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Fishing down, fishing through and fishing up: fundamental process versus technical details

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ABSTRACT: Fishing through, fishing up (i.e. the observation that mean trophic levels [MTLs] of catches are increasing with time) and the question of agreement between MTL from catches and surveys have been used to question fishing down the marine food web as well as the use of the marine trophic index as an effective ecosystem indicator. This has evolved into a crucial debate in marine ecology and fisheries management. We believe that fishing down, fishing through and fishing up the food web are not incompatible but only appear so because of confusion. Fishing down is an ecological process, which can be expected to either occur or not, i.e. it is a hypothesis which can be falsified and replaced by an alternative hypothesis that must also rely on ecological principles (rather than technicalities). In contrast, fishing through and fishing up reflect technical issues related to biases in the available data and/or to fishing behaviour and thus do not falsify fishing down. The latter could be falsified if, for instance, in an ecosystem subjected to intense fishing, the biomasses of all or several large predators increase and these increases go along with an increase in their mean lengths for an extended period of time. Thus, MTL remains one of the most operational indices available for testing fishing down. It is without doubt that, in various cases, MTL will not be effective because of various technical confounding factors, which can be clarified by local experts. Undoubtedly, MTL can be misused, usually when confounding effects cannot be properly disentangled, and thus it must be used and interpreted with caution.

KEY WORDS: Fishing down · Fishing through · Fishing up · Food webs · Fisheries management

> 'Fifty years ago, a single cod was large enough to feed a family of four or five. Today, it is barely enough for one', says Lord Perry of Walton, a member of the UK House of Lords (Masood 1997, p. 110)

HISTORY

Pauly et al. (1998a) used FAO catch statistics and trophic levels (TLs) of all species or groups of species contributing to global catches and showed that their mean TL (MTL) significantly declined from 1973 to 1994, at a rate of about 0.1 TL per decade. This was true of both marine and freshwater catches, as well as for the majority of the FAO oceanic subareas (i.e. Atlantic, Indian and Pacific Oceans, and the Mediterranean and Black Seas). This phenomenon is now known as fishing down marine food webs. The original work gave rise to criticisms (Caddy et al. 1998, Caddy & Garibaldi 2000), which led to the elaboration of the fishing down concept (see Pauly 2010, Stergiou & Christensen 2011, for discussions). Fishing down is an ecological process with strong theory

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behind it (see below; also see Pauly 2010, Stergiou & Christensen 2011) and formed the basis for the development of an ecological index (i.e. marine trophic index: Pauly & Watson 2005), which was included in the Convention of Biological Diversity list of indicators. In addition, fishing down was put to the test in at least 34 cases, in 30 of which there was evidence of fishing down at smaller spatial (local) scales, whereas in 4 cases, the evidence was inconclusive or negative (see Table 1 in Stergiou & Christensen 2011).

Essington et al. (2006) described a decline in MTL due to the sequential addition of low TL catches rather than to a decline of high TL ones using the term fishing through the marine food webs. These authors analysed the catches in 48 out of the 62 large marine ecosystems (i.e. they excluded 14 large ecosystems from their analysis) and found that fishing down occurred in 30 of the 48 large ecosystems, with those in the North Atlantic suffering the most collapses of high TL species. Of these 30 large ecosystems in which fishing down was identified, the catches of high TL species declined in 9 ecosystems, were stable in 6 ecosystems and increased in 15 ecosystems. They concluded that, in most cases, the sequential addition of low TL species was the underlying mechanism of fishing down, even though this is contradicted by the fact that globally, catches are not increasing, and in fact are going down (Watson & Pauly 2001, FAO 2010).

Recently, Branch et al. (2010) performed an analysis based on (1) the MTL of the FAO global catches (as did Pauly et al. 1998a) and of the catches in various large ecosystems after being processed by the Sea Around Us Project (see Watson et al. 2004); (2) better estimates of species' TLs; and (3) the MTLs from trawl surveys and stock assessments from various large ecosystems. They found that the MTL of the high TL (>3.5) species constantly declined since 1950 as opposed to that of all species combined, which declined between 1950 and the mid-1980s and then increased, as was previously known from other studies and localities (e.g. Greek waters: Stergiou 2005). In addition, the MTL of the species with TLs >3.25 declined from 1950 to 1995 and increased thereafter, and those of the species with TLs >3.00 declined from 1950 to the late 1970s and increased thereafter. Branch et al. (2010) also reported that the MTL from 29 trawl surveys increased from 1970 to the mid-1980s and declined thereafter, while the MTL from 242 stock assessments declined from the mid-1970s to 2000 and increased thereafter. Although their analysis might be marred by their non-consideration of fisheries expansion, particularly evident in the Sea Around Us data they used (see Swartz et al. 2010), Branch et al. (2010) maintained that catch MTL trends do not necessarily reflect similar trends in ecosystem MTLs. This important finding stresses the need to shift the scientific focus away from examining only what is removed out of the ecosystems (i.e. catches) towards the use of surveys and assessments that measure what is left in the ecosystems (Branch 2011).

Such divergence in findings, all of which attracted large media attention, is very crucial for marine ecology and fisheries management because fishing through, fishing up (i.e. the observation that MTLs are increasing with time) and the question of agreement between MTLs from catches and surveys have been used to question fishing down (and thus either directly or indirectly, often to question the poor state of the ecosystems and the fisheries they support), as well as the use of the marine trophic index as an effective ecosystem indicator (see e.g. Hilborn 2011). However, in order for fishing down to be rejected, these diverging findings must at least be incompatible with each other. We examine this issue in the next section.

THESIS

We believe that fishing down, fishing through and fishing up the food web are not incompatible but only appear so because of confusion. What is fishing down actually? Fishing down is an ecological process which can be expected to either occur or not, i.e. it is a hypothesis that can be falsified and replaced by an alternative hypothesis, which must also rely on ecological principles (rather than technicalities). The fishing down hypothesis is formulated based on the following processes. Historically, fishing gears generally targeted and eventually selectively removed large species and large individuals within a species (Birkeland & Dayton 2005, Fenberg & Roy 2008). Large species generally grow slower, mature later and have lower intrinsic rates of increase, which prevent the quick replenishment of their populations under exploitation (e.g. Jennings et al. 1998). Thus, after many decades of fishing, ecosystems, and hence the catches derived from these, will be dominated by relatively smaller species and individuals (or, to be more conservative, the proportion of smaller species and individuals will progressively increase at the cost of larger species and individuals).

Such a decline in the biomass of large predatory species has been independently shown to occur in various areas and at different spatial scales of the world oceans using different data and methods (e.g. Christensen et al. 2003, Myers & Worm 2003, García et al. 2007, Ainley & Blight 2009, Lotze & Worm 2009, Thurstan et al. 2010, Kaufman 2011, but see Hilborn 2007). This relative shift from large to small species and individuals will be reflected in the MTL of the catches because of the positive relationship between body length and TL, both among and within species (the latter is true for most carnivores; Pauly et al. 1998b, Pauly & Palomares 2000, Stergiou & Karpouzi 2002), with only a few exceptions such as sharks feeding on plankton and large parrotfishes feeding on algae.

In contrast, fishing through and fishing up reflect technical issues related to biases in the available data (e.g. catches, TL estimates) and/or to fishing behaviour (e.g. orientation of fishers to target small pelagic fish for economic purposes or certain species because of regulations; horizontal/vertical expansion of fisheries because of technological advances; exploitation of new species higher or lower in the food web; exploitation of new introduced species). Thus, fishing through or up the food web, the 'alternative hypotheses', have no ecology behind them. Technical issues related to fishing behaviour should be known to local experts, who should be able to provide the technical explanation for the non-existence of fishing down in local studies. Similarly, biased (or incorrect) estimates of MTL because of use of global, biased or incorrect TLs and/or biased or incorrect catches, is not evidence of the non-existence of the process itself in a particular area until such biases are accounted for (i.e. obtain more accurate and unbiased stock, area and length specific TLs: e.g. Karachle & Stergiou 2008; use of reconstructed catches accounting for all sources of catches: e.g. Zeller & Pauly 2007) and fishing down tested again with revised data. In other words, fishing down cannot be rejected on the basis of technical issues, in the same sense as the effectiveness of autoregressive integrated moving average (ARIMA) modelling is not in any way determined by the accuracy of the underlying dataset but by whether it can deal with the main characteristics of this dataset (i.e. trend, seasonality, periodicity, nonstationarity, persistence: Stergiou et al. 1997). Similarly, fishing down could be falsified if for instance in an ecosystem subjected to intense fishing, the biomasses of all or several large predators increase, and this increase goes along with an increase in their mean lengths for an extended period of time.

There is no doubt that there might be cases in which fishing down will not be detected. For example, when the proportions of species with high TL significantly decline and those with low TL increase, overall MTL might not change significantly due to over-aggregation of data, as was the case in a 2-century analysis of Adriatic Sea data (Fortibuoni et al. 2010). In addition, if low TL pelagics or invertebrates are intensely fished, they could be depleted, and if fishing had also depleted the larger fish in the past, MTL might increase because of the decline of low TL species producing a false fishing up (e.g. observed in the Mediterranean Sea and in some upwelling systems; Blanchard et al. 2010, Coll et al. 2010).

Just as setting a microscope to high or low magnification may reveal different microorganisms (Pauly 2011), selecting the 'resolution' of a study will also reveal different patterns. However, this does not mean that shrinking of marine food webs is not occurring or that there are not fewer and smaller sharks in the sea than 50 yr ago. In the next section, we present 3 examples to show how the selective use of a sampling method, a dataset or a time frame may mask or even distort the output of any analysis.

EXAMPLES

The first example comes from Venice Lagoon. Libralato et al. (2004) analysed the catches in Venice Lagoon during 1945 to 2001. They identified different phases in the evolution of catches and their MTLs. The Manila clam *Tapes philippinarum*, a low TL species, was introduced to Venice Lagoon in 1983. It quickly colonised the lagoon and became the main target species for a new fishery, accounting for up to 90% of the landings during 1992 to 1999. This 'expansion' of Manila clam catches led to a decrease in MTL for the years following 1990, verifying that this decline was, in fact, what Essington et al. (2006) later named fishing through. However, this decline was also true even when Manila clam catches were excluded from the analysis of MTL (see Fig. 2 in Libralato et al. 2004). Thus, fishing through in Venice Lagoon did not actually falsify fishing down but required local knowledge in order for this to be unmasked.

The second example comes from Buller's (2010) excellent book on giant salmon. That author recorded the number and sizes of large Atlantic salmon *Salmo salar* individuals in northern Europe. Based on the records in Volume II, the number of Atlantic salmon individuals caught by fly fishing in Norway and exceeding 26 kg in weight was 3 (12% of the total) for the period 1960 to 2009, compared to 11 (55% of the total) for the period 1870 to 1960 (Buller 2010). Moreover, the mean size of Atlantic salmon caught by fly fishing significantly declined between 1900 and 2009 in Norway (correlation coefficient = –0.46, p = 0.002, n = 42; Fig. 1) and other northeastern Atlantic countries, excluding Norway (correlation coefficient = –0.35, p = 0.004, n = 36; data not shown). However, if one includes in the Norwegian dataset, a single large salmon caught in 2008 (black dot in Fig. 1), the line is distorted upwards and the relationship breaks down, becoming non-significant (correlation coefficient = –0.29, p = 0.053, n = 43; Fig. 1). Even if the decline in mean size is not significant, could we persuade anglers that large Atlantic salmon are still there to be fished as they were 50 to 60 yr ago, or could we argue against the within-species fishing down of Atlantic salmon?

The last example refers to the results of the Mediterranean bottom trawl survey (MEDITS) regarding the assessment of Mediterranean demersal fish stocks (www.ifremer.fr/Medits_indices). MEDITS assesses the biomass and total length of 26 target species in the Aegean Sea and Cretan waters, and data are available for 1997 to 2006. The relationship between TL and length is known (Stergiou & Karpouzi 2002) only for 3 out of the 26 target species: European hake *Merluccius merluccius*, common pandora *Pagellus erythrinus* and John Dory *Zeus faber*. The biomass of all 3 species generally increased during 1997 to 2006, but the increase was not significant

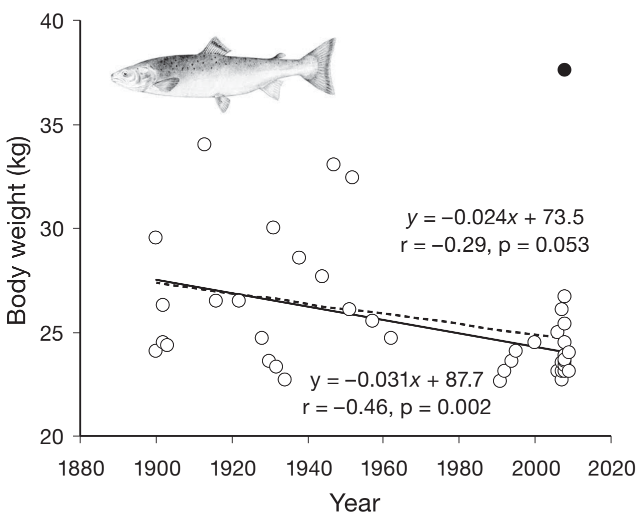

Fig. 1. *Salmo salar*. Body weight (kg) of large Atlantic salmon caught in Norway between 1900 and 2009. The continuous (significant) trend line excludes a single large individual caught in 2008, shown by the black dot; the dashed (non-significant) trend line includes this large individual

($p > 0.05$; Fig. 2A,C,E). At the same time, the mean length declined significantly from 1997 to 2006 for European hake and common pandora (Fig. 2B,D), whereas that of John Dory declined during 1997 to 2004 and increased during the last 2 yr, 2005 and 2006 (Fig. 2F). This supports fishers who maintain that hakes >70 cm seem to have disappeared from Aegean Sea catches, or, as fishers suggest, that large hakes have found a way not to be caught any more!

The MTL of the biomass of these 3 species combined did not change during 1997 to 2006, when a unique TL was used for each species (Fig. 3A), whereas it declined significantly (Fig. 3B) when using the size-specific TLs from Stergiou & Karpouzi (2002), which are less biased and more correct than the generic ones. This, in fact, shows that the use of length-specific MTLs would have most probably intensified global or local MTL trends of catches (Pauly et al. 1998b, Pauly & Palomares 2000), since MTL cannot capture the within-species fishing down (i.e. tropicalisation of stocks: Stergiou 2002) simply because the data required are largely unavailable. Thus, the use of generic species TL values leads to very conservative MTL estimates.

CONCLUSIONS

Our examples show that the selective use of data, methods and time frames may yield contradicting results regarding fishing down, MTL or length trends. However, irrespective of the method, dataset and time frame, they all clearly show that larger fish are being depleted and that fishing down, both within and among species, is not rejected.

Ideally, accurate estimates of year-, area- and size-specific TL values and annual mean lengths (and other ecological characteristics allowing size-based community analyses: e.g. Jennings & Dulvy 2005) for all species in the catches/surveys/assessments must be available in order to accurately test for fishing down. However, such a task requires tremendous resources, which will never be available, especially given the present dire straits of the global economy. Catch statistics are the cheapest annual 'surveys' that will most probably always be available for all countries at various spatial scales, whereas 'cheap' estimates of TLs of fishes and other commercially exploited organisms are also available in online databases (i.e. www.fishbase.org, www.sealifebase.org). Thus, MTL remains one of the most operational indices available for capturing the effects of fishing at the ecosystem level (and thus for testing fishing

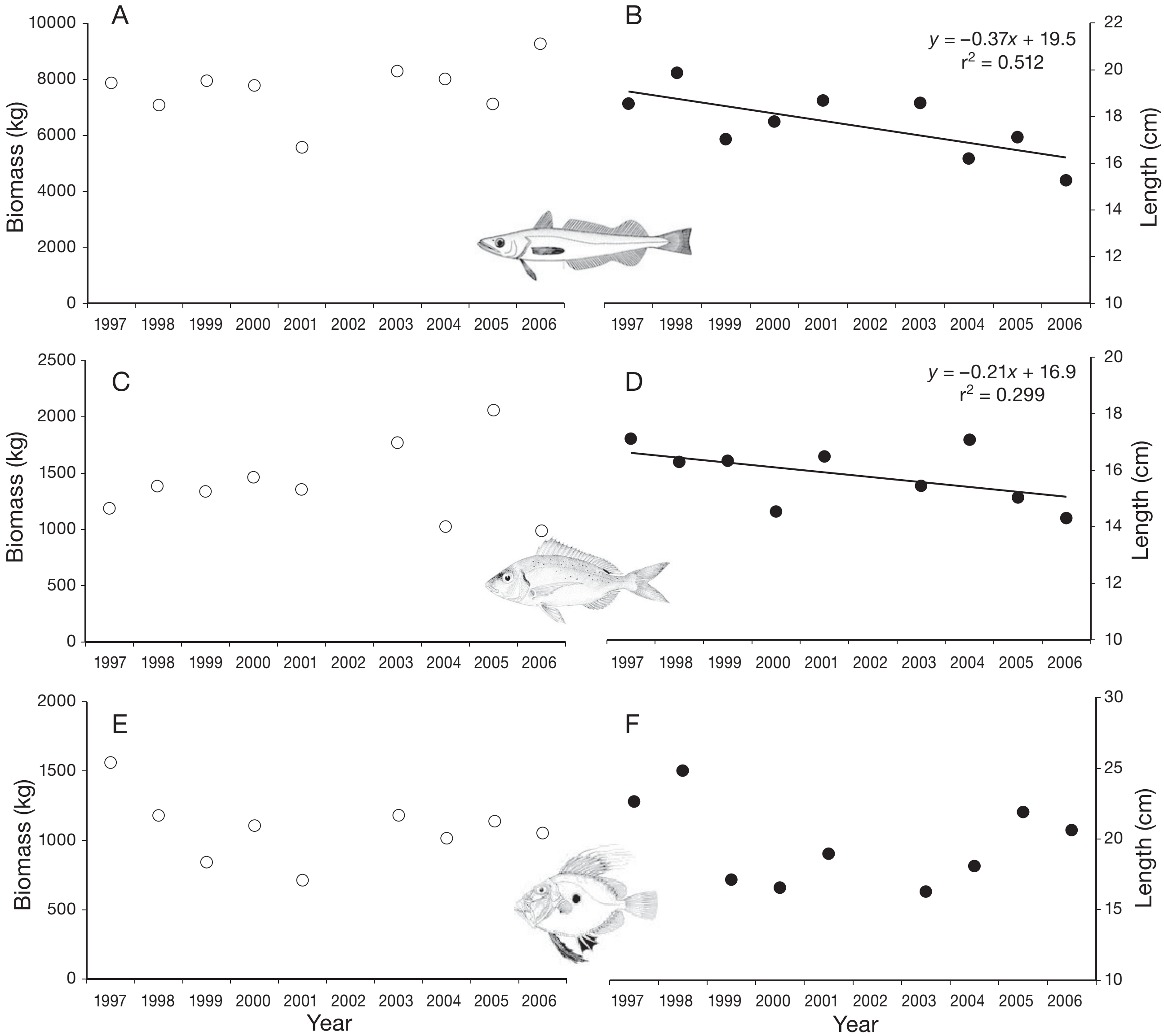

Fig. 2. Biomass (kg, ○) and mean total length (cm, ●) of (A,B) hake *Merluccius merluccius*, (C,D) common pandora *Pagellus erythrinus* and (E,F) John Dory *Zeus faber* for 1997–2006 in the Aegean and Cretan Seas (data from the Mediterranean bottom trawl survey [MEDITS] program, available at www.ifremer.fr/Medits_indices; preliminary data were also available for the first year of MEDITS, 1996, but did not cover all stations and areas)

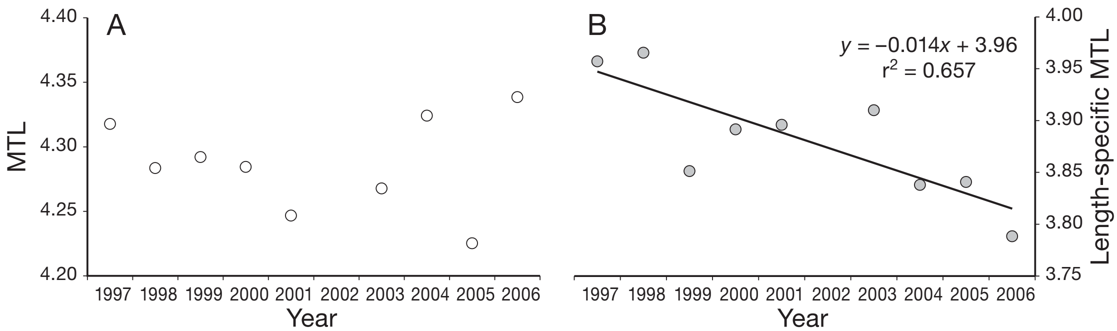

Fig. 3. (A) Mean trophic level (MTL, ○) and (B) mean size-specific trophic level (◍) of the biomass of hake *Merluccius merluccius*, common pandora *Pagellus erythrinus* and John Dory *Zeus faber* combined, 1997–2006

down). Naturally, better catch and TL estimates are needed for accurate computations of MTL. However, this is effectively realised for catches within the framework of the Sea Around Us project (www.seaaroundus.org; e.g. Zeller et al. 2006, 2007, 2008, 2011, Zeller & Pauly 2007) and for TLs within the framework of the FishBase team that constantly updates and statistically improves various life history estimates (e.g. see www.ecoknows.eu/).

However, it is without doubt that, in a few cases, MTL will not be effective because of various technical confounding factors, which by no means imply that the fishing down process itself is not working. Undoubtedly, MTL can be misused, usually when confounding effects cannot be properly disentangled, and thus it must be used and interpreted with caution.

The debate on using catch data or stock assessments and surveys might be of academic interest only, while the distinction between process and technicalities is academic as well as realistic, since, in fisheries management, it is better to be safe than sorry.

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