Global Trends in Marine Fisheries:
Ecological and Food Security Implications .

By

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Many laypersons in Western countries believe that widespread 'pollution' endangers ocean life, perhaps a lingering impact of books such as Rachel Carson's '*The Sea Around Us*' published in 1951, and the pronouncements of Jacques Cousteau. Fisheries, on the other hand, have long been seen as benign, and their expansion is seen, strangely, as unrelated to the decline of their target species, which is usually attributed to 'environmental change' or some form of 'pollution'.

Why is it so that commercial fishing, which after all, is devoted to killing fish and removing them from their habitat so we can eat them, has so long and so widely been perceived as having little if any impact on the populations that were being fished? This is probably due to notions from another age, when fishing was indeed a matter of wrestling one's sustenance from a foreign, hostile sea, and from tiny boats, close to one's village, using gears barely capable of making a dent in the huge populations of fish known to inhabit the ocean's depths. This perception is still there, and it is time to realize how wrong it is.

One of the effects of the perception of fisheries as local folklore, featuring self-reliant fishers as steward of local resources, is that we fail to even see the giant enterprise now feeding the tightly integrated, global market that supplies the fish we order in restaurants, or purchase in supermarkets. And the problem with this is that the giant enterprise in question is having so severe an impact on its own resources base that if present trends continue, it will collapse in the next decades, and drag down with it, into oblivion, many of the fishes it exploits, along with their supporting ecosystems. This is likely to be one reason why at least one among the major fish distributors in the world, Unilever, partnered with the World Wildlife Fund, in creating the Marine Stewardship Council, designed to bring market pressure to bear on what is perceived as underperforming management regimes.

Unsustainable fisheries have been with us for a long time. The earliest fishing implements so far identified are sophisticated bone harpoons, recovered from 90 000 years old middens by archeologists working a site in present day Congo (ex–Zaire). The main species that was targeted is a now extinct, 2 m long, freshwater catfish. Most probably, the fishers in question then moved on to other species. This pattern of fisheries exterminating the population upon which they originally relied, and then moving on to other species, has been going on ever since, with periods of 'sustainability' occurring as a result of certain species being exploited in only part of their range, due to limitation of our gear or crafts, or subsidies not yet secured.

This dynamic, obviously mimics the successive wars of exterminations humans conduced, on land, against large mammals and other animals. The best studied of these was conducted 13,000 - 12,000 years ago by 'Clovis' hunters in North America, so named after the site where their fluted arrow points were first found. Contrary to what earlier was conventional wisdom, the Clovis people were not the 'First Americans,' these probably having been coastal people, who may have relied on fishing for their subsistence. The Clovis people, on the other hand, were apparently the first to tackle the large mammals of the interior. Both archeology and model studies confirm that their decimation of 30 species of large and slow-reproducing mammals (mastodon, giant ground sloth, giant armadillo, western camels, etc.), proceeded in the form of a giant wave sweeping across North America over a period from about thousand years. Given the difficulty preliterate societies can be expected to have in conveying quantitative information on animal abundance across generations, this time span was sufficient for the Clovis hunters living past the crest of this wave to fail to realize what their ancestors had done and lost, a problem still occurring now, in form of 'shifting baselines'.

Ironically, there are those who, in spite of the evidence provided by numerous Clovis points embedded in the bones of fossil mammals, still argue that it is 'climate change' which drove these 30 species to extinction. Here, environmental changes are supposed to have eliminated, in a few centuries, species that had endured millions of years of – yes - environmental change, including glaciations that covered the northern part of North America under two kilometers of ice.

There is good evidence of a similar mammalian hecatomb 40 - 50,000 years ago in Australia, in this case associated with the very first arrival of *Homo sapiens*, who exterminated, over a short period, the larger representatives of the marsupial fauna that had evolved over millions of years on that continent.

Our last example here is the extermination of the large, ostrich-like moa in what is now New Zealand, by the ancestors of the present day Maori, who arrived from Polynesia in the late 13th Century, and who took only about 100 years to exterminate 11 species that had lived in the area for millions of years.

In the marine realm, the serial depletions of large coastal animals, accelerated with the development, during the Industrial Revolution, of vessels of unprecedented fishing power, such as stream trawlers. Added to the substantial, pre-existing fishing effort of the rowed and sailed craft that tended to operate inshore, these industrial vessels, targeting stocks of larger fishes further offshore, quickly reduced populations that had previously been perceived as immune to the effects of fishing. Denial is, however, still rampant, sometimes taking absurd forms, as illustrated here by a representative of the French fishing industry recently asserting, with regard to the demersal resources around France, that "the stocks are not declining, they are changing location".

The beginnings of change

The emergence of the United Nations' Convention on Law of the Sea (UNCLOS), in the late 1970s, which enabled countries to claim Exclusive Economic Zones reaching 200 miles into the open sea, including essentially all coastal shelves, put the responsibility for fisheries resource management squarely with maritime countries, thus ending many decades, even centuries in some cases, of fighting over traditional fishing grounds. Unfortunately, the opportunity that this implied was lost by most countries: the international race for fish that had characterized earlier fisheries development continued unabated, as governments or supranational entities - the United Nations Development Programme, the European Union (EU), or international developments banks subsidizing the growth of national fisheries, to replace the just displaced distant water fleet (DWF) of foreign countries, or via the DWF coming back through UNCLOS-sanctioned, and often bargain-priced 'fishing agreements,' as between the EU and individual West African countries.

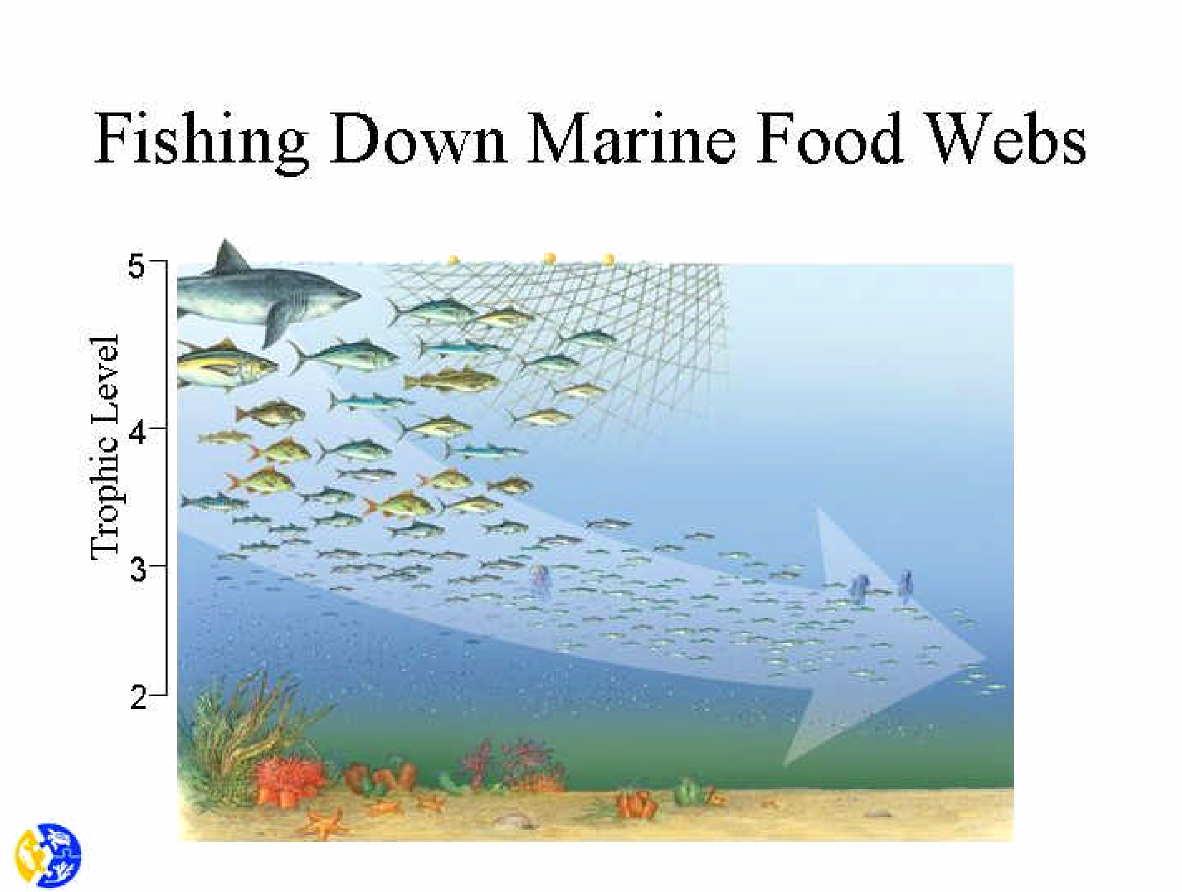
Fisheries scientists contributed to this, notably by publishing estimates of potential yields now known to have been wildly over-optimistic.

The post-UNCLOS technological and geographic expansion extended the trend of catch increase, if at a slower rate. Global catches began to decline in the late 1980s, a trend reversal due to broad-based collapse of the underlying ecosystems, long masked by systematic over-reporting by China, and the targeting of deep waters stocks. Several major studies then showed that marine fisheries impact their resources base and their supporting ecosystems far more strongly than commonly assumed, thus providing further support for our explanation of observed catch trends.

However, most government fisheries laboratories still work mainly along traditional lines, i.e., performing assessments for single-species fisheries, in view of estimating their Total Allowable Catch (TAC), while fighting off claims by conservationists asserting, with increasing public support, that these fisheries impact on numerous other ('by catch') species, and, in fact, engage in serial destructions of their supporting ecosystems.

Developing alternatives to these developments will require freeing these laboratories, and the regulatory agencies they are part of, from their subservient relationship with the fishing industry, and re-establish their role as guardian of what are, after all, publicly owned resources. Indeed, it is probably the perception of regulatory agencies as captive of the narrow interests of an extractive industry which is behind the widespread, if not well articulated public demands for some sort of 'ecosystem-based fisheries management ' (EBFM), as expressed, e.g. in the World Summit on Sustainable Development (WSSD), held in Johannesburg in 2002.

Thus, rather than railing about the imprecision of EBFM, we should treat it as a guiding principle, as is done in Canada with the concept of 'Good Government,' which underlies federal public policy, or the right to the 'Pursuit of Happiness,' which underlies much jurisdiction in the USA, or '*Liberté, Egalité, Fraternité*,' which inspire much of the public and political discourse in France. Indeed, it is our impression that broad concepts of this sort, despite their vagueness, provide one of the few avenues for framing debates about complex, value-laden issues. Moreover, a consensus could quickly emerge around the notion that EBFM should maintain, or where necessary re-establish, the structure and function of the ecosystems within which fisheries are embedded. This could involve, among other things, regulating fisheries such that the mix of species caught maintains the relative abundance of the same species in the ecosystems, just as the overall gas mileage of the cars in a country is, or can be regulated by putting a cap on the aggregate mileage of the cars sold by each manufacturer.



Fishing down marine food webs

Two measures that can be easily estimated from fisheries landings have shown themselves to be highly indicative of the status of the underlying ecosystems, and thus could be used for such monitoring: the mean trophic level (TL) of fish landed, and the mean maximum length (ML) of the species in the landings.

Eating and not being eaten is, besides reproduction, the main concern of organisms in ecosystems, and the latter can largely be described, therefore, as a meshing of food chains into complex food webs, within which an organism occupies a given position determined by its size, the anatomy of its mouth parts, and its feeding preferences (Box 1). One dimension of this position is the TL, expressing how many steps away an organism is located away from the basis of marine food webs, i.e., phytoplanktonic and benthic algae, assigned a definitional TL of 1, the same as for detritus, mainly derived from ungrazed, dead algae, and the excreta of herbivores.

Phytoplankton is grazed mostly by copepods and other small crustaceans, with a TL of 2, in stark contrast with terrestrial food chains, where the herbivores are often very large. The zooplankton, in turn is consumed mainly by small pelagic fishes (herring, sardine, anchovies), with TL of around 3, the imprecision stemming from the fact that they often consume a variable mix of phytoplankton, herbivorous and carnivorous zooplankton, and detritus. Small pelagics are caught in enormous quantities (38 million metric tons in 2000, i.e., 44 % of global marine landings), are either consumed by people (e.g. as canned 'oil sardine'), or 'reduced' to fish meal and oil, a key component of the chicken and pig feeds, and of farmed salmon. The typical table fish, however, the cod, snapper, tuna, halibut, etc., that restaurants serve whole, or as steak or fillet, are predators on the small pelagics and other smaller fishes and invertebrates, and tend to have TL of around 4, with 4.5 an upper limit reached by large sharks, bluefin tuna and other large predators such as some marine mammals. Trophic levels are variable in space and time, the latter variability referring both to seasons, and to the age (size) of fish (Box 3).

More importantly, in the sea, the high-TL organisms tend to be larger (typically 3-4 times in term of body length) than their prey, and need more time to reach maturity and reproduce, which renders them very susceptible to overfishing.

Combining all this, it can be concluded that, given the current technical ability to catch whatever marine species are abundant within an ecosystem, and the fact that large fishes are usually more valuable than smaller fishes, increased landings of fishes with lower TL imply a reduction of the abundance of the higher-TL species. Or put differently: non-sustainable fishing should manifest itself, at the ecosystem level, in a gradual shift of mean TL toward lower values, even if the individual species for which TACs exist appear to be fished sustainably.

This process, now known as 'fishing down marine food webs' (FD) was originally presented in 1998 (Box 2) based on the global database of landings created and maintained by the Food and Agriculture Organization of the United Nations (FAO), itself relying on data supplied by its member countries, some of them with only rudimentary fisheries monitoring systems. Particularly, these data tend to be over-aggregated in term of species landed (i.e., many species are lumped as 'mixed fishes'), and areas covered (e.g., fishes caught by a distant-fishing nation in the EEZs of different countries are lumped without indication as to their origins). Following comments suggesting that these defects of the FAO database may invalidate these conclusion, several replications of these findings, based on disaggregated data sets were published, establishing the validity of the FD concept, and its ubiquity.

In the process, a rule-based mapping technique was developed which allowed assigning, for the years 1950 to 2000, the FAO fisheries catches to the over 180,000 half lat./long degree cells comprising the world ocean, along with key attributes of these landings (i.e., their species composition, and hence their mean TL and their ML).

This allowed mapping the FD phenomenon, and simultaneously, eliminating the bias that was caused by fisheries statistics from small island and some other states, which combine landings of inshore reef fishes with those of adjacent large oceanic, high-TL pelagics such as tunas.

The resulting map showed how widespread the FD phenomenon. Indeed, it can be said to occur everywhere it matters, as the shelf areas where TL have strongly declined contribute a large fraction of world fisheries catches. Indeed, the rate of TL decline has mostly increased since the 1950s, with the strongest rate of decline in the 1980s. Global fisheries were operating, on the average at a TL of 3.37 in the early 1950s; now their mean TL is about 3.29, but this was as low as 3.25 in 1983. And remember: humans, so far, do not eat zooplankton (though exceptions exist: there is a market for jellyfish in Japan and other countries in North East Asia, to which some western countries have now begun to export this product).

This analysis is confirmed the mean maximum length reached by the species explicitly mentioned in global landing statistics. Here, declines of up to 1m over the 50-year period considered have occurred, mainly in the North Atlantic, but also in other areas where highly industrialized fisheries have removed most of the fish capable of reaching large sizes. This process, viewed globally, is proceeding in rather steady fashion, notwithstanding the mesh size and other single-species regulations meant to prevent the size of certain target species from falling below some critical levels (note that this does not consider the well-documented reduction in the average size within species).

In 1950, when the FAO began to assemble the global fisheries data set analyzed here, coastal fisheries had already impacted on inshore populations of fishes and invertebrates of both industrialized and non-industrialized countries. However, the serial depletion induced by the first industrial fisheries in areas such as the North Sea or New England, expanded, after the Second World War, to deeper waters, especially in the Southern Hemisphere (Box4).

Impacts on food security

The masking effect of geographic expansion would not have worked, however, were it not for a tightly integrated global market resulting from relaxation of investment regulations, opening of international banking and advances in telecommunications, capable of compensating through imports from the Southern Hemisphere for the shortfall in meeting the increasing demand for fish in the Northern Hemisphere due to increased recognition of the benefits of eating seafood and increasing affluence. In many developing countries the need to generate hard currency to pay down their debts is most easily accomplished either by either selling fishing access rights to countries willing to pay relatively high prices or by exporting high-valued fish. This has resulted in many coastal areas being overfished by DWF leaving few fish for small-scale subsistence, as seen in many developing countries. Indeed, nine of the top 40 fish exporting countries globally are considered low-income food deficit. This applies not only to demersal table fish, but also to other high-end seafood (e.g.

shrimps to Japan, USA or the EU), and to small-pelagics used fish meal, and fed to farmed animal, both terrestrial and aquatic (e.g., salmon).

The masking effect (to consumers in developed countries) of serial depletion coupled with a global market for seafood is further enhanced by fish farming, which many believe will 'relieve the pressure on overfished stocks.' Actually, it can do so only if the fish and other organisms that are farmed do not require fishmeal for their production (as is the case for clams and mussels, for the herbivorous tilapia farmed in much of tropical Asia, or for catfish in the USA). When they do, as in the case of salmon or other carnivorous fish, farming adds to the pressure, as it turns small pelagics and other fish perfectly fit for human consumption into animal feeds whose nutritive value is largely lost to humans when they must passes through the gut of a carnivore.

Some things that need to be done

Given the FD and related trends discussed here, it appears rather urgent to now implement the reforms long proposed by most fisheries scientists and economists: to radically reduce fishing capacity, notably by abolishing the government subsidies that keep otherwise unprofitable fleets afloat, and to strictly enforce various gear restrictions.

Such measures may not allow us to increase future landings, i.e., to continue to meet an ever-increasing human demand. Rather, these measures may allow us to sustain what we have, and which we are in the process of losing, thus intensifying the food security issues that reduced per capita fish supply in developing countries has begun to create.

However, we believe that these traditional measures, even if they succeed in stabilizing bulk fish supply, will not be sufficient to prevent the loss of large and hence vulnerable fish species. Given the 'shifting baseline syndrome' mentioned above, re-establishing functional ecosystems and sustainable fisheries will require us to identify firmly anchored baselines representing earlier states of the population and ecosystems in questions, and to rebuild our stocks accordingly. This makes the reconstruction and description (or simulation) of earlier states of ecosystems important and new areas of research, which will have to be multidisciplinary if they are to be successful.

As another important change, we will have to re-establish, as also demanded by the WSSD, the refugia earlier fish populations enjoyed, and which made it possible for some our fisheries to last for centuries, although they were not regulated. Some of these refugia, now called 'marine reserves,' or no-take zones, should be inshore, to protect coastal species; some will have to be large and offshore, to protect oceanic fishes. The alternative is that we lose many of the species upon which our fisheries have so far depended. No-take marine reserves will have to be perceived not as scattered and small concessions to conservationists, but as a legitimate and obvious management tool, required for preventing the entire distribution area of various exploited species from being accessible to fishing. Indeed, avoiding the extinction of species previously protected by their inaccessibility to fishing gear should become a major goal for future management regimes. This would not only enable fisheries, for the first time in their history, to become truly sustainable, and but also address the issue of uncertainty, as eloquently stated in a posthumous edition of some of Rachel Carson's re-discovered writings:

"… To convert some of the remaining wild areas into State and National parks, however, is only part of the answer. Even public parks are not what nature created over the eons of time, working with wind and wave and sand. Somewhere we should know what was nature's way; we should know that the earth would have been had not man interfered. And so, besides public parks for recreation, we should set aside some wilderness area of seashore where the relations of sea and wind and shore – of living things and their physical world – remain as they have been over the long vistas of time in which man did not exist. For there remains, in this space-age universe, the possibility that man's way is not always best."

Box 1. The Ecopath software and modeling approach

Ecopath was proposed as a software and approach for constructing ecosystem models in the early 1980s by Dr. J. J. Polovina of the US National Marine Fisheries Service, Hawaii. This was further developed and widely disseminated in the mid 1980s, by Dr. Daniel Pauly, who was assisted therein, from 1990 on, by Dr. Villy Christensen. After Drs. Daniel Pauly and Villy Christensen moved to the University of British Columbia, Dr. Carl Walters developed the Ecosim module, for time dynamic simulations; and the Ecospace module, which allowed a spatial component to be added to Ecopath.

Ecopath allows a rapid construction of ecosystem models using easily available literature and/or field data. Essentially, an ecosystem is viewed as constituted by one or two functional groups of plants and 20-50 functional groups of animals, which feed on plants and on each other. Each functional group is assigned a biomass (estimated from surveys or other field data), a diet composition and a feeding rate (estimated from empirical studies, and/or from comparative studies) and production/mortality rate (usually estimated from the age-composition of the animal in that functional group). Ecopath then establishes a balance between the groups, i.e., there must be enough food for all the consumers.

Earlier, Ecopath users laid much weight on the interpretation of ecosystem structure which the program can be used to describe in great details. Nowadays, Ecopath is mainly used as an approach to obtain the parameters for runs of Ecosim and Ecospace.

The software, now called Ecopath with Ecosim (EwE), is available online, as is the documentation of the multitude of papers that were written using this approach (see www.ecopath.org). Some contributions of Dr. Daniel Pauly on Ecopath are:

Pauly, D., V. Christensen and C. Walters. 2000. Ecopath, Ecosim and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science* 57: 697-706.

Christensen, V. and D. Pauly. 1992. The ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling* 61: 169-185.

Pauly, M.L. Soriano-Bartz and M.L.D. Palomares 1993. Improved construction, parametrization and interpretation of steady-state ecosystem models. p. 1-13. *In:* V. Christensen and D. Pauly (eds.) *Trophic models of aquatic ecosystems*. ICLARM Conference Proceedings 26.

Box 2: Fishing down marine food webs

Fishing down marine food webs' is the title of a contribution by Dr. Daniel Pauly and co-authors in *Science*, which describes the discovery that, increasingly, the fisheries of the world catch fishes with low trophic levels. (Trophic levels are the number of steps that organisms occupy above the trophic level of plants, which is set at 1. The fish we usually consume have trophic levels of 3.5-4.5 The fish that these predators consume have lower trophic levels and generally feed on herbivorous zooplankton, which have trophic levels of 2.). They interpreted this discovery as indicating a decline of large predatory fishes (with high trophic levels), and the relative increase in the ecosystems, and consequently in fisheries catches, of fishes and invertebrates with lower trophic levels.

This discovery led to a large number of follow-up studies, largely confirming the original findings, and as a result, the phrase, 'fishing down the food web,' has become a common expression in fisheries research. Some of Dr. Daniel Pauly's contributions on 'Fishing down marine food webs' are:

Pauly, D. and M.L. Palomares. 2005. Fishing down marine food webs: it is far more pervasive than we thought. *Bulletin of Marine Science* 76(2): 197-211.

Pauly, D. and R. Watson. Background and interpretation of the 'Marine Trophic Index' as a measure of biodiversity. *Philosophical Transactions of the Royal Society: Biological Sciences* 360: 415-423.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese and F.C. Torres Jr. 1998. *Fishing down marine food webs*. Science 279: 860-863.

INTERNATIONAL COSMOS PRIZE

Box 3: FishBase, the global online encyclopedia of fishes

FishBase is a huge online database on the fishes of the world (approximately 30,000 species of fish worldwide) backed up by servers in the United States, Sweden, France, Germany, Taiwan and the Philippines (see www.fishbase.org). It provides the key information from thousands of scientific papers and books on fishes, as extracted by a team of experienced encoders based in the Philippines, notably information on the food composition of thousands of fish species, from which their trophic level can be estimated. The database also includes images, identification keys, analytical tools and links to a multitude of other databases relevant to fishes. It is used by nearly one million users a month as evidenced by 'hits' averaging well above 10 million a month (see www.fishbase.org).

This database was initiated by Dr. Daniel Pauly in 1988, who hired Dr. Rainer Froese from Germany as project leader. They are coeditors of the 'FishBase book' which outlines the details of the creation of this database and the scientific background of its over 100 tables. Initially a project of the then International Centre for Living Aquatic Resources Management in Manila, Philippines (now WorldFish Centre in Penang, Malaysia), FishBase is now a joint project of eight FishBase Consortium members of which six are in Europe, one in Canada, and one in Malaysia. Some contributions of Dr. Daniel Pauly concerning FishBase are:

Froese and D. Pauly (Editors) 2000. *FishBase 2000: Concepts, Design and Data Sources.* ICLARM, Los Baños, Philippines, 346 p. [Distributed with 4 CD-ROMs; previous annual editions: 1996-1999; updates in www.fishbase.org]

Froese, R. and D. Pauly. 1994. FishBase as a tool for comparing the life history patterns of flatfish. *Netherlands Journal of Sea Research* 32(3/4): 235-239.

Pauly, D. and C. Binohlan. 1996. FishBase and AUXIMS as tools for comparing life-history patterns, growth and natural mortality of fish: applications to snapper and groupers, p. 218-243. *In:* F. Arreguín-Sánchez, J.L. Munro, M.C. Balgos and D. Pauly (eds.) *Biology, fisheries and culture of tropical groupers and snappers.* ICLARM Conference Proceedings 48.

Box 4: The *Sea Around Us* Project

The *Sea Around Us* Project is an activity of the Fisheries Centre, University of British Columbia, funded by a US foundation, the Pew Charitable Trusts of Philadelphia. The project is devoted to documenting and mitigating the impact of fisheries on marine ecosystems. The scope of the project is global and one of its key products is a large online database, accessible at www.seaaroundus.org, which documents world fisheries on a spatial basis for the Exclusive Economic Zones (EEZ) of all maritime countries and the 64 Large Marine Ecosystems (LME) defined for the world ocean.

Based on this large database, the *Sea Around Us* project has documented, to great public attention, several major features of world fisheries, notably over-reporting of marine catches by China, the historic decline of North Atlantic fish biomass, the impact of distant water fleets on west African fisheries resources, etc.

Dr. Daniel Pauly is Principal Investigator of the 10-member *Sea Around Us* Project, which he launched in 1999. Some publications emanating from the project are:

Watson, R., J. Alder, A. Kitchingman and D. Pauly. 2005. Catching some needed attention. *Marine Policy* 29(3): 281-284

Christensen, V., S. Guénette, J. J. Heymans, C.J. Walters, R. Watson, D. Zeller and D. Pauly. 2003. Hundred year decline of North Atlantic predatory fishes. *Fish and Fisheries* 4(1): 1-24.

Pauly, D. and J. Maclean. 2003. *In a Perfect Ocean: fisheries and ecosystem in the North Atlantic*. Island Press, Washington, D.C. xxx + 175 p.

Watson, R. and D. Pauly. 2001. Systematic distortions in world fisheries catch trends. *Nature* 414: 534-536.