



Food for Thought

Having to science the hell out of it[‡]

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A first-person account of the scientific career of the fishery scientist Daniel Pauly is given, starting with his studies in Germany and his work on a coastal lagoon in Ghana in 1971, through his trawl fisheries surveys in Indonesia (1975–1976), his work at the International Centre for Living Aquatic Resources Management in the Philippines (1979–mid-1990s), and his transition to the University of British Columbia, in Vancouver, Canada. Emphasis is given to the widely used major products of his and his collaborators' work (ELEFAN, Ecopath and FishBase) and to the *Sea Around Us*, a 15-year research activity that he led, which culminated in a reconstruction of global marine fisheries catches from 1950 to 2010, and which discovered a strong decline in catches since the mid-1990s.

Keywords: ecosystem modelling, fish growth, global fishery catches, scientific career, tropics.

Introduction

The 1970s were, for fisheries science and scientists, a period of transition. The world's marine fisheries catch, which had been increasing in the 1950s and 1960s—such that catch per capita increased despite massive population growth—transited to slower increases (Figure 1), punctuated by the spectacular collapse of the Peruvian anchoveta (*Engraulis ringens*; Pauly and Tsukayama, 1987). This general trend led to a frantic search for new fishing grounds, with industrial trawl and tuna fisheries expanding, for example, onto the previously underexploited Patagonian and Sunda shelves and the Indian Ocean, respectively (Swartz *et al.*, 2010).

In previous decades, the fisheries in what an ICES report called “Other areas” (Troadek *et al.*, 1980), many of them former colonies of European countries, had been a matter of taxonomists describing the strange fish that were caught, or anthropologists describing the strange mores of fishers (Firth, 1946; Pauly, 2006). In the 1970s, however, the international aid programmes and international banks that fuelled this expansion of industrial fisheries needed some sort of assessments to justify their ventures (e.g. the Asian Development Bank, which “[c]ommencing with its first fisheries

loans in 1969, [...] has made loans of US\$ 1055 million to a total of 51 fisheries projects in 17 [developing countries]”; Mannan, 1997). Fisheries science responded, led by the indefatigable John Gulland, a senior scientist at the Food and Agriculture Organization (FAO) of the United Nations, and this is where my story begins.

I received a “Diplom” in Fisheries Science and Zoology (equivalent to a Master's degree) in 1974 from Kiel University in Germany, based on fieldwork conducted in a small coastal lagoon in Ghana (Pauly, 1975). The idea for this locale was that it would prepare me for a career in tropical developing countries, where I planned to work, because it was (and still is) not easy to be bi-racial in Europe, and because I wished to somehow “help” (Pauly, 2011). And so it was: following an intervention by my thesis advisor, Professor Gotthilf Hempel (it would have not occurred without it, as I did not fit the profile of a German fisheries expert), I was hired by the German development aid agency (GTZ) to work in Tanzania. By way of training, GTZ sent me to learn about Indo-Pacific fish in Frankfurt's Senckenberg Museum, and arranged for a Zanzibari émigré to teach me Swahili. I became fluent in this language, but promptly forgot it because, in spring of 1975, GTZ sent

[‡]Food for Thought articles are essays in which the author provides their perspective on a research area, topic, or issue. They are intended to provide contributors with a forum through which to air their own views and experiences, with few of the constraints that govern standard research articles. This Food for Thought article is one in a series solicited from leading figures in the fisheries and aquatic sciences community. The objective is to offer lessons and insights from their careers in an accessible and pedagogical form from which the community, and particularly early career scientists, will benefit.

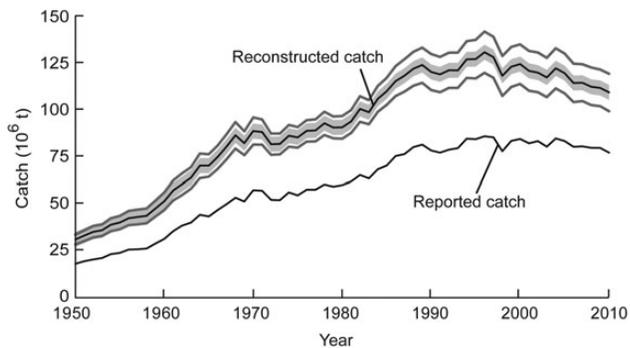


Figure 1. Reconstructed marine fisheries catch of the world, compared with the reported catch [adapted from Pauly and Zeller (2016)]. The relatively narrow confidence intervals for the reconstructed total catch were estimated using the Monte Carlo method, but had to be replaced, in the source publication, by unrealistically wide confidence intervals because one referee had a personal grudge against the Central limit Theorem.

me to Djakarta, Indonesia, the German-Tanzanian project I was initially hired for having failed to materialize.

Indonesia—1975–1976

Indonesia, i.e. the Java Sea and the southern tip of the South China Sea, where we were tasked to introduce Indonesians to the joys of industrial-scale bottom trawling, is also where I first understood the scientific challenges that faced fisheries science in “Other areas”, where a multitude of species are being exploited by a multitude of fishers, using a multitude of gears. Throughout my time in Indonesia, I remained largely oblivious to the habitat damage that bottom trawling causes (there was at the time no language for that). However, I understood, as soon as the first trawl haul appeared on the deck of our research trawler, that we never could obtain, for the species in the wiggling, variegated heap of fish and invertebrates on our deck, the detailed biological data that underpin stock assessments in northern temperate developed countries. Thus, the most abundant demersal species in our trawl survey off Western Kalimantan (Borneo), in the Southern South China Sea, the red filament threadfin bream (*Nemipterus marginatus*), made up only 1.2% of the catch. Clearly, this made yield-per-recruit analysis, the state of the art in population dynamics at the time, essentially useless (Pauly and Martosubroto, 1980).

I realized then and there that for fisheries science to be able to deal with tropical biodiversity, it would require more than the application of the tricks and approximations that were fashionable in fisheries science at the time. Rather, it was a genuine scientific problem, and this explains the title of this article, adapted from the utterings of a fictional astronaut left behind on Mars, who realized that to survive until he could be rescued, he was “gonna have to science the sh*t out of it” [from the film “The Martian”, based on Weir (2014)].

My first research programme

In January 1977, back at the Institute für Meereskunde, at Kiel University, I initiated a research programme (and doctorate thesis, again under Professor G. Hempel) consisting of:

1. developing a computer-based method for estimating growth and derived parameters (total mortality and gear selection) from

length frequency data (which are easy to collect), to replace the subjective pencil-and-paper methods then in use;

2. understanding the basic drivers of the growth of fish and aquatic invertebrates, such that the growth parameters of understudied species could be inferred; and
3. assembling all published estimates of natural mortality (M) in fish, and using them, jointly with easy-to-estimate correlates, to predict M in any species, anywhere.

Item (3), essentially a meta-analysis done at a time when I did not know the term, was the easiest of these three tasks. In 1978, I anxiously presented at an ICES meeting in Copenhagen, a first version of an empirical equation based on 122 estimates of M in a wide range of cold- and warm-water fish species that linked M to their growth parameters (L_{∞} and K of the von Bertalanffy growth equation) and the mean water temperature of their habitat (Pauly, 1978a). The audience included several of the reigning princes of fisheries science at the time, for example, Rodney Jones, David Cushing, and I think, even Ray Beverton, our king. I survived my presentation, as all questions were constructive, and none hostile. Later, the analysis was expanded to 175 cases, and published, with editorial help from Keith Brander, in this journal (Pauly, 1980). This was to become my first heavily cited paper. It also got the attention of John Gulland, whom I had met previously at a workshop in Thailand. John then tried to get me to work for FAO (I was willing, but we failed, because I had a French passport, but no support from France) and, for a while, he became a mentor nevertheless.

Item (1) was a bit more difficult; I had sought the help of a colleague skilled in mathematics, statistics, and programming (areas where I was never more than mediocre, notwithstanding Pauly, 1984), and predictably, he developed the outlines of a complex software that decomposed length frequency (L/F) distributions, assumed to be normal, assigned relative ages to them, and then fitted the growth curve which minimized the sum of least squared deviations. Approaches of this type succeeded later (Pope, 1987; Sparre, 1987), with one, called MULTIFAN, finding some practical use (Fournier et al., 1990, 1998), though apparently only for tuna [see Munro (2011)]. However, they seemed far too complex at that time for the user group that I had in mind. Moreover, these approaches all assumed a previous knowledge of whether the L/F samples at hand represented one or two cohorts per year (and their relative strengths, as inferred, e.g. from cpue data), which is precisely what was not known about tropical stocks.

Therefore, right after I began working at International Center for Living Aquatic Resource Management (ICLARM; see below), I conceived a non-parametric approach which did not require such prior knowledge, nor that the L/F samples be weighted by abundance (i.e. cpue). Also, I found a Filipino programmer, Mr Noel David, who translated the new approach, called ELEFAN, for Electronic Length Frequency ANalysis into BASIC, a popular programming language at the time (Pauly and David, 1981).

ELEFAN was an instant success among colleagues working in tropical developing countries, because its various versions offered an approach for analysing decades of accumulated L/F data, using the microcomputers that were then becoming available. This led FAO to incorporate ELEFAN into software series (Gayani et al., 1996, 2005), while an updated version will soon be available in R. On the other hand, ELEFAN triggered a strong adverse reaction—centred on the non-parametric nature of the approach, and the

absence of formal confidence intervals—among colleagues in developed-country laboratories in Europe, North America, and Australia, mainly because they did not bother to inform themselves about the problems that the ELEFAN approach was supposed to solve, or indeed, about the approach itself. Similar extreme reactions were also expressed later towards Ecopath and FishBase (both of which have nevertheless become mainstream; see below). They are probably what has given me the thick skin that allows me to ignore the criticisms that my work invariably generates in some quarters, and which I attribute mainly largely to the lack of familiarity with the data-poor tropical context for which I sought solutions.

Item (2) in the above list, on understanding the basic drivers of fish growth, was also solved—at least I think so [Pauly, 1981, and subsequent papers summarized in Pauly (2010a)]. Indeed, I think its solution is the best piece of science I ever did, although it did not get as much attention (and hence citations) as my other work. Essentially, I found that, given anatomical constraints (i.e. the surface area of gills), which determines the amount of oxygen that can be taken in by fish per unit time, their growth and final size is almost entirely determined by the ambient oxygen concentration and temperature, the latter affecting fish growth by increasing oxygen requirements.

Gill area is a constraint, especially when the fish of a given species (or local population) become large, because in order to function, their gills have to expose a surface to the water flowing through them, and this surface area cannot grow as fast as the volume (or body mass) that must be supplied with oxygen (Figure 2). Many colleagues argue with this point, but they should not: it is a fact of geometry (Pauly, 1997) and is also well documented empirically [see, for example, Muir and Hughes (1969), Hughes (1970, 1984), De Jager and Dekkers (1975), Palzenberger and Pohla (1992)].

The disparity between gill surface area growth (which limits the oxygen supply to the body) and body mass (which determines its oxygen requirements) elegantly explains a number of phenomena, for which various *ad hoc* explanations have been proposed. These phenomena include:

- Why fish and aquatic invertebrates grow the way they do (asymptotically, predictably, and temperature-dependent);
- Why fish reach maturity at a size that is a predictable fraction of their maximum size, even when the latter varies due to environmental forcing;
- Why young adults sometimes “skip” spawning, while old adults have long spawning seasons;
- Why the food conversion efficiency of fish and aquatic invertebrates varies with temperature and dissolved oxygen, but declines with size;
- Why aerating aquaculture ponds increase the growth and food conversion efficiency of farmed fish;
- Why fish larvae have very discernible daily rings on their otoliths (and squid larvae on their statoliths) and why they become less visible in adults;
- Why visceral fat is abundant in cold temperate fish exposed to strong seasonal temperature oscillations, but not in tropical and polar fish exposed to narrow ranges of temperature; and
- Why fish and aquatic invertebrates are spatially distributed the way they are, and how temperature shapes their seasonal migrations.

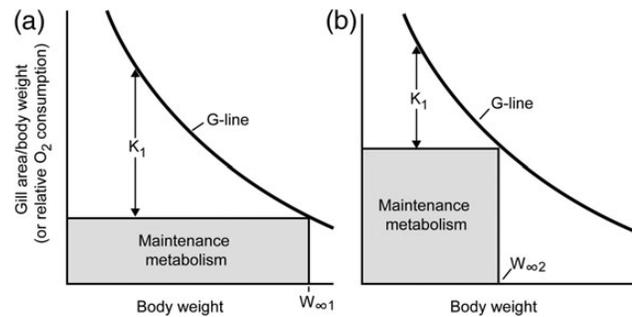


Figure 2. Diagrammatic representation of the key feature of the growth of fish: maintenance metabolism determines asymptotic weight (W_{∞}), given a “G-line” defined by the growth of the gills relative to body weight, because, at W_{∞} , relative gill area (and hence oxygen supply) is just enough for maintenance metabolism (shaded area). (a) Fish exposed to a low level of stress (e.g. relatively low temperature, abundant oxygen, and abundant food). (b) Fish exposed to a higher level of stress (low oxygen concentration, high temperature, causing rapid denaturation of body protein, and/or low food density, requiring O_2 to be diverted to foraging, rather than protein synthesis). Note that food conversion efficiency and hence also the “scope for growth” are directly related to the difference, in these graphs, between the G-line and the level of maintenance metabolism [see Pauly (1981, 2010a)].

Conventionally, in physics, chemistry, or other mature sciences, when a single hypothesis explains many phenomena, including some that had not been considered when that hypothesis was first formulated, this single hypothesis is preferred over the multiple *ad hoc* hypotheses that otherwise clutter a field (https://en.wikipedia.org/wiki/Occam's_razor). Not so, apparently, in fisheries science: the hypothesis in question (which, because of its various corroborations, I now think qualifies as a theory) is hardly ever used by anyone to explain patterns and results for which it clearly does better than the “local” explanations that are commonly advanced (Cury and Pauly, 2000). Yet, it pays off to consider it: one of the few authors to fully embrace this theory, Andy Bakun, could use it to explain the apparent mystery of why, for example, in typical underwater movies, larger reef fish appear to peacefully swim near smaller fish, although they could easily outswim and eat them (Bakun, 2011).

However, this situation might be changing now that climate change-induced ocean warming manifests globally (Rhein *et al.*, 2013) and locally (e.g. Keskin and Pauly, 2014; Tsikliras and Stergiou, 2014). My reason for optimism is because this theory explains, without *ad hoc* hypotheses, the observed poleward displacements of fish and invertebrates (Cheung *et al.*, 2013a), their tendency to move to deeper water (Perry *et al.*, 2005; Pauly, 2010a), and for their maximum size to decline (Cheung *et al.*, 2013b; see also Figure 2), all of which will have a large impact on fisheries (Cheung *et al.*, 2010).

The ICLARM years

The ICLARM, initially a Hawaii-based project of the Rockefeller Foundation, established itself in Manila, the Philippines in 1977, under the leadership of the late Jack Marr. He had written about the demise of the California sardine fishery, coordinated the research leading to a famous book (Marr, 1970), and acquired a deep knowledge of tropical fisheries, while Chair of the Indo-Pacific Fisheries Council, he later launched a massive FAO field project, the Indian Ocean Programme (Marr *et al.*, 1971).

Jack Marr had heard about my work in Indonesia, and offered me a 3-month consultancy in summer of 1978, to identify researchable issues on tropical marine fisheries for ICLARM. That consultancy was a real challenge, but to my great relief, I managed to draft a coherent account. Jack Marr sent it to a dozen leading fisheries scientists for review, including David Cushing and Brian Rothschild. To my surprise, it came back with positive comments and was published with the title *Theory and Management of Tropical Multispecies Stocks: a Review, with Emphasis on the Southeast Asian Demersal Fisheries* (Pauly, 1979), receiving hundreds of citations [see also Cushing (1982)]. It was a research programme and, as it turned out, my ticket for a postdoc at ICLARM.

Jack Marr had already left ICLARM when, in spring of 1979, I showed up again in Manila, shortly after my final doctoral examination. His successor, Ziad Shehadeh, a good-hearted US-Palestinian aquaculture expert, let me implement the research programme that I had defined, and also, after a few months of postdoc-ing, he promoted me to a sort of permanent position.

The 1980s then passed in a blur of conferences organized, courses, and workshops in fish population dynamics run on five continents and four languages, and a multitude of papers, books, and reports were published. The many topics I covered then—which also included aquaculture (Pullin, 2011)—were reviewed by colleagues in a book edited by Christensen and Maclean (2011), and it now makes me dizzy just thinking about that.

However, three themes from this period may be mentioned in following sections.

The multispecies, multifaceted fisheries of San Miguel Bay, Philippines

The fisheries of San Miguel Bay, in Bicol Province, in the northeast of the Philippines were the first multispecies fisheries that I studied in depth [the first fishery I studied, in Sakumo Lagoon, in Ghana, was essentially a single-species fishery for blackchin tilapia (*Sarotherodon melanotheron*; Pauly, 1976)]. The systematic study of the San Miguel Bay fisheries, by a group of ICLARM scientists, colleagues from the University of the Philippines, and—crucially—dedicated local research assistants, who spoke Bikolano, was truly multidisciplinary from the onset. Thus, our research assistants, when interviewing fishers in the villages surrounding San Miguel Bay, could not only ask about their catch, but also their income, their expenses, and even their dreams for their children—a level of detail possible only because the research assistants grew up in these same villages.

The data recorded over a 1-year cycle were analysed by fisheries biologists (Pauly and Mines, 1982), fisheries economists (Smith and Mines, 1982), and a rural sociologist who also lived on site for over a year (Bailey, 1982a, b), and led to solid management recommendations for the Philippine Government (Smith *et al.*, 1983). We also made them available to the local population via translation into two local languages (Smith and Pauly, 1983).

Our main result was that, while the fisheries in the bay had strongly reduced the multispecies fish assemblage in the Bay, they had remained largely profitable. However, the overwhelming majority of the profits went to a few fleet owners who exploited a loophole in Philippines law which enabled them (and still does to this day) to deploy so-called baby-trawlers in fishing grounds reserved for small-scale fishers, resulting in widespread misery around the bay.

This inequity is still not resolved, neither in the Philippines, nor in the world as a whole, and not only in fisheries (Piketty, 2014). However, I am pleased that this multidisciplinary, in-depth study of the fisheries of a remote bay in the Philippine led to the

knowledge, early in my career, that stock assessments, alone, do not lead to an understanding of what make fisheries “tick”. I also learned that when studying how natural resources are captured, one invariably hits political barriers protecting entrenched interests.

The Peruvian anchoveta fishery

Following an invitation by Wolf Arntz, also a former student of G. Hempel, and working at the time for GTZ in Peru, I applied—with the help of Maria-Lourdes “Deng” Palomares, then my research assistant, then student, now a colleague—the ELEFAN approach to 30 years of monthly L/F data on the Peruvian anchoveta (*E. ringens*). Then, we combined the fisheries catches and consumption by the predators of this small fish with a length-based form of Virtual Population Analysis (*en vogue* in the 1980s) to reconstruct monthly biomasses as a function of the anchoveta’s rate of natural mortality (M). Given that a time-series of independent acoustic estimates of anchoveta stock sizes was also available, and that the anchoveta consumption by various predators (seabirds, marine mammals and larger fish) could be computed, this indirect method allowed more or less monthly estimates of M , and their decomposition into predator-specific components. Cushing (1988), in a review, called the book in which these results appeared (Pauly and Tsukayama, 1987) “a formidable collection of papers” and a “triumph for Dr. Pauly”. Who am I to disagree?

Ecosystem modelling and the development of Ecopath

At least since Lindeman (1942), there has been agreement that representation of aquatic ecosystems emphasizing one or the other aspects of their structure and functioning is useful for their understanding (Pauly and Christensen, 2002). With Odum (1969), we also began to understand their patterns across wide ranges of conditions.

I have long been intrigued by ecosystem models; my Master’s thesis, on the ecology of a Ghanaian coastal lagoon, included a simple graphical model, which inventoried the main players in that lagoon, and made their ecological roles explicit (Pauly, 1975). Some pioneers began working on vast ecosystem models in the 1970s, but they were far too elaborate to be widely adopted, especially in the tropics. Also, the data requirements of these models could, at the time, be met only in a few well studied areas of the world, such as the North Sea (Andersen and Ursin, 1977) and the North Pacific (Laevastu and Larkins, 1981).

Thus, when I found out about the Ecopath approach and software for constructing ecosystem models that had been developed at NOAA (Polovina, 1984), and learned that its developer was not planning to work further on it, I adopted it and incorporated ideas of Ulanowicz (1986) and other theoreticians into it. After presenting a test case of the expanded Ecopath in Kuwait in 1987, which received John Gulland’s blessings (Pauly *et al.*, 1993), I undertook to disseminate it widely. I was aided therein by Villy Christensen, who joined ICLARM in 1990 from Denmark’s Fisheries and Marine Research Laboratory. Villy then led the work that established Ecopath as the most widely used approach/software for the rigorous description of aquatic ecosystem modelling (Christensen and Pauly, 1992a, b, 1993; Palomares *et al.*, 2009; Colléter *et al.*, 2015).

The key reason for this success, including in developing countries, was that Ecopath, like ELEFAN, could be implemented with the personal computers that had then become ubiquitous. Moreover, they could easily be parameterized using widely available data, for example, the multiple diet composition studies that had so far seemed of little use, complemented by empirical relationships such

as those developed by [Palomares and Pauly \(1998\)](#) to estimate the consumption per biomass of fish populations.

Later, Ecopath became even more popular, when a colleague at the UBC Fisheries Centre, Carl Walters, discovered that the easy-to-parameterize system of linear equations expressing the relationship between its state variables could be straightforwardly re-expressed as a system of differential equations specifying a time-dynamic simulation model ([Walters et al., 1997](#)). This new routine was called Ecosim, and the integrated software was “Ecopath with Ecosim” or “EwE”. A spatial version of EwE was soon added ([Walters et al., 1997, 1998; Pauly et al., 2000](#)). The package, incidentally, enabled an update of my first model of Sakumo Lagoon ([Pauly, 2002](#)).

While EwE’s career continues ([Colléter et al., 2015](#)), a mid-career evaluation was provided by NOAA, which considered it one of the top 10 research achievements in its 200 year history (see [celebrating 200years.noaa.gov/toptens.html](#)).

The 1990s: FishBase, some influential papers and the transition to UBC

My earlier comparative work on fish growth yielded, beside a published compilation ([Pauly, 1978b](#)), what we would now call a “database”. This was in the form of notecards in a wooden box, not usable by anyone else. Thus, I proposed in ICLARM’s first 5-year plan ([ICLARM, 1988](#)) that a widely accessible database should be created:

“The information gap [presently hobbling] tropical fisheries probably cannot be bridged using [only] classical means, such as maintaining extensive libraries, encouraging interlibrary loans and electronic data exchange. Rather it can be expected that shortage of funds for such classic activities will become increasingly problematic, and hence increase the isolation of scientists working on tropical resources from the mainstream of their science and from reference materials. [...] It is proposed to alleviate this problem by developing a self-sufficient database implemented on standard microcomputers [...] which would provide key-facts and information extracted from the literature. [...] These facts and information will include species identification keys, morphometric data, a summary of growth and mortality information for each species, and a summary of biological data on each species. Initially, data on about 200 major species will be provided on diskettes, with the ultimate goal of 2,500 species”. I consulted with Rainer Froese, who then joined ICLARM to implement these ideas, which, the reader will realize, was a first vision of what later was to become FishBase, the online encyclopaedia of fish ([www.fishbase.org](#)). His first suggestion was that the database should not cover only commercial fish, but all of them, that is, the 20 000 species that were then thought to exist.

Then, we went to work building a database, table by table, that could accommodate key information on fish, with emphasis on encoding contents, rather than trying to dazzle with a fancy interface ([Froese and Pauly, 2000](#)). Also, we did not implement various well-meaning suggestions that would have sunk FishBase (such as dumbing it down, requiring registration from users, and going commercial). Rather, we allowed the growth of its contents to make it attractive and useful for an ever widening range of user groups, with quantity slowly converting into quality.

Thanks mainly to Dr Cornelia Nauen, also a former student of Professor Hempel, who at the time worked at the European Commission’s Directorate General for International Cooperation and Development in Brussels, we secured a succession of large grants to implement FishBase and make it available to fisheries managers in the Commission’s ACP (Africa-Caribbean-Pacific) partner

countries, through training courses and annually updated CD-ROMs ([McCall and May, 1995](#)). As a result, FishBase was well known among fisheries scientists even before it came online in 1996. Its online version also became available to a wide public interested in the over 33 000 species of fish now included, as illustrated by ~50 million “hits” per month, from 0.3–0.5 million unique users, well beyond our expectations.

Given the success of FishBase, and because many users asked us to extend it to non-fish marine organisms, we offered our database design and the special software we developed for quick encoding and automatic verification of entries to anyone interested, but disappointingly, there were no takers. Therefore, in 2006, with the support of the Oak Foundation, and later the Marisla Foundation, we developed SeaLifeBase ([www.sealifebase.org](#)), which is similar to FishBase, but covers marine tetrapods (i.e. marine mammals, reptiles, and seabirds) and invertebrates ([Palomares and Pauly, 2015](#)). SeaLifeBase now covers nearly 130 000 marine species and has been used, jointly with FishBase, to document, for example, the marine biodiversity of many island ecosystems later designated as marine reserves ([Palomares et al., 2011, 2012](#)).

In the meantime, however, ICLARM was falling apart due to a massive crisis of its governance. In the late 1980s, because we were doing well, we had been invited to join the Consultative Group on International Agricultural Research (CGIAR). This is the network of then 14 mostly huge R&D centres, some of which had done the research behind the Green Revolution, and which we knew because one of its key members, the International Rice Research Institute (IRRI, now also the FishBase host), was based near Manila.

Joining the CGIAR, with its sprawling bureaucracy and top-down, military-style management, implemented by a succession of inept leaders proved deadly for the creative spirits that had made ICLARM the powerhouse it was. Thus, in 1994, I accepted an offer from Tony Pitcher, then Director of the Fisheries Centre at UBC, in Vancouver, Canada, to start working there, as a Professor of Fisheries.

This quick ascent through the academic ranks was due, in the main, to me having previously worked at ICLARM as if I had been in academia. Thus, besides publishing, I had taught courses at the University of the Philippines (where I had about two dozen masters students), at the University of Kiel (from which I also received a “Habilitation” in 1984, and where I had my first doctoral students), and at various other universities, mainly out of a sense that this was the right thing to do. I presume the multitude of ELEFAN, FishBase, and other courses I gave in various countries also helped.

The transition from Manila to Vancouver was not easy. I had a wife with a senior position at the Manila International School, and two children—a son (born in Djakarta) and a daughter (born in Manila)—whose schooling was not complete, and projects, notably FishBase, which still required nurturing [see [Froese and Pauly \(2000\)](#)]. Thus, from 1994 to 2000, I commuted across the Pacific, spending every year 7 months in Canada and 5 months in the Philippines.

This period also saw the first of five contributions in *Nature and Science* dealing with the global impact of fisheries on marine ecosystems ([Pauly and Christensen, 1995; Pauly et al., 1998a, Watson and Pauly, 2001; Pauly et al., 2002, 2003](#)), whose origins, main features, and impact on our discipline were reviewed in [Pauly \(2010b\)](#). These contributions, by covering the years from 1995 to 2003, bracketed the period during which a wide swathe of the lay public realized, aided by [Jackson et al. \(2001\)](#) and [Myers and Worm \(2003\)](#), that the world was experiencing a systemic crisis of fisheries, and not only a succession of isolated, unconnected collapses.

At UBC, I initially taught ecosystem modelling, and thus introduced Ecopath to my new colleague Carl Walters, whose brilliance boosted Ecopath to a level that I could never have imagined (see above). This is, to a large extent, what turned the Fisheries Centre into a global hub for marine ecosystem modelling. We shall see if this can be maintained, given that, like ICLARM (called WorldFish since it decamped to Malaysia), the Fisheries Centre became, like many other research powerhouses, a victim of its own success, and was taken over by a larger body (UBC's Faculty of Science), renamed (to Institute for the Oceans and Fisheries), and given a broader and blander mission.

Also, I continued writing papers on various new issues (e.g. on marine mammals; Pauly *et al.*, 1998b), syntheses of previous work (Pauly, 1998a, b), a scholarly book on Charles Darwin and fish (Pauly, 2004), and whimsical essays (Pauly, 1994), of which one, “Anecdotes and the shifting baseline syndrome of fisheries” (Pauly, 1995), was to become quite successful. Indeed, some authors suggested it helped launch historical ecology as a distinct discipline (Engelhard *et al.*, 2015), as also suggested, for example, in the books by Jackson *et al.* (2011), Kittinger *et al.* (2014), and Rost (2014).

In my various interactions in Canada, in the mid-1990s, I experienced a fisheries community still debating the 1992 moratorium of the fishery for northern cod (*Gadus morhua*) off Newfoundland and Labrador. Not having worked on that fishery, I never intervened in these debates and neither in the debates on the decline of the stocks of Pacific salmon off British Columbia. To me, the issue at hand seemed not so much the specific aspects of the biology of the resources in question, or of the mathematical models used to manage them, but that the conversation was confined to the academe and government scientists, without input from Civil Society.

Thus, I sought collaborations with various non-governmental organizations (NGOs), ranging from WWF [see Bonfil *et al.* (1998)] to the nascent Marine Stewardship Council (MSC; Pauly, 1996)—about which, however, I later changed my opinion, due to the MSC increasingly certifying fisheries whose “sustainability” was widely questioned (Jacquet and Pauly, 2007; Jacquet *et al.*, 2010). And so, I was invited to a one-day scoping workshop on 10 November 1997, by The Pew Charitable Trusts.

The 2000s to the present—the *Sea Around Us*

The Pew Charitable Trusts, then a foundation (now an NGO), and more precisely Dr Joshua Reichert, then the Director of its Environment Program, was at the time looking for a partner in assessing the “health” of the oceans, to provide the scientific framework for its advocacy. Five very senior US scientists and I were thus invited to a small workshop at the Trusts' headquarters in Philadelphia. Most of the senior colleagues quibbled about the notion of marine ecosystem “health” and proposed to set up costly data acquisition systems that would need a decade to produce useful data. In contrast, I proposed that the existing marine fisheries of the world should be seen as an ongoing “monitoring program”, from which we could draw insights through judicious analyses of their catches. The paper on “*Fishing down marine food webs*”, by Pauly *et al.* (1998a), implementing this approach, was under review at the time, and thus, I knew of what I spoke. I carried the day and was invited to submit a detailed proposal, which all of its eight reviewers found wanting, with arguments ranging from the usual (“it can't be done”) to the brazen (“give us the funding; we would do a better job of it”). Dr Reichert then took a big risk, and the *Sea Around Us* project, named after the third book of one of my two scientific heroes (Rachel Carson; the other is Charles Darwin), began in mid-1999.

The *Sea Around Us* was one of the first scientific projects, and certainly the largest, meant to provide a science-based context for the advocacy work of The Pew Charitable Trusts and other environmental NGOs working on oceans and fisheries. Its mission was “to investigate the impacts of fisheries on marine ecosystems, and to propose policies to mitigate these impacts” (Pauly, 2007). Specifically, it asked six questions about the North Atlantic (and by extension the world's oceans):

1. What are the total fisheries catches from the ecosystems, including reported and unreported landings and discards at sea?
2. What are the biological impacts of these withdrawals of biomass for the remaining life in the ecosystems?
3. What would be the likely biological and economic impacts of continuing current fishing trends?
4. What were the former states of these ecosystems before the expansion of large-scale commercial fisheries?
5. How do the present ecosystems rate on a scale from “healthy” to “unhealthy”?
6. What specific changes and management measures should be implemented to avoid continued worsening of the present situation and improve North Atlantic ecosystem's “health”?

These questions, it will be noted, are not those that fisheries scientists usually are asked to answer. Indeed, fisheries scientists often think that such *strategic* questions are outside their purview, if only because our discipline is very applied and *tactical*. Thus, most colleagues are directly or indirectly tasked with forecasting biomass and suggesting fishing levels and quotas, often using very sophisticated models (Quinn, 2003).

However, environmental NGOs are not competent, nor in fact, interested in dealing with this tactical level. Instead, they can pose, on behalf of society as a whole, *strategic* questions, for example, regarding the mix of fisheries and the environmental state we should have. Indeed, this is one of the things that democracy is for: to allow groups of citizens to argue for environments they see for themselves and their children. This is sometimes difficult to accept for fisheries scientists who may see themselves as working for “the fishers” or “the fisheries”, and who perceive any other ethos as implying bias and advocacy. However, they increasingly will have to accept that fishers and fishing enterprises are not, about the oceans, the only legitimate stakeholders; the public at large has a stake as well. Moreover, they are the one who, though their taxes, finance governments' research.

In the first 5 years of its existence [summarized in *Sea Around Us* (2005)], we documented that we had provisionally answered the above six questions for the North Atlantic and were on our way to tackle the same questions for the world oceans. Major steps in this were (i) papers in *Nature* (Pauly *et al.*, 2002) and *Science* (Pauly *et al.*, 2003), documenting the main trends in global fisheries, and particularly demonstrating that the world catch, which was at the time supposed to be increasing (FAO, 2000), was actually declining, a fact then masked by exaggerated catch data from China (Watson and Pauly, 2001); (ii) a book on the state of fisheries and ecosystems in the North Atlantic Ocean (Pauly and Maclean, 2003); and (iii) the demonstration that the biomass of large fish in the North Atlantic had radically declined since the onset of industrial fisheries (Christensen *et al.*, 2003).

In this period, our “spatialization” of the “catch” database maintained and distributed by FAO, based on member country

contributions (Watson *et al.*, 2004), available through our website (www.searoundus.org), began to be used by a large number of authors and research groups around the world, which led to many insights and publications, notably many articles published in *Science* and *Nature*.

As noted, our publications during this period covered all the six questions mentioned above, but gradually—and this tendency became stronger in the last decade—we began to realize that Question 1, that is, “What are the total fisheries catches from the ecosystems, including reported and unreported landings and discards at sea?”, was the most important of all, because everything else, including elaborating sound management policies, depends on accurate catch data, including that of fisheries that may be illegal (Belhabib *et al.*, 2014).

We also gradually realized that the “catch” (actually “landings”) data disseminated by FAO and used more or less uncritically by all researchers working on international fisheries throughout the world are profoundly biased. This is because FAO member countries, which contribute their data on a voluntary basis (Garibaldi, 2012), often do not cover small-scale fisheries (which are generally not small; Zeller *et al.*, 2014), do not include discarded fish (although they have been caught; Zeller and Pauly, 2005), and do not attempt to estimate illegal and unreported catches. Rather, problematic or difficult fisheries are ignored (treated as “no data”), and their catches (which are never zero, otherwise they would not take place) are also ignored, and thus set at a figure of *precisely* zero. These data thus do not adequately reflect catch levels and their changes, notwithstanding a “six-decade effort to catch the trend” (Garibaldi, 2012).

At the very beginning of the *Sea Around Us*, we had made various attempts at complementing and correcting official catch statistics [see, for example, Pitcher *et al.* (2002) and contributions in Zeller *et al.* (2001, 2003)]. However, it was only later that we fully realized the extent of this bias and the need for it to be addressed in a systematic fashion (*Sea Around Us*, 2010).

After several years of broad-based research [summarized in Pauly and Maclean (2003) and *Sea Around Us* (2005)], we realized that the most straightforward way to address this issue and the six above questions was through bottom-up catch “reconstructions” [see also Pauly and Zeller (2003)]. These began formally in 2004, when the Western Pacific Regional Fishery Management Council, the management body overseeing the US fisheries in the Central Pacific, contracted us to reconstruct the catch of the US Pacific flag territories (Zeller *et al.*, 2005, 2007).

Catch reconstruction, as a process, consists of a set of procedures inspired by Pauly (1998c) and operationalized in Zeller *et al.* (2007, 2014) to derive from various sources a coherent time-series of likely total catches for *all* fisheries of a country or area, including fisheries for which no official catch statistics exist; catch reconstructions are the products of these procedures. The word *reconstruction* and the concept are derived from the science of linguistics (one of my hobbies), which “reconstructs” extinct words and/or languages from daughter languages.

With the crucial assistance of Dirk Zeller, the 273 catch reconstructions described in 200 distinct documents were finally completed. These reconstructions pertain either to the complete Exclusive Economic Zones of countries or their overseas (island) territories, or parts of their EEZs, and were performed either by members of the *Sea Around Us* (staff, graduate students, and volunteers) or by about 300 friends and colleagues who are members of a large network created in the course of my career, working with *Sea Around Us* team members.

This allowed us to achieve a high degree of compatibility between the reconstructions, which all covered the same period (1950–2010), used the same sectoral breakdown (industrial, artisanal, subsistence, and recreational), and accounted for both landing and discards.

The sums of all these reconstructions (Figure 1; Pauly and Zeller, 2016) are thus an improved estimate of the world’s marine catch that can be used for various policy-relevant inferences, notably on small-scale fisheries, which have so far often been neglected by policy-makers. It shows that we are catching far more fish than is being reported, which implies that fisheries contribute more to our food security than we knew. It is also shown that the global catch, since the mid-1990s, has been declining at a fast pace. However, this not because prudent management has imposed low quotas in some countries (a strong decline remains when the catch of countries using quota management is subtracted; Pauly and Zeller, 2016). Rather, this decline of the global catch is mainly the result of a globally excessive fishing effort (Anticamara *et al.*, 2011), fuelled by huge capacity-enhancing subsidies (Sumaila *et al.*, 2016). Here again, limiting one’s focus on a few developed countries with functioning fisheries management systems would lead to misleading conclusions about the state of global fisheries [see also Pauly *et al.* (2015)].

In mid-2014, after 15 years of fruitful collaboration, we transitioned from The Pew Charitable Trust as our main funder to the Paul G. Allen Family Foundation, which owns Seattle-based Vulcan, Inc., and uses it to backstop the philanthropic activities it funds. In our case, the backstopping was the complete redesign and rebuilding of our website (www.searoundus.org) by an energetic group of software designers and programmers, such that it draws on the contents of our newly developed database of reconstructed catches.

Thus, we now can make available to scientists, fishery managers, NGO staffers, students, and the lay public, detailed catch statistics by sector, by taxon, and other criteria, spatialized by countries’ EEZs, Large Marine Ecosystem, and by other geographic entities. All the data we present and are based on the above-mentioned reconstruction documents (also available in our website), and of which, over a third have to date been published in the peer-reviewed literature. The database and website redevelopment allow a seamless transition between new data that are entered at one end—for example, correction of erroneous data as pointed out by users and frequent updates—and the output, that is, maps and time-series graphs of catches or fisheries status indicators.

Regarding the latter, we emphasize “stock-status plots” (Froese *et al.*, 2012; Kleisner *et al.*, 2013) and the trends of declining mean trophic levels documenting “fishing down marine foodwebs” (Pauly *et al.*, 1998a). Indeed, the latter are now shown to be ubiquitous thanks to a routine that overcomes the masking effects of the offshore expansion of fisheries (Kleisner *et al.*, 2014), not considered by critics (Pauly and Grüss, 2015; www.fishingdown.org).

Looking forward: no more pyramids

The catch reconstruction work above and the efforts to make its results globally available will have a highlight, later in 2016 through the publication of a “Global Atlas of Marine Fisheries: Ecosystem Impacts and Analysis” (Pauly and Zeller, *in press*), which will include, besides global chapters on methods and selected themes from the work of the *Sea Around Us*, 273 one-page chapters, each covering the EEZ of a country or island territory, or a part of the EEZ of larger countries.

The year 2016 is also when I turn 70, and thus, it is fairly certain that I won’t be able to initiate and/or coordinate any more work of a

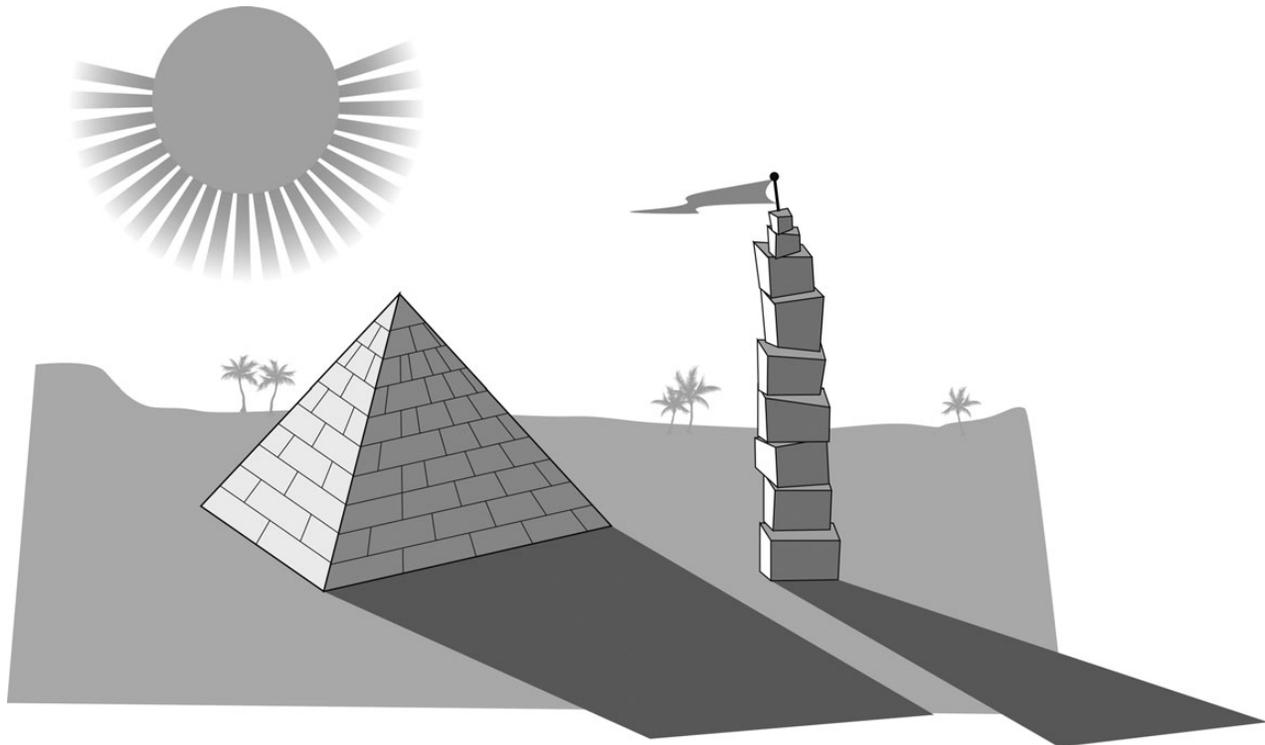


Figure 3. Pyramid and tower as metaphors of two working styles (see text).

pyramidal nature (Figure 3), a term I now explain. Assuming that a goal, or an insight we seek corresponds to a certain “height”, and that all we have to reach that height are variously shaped stone blocks, there are two basic ways of getting there: quickly piling one block onto the other, and building a tower, or cooperating with lots of people, and using the blocks to build a pyramid. The latter gets to the desired height slowly (because pyramids must have an obtuse top angle), but once you get there (if colleagues and funders had the patience) what you have produced is something that won’t fall down easily. In the future, however, I will build (little) towers, no more pyramids.

I am particularly happy about having succeeded in helping to empower fisheries scientists and managers in tropical developing countries by developing tools, concepts, and databases designed for use in those parts of the world that are data-poor, and which had been neglected by fisheries science and in studies that claim to be global, but are not (Pauly *et al.*, 2015). In return, I get many citations to my work from tropical developing countries, in addition to those from developed countries, where data availability turns out not to be great, either.

Overall, however, I attribute the modicum of success I had had to two factors: (i) luck in having had bosses (G. Hempel, J. Marr[†], Z. Shehadeh[†] and T. Pitcher) who provided me with opportunities, and colleagues/friends, many of whom helped construct the pyramids mentioned above and (ii) working hard on these pyramids, that is, long hours, non-stop, for decades, to compensate for my inability to build elegant, that is, svelte and tall towers.

Thus, if I have any advice to give, it is that one should have friends, and work hard.

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