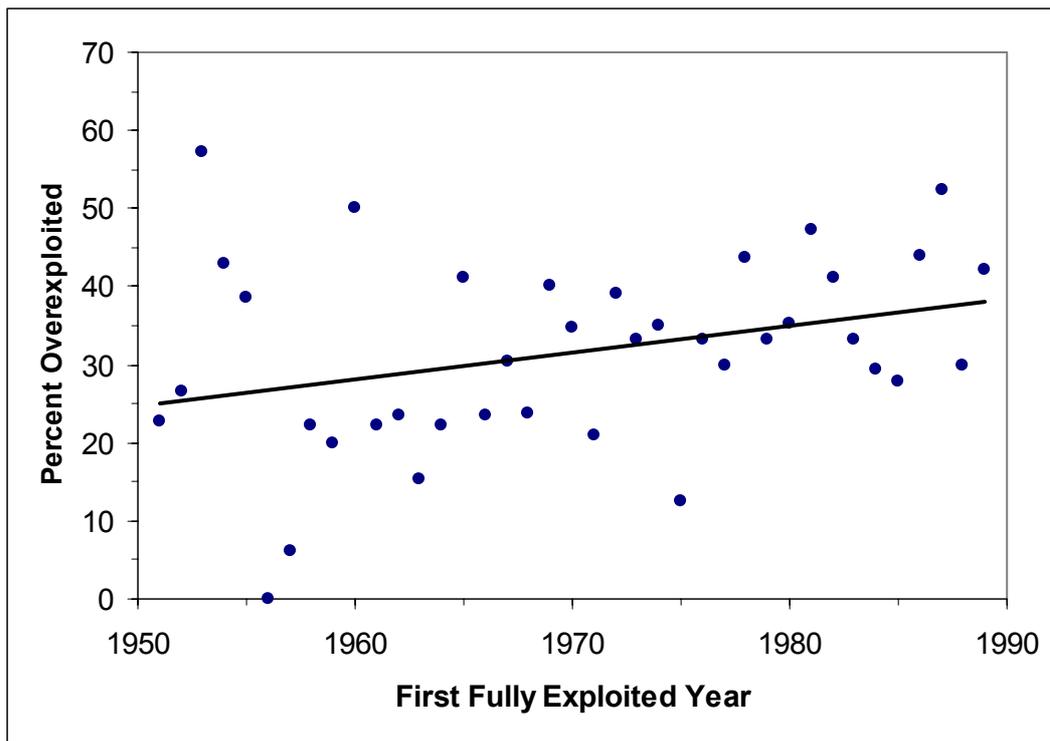


Figure 3. Percentage of species items in FAO production data that were overfished within 10 years after the fishery was first fully exploited.

Resilience

We suspected that the accelerating pace of overfishing visible in the world catch was due to increased targeting of species with low resilience to fishing, such as sharks and deep-water species. We therefore had a closer look at changes in species composition (Table 2): of the species items that reached the 'fully exploited' status between 1951 and 1960 only 4 (2%) were from deep sea and 5 (3%) from reef-associated habitats. In 1979-1988, contributions from these generally more vulnerable groups had grown more than 5-fold in numbers and doubled in percentage of species items.

Table 2. Species composition by preferred habitat from FAO production data in the 1950ies and 1980ies, considering only species items that reached at least one year of 'fully exploited' status during these periods.

| Preferred Habitat | 1951-1960 | 1979 -1988 |
|--------------------------|------------------|-------------------|
| Demersal | 73 (44%) | 195 (36%) |
| Pelagic | 34 (20%) | 112 (20%) |
| Reef-associated | 5 (3%) | 26 (5%) |
| Deep Sea | 4 (2%) | 27 (5%) |
| Mixed habitats | 52 (31%) | 190 (35%) |

Of the 144 items that were reported at the species level and were 'fully exploited' in 1951-1960 (as opposed to aggregated groups reported at generic and higher taxon levels, which may change in composition over time) only 87 (60%) reached at least one year of full exploitation in 1979-1988, suggesting that the remaining 40% had been overfished and not fully recovered 30 years later.

We examined the resilience of fish species that reached the 'fully exploited' status for the first time in 1998 or 1999, following an approach suggested by Musick (1999) and life-history data from FishBase (Froese and Pauly 2000). Of these 24 new species (Table 3), 3 had high, 5 medium, 8 low, and 8 very low productivity and thus resilience to fishing. The group contained seven sharks and one ray. Five species were from deep-water and three from reef-associated habitats. It is probably a fair assumption that these 'new resources' will be even faster overfished than their many predecessors. Another way of looking at these new resources suggests that one third (very low resilience / productivity) should not be fished at all, and another third (low productivity) can probably not be fished economically on a sustainable basis. Most of the remaining species (medium productivity) would require strict and intelligent management to support a profitable fishery of any scale. Of the three species with high productivity, the Broad-striped anchovy has already been minor commercial as bait fish, the Tiger-toothed croaker was already a commercial species but probably reported previously as part of an aggregated group, and the South American pilchard is also not a new resource but now reported under the new scientific name *Sardinops neopilchardus* (previously included in *S. sagax*). Thus, it seems that continuously switching from overfished to new resources, which characterized the fisheries of the 20th century, is not an option for the 21st century due to lack of suitable resources. The only option to maintain and eventually increase yields will be the restoration and sustainable use of suitable stocks with high productivity, a conclusion also reached by the recent Earth Summit in Johannesburg, August/September 2002.

To understand how long-term sustainable fisheries were performing in recent years, we counted for every fishery the 'fully exploited' years between 1951 and 1988, and compared them with the performance during 1989-1998. Of the 25 fisheries that had 30 or more years of status 'fully exploited' before 1989, 8 were partly (1-9 years) and 2 were fully (10 years) overfished thereafter, and one fishery had collapsed, suggesting that--despite various programs to retire fishing vessels--fishing effort has increased in recent years.

Table 3. Fish species reaching 'fully exploited' status in FAO production statistics in 1998-1999. The Remarks column indicates life history parameters used to derive status of resilience to fishing pressure, where K is the von Bertalanffy growth coefficient, tmax is maximum age in years, and tm is age at first maturity in years.

| Species | Name | Habitat | Resilience | Remark |
|-------------------------------------|---------------------------|-----------------|------------|--|
| <i>Otolithes ruber</i> | Tiger-toothed croaker | Benthopelagic | High | Fast growth, early maturity. |
| <i>Anchoa hepsetus</i> | Broad-striped anchovy | Pelagic | High | Fast growth, high fecundity. |
| <i>Sardinops neopilchardus</i> | South American pilchard | Pelagic | High | Fast growth, high fecundity, early maturation. |
| <i>Lithognathus mormyrus</i> | Striped seabream | Benthopelagic | Medium | K = 0.2, tm = 2. |
| <i>Microgadus proximus</i> | Pacific tomcod | Demersal | Medium | tm = 2, tmax > 4. |
| <i>Paralichthys californicus</i> | California flounder | Demersal | Medium | tmax = 6. |
| <i>Urophycis brasiliensis</i> | Brazilian codling | Demersal | Medium | Little studied; resilience assumed same as of congener (<i>U. chuss</i>) of similar size. |
| <i>Caranx ruber</i> | Bar jack | Reef-associated | Medium | tm = 3. |
| <i>Lampris guttatus</i> | Opah | Deep-water | Low | Little studied; max length 200 cm; life span probably beyond 11 years. |
| <i>Lepidocybium flavobrunneum</i> | Escolar | Deep-water | Low | Little studied; max length 200 cm; life span probably beyond 11 years. |
| <i>Glyptocephalus zachirus</i> | Rex sole | Demersal | Low | tmax = 17 |
| <i>Paristiopterus labiosus</i> | Giant boarfish | Demersal | Low | Little studied; max length 100 cm, life span probably beyond 11 years. |
| <i>Pseudotolithus brachygnathus</i> | Law croaker | Demersal | Low | Synonym of <i>P. senegallus</i> . Little studied; max length 230 cm, life span probably beyond 11 years. |
| <i>Dissostichus mawsoni</i> | Antarctic toothfish | Pelagic | Low | tmax >=11. |
| <i>Labrus bergylta</i> | Ballan wrasse | Reef-associated | Low | K=0.11, tm=6, tmax=26 |
| <i>Semicossyphus pulcher</i> | California sheephead | Reef-associated | Low | Little studied; changes sex from female to male; longevity reported at 50 years, suggesting slow growth and late maturation. |
| <i>Centroscymnus crepidater</i> | Longnose velvet dogfish | Deep-water | Very low | Shark, low fecundity (4-8 young). |
| <i>Deania calcea</i> | Birdbeak dogfish | Deep-water | Very low | Shark, low fecundity (6-12 eggs in uterus) |
| <i>Raja georgiana</i> | Antarctic starry skate | Deep-water | Very low | Ray, little studied, probably slow growth and low fecundity. |
| <i>Mustelus henlei</i> | Brown smooth-hound | Demersal | Very low | Shark, low fecundity, 3-5 young per litter. |
| <i>Notorynchus cepedianus</i> | Broadnose sevengill shark | Demersal | Very low | Shark; maturity 11 - 21 years. |
| <i>Alopias superciliosus</i> | Bigeye thresher | Pelagic | Very low | Shark, usually 2 young per litter only. |
| <i>Alopias vulpinus</i> | Thintail thresher | Pelagic | Very low | Shark, usually 2 young per litter only. |
| <i>Carcharhinus brachyurus</i> | Copper shark | Pelagic | Very low | Shark, K = 0.04, maturity 13 years. |

Dynamics of Recovery

We examined the success of management in restoring collapsed fisheries. Of the 690 fisheries in the FAO production data that had reached full exploitation during 1951 and 1988, 152 (22%) collapsed within this period. Of these, only 33 (22%) recovered to at least one year of 'fully exploited' status in less than 10 years after their first collapse, with an average recovery

time of 4.1 (s.e. +/- 0.47) years. Of the 232 fisheries in the ICES catch data for the Northeast Atlantic that had reached full exploitation between 1974 and 1988, 83 (36%) collapsed within this period. Of these, 23 (28%) recovered in less than 10 years, with an average recovery time of 5.1 (s.e. +/- 0.58) years.

Grainger and Garcia (1996) used a similar approach in analysing FAO production data and found similar trends as in Figures 1) and 2), i.e., a transition from mainly 'undeveloped' to mainly 'mature' and 'senescent' fisheries, where their 'mature' is similar to our 'fully exploited', and 'senescent' similar to our 'overfished' and 'collapsed' state. However, because of their restriction to the 200 top marine resources, their analysis does not reveal the dynamics of overfishing shown here.

Alternative Management Regimes

The main cause of overfishing is excessive fishing effort, expressed not only in boats, horsepower, or hours spent fishing, but also in advanced technology such as highly sophisticated tools to find and catch fish. Controlling fishing effort is difficult and is the very area where fisheries management continues to fail. This can be blamed in part on management regimes that are neither understandable nor observable by fishers and the public. However, overfishing can also be seen on the fish themselves. As has already been pointed out by the founders of modern fisheries science (Beverton and Holt 1957), fishing reduces the average size in the catch. We used length- frequency data in FishBase (Froese and Pauly, 2000) to demonstrate this effect. For 697 length-frequency studies on species classified in FishBase as "commercial" or "highly commercial" we calculated length at first maturity (L_m) as a function of maximum length, based on empirical equations in Froese and Binohlan (2000). We also calculated the mean length (L_{mean}) of the specimens used in the length frequency studies. We then plotted the L_{mean}/L_m ratio over the years when the studies were made. As can be seen in Fig. 4, the majority of studies shows mean size well below the size at first maturity. Although we expected the L_{mean}/L_m ratio to decline over time we could not show such trend with the data at hand.

Holt (cited in Beverton 1992a) pointed out that the maximum possible yield that can be obtained from a given year class is correlated with a certain length (L_{opt}) of the fish, which can be easily obtained from growth parameters or from an empirical relationship (Froese & Binohlan 2000). L_{opt} is typically slightly larger than the length at which fish spawn for the

first time in their life. Thus, by restricting catches to fishes with a length above L_m one not only gets the maximum possible yield from a given stock, but also increases the spawning stock biomass, because every fish caught had a chance to reproduce. Also, fishes escaping capture at that size would not be targeted anymore. Such large fish have high fecundities and provide an additional safeguard against occasional recruitment failures caused by, e.g., environmental conditions. Thus, we propose the mean length (L_{mean}) in commercial landings in relation to the length at first maturity (L_m) as indicator (L_{mean}/L_m) for sustainable management, with values at and above 1.0 indicating sustainable fisheries.

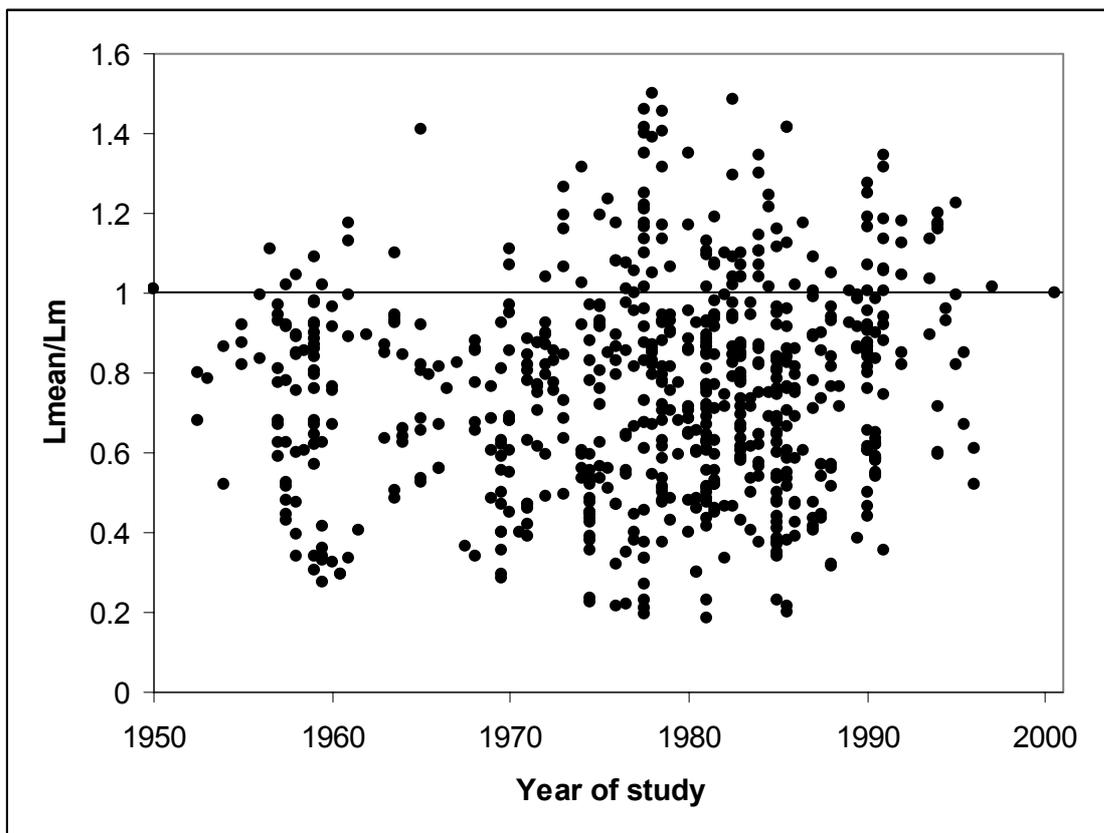


Figure 4. Ratio of mean length to length at first maturity for 697 length-frequency studies. Note that L_{mean}/L_m values below 1 indicate that the majority of fish in the sample had no chance to spawn before being caught.

We realize that at low fishing efforts the size of the landed fish is not a matter of concern. However, in heavily exploited stocks the notion of 'size does not matter because there is no relationship between recruitment and spawning stock' is obsolete, as there is now a consensus that there is increased probability of low recruitment at low spawning stock biomass (Dengbol 2001, Myers and Barrowman 1996). In well-managed stocks it will be possible to restrict landings to specimens that are larger than L_m and by doing so obtain maximum yields, increase spawning stocks, and reduce recruitment variability. The authors would be delighted to participate in projects trying to implement such management regime.

Sustainability Indicators

Dengbol (2001) lists the following desirable properties for sustainability indicators:

Observable

- within economic resources for research on a sustained basis
- by stake holders, either directly or by transparency in the observation process

Understandable

- they should have research-based substance, reflect analytical soundness
- they should reflect features in accordance with stakeholders' understanding of the resource system

Acceptable

- by fishers
- by the public at large

Related to management

- they should indicate a direction of action - qualitatively or through associated reference points
- they should respond to management measures

Rating our Lmean/Lm indicator against these properties results in the following:

Observable: Length at first maturity is known for most exploited fishes and can be easily observed by researchers, anglers and fishers. Preliminary values can be obtained for all commercial fishes on the Internet from www.fishbase.org. Posters can be devised for major commercial species showing the actual size at maturity and allowing consumers, traders, customs, and fishers to judge whether a given specimen is a juvenile and thus should not have been caught.

Understandable: The one management measure that fishers are most willing to accept is increase in size at capture (Schnack, pers. comm., 2001), as common sense tells them that there is something wrong with targeting juveniles in a stock that is quickly decreasing. Most consumers are not aware that they are buying juveniles. A simple experiment in a fish market in the Philippines showed that consumers were embarrassed when they realized--through a poster as described above--that the fish they had just bought had had no chance to reproduce, the implication for future fish supply being immediately clear to them. The scientific soundness of this approach has already been pointed out by the fathers of fisheries science (Beverton & Holt 1957).

Acceptable: We believe that this approach will be acceptable to fishers, because it is observable, understandable, and easy to control and thus the likelihood of cheating by fellow-fishers--probably a major general incentive for cheating--is much reduced. The public at large can be expected to appreciate the simple concept behind this 'common sense' approach.

Related to management: The indicator suggests a clear direction of action: 1) change the fishing effort to target cohorts after the first and before the second spawning only; 2) together

with all stakeholders, agree on long-term goals and determine the percentage that shall be taken from cohorts to achieve the goals; 3) determine the actual amount to be taken in a given year through surveys shortly before or during the spawning season, assessing the strength of the cohort reaching L_m .

This proposed indicator and resulting management regime drastically changes the role of fisheries research, which is not asked anymore for sophisticated models predicting next year's catch. Some applied research will be needed to determine the best means to narrowly target only a certain size class of the various species. But mostly fisheries research would be relieved from the 'predicting recruitment' pressures and could shift focus, e.g., towards research in the context of restoring and stabilizing aquatic ecosystems.

Impact of Fishing on Census of Marine Life

International efforts have started to better understand the diversity of life in the Ocean, including a 'Census of Marine Life' (www.coml.org; Malakoff 2000). So far there is no clearly documented case of a marine species being extinct as a result of overfishing (Beverton 1992b), although there are an increasing number of 'near-extinctions' and local extirpations (Roberts et al. 1998). However, there is no doubt that fishing has considerably altered most marine ecosystems by drastically reducing the numbers of top predators, increasing the numbers of invertebrates such as jellyfish, and shifting benthic communities to species that can withstand constant ploughing by trawls (Pauly et al. 1998; Roberts et al. 1998). Thus, while a current census of marine life will still be able to approximate the evolutionary species composition of large marine ecosystems, it will not be able to determine the evolutionary relative abundance of species and their respective roles in the ecosystem.

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