‘Fishing down marine food webs’ was not refuted[1]

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Abstract

This contribution was written a quarter of a century after the publication of ‘Fishing down marine food webs’ (Pauly *et al.* 1998, *Science* 279), which is widely cited and has become influential despite unavoidable shortcomings. A paragraph-by-paragraph analysis of the ‘refutation’ by Branch *et al.* (2010, ‘The trophic fingerprint of marine fisheries,’ *Nature* 468: 431-435) is presented, along with comments on other critiques. The major conclusion of this detailed analysis is that T. Branch and his co-authors ran roughshod over basic ecological principles, common sense, and scientific ethics. The peer reviewers either failed to catch these problems or were complicit in the lamentable display of bad science, of which several examples are provided.

Introduction

In the fall of 1998, *Science* published a paper titled “Fishing down marine food webs’ (‘FD’ from now on, for both the phenomenon and the article which documented it, i.e., Pauly *et al.* 1998). FD demonstrated a tendency for the mean trophic levels (*MTL*) of the taxa in the catch of marine and freshwater ecosystems exploited by industrial fisheries to decline gradually, based on a combination of reported catch data by taxa from various parts of the world and the trophic levels (TL) of these taxa. Pauly *et al.* noted that this effect occurred mainly in Northern Hemisphere and in inland fisheries as well and attributed it to high-trophic level (i.e., larger) fish being both more sought after and more vulnerable to fishing than lower-trophic level (i.e., smaller) fish. However, at the time, FD was not presented as occurring everywhere, nor that it *had* to occur.

FD offered a new view of the impact of fisheries, which led the article to accumulate a high number of citations (over 6,400 in Google Scholar in late June 2024). The findings went unchallenged by the vast majority of those who cited it. A review of 129 articles published from 2016 to 2018 that cited FD found that 80% were positive (Santos and Vianna 2020).

However, in 2010, a paper was published in a prestigious journal that presented FD as a figment of my imagination[2], not supported by empirical data and at variance with the results of their elaborate ecosystem simulations (Branch *et al.* 2010). I was taken by surprise by this attack, and my counterarguments – which involved more than just a few words - fell on deaf ears when journalists asked me to explain how I could have been so wrong. Also, I never could explain (because journalists prefer short answers) why this attack was largely based on data provided by the *Sea Around Us*, of which I am the Principal Investigator, and that two members of the *Sea Around Us* were co-authors of the paper in question[3]. But I remained focused on my other research. I chose only to publish a short essay on why, in science, we praise those who discover phenomena that others couldn’t see, although they had access to the same data (Pauly 2011; see Appendix 1).

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[1] Cite as Pauly, D. 2024. ‘Fishing down marine food webs’ was not refuted, p. 94-126. *In:* D. Pauly and V. Ruiz-Leotaud (eds). *Marine and Freshwater Miscellanea V*. Fisheries Centre Research Reports 32(4). Institute for the Oceans and Fisheries, University of British Columbia, Vancouver.

[2] In the process, T. Branch and his co-authors also assumed the non-existence of numerous instances of FD that had been published well before 2010 in serious outlets by independent authors, as listed in www.fishingdown.org (see ‘Case studies’).

[3] The reason was that the data transfer and the co-authorships were arranged surreptitiously, behind my back (see Comment 9 below).

Banobi, Branch, and Hilborn (2011; all three authors cited here because the last two are recurrent characters in what follows) listed FD in a presumptuous paper in which they considered the articles they had "*refuted*". Yet, FD was the paper that didn't exhibit a declining or stagnating annual citation rate following its four 'refutations' (Figure 1). The thousands of positive citations that the FD has received show that their claim of 'refutations' was refuted by severa hundreds if not thousands of other marine biologists and/or fisheries scientists. Rather, it is the analysis of FD by Branch *et al.* (2010) which, as I will demonstrate in what follows, was poor science.

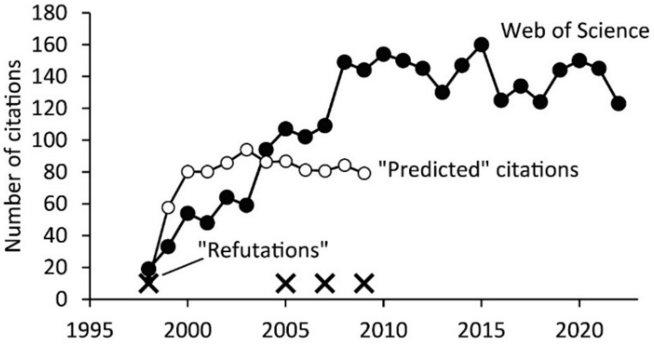

Figure 1. Time series of citations in the Web of Science received by Pauly *et al.* (1998) from 1998 to 2022 (n = 2813, and >6000 in Google Scholar), compared to the number of citations "predicted" by Banobi *et al.* (2011), based on the average shape of citation time series in *Science*. The so-called "refutations" (X shapes) alleged by Banobi *et al.* are dealt with in Comment 4 for Caddy *et al.* (1998), 1 for Essington *et al.* (2006), 12 for de Mutsert *et al.* (2008), and 14 for Litzow and Urban (2009).

However, having been publicly accused of making things up in various interviews by T. Branch, R. Hilborn, and their associates (while I do not mention them in interviews and generally avoid citing them in my papers; see e.g., Appendix 1), the time has come to re-establish some balance, and what follows is going to be rather blunt, as were my answers in a lengthy interview on this subject (https://reflectionsonpaperspast.com/2021/03/04/revisiting-pauly-et-al-1998/). What comes next, following Table 1, which lists and defines the acronyms used in this contribution, is the text that Branch *et al.* 2010) published, chunked in the form of numbered '**Assertions**' (in italics), each covering a paragraph, followed by my numbered '**Comments**'. The only change made to their text is that to facilitate understanding, the references are identified by 'author(s) (year)' rather than by the numbers that many journals require. (Note that this procedure would not be acceptable to any peer-reviewed journal).

Table 1. Acronyms used in this contribution

CMSY	A stock assessment method for estimating biomass and fishing mortality trends for catch time series and ancillary information
EEZ	Exclusive Economic Zone; the sea area extending 200 miles offshore in which maritime countries have jurisdiction
FAO	Food and Agriculture Organization of the United Nations, based in Rome
FD	Fishing Down (marine food webs), the process wherein (industrial) fisheries tend to reduce the mean size and trophic level of the fish in the ecosystems they exploit, which is generally reflected in declining *MTL* (or *RMTI*)
FiB	Fishing-in-Balance index, whose increase suggests an offshore expansion of fisheries
MTI	Marine Trophic Index, i.e., the name that the Convention on Biological Diversity (CBD) chose for the *MTL*
MTL	Mean Trophic Level (of the catch), time series of which can be used to test if fishing down (FD) occurs in a given ecosystem
RMTI	Regional Marine Trophic Index; as spatially disaggregated form of the *MTC* (or *MTI,* which is equivalent)
TE	Transfer efficiency of biomass between the different trophic levels of an aquatic ecosystem, often assumed to average 10% (see Pauly and Christensen 1995)
TL	'Trophic levels' range from 1 (in primary producers) to 2 (herbivores) and about 5 (miscellaneous carnivores). The TL of marine fish and invertebrates is fractional (e.g., 2.3; 3.7; 4.2), and varies between life stages and also spatially and seasonally

Assertion 1: *"Abstract: Biodiversity indicators provide a vital window on the state of the planet, guiding policy development and management (Secretariat of the Convention on Biological Diversity 2006; Butchart et al. 2010). The most widely adopted marine indicator is mean trophic level (MTL) from catches, intended to detect shifts from high-trophic-level predators to low-trophic-level invertebrates and plankton feeders (Pauly et al. 1998; Pauly and Palomares 2005; Pauly and Watson 2005). This indicator underpins reported trends in human impacts, declining when predators collapse ("fishing down marine food webs;" Pauly et al. 1998) and when low-trophic-level fisheries expand ('fishing through marine food webs;' Essington et al. 2006)."*

Comment 1: The notion that 'fishing through marine food webs' (i.e., a decrease of *MTL* due solely to an increase of the catch of low-trophic level taxa, without concomitant decrease of the catch of high-trophic level taxa) is not relevant to a discussion of FD. The feature of the *MTL* diagnosed as 'fishing through the food web,' which Essington *et al.* (2006) touted as a new complement and/or substitute to FD, was discussed as a 'bottom-up effect' as early as 1998 (Caddy *et al.* 1998; Pauly *et al.* 1998b). Suppressing its effect without affecting FD is straightforward, as it simply consists of computing the *MTL* from catch and trophic level data from data that exclude the lowest trophic levels.

We will see below, via a case study of India's neritic fisheries, that the use of a 'cut-off TL' (Pauly and Watson (2005)[4] usually makes downward trends of *MTL* more visible in ecosystems where small pelagic fishes, whose biomass can strongly fluctuate, contribute a large fraction of overall catches.

Moreover, Branch *et al.* and other proponents of 'fishing through marine food webs' have often failed to note that for the phenomenon to apply generally, the observed decline of *MTL* must be associated with an increase in total catches. Such net increases of catches occasionally occur; one example is Peru, where the fishery for the Peruvian anchoveta (*Engraulis ringens*) in the 1950s grew initially without the tuna and bonito (*Sarda chiliensis*) catches being affected (Pauly *et al.* 1987; see also Comment 6).

Another example is the Omani EEZ, where the Indian oil sardine (*Sardinella longiceps*) population and catch massively increased since 2011 without the catch of higher trophic levels declining. However, as a rule, fisheries where the *MTL* decline also have declining total catches; indeed, since 1996, this is the pattern in global marine fisheries.

The *MTL*–catch association illustrated on a global basis in Figure 2 does not exhibit the catch increase required by 'fishing through,' at least not since 1996. (The *MTL*-biomass association is discussed and illustrated further below). Thus, overall, 'fishing through the food web' is, to FD, a footnote of no generality, while its main feature and its consequences were (and continue to be) misunderstood even by its adherents.

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[4] Incidentally, Equation 2.1 in that paper, which was supposed to show how the TL of a taxon of predators (*i*) could be computed from the TL of it prey organisms (*j*) and their fraction (C) in the composition of the diet of *i*, lacked '+1' on its right side.

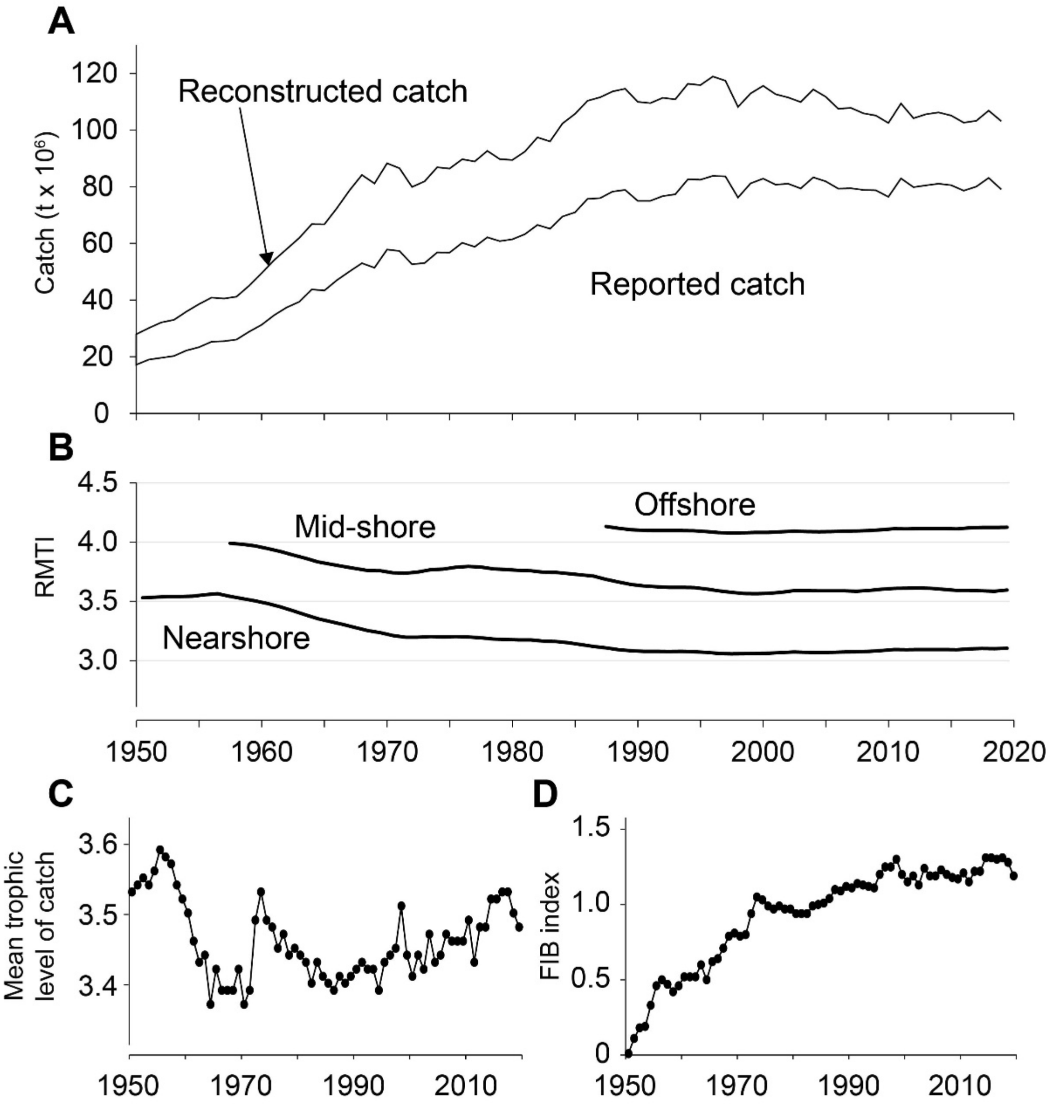

Figure 2. The world marine catch and its trophic level global trends. **A**: Since 1996, global catches have declined (if considering 'reconstructed' catches; Pauly and Zeller 2016) or stagnated (if considering only catches reported annually to the FAO by its member countries).d **B**: Decline of the inshore *MTL* from 3.43 in 1950 to 3.10 in 2019, i.e., 0.06 TL per decade, while the mid-shore *MTL* declined from 3.99 to 3.59 in 2019, i.e., also 0.06 per decade, as computed by the *RMTI* routine of Kleisner *et al.* (2014); the offshore catches (*MTL* ≈ 4.1) exhibit no decline, as expected from fisheries which focus exclusively on large pelagic fishes such as tuna. **C**: The *MTL* of the global marine catch, exhibiting a decline from the mid-1960s to early 1970s when the huge catch of Peruvian anchoveta grew to become a large fraction of the world catch (then collapsed), followed by FD, seemingly reversed by an *MTL* increase due the growth of offshore fisheries targeting high-TL fish. **D**: The Fishing-in-balance index (defined in Comment 4) confirms the spatial expansion of (industrial) fisheries from the early 1950s to about 2000.

Assertion 2: *"Abstract (cont.) The assumption is that catch MTL measures changes in ecosystem MTL and biodiversity (Butchart et al. 2010; Pauly and Watson 2005). Here, we combine model predictions with global assessments of MTL from catches, trawl surveys, and fisheries stock assessments (Worm et al. 2009) and find that catch MTL does not reliably predict changes in marine ecosystems. Instead, catch MTL trends often diverge from ecosystem MTL trends obtained from surveys and assessments. In contrast to previous findings of rapid declines in catch MTL (Pauly et al. 1998), we observe recent increases in catch, survey, and assessment MTL. However, catches from most trophic levels are rising, which can intensify fishery collapses even when MTL trends are stable or increasing. To detect fishing impacts on marine biodiversity, we recommend greater efforts to measure true abundance trends for marine species, especially those most vulnerable to fishing."*

Comment 2: It will be shown below that it was not the case that "catches from most trophic levels [were] rising" when this was written, and even less so currently (**Figure 2**).

Assertion 3: *Adoption of an ecosystem approach to fisheries requires managers to conserve marine biodiversity, not just focus on fished stocks (Pikitch et al. 2004). Biodiversity indicators are used to assess the impacts of fishing and the effectiveness of management, and thus guide the development of future policies (Rochet and Trenkel 2003). The most widely used indicator, catch MTL, measures shifts in reported catches from high-trophic-level predators such as cod to low-trophic-level species such as filter-feeding oysters and small herbivorous fish 3,13. In 1998, catch MTL was reported to be declining at an alarming 0.1 units per decade ("fishing down marine food webs"(Pauly et al. 1998l; Yang 1982), and was interpreted to result from broad reductions in top predator biomass (Pauly et al. 2013; Pauly and Palomares 2005; Pauly and Watson 2005). Catch MTL was the primary marine index chosen by the Convention on Biological Diversity to measure global biodiversity, and has been applied widely to report on the state of the marine environment (Secretariat of the Convention on Biological Diversity, 2006; Pauly and Watson 2005; Rochet et al. 2003).*

Comment 3: Correct.

Assertion 4: *"Catch MTL is interpreted to track changes in the underlying ecosystem (Pauly et al. 1998; Pauly and Palomares 2005; Pauly and Watson 2005; Pauly et al. 2005), but its usefulness as an indicator has been questioned because catches are influenced by changes in economics, management, fishing technology, and targeting patterns (Essington et al. 2006; de Mutsert et al. 2008; Caddy and Garibaldi 2000; Caddy et al. 1998; Powers and Current 2010; Sethi et al. 2010; Litzow and Urban 2009)."*

Comment 4: It is trivially obvious that "changes in economics, management, fishing technology, and targeting patterns" will influence what species are targeted, caught, and landed. However, it is far more frequent in the history of fisheries (Sarhage and Lundbeck 1992) that abundant species are targeted first and that the "changes" emerge as a result of their decline. Thus, Branch *et al.* inverted cause and effect, which frequently occurs when people don't fully understand what they are writing about or think that it benefits them not to understand something. Similarly, management measures are usually put in place after a stock has been depleted, as is well documented in a now classic article by Ludwig, Hilborn, and Walters (1995)[5].

An example is the fishery for the orange-footed sea cucumber (*Cucumaria frondosa*) around St. Pierre and Miquelon, a small French island territory south of Newfoundland in Eastern Canada, which targets this extremely valuable species that was completely ignored before the collapse of Atlantic cod (*Gadus morhua*) in the 1980s/1990s in the Northwest Atlantic (Forest 2022; Palomares and Pauly 2022). Indeed, some fisheries, which seem to result from "changes in economics, management, [etc.]" are *created* by the collapse of formerly abundant high-trophic-level predators. A well-documented case is the booming fishery for American lobster (*Homarus americanus*) in the Gulf of Maine, which would not exist if the local cod stock had retained its former abundance (Steneck 1997; Steneck and Wahles 2013), as cod prey on lobsters.

Here may also be the place to dispose of the first of the four alleged 'refutations in Figure 1, i.e., that of Caddy *et al.* (1998) - all staffers of the Rome-based Food and Agriculture Organization of the United Nations (FAO), who, according to Banobi *et al.* (2011), refuted FD in terms of "taxonomic resolution of data inadequate, landings poor indicator of ecosystem, bias due to expansion of aquaculture."

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[5] The second author of Ludwig, Hilborn, and Walters (1995), however, doesn't want anything to do with it anymore, as it likely does not sit well with the fishing industry that now funds much of his work (Bernton, 2016).

First, it must be noted that Caddy *et al.* did not disagree with, and hence have not refuted, the main finding of FD; rather, they wrote, "[w]e do not disagree that a general decline in mean trophic level of marine landings is likely to have occurred in many regions" – which was precisely the point of FD.

However, things are never the way they ought to be, and they added to the above sentence, "…but we are not convinced that the explanation is solely a result of 'fishing down marine food webs' or that the analysis of the FAO data, as undertaken by Pauly *et al.* substantiate such a thesis." There is no 'refutation' there; they only asked for a stronger case, which time and more scientific evidence have provided.

In contrast to Branch *et al.,* who, against all evidence, claim that FD does not occur (i.e., that I made it up), the comment of Caddy *et al.* (1998) raised a set of questions that required deeper explorations. In fact, those four points perfectly articulated a research program that I, with various colleagues, pursued in the years following the publication of FD. As it turned out, each of Caddy *et al.*'s points reinforced our original conclusions. In effect, they became 'judo arguments' (Asimov 1977), which occur when an opponent's efforts are used against them: the detailed examination of their arguments strengthened the case for FD. This is presented based on text from Chapter 2 in Pauly (2010), slightly edited and updated.

"Taxonomic Resolution of Data Inadequate"

The "taxonomic resolution" issue, as viewed by Caddy *et al.*, has two parts. The first, they suggested, is that fish, during their ontogeny, change their food organisms and hence their trophic levels. For example, the trophic level of fish in the eastern Mediterranean has been shown to vary seasonally (Karachle and Stergiou 2006). However, this is not likely relevant here, as the fishing down analyses are conducted at the scale of decades. More pertinent here is that most fish (except herbivores, which contribute minuscule amounts to global fisheries catches) have a lower trophic level when they are small and young than when they are large and old (see Figure 3).

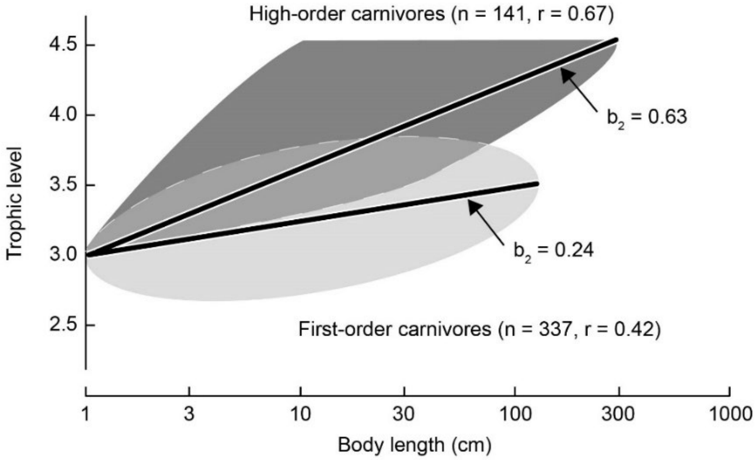

Figure 3. Relationship between 588 estimates of trophic level and the logarithm of body length (in cm) in 180 fish species. The regression lines, forced through TL = 3 for larvae of 1 cm (because they overwhelmingly consume herbivorous zooplankton), have slopes b_1 = 0.24 for first-order carnivores (light grey; e.g., anchovies, sardines, herring, and other small pelagic and demersal fishes), and b_2 = 0.63 for higher-order carnivores (darker grey; e.g., groupers, gadoids, and other larger demersal fishes, large pelagic fishes such as tuna and billfish). Simplified from Pauly *et al.* (2001; based on FishBase, www.fishbase.org).

Thus, as fishing mortality increases through time (and it does: this is the whole point about how overfishing induces changes in species composition and FD), the proportion within a species of large (and hence high-trophic-level) fish will decline. In contrast, the small (low-trophic-level) fish will increase. This can also be expressed through ugly-looking equations, which the alert reader can find in Pauly *et al.* (2001a), where an age-structured model was described that was applied to northern cod off eastern Canada, and in Pauly and

Palomares (2002), where a generic length-structured model is presented with an application to European hake (*Merluccius merluccius*) in the Mediterranean. The results: not considering the relationship between ontogeny and trophic level when dealing with fishing down has the effect of *under*estimating the fishing down effect (by 10-15%; see also Liang and Pauly 2017).

This was the first part of the answer to the questions posed by Caddy *et al.* and judo argument No. 1. This is also evidence that the article of Banobi *et al.* (2011) may have been written in bad faith, as the fallacious nature of Caddy *et al.*'s argument was self-evident, and had been repeatedly commented upon, notably in Pauly and Watson (2005); this also applies to the other arguments of Caddy *et al.*, discussed further below.

The second aspect of the taxonomic resolution problem, as seen by Caddy *et al.*, was the degree of aggregation of the underlying FAO data, which they knew very well, given that one of the '*alia'* (R.J.R. Grainger) was the chief of FAO's Information, Data, and Statistics Unit, in charge of assembling their global catch data.

Caddy *et al.* pointed out that of all fish caught, "*about 20% cannot even be assigned to the level of Family,"* they failed to mention that there is a clear pattern to this reporting nonetheless: while high-latitude countries (north and south) report about 90% of their catches to FAO at the level of species, low-latitude countries (and China) tend to report them primarily as 'mixed fishes' and other unhelpful categories (Pauly and Palomares 2005). The lack of taxonomic resolution masks the FD trend because within a given broad category, the highest trophic levels, which are the most sensitive to the fishing pressure, are decreasing more than the lower ones. This effect, which occurs mainly in the tropics (because catch data are often reported in broad categories, is illustrated in Figure 4).

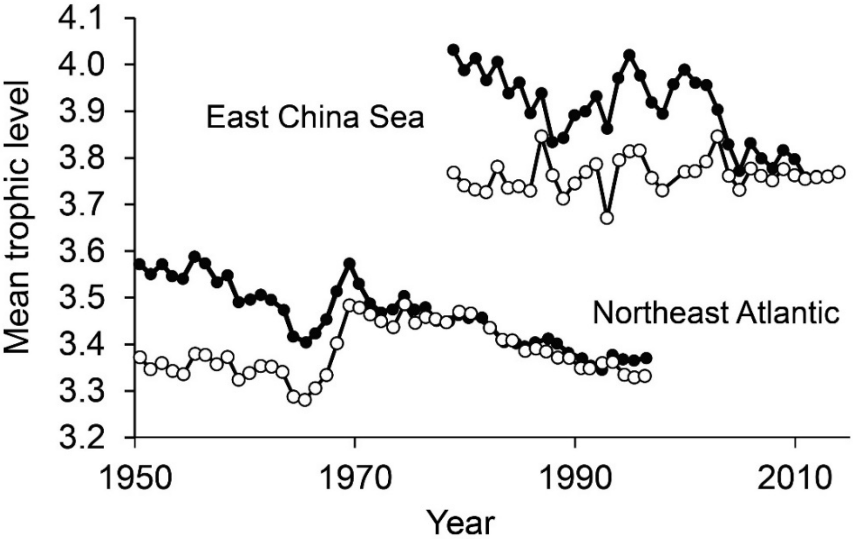

Figure 4. Two cases in which the clear downward trend in mean trophic level of catch data originally presented in detailed taxonomic categories (black dots) completely disappears when the same catch data are presented in coarser categories (open dots). In the Northeast Atlantic (FAO Area 27; lower lines), with 80% of the original data reported as species, the downward trend disappears when these data are grouped into FAO's International Standard Classification of Aquatic Animals and Plants, or ISCAAP (adapted from Pauly and Palomares 2000). The same occurred when catch data from the East China Sea Large Marine Ecosystem (LME), including 22 species in 5 genera, were lumped into Orders or higher groupings (Liang and Pauly 2017). The converse thus applies that if an FD signal appears in over-aggregated data, the FD would be more pronounced in taxonomically disaggregated data.

Contrary to the notion that over-aggregated data generate trends that can be misinterpreted as fishing down, Figure 4 shows the exact opposite. Thus, the poor resolution from tropical countries will cause an *underestimation* of the strength of the fishing-down phenomenon. This is judo argument No. 2.

“Landings [are] poor indicator of ecosystem [status]”

Caddy *et al.* doubted that the relative abundance of species in landings reflected their relative abundance in the ecosystem. As Pauly (1998b) pointed out, “Peruvian landings consist mainly of anchoveta because these are abundant in the Peruvian upwelling ecosystem, and Indonesian coastal fishers land ponyfishes[6] because these are abundant on the Sunda Shelf. Off Newfoundland, Canada, where cod was targeted until it recently collapsed, a fishery for invertebrates has recently developed. It can be safely expected that Newfoundland’s future landing statistics will reflect the species shift that occurred in the ecosystem around that island.”

This is what I thought at the time. However, was it really correct? Understanding this issue in specific cases is very much a matter of considering the capabilities of the fishing gears that are deployed. Thus, as Pauly *et al.* (1998b) responded, the “correspondence between relative abundance in the landing and in the ecosystems was not the rule before fisheries became globalized, and only selected species were exploited by nearshore gear. Now, with inshore, offshore- and distant-water fleets competing to supply increasingly integrated global markets, abundant species are exploited wherever they occur (Grainger and Garcia 1996), and landings will tend to reflect their relative abundance.” Also, in many cases, markets were more selective in the past. They concentrated on a few locally known and appreciated species, as opposed to the situation prevailing nowadays, where, at least in wealthy countries, the markets display vast arrays of seafood of uncertain origin and identity (Jacquet and Pauly 2008), all the way down to surimi ‘fish’ sticks now available at a local supermarket in Sète[7].

As it happened, the correspondence hypothesis was tested by comparing commercial trawler catch composition with the species’ relative abundance in the Celtic Sea ecosystem, as assessed by trawl surveys (Pinnegar *et al.* 2002). The results were surprising – or, upon reflection, perhaps not: the decline of the mean trophic level was less pronounced in the commercial catch than in the survey catch, i.e., in the ecosystem. Pinnegar *et al.* (2002) attributed this to the skippers’ attempts to maintain a high-value catch by targeting larger, high-trophic-level fishes (which are usually more valuable, see Tsikliras and Polymeros 2014).’

If this can be generalized – and there is no a priori reason why it cannot be – this means that a declining trend in the mean trophic level of landings would, other things being equal, actually underestimate the extent of fishing down that occurs in the ecosystem. This is judo argument No. 3 (and another case turned up recently; Liang and Pauly 2019, 2022).

“Bias due to expansion of aquaculture.”

Caddy *et al.* (1998) suggested that “aquaculture production may not have been fully excluded from [our] analysis” and suggested, along with Pinnegar *et al.* (2003), that fishing down may be an artifact resulting from the statistics we used. Caddy *et al.* pointed out that, at the time, FAO data did not distinguish well between fisheries catches and aquaculture production, particularly in the Mediterranean. (Again: they were more critical of FAO data than anyone before had dared to be!).

Yet here as well, they failed to consider what the effect of such over-aggregation would be on trends of mean trophic levels. In the case of mariculture, in countries other than China, the trend has been, over the last 50 years, that the farming of low-trophic-level animals (oysters, mussels, etc.) has remained stagnant or has even declined, while the culture of high-trophic-level fishes such as salmon, seabass, and bluefin tuna (or shrimps, because they are fed fishmeal) has grown rapidly. The result is that we are, with regard to aquaculture, “farming

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[6] These are fishes of the Family Leiognathidae, previously abundant throughout the tropical Indo-Pacific (see Pauly and Pauly (1981), which are much appreciated in Western Indonesia, but discarded by trawlers everywhere. Where trawling occurs, ponyfishes, also known as ‘slipmouths’ and ‘slimies’ tend to decline faster than overall biomass (Tiews *et al.* 1967; Pauly 1977, 1979).

[7] The book from which this section is adapted was written in early 2009 while I was spending a half-sabbatical in Sète, a town on the French Mediterranean Coast.

up the food web" (Pauly *et al.* 2001b), particularly in the Mediterranean (Stergiou *et al.* 2009). Thus, if the FAO data at the time indeed included a substantial amount of aquaculture production, this would have again led to an underestimation the fishing-down effect. This is judo argument No. 4.

Banobi et al. forgot "Eutrophication and Other Bottom-Up Effects"

In the Mediterranean, then the focus of J.F. Caddy's work, and in other coastal areas, river discharges in the second half of the 20th century included huge amounts of nutrients because of changing land use, especially the application of fertilizers (see, e.g., Caddy *et al.* 1995; Maranger *et al.* 2008). These nutrients, particularly in the oligotrophic Mediterranean, have increased primary production, which can be expected to have led to increased biomass of low-trophic-level small pelagic fish populations (anchovies, sardines, mackerels, etc.).

Thus, a situation can be contrived wherein the *MTL* of the catch from an ecosystem would decline because of the increased contribution of small pelagic fish to fisheries catches, even though the contribution of larger, higher-trophic-level fish might not change. Such an 'addition without depletion' scenario is the basis of 'fishing through the food web,' proposed by Essington *et al.* (2006) as an extension of, or corrective to FD. There are two ways to evaluate the validity of this proposition. One, relatively straightforward approach is to compute mean trophic levels from catch or landing data that exclude fish with low trophic levels (Pauly and Watson 2005), whose short-time fluctuations often obscure long-term trends.

Figure 5, whose panels A to L are based on Bhathal and Pauly (2008), displays the time series of 12 truncated mean trophic levels for all of (mainland) India's States and Union Territories, and all but one shows a clear declining trend. On the other hand, a similar study, which disaggregated the catch data only between the west and east coasts of India, and which failed to exclude lower-trophic-level fish (and tuna, which don't belong in a study of shelf fisheries), showed evidence of FD only for the west coast of India (Vivekanandan *et al.* 2005). Here, panels A to K (L is the only exception) show that fishing down was not due to increasing catches of small pelagic (here: Indian oil sardines) or other species with trophic levels < 3.25.

Also, panels M and N jointly suggest that an offshore expansion of fisheries occurred along the entire Indian coast, as noted by Bhathal and Pauly (2008), and confirmed by Panel O.

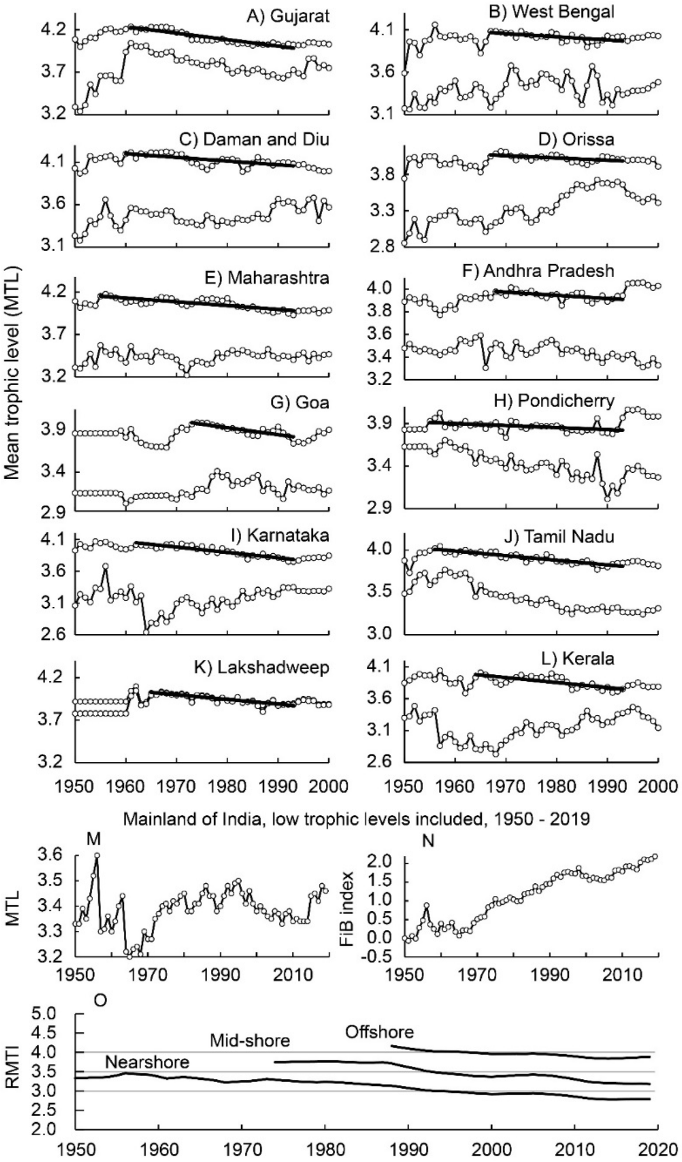

Figure 5. Trend in mean trophic level (*MTL*; 1950-2000; A-L), mean trophic level and fishing-in-balance index (*MTL* & FiB;1950-2019; M-N) and regional marine trophic index (*RTMI*; 1950-2019) of fisheries in the EEZ of mainland India, jointly illustrating (*i*) that computing the *MTL* only with trophic levels > 3.25 (thus eliminating oil sardine and other small pelagic fish) makes 'fishing down' (FD) visible when it was not previously, and (*ii*) that assessing all catches including small (e.g., oil sardine) and large pelagic fish (e.g., tuna) with a method accounting for spatial expansion of fishing operations confirms the occurrence of FD. Panels A to L were adapted from Bhathal *et al.* (2008), with the data past 1995 reflecting both the deterioration of fisheries statistics (along with others; Herrera and Kapur 2000), and increasing offshore fishing, while panels M, N, and O are an output of the website of the *Sea Around Us* (www.seaaround.us.org; April 2023) suggesting a robust offshore expansion of Indian fisheries.

Similarly, Stergiou (2005), based on catch data from Greek waters, analyzed trophic level 'slices,' i.e., 3.00 to 3.49, 3.50 to 3.99, etc. (see Appendix Figure A1). His results showed that the addition of low-trophic-level fish to the catch (as required by fishing 'through' the food web) is not necessary for FD to occur, and the higher-trophic fish declined the fastest. This is judo argument No. 5.

Another way to examine the possibility of a bottom-up effect is to account explicitly for the fact that marine ecosystems operate as pyramids, wherein the primary production generated at trophic level 1 moves up toward the higher trophic levels, with a huge fraction of that production being devoted to the maintenance, reproduction, and other activities of the animals in the ecosystems (Cury *et al.* 2003). Thus, notwithstanding a human preference for catching and consuming large predators (Tsikliras and Polymeros 2014), deliberately fishing down should enable more of an ecosystem's biological production to be captured by fishing. However, any decline in the mean trophic level of such fisheries catches should be matched by an ecologically appropriate increase in these catches, the appropriateness of that increase being determined by the transfer efficiency between trophic levels. Thus, a Fishing-in-Balance (***FiB***) index can be defined that:

- Will remain constant (remain = 0) if trophic level changes are matched by "ecologically correct" changes in the catch;
- Will increase (> 0) if either (a) a "bottom-up effect" occurs, for example, an increase in primary production in the Mediterranean (which triggered Caddy *et al.*'s concerns), or (b) a geographic expansion of the fishery occurs, and the "ecosystem" that is exploited by the fishery has been in fact expanding;
- Will decrease (< 0) if discarding occurs that is not considered in the "catches" or if the fisheries withdraw so much biomass from the ecosystem that its functioning is impaired (which corresponds to the "backward-bending curves" mentioned in FD)[8].

Bhathal and Pauly (2008) presented the equation defining the *FiB* index and the basis of its interpretation in spatial terms[9], and Figure 5N presents an example. Other examples may be found in Sherman and Hempel (2008) and at www.seaaroundus.org. Jointly, they illustrate that accounting for bottom-up effects in the context of fishing down is straightforward and leads to new insights into the functioning of marine ecosystems. This was the 6th and final judo argument.

Overall, the investigations which Caddy *et al.* (1998) forced us to perform ended up strengthening our original conclusions. The fact of the matter is that the first signal we detected, suggesting a trophic decline, was muted by the noise of the many different confounding factors, which Caddy *et al.* pointed out. It is to such criticism, even from detractors, as Caddy *et al.* indisputably were, that scientists are indebted.

Assertion 5: *"Here we conducted the first large-scale test of whether catch MTL is a good indicator of ecosystem MTL, marine biodiversity and ecosystem status. We identified four main patterns of fisheries development and modelled their influence on MTL, and then compared these theoretical predictions with estimates of MTL from global compilations of catches, long-term trawl surveys, and fisheries stock assessments (Worm et al. 2004), addressing three key questions: (1) whether catch MTL is positively correlated with ecosystem MTL, (2) what is the global MTL trend based on data from different sources, and (3) whether trends in MTL are informative about trends in marine ecosystem status."*

Comment 5: Fair enough

Assertion 6: *"We compiled ecosystem models (Christensen and Walters 2004) from 25 different ecosystems around the world and simulated four main scenarios to examine the theoretical relation between catch MTL and ecosystem MTL (Fig. 1). The four scenarios were 'fishing down' (Pauly et al. 1998), as already outlined, 'fishing through' (Essington et al. 2006), in which sequential expansion of low-trophic-level fisheries rather than collapses of top predators drives MTL, 'based on availability' (Sethi et al. 2010), in which easily accessible species with high biomass are targeted first before expanding to less-accessible stocks with lower yields, and 'increase to overfishing', in which all species are fished with growing intensity over time until depleted."*

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[8] These three points also form the basis of the *RMTI* routine of Kleisner *et al.* (2014) and the Excel spreadsheet routine of Liang *et al.* (2017). The *FiB* index is defined as $\mathrm{FiB}_k = \log[Y_k \cdot (1/TE)^{MTL_k}] - \log[Y_k \cdot (1/TE)^{MTL_o}]$, where *Y* is the catch and *MTL* is the mean trophic index value for year *k*, while Y_o and MTL_o are the catch and *MTL* value for the first year of data, and *TE* is the transfer efficiency between trophic levels, with *TE* = 0.1 (Pauly and Christensen 1995).

[9] And thus Branch *et al.* (2010) will have known about it.

Comment 6: The irony here is that the term "fishing down marine food webs" was coined by Christensen (1996); under that subtitle, he wrote that "[i]n unfished areas we can expect ecosystems to be in some sort of balance, often with relatively high abundances of predatory fish. Initially, fisheries may target the larger, predatory, and often higher-priced species. Gradually, the fishing pressure will make the larger species scarce, and fishing will move towards the smaller species. As this develops, we may or may not experience increasing catches overall, but typically the catch per effort will diminish, making us perceive the development as a fishery crisis."

This insight was based on 36 Ecopath models (i.e., static representations of ecosystems' food webs rather than time-dynamic simulation models), which showed that ecosystems that were exploited at lower trophic levels generated higher catch than those that were exploited only at high trophic levels (e.g., as for the oceanic systems in Figure 6A and B)[10]. Note, though, that 'fishing down,' as conceived by Christensen (1996), implies that views catches as largely determined by the primary production of an ecosystem, while in FD, it is the changes in *MTL* that are emphasized; these changes are caused by catch composition changes themselves caused by industrial fleets capable of accessing all resource species in an ecosystem. This difference is highlighted in Figure 6C to E), which feature the trend in *MTL*, *FiB* index, and *RMTI* in the Peruvian upwelling, exploited by industrial fisheries in the early 1950s for its (high-trophic level) tuna and bonitos, whose yields were later dwarfed by catches of the low-trophic level anchoveta (see Caillaux and Mendo 2024 and Comment 1).

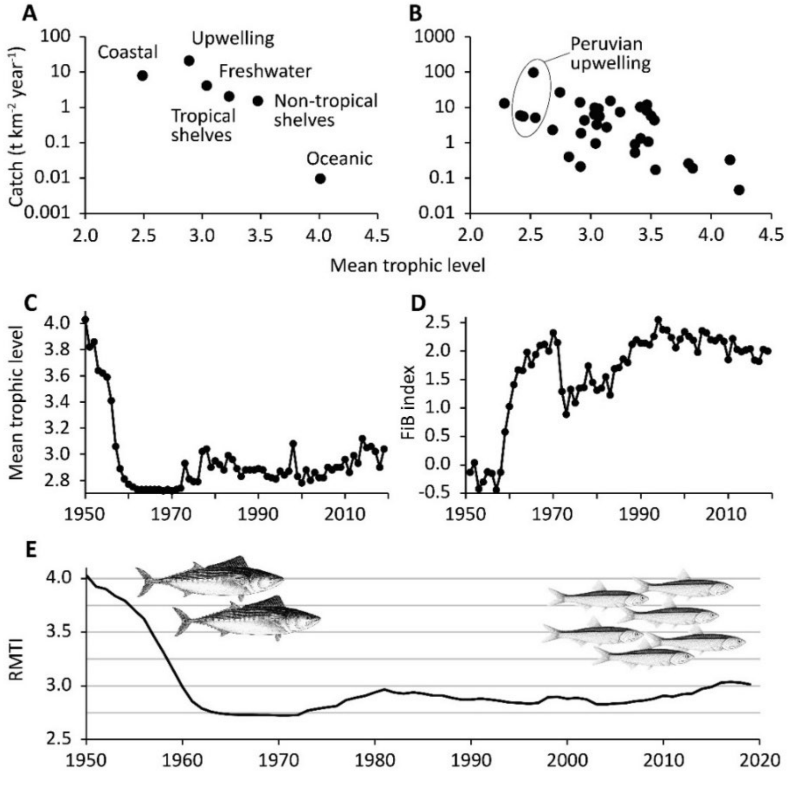

Figure 6. Comparing exploiting different ecosystems by fishing them at different trophic levels (*MTL*), reflecting a state, with fishing down (FD) as a process. A: average annual catch of finfish (log scale) vs. *MTL* in six different ecosystem types modelled with Ecopath (from Christensen 1996, based on Pauly and Christensen 1995). B: log(mean annual catch) vs *MTL* in 36 Ecopath ecosystem models (from Christensen 1996); note estimates for the Peruvian upwelling ecosystem. C: Trend in *MTL* in the Peruvian EEZ. D: FiB index in the Peruvian EEZ. E: The Regional Marine Trophic Index (*RMTI)* for the Peruvian EEZ suggests that in this EEZ, dominated by an intense upwelling, the *MTL* of the fishery is quickly brought the initially high *MTL* of that system down to the low level reported by Christensen (2006) as a feature of that upwelling ecosystem.

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[10] Note that oceanic systems could be exploited differently, by targeting small, low-trophic level mesopelagic fishes. Such fisheries may still develop on a large scale (see Discussion).

Assertion 7: *"The simulations show that 'fishing down' and 'fishing through' both produce declining trends in catch MTL, but that 'fishing down' results in greater initial declines in ecosystem MTL, and more collapsed species than does 'fishing through.' These scenarios predict that, at the end of the simulations, most species are depleted (and many are collapsed to less than 10% of unexploited biomass), but MTL has returned to values observed in unexploited systems, because species across all trophic levels are equally depleted."*

Comment 7: 'Equal depletion' of all trophic levels under intense fishing may be possible in (bad) simulation models, notably in those used to support 'balanced harvesting' (see critique in Froese *et al.* 2015), and apparently in the Atlantis modeling software (Fulton *et al.* 2011) used by Branch *et al.* for their simulations, but it doesn't occur in reality. Depleting the biomass of an ecosystem modifies its structure (which is largely defined by the biomass flows therein), and the top predators of a diminished ecosystem will be most affected (Figure 7).

Simulations using the TL-based ecosystem EcoTroph model, which is based on quantifying the flow of biomass surging up the food web from low to high TLs, highlight the cumulative effects of the catch from one TL to the next (Gascuel and Pauly 2009; Rehren and Gascuel 2020). As a result, high TLs are strongly affected by any loss in prey abundance and invariably experience a larger depletion (just as large fish are more affected by fishing due to the cumulative effect of catching successive year classes).

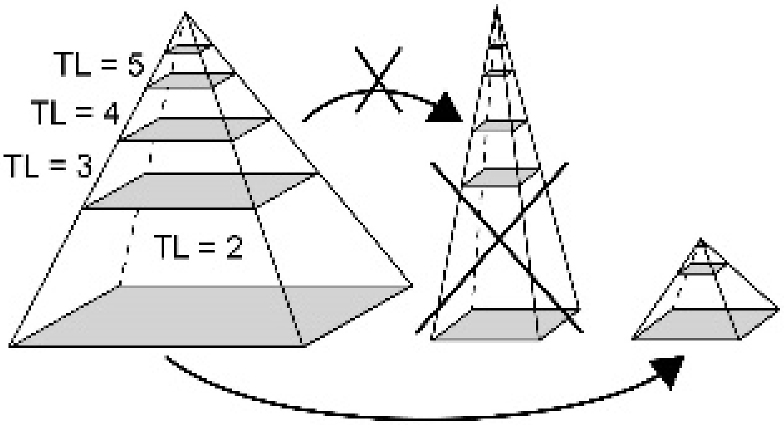

Figure 7. Mature ecosystems, which include a full complement of predators at higher trophic levels, can maintain themselves through large biomass flows toward high trophic levels (left pyramid). Reducing these flows (e.g., by fishing at all trophic levels, as modelled by Branch et al. and the advocates of "balance harvesting") does not lead to ecosystems such as illustrated by the pyramid at the center, which would imply unreasonably high transfer efficiencies between trophic level (i.e., a very acute angle on top of the pyramid). Rather, this leads to ecosystems, as illustrated by the pyramid on the right, which have fewer trophic levels (i.e., the top predators are gone) and low overall transfer efficiency (as expressed by the obtuse angle on top of the pyramid). This means that their primary production is not optimally utilised, and contributes (as detritus) to further ecological degradation, e.g., by facilitating harmful algal blooms and/or other organic pollution. The pyramids are based on Odum (1969, 1971) and Christensen and Pauly (1992).

On land, this is the reason why the large national parks, which, e.g., in East and Southern Africa include dozens of lion prides and thousands of wildebeests, cannot be parcelled out into small municipal parks, each with one couple of lions chasing two dozen wildebeests. This is similar in the sea, and ecosystem simulations that assume the proportion of the various species of an ecosystem will remain self-similar when the size of this system is drastically reduced are absurd and negate a century of research in ecology (see, e.g., Colinvaux 1978, whose book has a title that says it all: "*Why Big Fierce Animals Are Rare – An Ecologist's Perspective*").

This gross but self-serving error demonstrates that the purpose of the simulations performed by Branch *et al.* was not to investigate how FD relates to real ecology, but to try to show, at any cost, that FD doesn't occur.

Assertion 8: *"More variability is observed in outcomes from the 'based on availability' scenario, which generally predicted declines in catch MTL, but less change in ecosystem MTL. Finally, the 'increase to overfishing' scenario hardly influenced catch and ecosystem MTL, but resulted in many collapsed species. These results (Fig. 1) are averaged over all models, and obscure substantial differences observed in particular models (Supplementary Figs 1-4). Overall, catch and ecosystem MTL were negatively correlated in many ecosystem models (35-38% of all models) in the 'fishing down', 'fishing through', and 'based on availability' scenarios, but usually positively correlated for the 'increase to overfishing' scenario and for additional scenarios in which fishing was applied evenly across all species (Supplementary Figs 5-10). Importantly, this shows that when fishing disproportionately affects one part of the food web, the relation between catch MTL and ecosystem MTL often breaks down. When fishing similarly affects all species, catches act as a representative sample of ecosystem changes."*

Comment 8: Given the misleading caricatures that the simulation modelling by Branch *et al.* generated, which are addressed in Comment 7, it appears superfluous to delve deeper into the outcome of the simulations, which their authors, sadly, mistook for reality.

Assertion 9: "*We calculated catch MTL from global fishery landings, finding substantially different values and trends to those reported in Pauly et al. (1998; Fig. 2a). In particular, catch MTL has not declined steeply since the 1970s, but initially declined and then increased from the mid-1980s. Other recent publications reporting similar trends (Butchart et al. 2010; Tacon et al. 2009, 2010) have not explained why their results differ from those in ref. 3. We discovered that these differences arose from updates to the main source of trophic level estimates, FishBase (Froese and Pauly 2010), and not from changes in relative catches among species. One key change was increasing the trophic level estimate of anchoveta from 2.2 to 2.7, which markedly altered the global catch MTL trend, and highlights the sensitivity of catch MTL trends to uncertainty in trophic level estimates (for more details see Supplementary Materials and Supplementary Figs 12-14).*"

Comment 9: Now we are getting closer to the crux of the story, i.e., that changes in the estimate of trophic level of some important key species make earlier reported trends in *MTL* doubtful, and that initially downward trending *MTL* started to increase in the mid-1980s.

As it turns out, T. Branch, before publishing his critique, did consult at three levels with the *Sea Around Us*. He corresponded with Dr. M.L. 'Deng' Palomares regarding the trophic levels associated, in FishBase, with each study of the food of fish encoded in FishBase, and they agreed on a new protocol that was implemented in FishBase. Overall, the changes and/or improvements in mean trophic level for single species turned out to be a red herring.

What mattered were the features of the catch data that Branch *et al.* used, and this requires a back story. T. Branch also corresponded in 2009 (behind my back as Principal Investigator of the *Sea Around Us*) with Reg Watson and his research assistant Grace Pablico about the transfer of *Sea Around Us* data in exchange for co-authorship of these two[11]. Simultaneously, Branch corresponded with me about the *MTL* data by Large Marine Ecosystem (LME) in Butchart *et al.* (2010), in which Reg Watson and I were co-authors, and which also suggested an increase in *MTL* from the mid-1980s on[12].

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[11] Reg Watson also worked at the time with T. Branch and S.A. Sethi on another paper which attempted to undermine FD (Sethi *et al.* 2010), although he had previously co-authored with me several articles that contributed to establishing the ubiquity of FD, notably Pauly and Watson (2005), which rebutted Caddy *et al.* (1998). The amazing thing is that this same Reg Watson, after Branch *et al.*'s paper was published (of which he was a co-author), offered me to help draft a rebuttal (unbelievable, but true!). A real science weathercock.

[12] This increase was caused by the expansion of fisheries, which also marred the data analyzed by Branch *et al.* (2010), as suggested in this comment and elsewhere in this contribution.

At the time, a former student of mine and I had just published a first paper about the spatial expansion of Indian coastal fisheries (Bhathal and Pauly 2008), the first of a series on the global expansion of fisheries (e.g., Swartz *et al.* 2010; Pauly and Watson 2011; Kleisner and Pauly 2011; Coulter *et al.* 2019). These articles, however, only re-examined, in a 21st century context, an expansion process that was very old (Sarhage and Lundbeck 1992) but which accelerated with the introduction of *industrial* fishing vessels, large, capital-intensive boats with engines burning fossil fuel, i.e., coal, then diesel oil (Roberts 2007).

Thus, I alerted T. Branch of the fact that both the *Sea Around Us* catch data by LME and the FAO catch data from which they are mostly derived would be biased by the spatial expansion of fisheries the same way that report of high potato yields from a farm would be biased if the sizes of its potato fields were increasing. Or, in fisheries terms, if an industrial fleet, after exploiting coastal waters to reduce the mean trophic level of its catch, moves offshore, it will encounter previously unfished stocks of larger, high trophic levels, and the *MTL* of its catch will increase. However, it will have achieved this by expanding into a new area, like the potato farmer, who planted new fields with seed potatoes.

To me, there was no need to follow up on this: it is evident that any responsible scientist, made aware of this issue, would have attempted to correct it, or would at least have mentioned it as a possible source of uncertainty in their paper. But no: T. Branch was so eager to have a paper in *Nature* that ethical (yes, ethical!) considerations were thrown overboard (if they were ever on it). Also, they were lucky to have reviewers who overlooked this glaring issue (which is perhaps why T. Branch never alluded to it!).

As previously mentioned, when the paper appeared, I was completely unprepared to respond to the questions of journalists, who had no time for lengthy explanations on fisheries expansion, potato fields, and scientists having to adjust their microscope if they wanted to see anything (Pauly 2010; see Appendix 1). I had been had.

But, having learnt my lesson, I thought of two ways the *Sea Around Us* should consider fisheries expansion. The first of these is that when spatializing catches, the ½ degree latitude/longitude cells of a taxon's distribution that are coastal should receive the low catches of a new fishery exploiting that taxon. In contrast, cells further offshore should receive increasing catches, as Watson and Morato (2013) suggested, up to its maximum catch (and beyond) obtained from the entire distribution (accessible to that fishery). This is now part of the catch spatialization routine of the *Sea Around Us* that allocates global marine fisheries' catches to the about 150,000 ice-free half-degree latitude/longitude cells comprising the world's ocean.

The second approach to considering fisheries expansion was inspired by the Fishing-in-Balance (*FiB*) Index presented in Bhathal and Pauly (2008), used with catch data and the *MTL* to detect and quantify the tendency of fisheries to expand, which I thought could be modified to account for the apparent (offshore) increase in *MTL* (see Kleisner and Pauly 2011). This turned out to be possible, and the result was a program in R, documented in Kleisner *et al.* (2014), which, given a time series of catches and their mean trophic level, separates out the likely inshore catch and its mean trophic level from offshore catches and their mean trophic levels.

A brilliant PhD student from China, who was working with me then, translated the R software of Kleisner *et al.* (2014) into an Excel spreadsheet (Liang and Pauly 2017). Daliri *et al.* (2021) applied her simple-to-use routine to a demonstrate that the Iranian fisheries in the Northern Arabian Sea are fishing down the resources they exploit. A first analysis, which did not account for the geographic expansion of the fishery (Mashjoor *et al.* 2019), proclaimed that the Iranian vessels had been 'fishing up' - just like our innumerate potato farmer, and Branch *et al.*

One should note, finally, that Branch fails to understand the potato field expansion analogy because he argues that *"[r]ecently, the argument for fishing down has shifted to fisheries expansion as the primary reason why declining mean trophic level in catch has not yet been detected in all areas of the world (Pauly and Palomares 2005; Bhathal and Pauly 2008; Kleisner et al. 2014; Grüss 2015). Here, the basic premise is that fisheries first fished down the nearshore species, then expanded to offshore predators (including tunas), and this is argued to mask the evidence for fishing down. Fisheries expansion has certainly occurred (Morato et al. 2006; Swartz et al. 2010), but shifting from low- to high-trophic levels over time is evidence for fishing up marine food webs, not fishing down marine food webs"* (Branch 2015).

This very first word of this quote is a misstatement because fisheries expansion as a masking factor for FD was already highlighted in Pauly *et al.* (1998s), i.e., "the exception [to FD] (where landings continue to increase as trophic levels decline) is the Southern Pacific (Fig. 5C), where the westward expansion of horse mackerel fisheries is still the dominant feature, thus masking more local effects."

Perhaps more importantly, this quote demonstrates that T. Branch sees fisheries as disconnected from ecosystems. Thus, in this absurdist view, if the fisheries can maintain or even increase their catch of high-trophic level fish by moving from coastal to offshore ecosystems, everything is fine, and FD does not occur. The fact is, however, that when one can separate coastal and offshore ecosystems - and we now can, thanks to the routines of Kleisner *et al.* (2014) and Liang and Pauly (2017) - coastal FD becomes evident, along with the high *MTL* of offshore areas (see Figure 2B and 5O). A particularly good application is provided by Lavin *et al.* (2023), who used this routine to identify a strong FD masked by expansion into deeper water, which also masked the effects of warming waters around Aotearoa- New Zealand.

Assertion 10: *"In addition to anchoveta, global catch MTL trends are affected by other highly fluctuating stocks of small pelagic fishes. Dips and recoveries in catch MTL in the 1960s and 1980s were caused by the respective rapid development and collapse of anchoveta and sardine fisheries, which fluctuate in response to climate and fishing and are often out of phase with each other (Chavez et al. 2003). Catch MTL is much smoother over time when recalculated without these two species (Fig. 2a). Examining species grouped by 0.1 trophic level bins (Fig. 2c) reveals that catches of small pelagic species peaked at various times from the 1960s to the present (Chavez et al. 2003). Consequently, trends differ considerably when small pelagics are excluded by re-estimating catch MTL from groups with trophic levels above 3.0, 3.25 or 3.5 (ref. 5) (Fig. 2a)."*

Comment 10: That the strong fluctuations of the usually large biomass of low-trophic level, small pelagic fishes such as the Peruvian anchoveta cause problems when interpreting mean trends of *MTL* was evident from the start and was discussed in Caddy *et al.* (1998), Pauly *et al.* (1998b), Pauly and Palomares (2000; 2005) and Palomares and Pauly (2010). This is the reason why, e.g., Figure 5 in Pauly and Palomares (2005) shows two time series of *MTL*, one with and the other without the Peruvian anchoveta, with the latter declining as well, as does a similar series in Caillaux and Mendo (2024 – this volume).

A more rigorous approach is to systematically exclude low-trophic level taxa (e.g., those below trophic level of 3.25), as performed by Bhathal and Pauly (2008), which resulted in the downward trend of *MTL* in 11 of 12 maritime States and Union Territories of India becoming very clear (Figure 5), which they had not been previously, as they were partly masked by the strong, environmentally-driven biomass fluctuation of the Indian oil sardine (discussed in Longhurst and Pauly 1987). Indeed, this approach allows the conceptual and practical distinctions of environmental effects from fishing impacts on fish stocks, with the former impacting mainly low-trophic level catches and the latter high-trophic fish.

This is the reason why the *Sea Around Us* website, which provides for the computation of time series of *MTL* for all Exclusive Economic Zones (EEZ), Large Marine Ecosystems (LME), and other geographies, now allows for choosing the lowest (and highest) trophic level taxa in catches to be considered, as opposed to all taxa being considered.

Assertion 11: *"Declining trends in catch MTL within the remaining higher-trophic-level groups are driven by the collapse in Atlantic cod catches since the 1960s; removing Atlantic cod results in increasing catch MTL trends for groups above trophic levels 3.0, 3.25 and 3.5 (Supplementary Fig. 14). However, although Atlantic cod catches declined, catches of most other high-trophic-level predators expanded over time (Fig. 2c), while global catches increased until the mid-1980s and then levelled off (Pauly et al. 1998, Zeller et al. 2005; Watson and Pauly 2001) (Fig. 2b). Overall, fishing pressure has expanded at all levels of marine food webs, similar to our model scenario 'increase to overfishing'."*

Comment 11: The inference that Atlantic cod (*Gadus morhua*) is, globally, the only high-trophic level predator that has declined since 1950, i.e., that "most other high-trophic-level predators expanded over time" is ludicrous, especially given that Paulik (1971) wrote over 50 years ago of the 'ghosts of past fisheries,' and Ludwig, Hilborn and Walters wrote that "[a]lthough there is considerable variation in detail, there is remarkable consistency in the history of resource exploitation: resources are inevitably overexploited, often to the point of collapse or extinction."

Unfortunately, there is an 'embarrassment of riches' for refuting this particular piece of irresponsible nonsense, notably given that the 'Redlist' of IUCN (https://www.iucnredlist.org/) assesses that 37% of the extant shark and ray species of the world are in danger of extinction, many critically so, with the overwhelming majority of them having faced a major reduction of their number and biomass since 1950, and especially in the last decades.

One could also proceed alphabetically country by country, with the white shark (*Carcharodon carcharias*) having been extirpated from the coast of **A**lbania (Soldo and Jardas 2002), Nassau grouper (*Epinephelus striatus*) spawning aggregations having vanished in **B**elize (Fulton 2023), the Chinese bahaba (*Bahaba taipingensis*) in **C**hina being "critically endangered" (https://www.iucnredlist.org/; see also Sadovy and Cheung 2003), … and so on, all the way to **Z**anzibar (Tanzania), where "the highly experienced fishermen perceived that families of fish species such as Lutjanidae (Emperor snapper), Rhinobatidae (Giant guitarfish), Scaridae (Green humphead parrot fish), Scombridae (Kanadi-kingfish), and Sphyranidae (Scallop hammerhead) are the most threatened fish species in the study area. For instance, the fishermen [reported] that fish species such as Green humphead parrot fish, Javelin grunter, Twinspot red snapper, Rosy dwarf monocle bream, and Green jobfish started to disappear systemically over the last four decades. The observed results are in line with the study conducted by Katikiro (2014), Division of Fisheries (2013), and van der Elst *et al.* (2005), who lamented the decline of fish stock in the western Indian Ocean" (Benansio and Jiddawi 2016).

Assertion 12: *"Ecosystem MTL estimates were calculated in two ways: survey MTL from biomass estimates from 29 long-term trawl surveys, and assessment MTL from biomass estimates of 242 fisheries stock assessments. Trawl surveys offer consistent time series of ecosystem biomass, whereas assessments combine information from multiple sources to estimate biomass trends, focusing on important commercial stocks. Survey MTL is affected by catchability differences among species, and both survey MTL and assessment MTL are dependent on the selection of species that are surveyed or assessed, but both sources provide MTL estimates that can be used to measure ecosystem changes directly. We found that survey MTL and assessment MTL were higher than catch MTL (Fig. 3), reflecting the greater focus of surveys and stock assessments on bottom-dwelling high-trophic-level fish species that account for only a moderate proportion of total catch weight."*

Comment 12: If time series of (trawl) survey data were available for the entire world, not only could (demersal) biomass-based time series of *MTL* be computed for every maritime country, but it wouldn't be necessary to rely on an index such as the *MTL*, as the impact of (trawl) fisheries on ecosystems could be assessed directly. However, trawl surveys are very expensive, and in much of the Global South, they are usually conducted by vessels of opportunity deployed to support research funded by wealthy countries and led by their scientists.

Historic examples are the survey of Philippine waters conducted with a U.S. trawler (Warfel and Manacop 1950), the internationally-funded Guinean Trawling Survey (Williams 1968; Fager and Longhurst 1968), the German-led surveys in Indonesia (Pauly and Martosubroto 1996), and the numerous surveys by the Norwegian R/V Fridtjof Nansen (see, e.g., Strømme *et al.* 1981[13]). The main regular surveys conducted by a developing country I am aware of are those performed annually by Thai research trawlers in the Gulf of Thailand (Eiamsa-Ard and Amornchairojkul 1997). Thus, making the point that regular biomass surveys lead to *MTL* estimates that better reflect fisheries' impacts on ecosystems is equivalent to mocking a newspaper delivery boy for riding a bike instead of a chauffeur-driven Cadillac.

Rather, the issue is whether trawl surveys exist, which, as Branch *et al.* claim, show increasing biomass-based *MTL* in areas and for periods in which catch-based *MTL* decreases. One reason to doubt this is that the FAO catch data upon which the *Sea Around Us* catch (and *MTL*) time series are based start in 1950. The 1950s, however, were at the end of the period when the high biomass accumulated during the WWII-induced years of reduced fishing in the waters of industrialized countries was quickly demolished by renewed fishing activity (see, e.g., Bavinck 2010; Holm 2012). Catch-based estimates of *MTL* can track – indirectly – the changes in fish community composition during this early period, for which trawl surveys are mostly unavailable. When these regular surveys began in the 1970s and 1980s, the large changes in species compositions implied in FD had already occurred. Hence, these surveys, to a large extent, are now largely tracking noise.

This is the case in the Northern Gulf of Mexico, where the first trawl survey that de Mutsert *et al.* (2008) could dig up was performed in 1965 or about (see their figure 1), and where, indeed the "survey data show steady mean trophic level, not declines." Moreover, this survey and the many that followed produced much higher *MTL* than the reported catches could because the demersal fisheries in the Northern Gulf of Mexico consist largely of shrimp fisheries, which regularly discard at least 80% of their catch, and keep only the shrimps (Graham 1996). This implies that the 'catch' statistics from the Northern Gulf of Mexico (actually: landings statistics) do not allow the computation of reliable estimates of catch-based *MTL*.

A similar process occurred in tropical developing countries, where the first 'historic' trawl surveys (see above) gave us glimpses of an original abundance that was quickly demolished and would have been missed in subsequent monitoring surveys (if any).

Assertion 13: *"Survey MTL initially declined, but is now higher than in the 1970s, whereas assessment MTL declined until the 1990s before recovering to within 0.05 units of the start value. Catch MTL was not positively correlated with ecosystem MTL. When all data are combined, catch MTL was negatively correlated with both survey MTL (Pearson correlation r = -0.55) and assessment MTL (r = -0.31) (Fig. 3); when restricted to a common set of stocks, catch MTL was also negatively correlated with assessment MTL (r = -0.41) (Supplementary Fig. 18). These results indicate that catch MTL does not track changes in ecosystem MTL."*

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[13] There are dozens of reports of *R/V Fridtjof Nansen* survey from different part of the world (see '*Fridtjof Nansen*' in Google Scholar. However, the haul-per haul data of these valuable surveys are regrettably not publicly available.

Comment 13: The opacity of the manipulations performed by Branch *et al.* makes it extremely difficult to duplicate their work. Thus, it may be appropriate to deal only with their conclusion that "*catch MTL does not track changes in ecosystem MTL.*"

Gascuel *et al.* (2016) would not agree with this. They compared trends in landing-based and survey-based *MTL* (accounting for all 1950-2010 European catch and all 1985-2010 surveys, representing more than 22,000 hauls) and concluded that FD occurred in European seas, i.e., that "[i]n contrast to other studies (e.g., Branch et al. 2010; Branch 2012), trophic indicators based on landings appeared little sensitive to the uncertainty that exists regarding values of trophic levels per species" and that "the landing-based indicators (*MTL, MTI*, and *MML*) appeared to be highly correlated with survey-based indicators for most ecosystems, which contrasts with the results of Branch et al. (2010)."

The statement by Branch *et al.* (2010) that "catch *MTL* does not track changes in ecosystem *MTL*" is also in direct contrast with Figure 8, which presents published time series of biomass and corresponding *RMTI* time series throughout the world. As may be seen, this comparison supports the conclusion that biomass and trophic level trends correlate positively, not negatively.

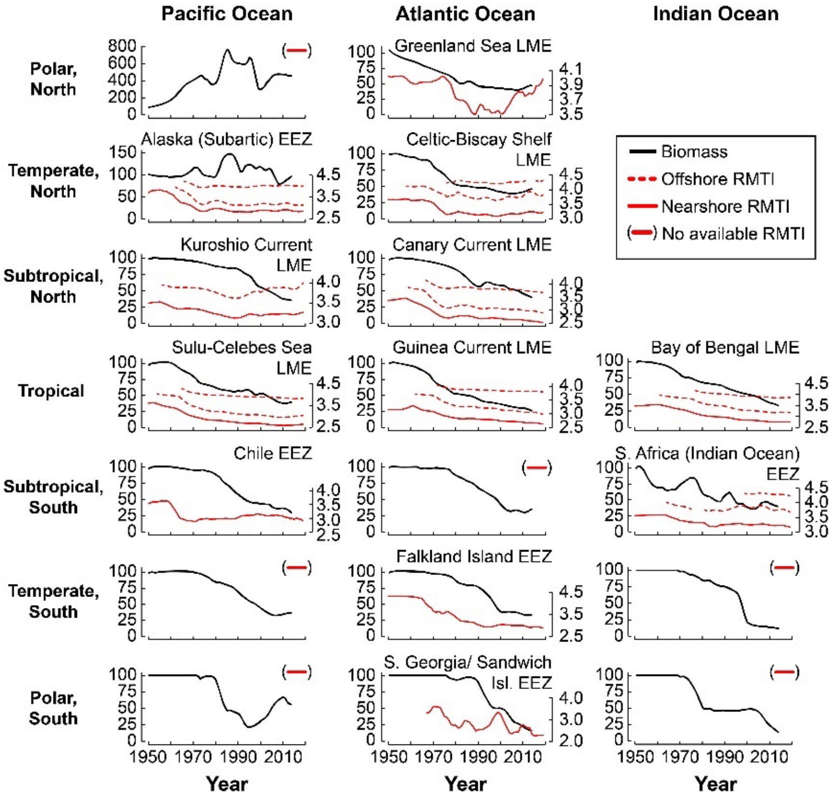

Figure 8: Biomass trends in the major climatic zones of the Pacific, Atlantic, and Indian Oceans, with the *RMTI* in the best corresponding LME or EEZ of each climatic zone superposed (in red, with some climatic zones lacking the catch data from which *RMTI* could be calculated). The biomass trends are the means trends of CMSY+ assessments (informed by the 'RAM Legacy Database' wherever possible) of abundant species in each climate zone (from Palomares *et al.* 2020), while the mean trophic levels are the *RMTI* trends in Large Marine Ecosystems overlapping with these climate zones www.seaaroundus.org. Overall, the trends of biomass on mean trophic level are similar and trend downward (see text).

Assertion 14: *"We also compared catch, survey and assessment MTL in individual ecosystems, finding that catch MTL is negatively correlated with survey MTL for 13 of 29 surveys, and negatively correlated with assessment MTL in 4 of 9 ecosystems. Three examples demonstrate these differences. In the Gulf of Alaska, catch and assessment MTL are dominated by Alaskan pollock and failed to capture the well-documented regime shift from low-trophic-level shrimp and crabs to high-trophic-level fish in the late 1970s (Anderson and Platt 1999; Mantua et al. 1997) but the Gulf of Alaska small-mesh shrimp survey did detect this shift, increasing 0.8 units (Fig. 4b, survey 3 in red)."*

Comment 14: The excellent review by Litzow and Urban (2009) of 112 years of *MTL* changes in the catches of Alaska's industrial fisheries, which indeed shows periods of *MTL* increases, is not a 'refutation' of FD because no one ever claimed that it occurs everywhere. FD is extremely widespread – even more so than originally described – but it is not something like gravity, impacting everything everywhere. Rather, it is the result of widespread policies that allow FD to occur or even encourage it, in the mistaken belief that it will increase fisheries catches.

In contrast, in Alaska, the prudent management of the fishery for Alaska pollock (*Gadus chalcogrammus*), besides favorable oceanographic conditions, has maintained a huge biomass of this high-trophic level predator, which allows the taking of a large and profitable catch, which year for year, dominates the catch of all other Alaskan fisheries. Thus, the *MTL* from Alaska is now high, and if it were used as the sole indicator of the status of Alaskan fisheries (which one should never do), one would conclude that Alaska fisheries are better managed than those, e.g., in the Gulf of Thailand. And this would be correct. So, what is the point?

Again: nobody ever claimed that FD has to occur. FD is widespread because bad management decisions are widespread internationally. FD doesn't occur in Alaska, and thus, we are happy, but this doesn't provide an argument against the use of *MTL* (or, better, *RMTI*) to describe the status of fisheries.

Assertion 15: *"Conversely, the early-1980s collapse of cod and shift to invertebrates in eastern Canada (Fig. 4g, h) is captured by dramatic declines in catch MTL, but hardly visible in trawl surveys in the region, which lacked invertebrate data."*

Comment 15: Yes, obviously, if your sampling device (here, a trawl) is not designed to catch invertebrates, then it won't catch invertebrates. This, incidentally, doesn't invalidate the trawl survey any more than the fact that the *MTL* will stay more or less constant when the catch is dominated by a single species (such as Alaska pollock) invalidates FD (see Comment 14). The point is that every method has advantages and disadvantages and that, therefore, the status of fisheries should be evaluated using all applicable methods. I assume here that only fanatics would disagree, but you never know…

Assertion 16: *"Finally, in the Gulf of Thailand, where almost all fished species collapsed and survey MTL declined (Christensen 1998), catch MTL increased continuously (Fig. 4m). The Gulf of Thailand pattern resulted from fishery development similar to the "based on availability"' (Sethi et al. 2010) scenario: fisheries first targeted the most accessible species yielding the highest revenue-mussels, shrimps and small fish-before expanding to high-trophic-level fish."*

Comment 16: This is an erroneous interpretation of what occurred in the Gulf of Thailand. Until the early 1960s, the Thai fisheries were narrowly coastal and artisanal, relying on hook and lines, traps, and lift nets to catch mainly small pelagic fishes, notably stolephorid anchovies (the basis of *nam pla*, or fish sauce; Pauly 1996), and Indian mackerel (*Rastrelliger kanagurta*), of which large quantities were exported (Butcher 1996). Also collected in shallow waters were mussels, oysters, other bivalves, and other invertebrates (crabs, shrimps, etc.), which, jointly with the small pelagic fishes, represented the overwhelming bulk of the decidedly pre-industrial, low-trophic level Thai marine catches until the early 1960s.

There had been attempts to introduce trawling, the quintessential industrial gear, in Southeast Asia prior to the Second World War (WWII), e.g., by the English in Malaysia and the Dutch in Indonesia (Pauly and Chua 1988; Butcher 1996), but these experiments failed, mainly because the trawls were too heavy. However, a German fisheries expert, Dr. Klaus Tiews, then working for FAO in the Philippines in the 1950s, had noticed that Filipinos, using U.S. jeep engines mounted on small local fishing boats (*banka*) pulling a high-opening, light trawl, were exploiting the then rich waters of Manila Bay. He helped transfer this technology to Thailand (see Tiews 1969), where it was adapted to local conditions, then took off like a rocket (Tiews 1973; Eiamsa-Ard and Amornchairojkul 1997; Pauly and Chuenpagdee 2003).

The catch of these new Thai trawlers skyrocketed, and predictably, their catch-per-effort (CPUE) declined, from about 250 kg·hour^{-1} in 1963 to 50 kg·hour^{-1} in the 1990s (Ritragsa 1976; Eiamsa-Ard and Amornchairojkul 1997), with no current data suggesting that the downward trend has reversed and which are about 20 kg·hour^{-1} at present. They expanded from the inner Gulf of Thailand to the entire gulf (including Cambodian waters), the Thai Andaman coast, north to Burma/Myanmar, and south to the Malaysian coast of the Strain of Malacca, where they were soon emulated by Malaysian trawlers, then Indonesian trawlers (Martosubroto *et al.*1996). I know this well because my first scientific job, in 1975-1976, between my first degree and my doctoral work, was to help introduce trawling further south, i.e., into the Java Sea, via an Indonesian-German project conceived by the indefatigable Klaus Tiews (see Grémillet 2021).

Getting back to Thailand: obviously, one can plot the *MTL* of the coastal fisheries of Thailand, record that it increased as trawlers began to land enormous catches of previously inaccessible high-trophic level demersal fishes (e.g., large groupers and snappers), and then descended again. A similar 'up-and-down' *MTL* trajectory occurred in Mauritania (Lemrabott *et al.* 2024).

To make any sense, however, the FD concept must apply to areas (or better ecosystems) where the bulk of the fish and larger invertebrates can potentially be caught by the ensemble of fishing gears that are deployed (which implies industrial fishing). This had not been stated in the original description of FD, but it should have been obvious: you can't fish down a marine ecosystem with gear operated by hand, reaching a depth of only a few meters. But I had not counted with 'colleagues' such as T. Branch and the others, who considered it a scientific achievement when they convinced a few journalists that the MTC went 'up and down' in the Gulf of Thailand, and hence FD was not occurring there and thus not elsewhere, either.

Assertion 17: *"Global fisheries are at a crucial turning point, with high fishing pressure throughout marine food webs being offset in some regions by rebuilding efforts (Worm et al. 2009). To measure the successes and failures of management, it is important for biodiversity indicators to track fishing impacts. Indicators such as catch MTL use readily available data and are quick and easy to calculate, but without improvement are ineffective measures of trends in biodiversity."*

Comment 17: Here, one could challenge the representativeness of the case studies in Worm, Hilborn *et al.* (2009), which was based overwhelmingly on case studies from wealthier countries (see Figure 9). Instead, I would suggest that the Regional Marine Trophic Index (*RMTI*; Kleisner *et al.* 2014), i.e., the version of the *MTL* that accounts for offshore expansion is the improvement that is here implicitly called for. So, maybe this point by Branch *et al.*'s was not completely useless, because it forced us to think more deeply about potato fields, and fisheries expansion.

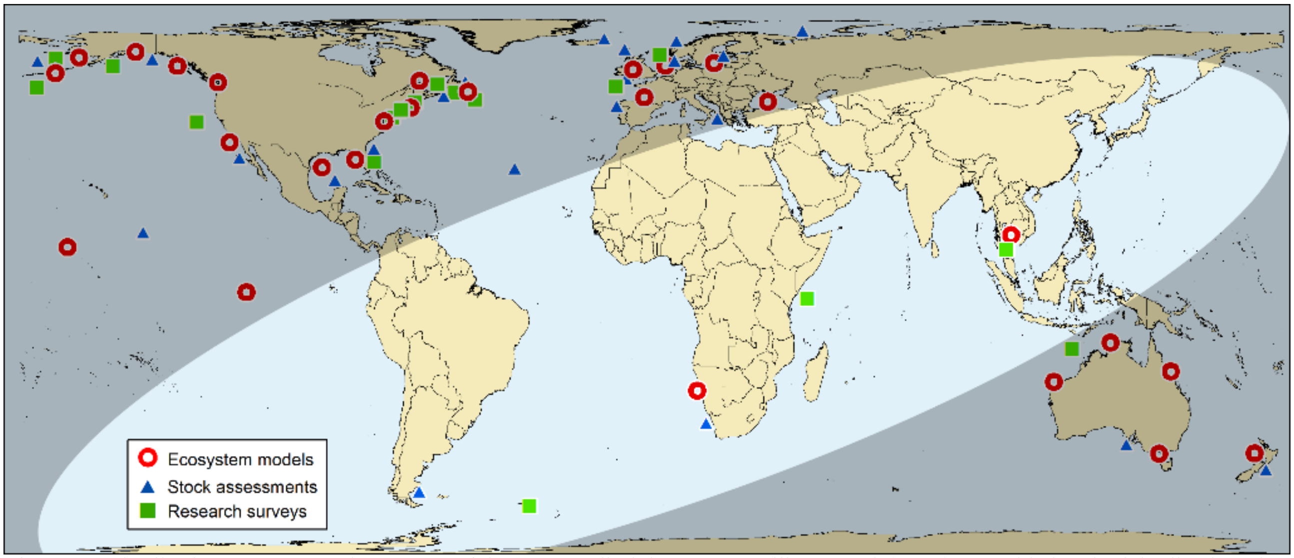

Figure 9. Distribution onto an equal-area map of the 'case studies' that Worm, Hilborn *et al.* (2009) assembled and originally plotted on a Mercator projection map (which is biased toward the high-latitudes areas of the northern Hemisphere) to suggest that theirs was a 'global' study. However, its coverage for Africa, Asia, and South America (light area) was ridiculously small and highly selective, even when considering that less fisheries research is performed and published in the Global South (see also Pauly *et al.* 2018).

Assertion 18: *"Our theoretical models and empirical comparisons of catch MTL with ecosystem MTL suggest that catch MTL does not reliably measure the magnitude of fishing impacts or the rate at which marine ecosystems are being altered by fishing. Instead, we recommend a greater emphasis on measuring and reporting changes in marine biodiversity by tracking trends in abundance relative to reference points for conservation and sustainable use."*

Comment 18: This again refers to the chauffeur-driven Cadillac of Comment 12.

Assertion 19: *"To target limited resources in the best way, we should focus on assessing species vulnerable to fishing that are not currently assessed, and on developing and expanding trend-detection methods that can be applied more widely, particularly to countries with few resources for science and assessment. Through such efforts we can better detect and convey the true impact of fisheries on marine biodiversity."*

Comment 19: Yes, it would be nice if more colleagues would focus "on developing and expanding trend-detection methods that can be applied more widely, particularly to countries with few resources for science and assessment" rather than publishing personal attacks that undermine with spurious arguments the few indicators that are currently available. But this is not an isolated case: similar bad-faith arguments were advanced to knock down 'stock-status plots', which the *Sea Around Us* uses to characterize the status of countries' fisheries (Hilborn and Branch 2013), although they never criticized their use by scientists working in FAO, where they were invented (Grainger and Garcia 1996; see Kleisner *et al.* 2013; Pauly 2013).

I experienced a similar attack when I launched the ELEFAN (Electronic Length-Frequency Analysis) approach and software for estimating growth parameters in small tropical fish and invertebrates (e.g., shrimp, squids), for example (see, e.g., Jackson *et al.* 2000). Now, ELEFAN is widely accepted, especially in the Global South and by FAO, which disseminates a version via its software series (Gayanilo *et al.* 1996, 2005). Another example is the resistance against the CMSY method of Froese *et al.* (2017), emanating from the same group, which is also failing to halt the wide acceptance of this new method in the Global South and elsewhere (see Nisar *et al.* 2021 Miyagawa *et al.* 2021, and especially Froese *et al.* 2023, who present hundreds of applications of CMSY and CMSY++).

What we have here is analogous to the desperate stand of the Italian 'abaquists' of the 11th century, who resisted the use of 'Arabic numbers' (which originated in India) because they were much simpler to use than the Roman numeral still current at the time. These 'number experts' used abacuses to keep the accounts of merchants and the replacement of Roman numerals (so difficult to handle that you need to go to a university to learn how to do multiplications) with Arabic numbers, and they knew that the Arabic numbers would make their expertise redundant and ruin their business (which they did). Thus, the expert went after Arabic numerals and those who used them, with the full support of the Church (obviously!), which had identified Arabic numerals as marks of the devil.

I cannot help but think that the experts who profess the need for "developing and expanding trend-detection methods, [etc.]" but do not do so and instead spend their time knocking people who try to empower their colleagues, notably in the Global South, are the 21st century's equivalent of the abaquist of lore, afraid to lose the privileges they derive from their meager expertise.

Assertion 20: *"Methods Summary: Each taxon in the analysis was assigned a diet-based fractional trophic level, mostly from the online database FishBase (Froese and Pauly 2010). Primary producers are trophic level one by definition, and were not included in our analyses; herbivores and filter feeders are trophic level two; and omnivores and carnivores are at higher trophic levels. MTL is the catch- or biomass-weighted average of trophic levels of taxa recorded in a particular year."*

Comment 20: Sure.

Assertion 21: *"Ecopath with Ecosim models (Christensen and Walters 2004) were compiled from well-documented sources and run for 100 years with zero catch to reach unfished states, and then four main scenarios of fishery development (fishing down (Pauly et al. 1998), fishing through (Essington et al. 2006), based on availability (Sethi et al. 2010) and increase to overfishing) were applied during years 101 to 200."*

Comment 21: The simulations *à la* Branch *et al.* were discussed previously (see Comment 7), and there is no need to revisit this sad topic; 'fishing through' was also dealt with previously (see Comment 1). Thus, here is the opportunity to look deeper at the weird concept of fishing "based on availability" which Branch *et al.* repeatedly cites, as if it contains deep insights. The title of Sethi *et al.* (2010) gives a clue: these authors have discovered that fishers want to have a profitable catch. Great! However, who said that fishers seek high-trophic level fish because of their high trophic levels? No one.

FD is the result of attempts to maximize (short-term) profits by catching and landing as many high-value fish and invertebrates as possible, be they (small, low-trophic level) shrimps in the Gulf of Mexico (where at least 4 kg of fish bycatch is discarded for every kg of shrimp landed; Graham 1996) or large, high-trophic level fish, which fetch a higher price than small ones (Pinnegar *et al.* 2002; Tsikliras and Polymeros 2014). FD is, wherever it occurs, the result of a multitude of tactical and, yes, economic decisions. No one has ever suggested otherwise, and to elevate the Sethi *et al.* (2010) 'discovery' of profit as the driver of fisheries as an argument against FD is outright silly.

Assertion 22: *"Global catch data were obtained from the United Nations Food and Agriculture Organization (FAO), while catch data for individual Large Marine Ecosystems came from the* Sea Around Us Project *of the University of British Columbia; trends in catch MTL from these two sources are nearly identical."*

Comment 22: The statement that the "trends in catch *MTL*" based on catch data from the FAO and the Large Marine Ecosystem (LME) catch from the *Sea Around Us* were "nearly identical", assumes that the reader will not know that the spatial resolution of the FAO catch data is extremely coarse, while that of LME is much finer. FAO divides the world ocean into 19 giant areas with rectilinear borders that include both coastal waters and large chunks of the high sea, while the *Sea Around Us*' LME data referred to 66 mainly coastal areas with predominantly natural borders (Sherman and Duda 1999). The seemingly innocuous statement that the *MTL* trends in these completely different geographies were 'nearly identical' is as credible as the notion that Swift's Brobdingnagians and Lilliputians were 'nearly identical' – excepting for their size.

Assertion 23: *"Long term scientific trawl surveys from 15 Large Marine Ecosystems provide biomass estimates for regularly recorded taxa, and were obtained from a variety of sources. Biomass estimates for individual taxa were typically not corrected for differential catchability among taxa; furthermore, invertebrate biomass estimates were seldom included in the provided data. MTL time series from individual surveys were combined into a single global time series using a linear mixed effects model with 'Large Marine Ecosystem' modelled as a random effect."*

Comment 23: Good.

Assertion 24: *"Stock assessment biomass values were obtained from the RAM Legacy database; total biomass was preferentially used in the analysis unless spawning biomass was the only time series available. Pearson correlations (r) were used to assess whether MTL followed the same trends in catches, surveys, and assessments, with statistical significance assessed after accounting for autocorrelation within time series."*

Comment 24: Stock assessments by FAO Statistical Area done by the *Sea Around Us* using an updated version of the CMSY method (Froese *et al.* 2017), all of which also used the changes in biomass documented in the RAM Legacy database (see Palomares *et al.* 2020) are shown in Figure 8, with corresponding mean trophic level trends superposed (from the *Sea Around Us* website (www.searoundus.org). It can be seen that the (declining) trends are similar. Thus, Branch *et al.*'s negative correlations between the stock assessment biomass and the survey data they analyzed were as fantasy-driven as their modelling.

Comment 25: Discussion

I do not have the fortitude to wade into the Supplementary Materials (incl. figures) that Branch *et al.* assembled. Therefore, I cannot exclude that it contains pearls of wisdom that would invalidate some aspects of the above critique.

With this caveat, I conclude that, to a large extent, the paper by Branch *et al.* (2010) was a hatchet job designed to compile anything that looked like arguments against a description of a major trend in fisheries (i.e., FD) that questioned their sustainability. That it emanated from an institution that has, since the days of the notorious fishery lobbyist W.M. Chapman (Finlay 2011; Pauly and Froese 2020), housed apologists for the fishing industry, notably R. Hilborn, was therefore not surprising, and neither were the ethical issues raised in Comment 9.

I invite readers to weigh Branch *et al.*'s attack against the many articles which, since 2010, have been published in the primary literature by a multitude of authors from a wide range of countries (in www.fishingdown.org). Each of these papers is independent evidence against the 'simulations' by Branch *et al.*, whose simulations were indeed …simulations.

The book with the optimistic title of 'Recovery" (Hilborn and Hilborn 2019) also inveighs against FD, mainly by repeating the previously discussed arguments, which there is no need to rehash here. Rather, I point to Figure 10, which contrasts the biomass of "[t]he total abundance of Atlantic cod from 1970 to 2012…" (Figure 10B) with the biomass Atlantic cod off New England (Figure 10A, in 1842, and from 1970 to 2001, from Rosenberg *et al.*

2005) and off Eastern Canada from 1840 to the near present (Figure 10C), the latter driven down by trawler catches in the late 1960s (Figure 10D; Schijns *et al.* 2021).

As can be seen from Figure 10B, cod biomass estimates for the period from 1970 (Hilborn and Hilborn 2019) give a rosy but inaccurate picture of the 'recovery' of Atlantic cod, which doesn't even begin to be corrected by the second part of their caption, i.e., that " …many individual cod stocks remain in poor condition."

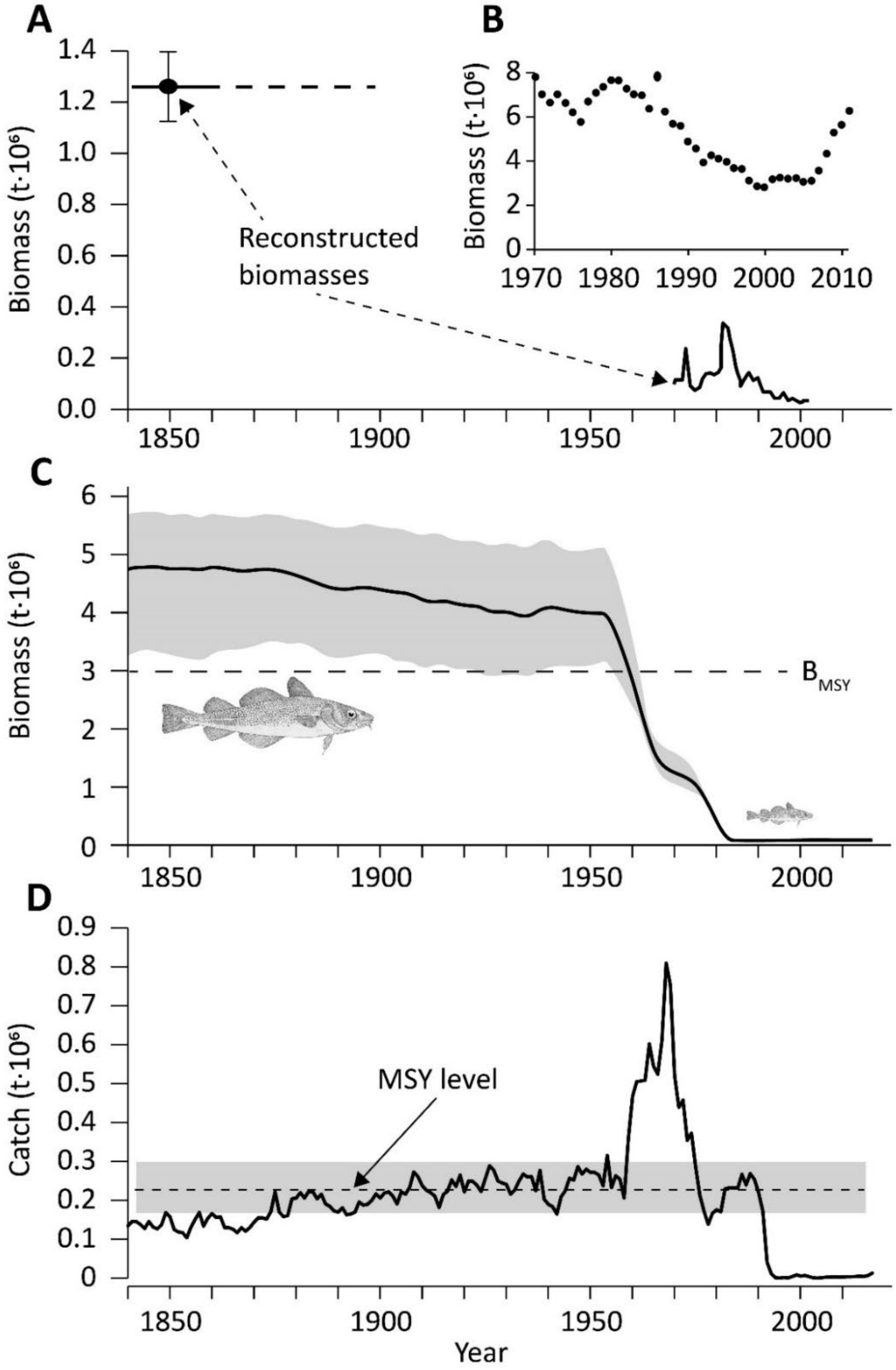

Figure 10. Biomass of Atlantic cod (*Gadus morhua*) in the North Atlantic. A: Reconstructed biomass off New England for the year 1852, in contrast to the biomass from 1970 to 2002 (from Rosenberg *et al.* 2006); B: Biomass of all cod stocks in the North Atlantic (from figure 5.5 in Hilborn and Hilborn 2019), suggesting a massive rebuilding… if one ignores the fact that these stocks where mostly depleted or collapsed in 1970; C: Reconstructed biomass of Canada's Northern cod from 1840 to 2019 (from Schijns *et al.* 2021), and D: time series of the Northern cod catches whose massive increase in the 1960s caused the demise shortly thereafter of a fishery that a lasted for nearly 5 centuries before the introduction of industrial trawling.

What we have here, rather, is a deliberate use by the authors of a shifted baseline (Pauly 1995) via the truncation of time series[14], to manipulate their readers into believing that, in the North Atlantic, cod are well on their way to recovery - while they are not. Note that the trick with the truncation of time series is commonly used in stock assessment (Schijns and Pauly 2021), notably by government scientists who don't want to be bothered with having to deal with collapsed stocks, and by academics funded by the fishing industry.

Finally, I should mention that the world ocean is more than ever in danger of being 'fished down.' One of the drivers are the phantom recoveries predicted by the overparameterized models used for stock assessments by government scientists in many countries which results in usustainable quota for stock that are already depleted (Edgar et al. 2024; Froese and Pauly 2024). Another driver is the frantic search for increasing supply of animal protein to feed the salmon, groupers, tuna, and other carnivorous fish the Norwegian-type aquaculture require. This increasingly include Antarctic krill (*Euphausia superba*) and copepods referred to as 'redfeed,' both of which are literally 'pumped' into the maw of an insatiable industry, and even more ominously, mesopelagic fishes. Until now, mesopelagic fishes, notably myctophid have been minimally exploited (Pauly *et al*. 2021), but all indications are that this will change in the near future (Hidalgo and Browman 2019; Standal and Grimaldo 2020), notwithstanding the sustainability of the tuna fisheries, many of which operate atop a plankton - mesopelagic fish – tuna ecosystem (see, e.g., Pauly and Christensen 1993).

A third driver of future fishing down, i.e., to marine catches consisting of lower trophic levels is the size reduction that ocean warming and deoxygenation will increasingly impose on fish and marine invertebrates (Cheung *et al*. 2013; Cornwall 2022; Bakun 2022; Pauly and Froese 2020; Pauly *et al*. 2022, and see contribution in Pauly and Dimarchpoulou), which will also reduce *MTL*, albeit to a lesser extent (see Figure 3) than extensive krill or mesopelagic fisheries. However, if not halted by a drastic reduction of our greenhouse gas emissions, ocean warming, and deoxygenation have the real potential to transform the global ocean into a 'Canfield Ocean' (Canfield 1988; https://en.wikipedia.org/wiki/Canfield_ocean), at which point nobody will need to worry about FD.

Acknowledgements

I thank Elaine Chu for Figures 1 – 10, and Rainer Froese, Jennifer Jacquet and Didier Gascuel for useful comments on the draft of this contribution.

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[14] The reason one can tell that this truncation was deliberate is that a contribution exists (Hilborn and Litzinger 2009) whose B_{MSY} estimate for the Northern cod, of 2.8 million t (which is similar to 3 million t estimated by Schijns *et al*. (2021; see Figure 10C), was based on data going back earlier than 1970.

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Appendix 1: On focusing one's microscope

Scientific discoveries are often a matter of focusing one's microscope — actual or virtual — and so rules have emerged on how to focus. For instance, plant and animal cells were discovered in the second half of the 17th century by Robert Hook and Anton van Leeuwenhoek, but it took over 150 years of arduous work to fully establish their role as building blocks of all living things. Kaspar Friedrich Wolff, who established that all plants were composed of cells, could be mentioned here, or Theodor Schwann, who demonstrated the same for animals.

Establishing this fundamental role of cells was complicated by the wide difference of cell sizes and other properties in various organs, and by the existence of acellular tissues in both plants and animals. But throughout these 150 or so years of sometimes bitter debate about the roles of cells, one thing was clear all along: Those who didn't believe in cells had to adjust their microscope in the manner of those who saw them, and not the other way around. Why? Because if the "cell denialists" (for lack of a better term) adjusted their microscopes such that they showed only objects larger or smaller than cells, then obviously cells were not detected, as also was the case if the dye they used to highlight their tissue samples did not generate sufficient contrast, or if they were clumsy and their samples were too thin or too thick for cells to be visible.

In other words: It was easy not to see cells, and this is why we celebrate those who did, along with those scientists who discovered things that others couldn't see, be those things natural selection, plate tectonics or the structure of DNA.

In 1998, my co-authors and I first described the phenomenon now known as 'fishing down marine food webs' mainly because we were lucky both with the data available at the time and with the setting of our conceptual 'microscopes.' The global catch data then at our disposal pertained to FAO's 18 large 'statistical areas,' and we could detect a strong fishing down signal in about half of them. We suggested that the fishing-down process might be widespread, but we didn't have a solid explanation at that time for why it did not seem to be occurring in all areas. "Fishing down" is essentially what happens when the fishes (and invertebrates) of a given ecosystem become vulnerable to fishing, e.g., to newly introduced trawlers. In such cases, the larger, longer-lived fishes of the top of the food web (which have high trophic levels) are depleted faster than the smaller, shorter-lived fish and invertebrates (which tend to have lower trophic levels). Thus, time series of multispecies catches from the ecosystem and assemblage in question will exhibit declining mean trophic levels.

Subsequent research by myself and my associates and by a number of independent authors throughout the world has helped to address the arguments of early critics of the fishing-down concept and to establish its general occurrence (see Figure 1 for an example) and intensity (about 0.05 - 0.10 TL per decade). Also, we were able to identify many of the factors that can cause the effect to be masked, thus knocking our microscope out of focus.

I have recently reviewed this work — in Chapter 3 of a book called *5 Easy Pieces: The Impact of Fisheries on Marine Ecosystems* — with reference to so-called 'judo arguments' that Isaac Asimov names for points that your opponent makes that can be turned around and actually strengthen your case. For example, one judo argument against the fishing-down concept was that it originally considered shifts in between-species composition, but not within-species changes in size and hence trophic level. This particular point turns into a judo argument once you consider that, when fishing intensifies, large fish (e.g., cod, grouper, or tuna) become smaller and hence tend to have lower trophic levels, trends that intensify the fishing-down effect. The other judo arguments were similar, with the fishing-down denialists repeatedly ending on the mat.

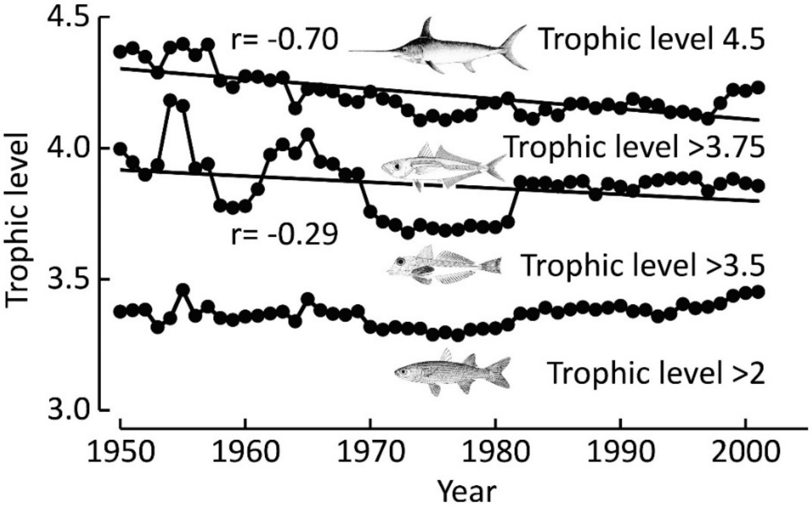

Figure 1. Fishing down in the eastern Mediterranean, as established using Greek fisheries catch statistics by K. Stergiou (In: State of the Hellenic Marine Environment 2005). Critics of fishing down cannot explain why such patterns repeatedly emerge, so they ignore the papers that present them. This specific graph, documenting fishing down by trophic level 'slices' also refutes the notion of 'fishing through,' which asserts that fishing down is an artifact caused by the inclusion, when computing mean trophic levels, of increasing catches of low-trophic-level organisms.

Recently, *Nature* published a paper on trends in fisheries that also had its microscope out of focus, and which consequently presented a confused picture, with fishing down sometimes visible, sometimes not. It will be shown elsewhere[15] that its authors' equally confused prose leads to several judo arguments. Notably, they did not consider the spatial expansion of fisheries, which is one of the strongest masking effects for fishing down.

Indeed, fisheries expansion, proceeding at rates ranging between 1 million and 4 million square kilometers per year from 1950 to the near present, is a masking factor that we had already identified and warned colleagues against. Thus, if you exploit a shelf ecosystem with a trawl fishery that reduces the abundance and size of the big fish and, indeed, the biomass of the entire exploited species assemblage, there is a point at which you will want to expand in deeper, offshore waters to access previously unexploited, large, high-trophic level fishes, and so on...

Consequently, if you compute time series of mean trophic levels in catches from an expanding area, chances are that you will fail to detect any fishing-down effect. This masking effect is the reason why, in science, we standardize key variables. For example, agronomists working on rice production use standardized paddies for their different treatments, and do not allow for expansion of the area planted. Similarly, when making statements about the health of the global ocean, or the status of the world's marine fisheries, researchers must use studies that do not represent a grossly biased sample, drawn from the well-managed fisheries of a few countries or regions at the world's end, like Alaska or New Zealand, lest one's microscope be, again, out of focus.

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[15] This is now presented above, in the paper of which this an appendix.