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Fishing down the food web: an Icelandic case study

Abstract

'Fishing down marine food webs' (FDMW) occurs when the mean trophic level (TL) of fisheries landings decline over time, reflecting a decreasing abundance of high-TL (predatory) fishes in the underlying ecosystems. The FDMW phenomenon, which implies a lack of sustainability at the ecosystem level, and which has been demonstrated to occur throughout the world, is shown here to exist around Iceland as well. Based on the longest series of standardized catch data ever assembled for Icelandic waters, we show that the mean TL of landings has been decreasing during most of the 20th century as catches of high trophic level species, mainly cod, have declined while the fisheries have moved onto other species, especially small pelagics and invertebrates. Suggestions are presented on how these results may be used for monitoring performance in the context of at transition toward ecosystem-based management.

Fishing down the food web as a global phenomenon

Fisheries evidently must impact on the abundance of the species they target. It is less evident - though increasingly well demonstrated - that fisheries also impact the species they do not target - the by-catch -whether that by-catch is subsequently discarded or not (Alverson et al. 1994). Even less

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evident - at least to managers accustomed to dealing with single species - is that fisheries also impact species they do not catch, either through habitat modification or through their appropriation of biological production (Pauly and Christensen 1995).

These impacts are among the many reasons why it is now widely agreed that some form of 'ecosystem-based' management of fisheries is in order, even though there is at present, no sign of a scientific consensus as to how to implement such form of management (NRC 1999). It does seem, however, that any consensus on 'ecosystem-based' management will have to include the maintenance, in some form, of the ecosystem in which fisheries resource species are embedded, which itself requires indicators capable of tracking ecosystem states.

Pauly et al. (1998a) suggested that the mean trophic level (TL) of the fish and invertebrate species landed by fisheries provides such an indicator, due to the integrative nature of TL, which correlate with body size (and hence longevity), and which thus link the role played by different species within ecosystems' food webs to their vulnerability to exploitation.

Food webs can be defined in terms of TL:

- algae, at the bottom of the food web have a TL of 1;
- herbivorous zooplankton, which feeds on (microscopic) algae have a TL of 2;
- large zooplankton or small fishes that feed on herbivorous zooplankton have a TL of 3; etc. (Lindeman 1942; Odum and Heald 1975).

Large, long-lived fishes (cod, groupers, etc.), usually have TL s between 3.5 and 4.5, because their food tends to be a mixture of low and high- TL organisms. Thus, fisheries, when removing large fish tend to reduce the mean TL of the fish remaining in an ecosystem, which eventually leads to a trend of decreasing TLs in the landings extracted from that ecosystem, a phenomenon referred to as 'Fishing down marine food webs (FDMW; Pauly et al. 1998a).

Several objections have been raised to the use of mean TL as indicator of the ecosystem impact of fishing (Caddy et al. 1998), and these are addressed in Pauly et al. (1998b) and Pauly and Palomares (2000). One of the objections pertained to the use of the global fisheries statistics created and maintained by the Food and Agriculture Organization (FAO) for the demonstration of FDMW: Caddy et al. (1998) felt these statistics, to be too crudely aggregated (in taxonomic terms) to provide a consistent signal.

The answer to this, obviously, is to replicate the exercise in Pauly et al. (1998a) using better, more detailed data, including data starting earlier than the FAO statistics (i.e., earlier than 1950). Pauly et al. (2001) present such analysis for Canadian waters, and also address other issues raised by Caddy et al. (1998), notably the effect of within-species change in TL. Stergiou (2000) presents a similar analysis for Greek waters, while Pinnegar et al. (2002) presented a detailed case study of FDMW for the Celtic Sea.

This contribution replicates Pauly et al. (1998a) for Icelandic waters, i.e., in an area where long time series of relatively reliable catch data existed, or could be straightforwardly reconstructed, and where the management of major commercial species is generally considered successful - at least in comparison with other areas of the North Atlantic.

Hence a demonstration of FDMW in Icelandic waters would both corroborate the generality of the FDMW phenomenon, and indicate the need for management measures reaching beyond ensuring sustained yields of major species. Before dealing with FDMW around Iceland, we must however provide a context in form of a brief review of the relevant fisheries.

Fisheries in Icelandic waters

As in other areas of the North Atlantic, cod (*Gadus morhua*) has always been the most important species in Icelandic waters, although its relative importance has been declining during the later part of the 20th century (fig. 1). Other large gadoids such as saithe (*Pollachius virens*) and haddock (*Melanogrammus aeglefinus*) have also been fished extensively for the whole 20th century by the groundfish fleet, which, in the later part of the century also moved to deeper water to target redfish (*Sebastes* spp.) and Greenland halibut (*Reinhardtius hippoglossoides*). Pelagic fisheries concentrated exclusively on herring (*Clupea harengus*), until its collapse in the late 1960s, which led to capelin (*Mallotus villosus*) and recently blue whiting (*Micromesistius poutassou*) becoming the major species targeted by the pelagic fisheries. Invertebrate fisheries began around the middle of the century, initially based on Northern shrimp (*Pandalus borealis*) and Norway lobster (*Nephrops norvegicius*), the former eventually becoming one of the most valuable fisheries in Icelandic waters. Whaling was quite important for the economy in the first decade of the 20^{th} century, but was much lower after the First World War (WWI).

Foreign boats have always long been fishing in Icelandic waters (fig. 1). Initially, English and German vessels dominated the foreign groundfish fisheries, and Norwegian vessels the pelagic fisheries. However, most foreign fleets were expelled from Icelandic waters as the economic exclusive zone was gradually extended, from 4 miles in 1952 to 200 miles in 1975. Presently, most fisheries around Iceland are under the sole jurisdiction of the country, which thus cannot ignore its responsibility with regard to maintaining the productivity of the stocks upon which much of the economy depend.

Material and Methods

The catch database used here is documented in Valtysson (2002), reaches back to the beginning of the 20 century, and includes catches from the fleets of all countries known to have fished in Icelandic waters (fig. 1).

Each of the species reported in this catch database was assigned a TL, calculated from

$$TL_i = 1 + \sum_{j=1}^{n} DC_{ij} TL_j$$

where i is the predator; j the nth prey; and DC_{ij} is the diet composition, expressing the fractions of each j in the diet of i. Assignment of TL starts with plants and detritus, both with a definitional TL value of 1.

The DC_{ij} and TL_j used here were calculated based on diet composition data in Pálsson (1977, 1983) and Anon (1997). The TL of species for which diet information was not available from Iceland was estimated from diet composition from other areas, either for the same or closely related species, with FishBase serving as our main source of information (Froese and Pauly 2000; *www.fishbase.org*).

For all but one species the TL estimates thus obtained are assumed to apply to an average fish, i.e., ontogenic changes of diet are assumed to

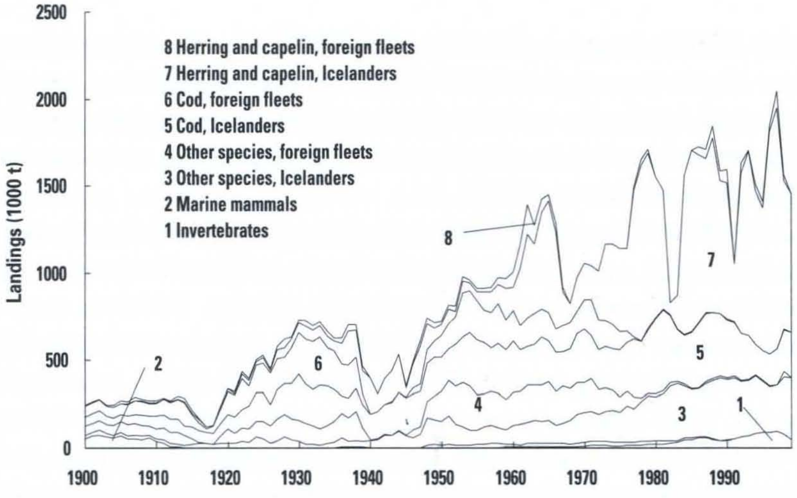

Figure 1: Time series of aggregated landings from Icelandic waters (ICES area Va and Icelandic EEZ) during the 20th century.

have negligible effect on the estimate of TL. For cod, the most important species in Iceland, enough diet composition data (Pálsson 1983) and information on size composition in landings (since 1969) were available for size specific estimates of TL to be computed for comparison. These were then used, along with the TL estimates for other species, to compute annual estimates of mean TL from

$$\bar{TL}_k = \sum_{i=1}^{m} Y_{ik} TL_i \ / \sum_{i=1}^{m} Y_{ik}$$

where Y_{ik} is the landings of species i in year k, and TL_{ik} its trophic level.

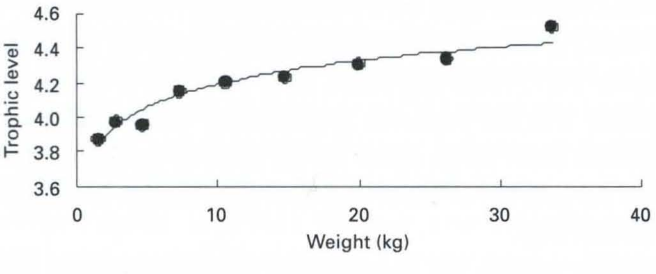

Figure 2: The relationship between trophic level and size of cod.

Results and Discussion

The diet composition data from Iceland used here led to TL estimates (table 1) similar to those derived from diet composition data from other areas (Armstrong 1982, dos Santos and Falk-Petersen 1989; Froese and Pauly 2000, Pauly et al. 2001). Conversely, we assume that the TL estimates we derived from diet compositions from other areas did not bias the results of our analysis. We also note, in passing, that, once body size is accounted for, TL estimates based on diet composition data are similar to estimates based on stable isotope ratios (Kline and Pauly 1998; Pinnegar et al. 2002), and hence do reflect the average position of fish within marine food webs.

Fig. 2 shows how in cod, TL changes with size, this relationship being described by

$$TL = 3.736 + 0.195 \ln(W)$$

where W is the body weight of cod, in g.

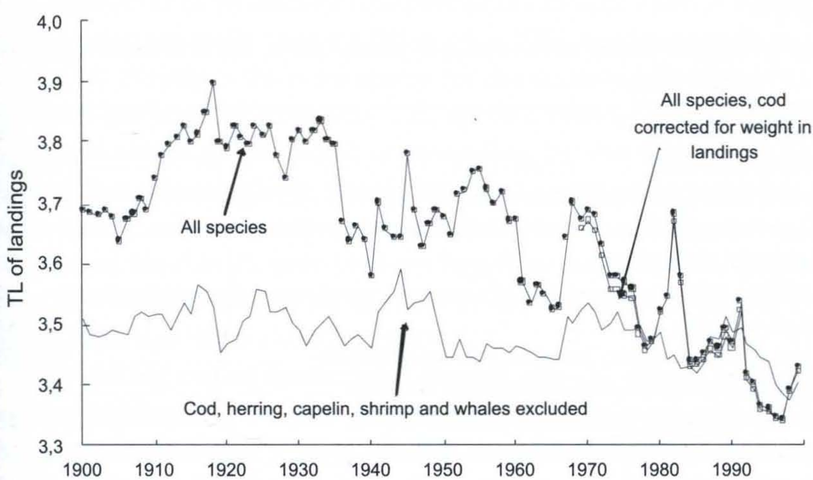

Figure 3: Time series of mean TL of all fisheries in Icelandic waters.

Thus, as increasing fishing mortality reduces mean body size, TL is reduced as well, a feature not considered in Pauly et al. (1998a), but later found not have much impact on observed mean TL trends, which appear more strongly impacted by changes of species composition than by within-species changes of TL (Pauly et al. 2001). Fig. 3 similarly shows that, while the FDMW phenomenon is very marked in Icelandic waters, accounting for change in cod size does not have a major effect on the general trend. This, although it duplicates a similar finding for the coast of Eastern Canada, is a somewhat surprising result. It suggests however, that FDMW is a robust phenomenon, detectable even in data-poor environment. We would however be curious to see if this is also the case with longer time series of size at age data or interannual or between-population differences in diet composition. It will be of interest, for example, to compare years when capelin is abundance with other years, as it has been shown that the growth of individual cod is largely controlled by capelin abundance (Jakobsson and Stefánsson 1998).

Overall, fig. 3 shows an increase in TL in the beginning of the 20th century from about 3.6 until after WWI, then a succession of steps, starting with stability at slightly more than 3.8 in the interwar period, a drop of 0.2

Table 1: Estimated trophic levels of major exploited species, and of common food groups around Iceland.

Species or group	TL
Seals, Greenland shark	4.6
Greenland halibut, halibut, toothed whales, average cod	4.0
Lings, grenadiers, humpback whale, minke whale, tusk, whiting	3.8
Dogfishes and skates, saithe	3.7
Blue whiting, catfishes, lumpsucker, Norway pout, squid, salmonids, long rough dab	3.5
Haddock, sandeels	3.4
Blue and sei whale, capelin, fin whale, herring, redfishese	3.3
Eelpouts, great silver smelt, chimaeras, misc. flatfishes	3.2
Crabs, Norway lobster, whelk, benthos (other)	2.5
Sea urchins, shrimps, euphausiaceans	2.3
Ocean quahog, scallop	2.1
Polychaets, (detritivorous), herbivorous zooplankton	2.0
Algae	1.0

TL units in the mid 1930s, some stability until the mid 1950s, then a more marked decline to the present value of about 3.4. The overall decline for the 20th century is about 0.0036 TL per decade and 0.0053 TL if we consider only the years since WWI.

Trophic levels increased at the start of the 20th century due to decreasing catches of baleen whales, which though large, have the low TL that befits zooplankton feeders (see Table 1). Mean TL after WWI were influenced mainly by the sustained, high catches of cod, a species with a high TL. This changed around 1935 when cod catches declined considerably and the TL of catches subsequently fell. Herring catches are also increasing during this time, further increasing the downward TL trend. The high catches of the large pelagic stocks feeding low in the food web, herring and capelin became the main reason why the TL of Icelandic catches failed to recover their pre-1935 levels. Fluctuating landings of these two large stocks do also largely explain the fluctuating decline in TL after 1955. Herring fisheries became extensive shortly before WWII, and reached a peak in the 1960s, with a corresponding drop in TL. The herring fishery collapsed in 1968 and the TL of catches increased again but dropped again to low levels when pelagic fishers began exploiting capelin. The small TL peaks from 1980 to 1990 correspond to temporary collapses of the capelin stock. Landings of cod have also generally been declining since 1955, further magnifying this drop in TL. Shrimp is the main reason for the declining TL after 1990, but increased landings of other low T.L. species such as green sea urchin (*Strongylocentrotus droebachensis*), ocean quahog (*Arctica islandica*) and various flatfishes also contribute. The shrimp stock expanded in size when predation by the cod was reduced due to low size of the cod stock after 1990. The upward trend in TL after 1998 can largely be attributed to a larger cod stock, both contributing to an increase in cod catches and decline in the shrimp stock and hence shrimp catches.

When the big impact species (cod, herring, capelin, shrimp and whales) are excluded from the analysis we get a fairly stable picture, with the TL of the fisheries fluctuating around 3.5. The exception is a substantial decline in the latest years. These are mainly due to the declining catches of high TL Greenland halibut and saithe as they have been overfished and increasing catches of low TL sea urchin, ocean quahog and flatfishes.

As with other fisheries in the northern regions, the Icelandic fisheries are generally high TL fisheries (Pauly et al. 1998, Pauly et al. 2001). The downward trend in the TL of Icelandic fisheries is, however, a fact. The declining TL level of the Icelandic fishery is a reflection of increasing interest in pelagic species and invertebrate due to new fishing technology, fish processing technology and marketing. However, these are of course driven by restrictions in groundfish catches due to declining stocks. The changes in TL are therefore not pronounced within each fishing boat class [data not shown], but rather reflect changing composition of the fishing fleet and fishing gear used.

It is also noticable that large high TL species such as Atlantic halibut and common skate (*Raja batis*), whose stocks were decimated by overfishing were never common enough to have any significant impact on the overall TL change.

Studies should be conducted on whether the FDMW trends based on catch or landing data under- or overestimate the TL trends in the underlying ecosystems, as can be ascertained from fisheries independent data, notably trawl survey. Pinnegar et al. (2002) found the FDFW trends based on trawl surveys to be stronger than those based on catch data, suggesting that over time, skippers attempt, but eventually fail to maintain high catches of high-TL fishes. This interesting result still needs verification from other areas. Close look at the Icelandic trawl survey data, now covering 17 years since 1985 would for example be a good candidate.

The question that remains is how dangerous the FDMW phenomenon is to the ecosystem(s) within which the marine fisheries around Iceland are embedded. Is there some TL/catch combination on the line fitted to the data in Fig. 4 that should be avoided at all cost? Or should alarm bells ring only when the annual data points start moving below that line, i.e., when the TL/catch plot (fig. 4) starts to 'bend backward' (Pauly et al. 1998a), and decrease in TL cease to lead to increasing catches?

Ecosystem collapse have been simulated by Vasconcellos and Gasalla (2001), and occurred at values of TL= 3.2, the same value that occurred when Northern cod collapsed in Eastern Canada, and close to the value for Icelandic fisheries in 1994 to 1996, when the Icelandic cod stock was at the historically lowest level ever (Anon 2001). A further point to consider

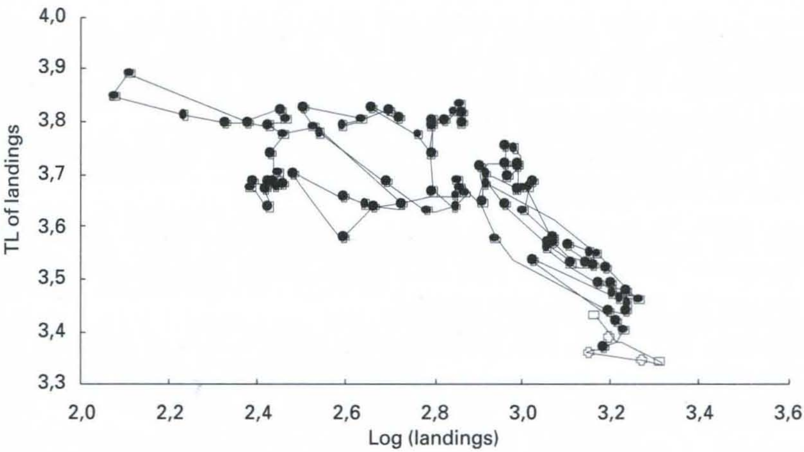

Figure 4: Trophic level of landings (with "average cod") vs log landings, 1995 – 1999 shown with open circles.

regarding this is that despite the fact that the stock size increased somewhat after 1995, the stock was still overestimated by fishery scientists for at least four years in row after 1996. This error was larger than ever before despite quite advanced assessment methods being used and considerable and improved data collection from the fisheries. Perhaps this implies some underlying changes in the entire ecosystem due to overexploitation of the top predators. Clearly, caution is warranted, as are attempt to identify such threshold in similar fisheries (Pauly et al. 2001), notably those of Greenland, Faeroe Islands, northern Norway, which are most similar to those in Iceland.

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References

Alverson, D.L., M. Freeberg, J. Pope and S. Murawski 1994). A global-assessment of fisheries by-catch and discards: A summary overview. FAO Fisheries Technical Paper No. 339, Rome, 233 p.

Anon, 1997. Fjölstofnarannsóknir 1992-1995. Fjölrit Hafrannsóknastofnunar 57. 410 p. [Multispecies research 1992-1995]

Anon, 2001. State of marine stocks in Icelandic waters 2000/2001 - Prospects for the quota year 2001/2002. Fjölrit Hafrannsóknastofnunarinnar 80. 186 p [see *www.hafro.is*]

Armstrong, M J., 1982. The predator-prey relationships of Irish Sea poor-cod (*Trisopterus minutus L.*), pouting (*Trisopterus luscus L*), and cod (*Gadus morhua L.*). J. Cons. int. Explor. Mer 40:135-152.

Caddy, J.F., J. Csirke, S.M. Garcia, and R.J.R. Grainger. 1998. How pervasive is "Fishing down marine food webs?". Science 282: 183 [full text (p. '1383a') on *www.sciencemag.org/cgi/content/full/282/5393/1383]*.

dos Santos, J. and S. Falk-Petersen, 1989. Feeding ecology of cod (*Gadus morhua L.*) in Balfjord and Ullsfjord, northern Norway, 1982-1983. J. Cons. int. Explor. Mer. 45:190-199

Froese, R. and D. Pauly (Editors) 2000. FishBase 2000: Concepts, design and data sources. ICLARM, Los Baños. 344 p. [Distributed with four CD-ROMs; see *www.fishbase.org* for updates]

Jakobsson, J. and Stefánsson G. 1998. Rational harvesting of the cod-capelin-shrimp complex in the Icelandic marine ecosystem. Fisheries Research 37: 7-21.

Kline, T.C., Jr. and D. Pauly. 1998. Cross-validation of trophic level estimates from a mass-balance model of Prince William Sound using $^{15}N/^{14}N$ data. p. 693-702. In: T.J. Quinn II, F. Funk. J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, C.-I. Zhang (eds.). Proceedings of the International Symposium on Fishery Stock Assessment Models. Alaska Sea Grant College program Report No. 98-01. Alaska Sea Grant, Fairbanks.

Lindeman, R.L. 1942. The trophic-dynamic aspect of ecology. Ecology 23(4):399-418.

NRC. 1999. Sustainable marine fisheries. U.S. National Research Council.

National Academy Press, Washington D.C. 164 p.
Odum, W.E. and E.J. Heald. 1975. The detritus-based food web of an estuarine mangrove community. p. 265-286 In: L.E. Cronin (ed.) Estuarine Research. Vol. 1, Academic Press, New York.
Pálsson, Ó.K. 1977. Framleiðslugeta og nýting dýrastofna á Íslandsmiðum. Rit Landverndar 5: 43-55. [The production and exploitation of animal species in Icelandic waters].
Pálsson, Ó.K. 1983. The feeding habits of demersal fish species in Icelandic waters. Rit Fiskdeildar 7 (1): 1-60
Pauly, D. and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature 374:255-257.
Pauly, D. Christensen, V., Dalsgaard, J., Froese, R. and Torres Jr, F. 1998a. Fishing down marine food webs. Science. 279: 860-863
Pauly, D., R. Froese and V. Christensen. 1998b. How pervasive is "Fishing down marine food webs": response to Caddy et al. Science 282: 183 [full text (p. '1383a') on *www.sciencemag.org/cgi/content/full/282/5393/1383]*.
Pauly, D. and M.L. Palomares 2000. Approaches for dealing with three sources of bias when studying the fishing down marine food web phenomenon. p. 61-66. In: F. Durand (ed.) Fishing down the Mediterranean food webs? Proceedings of a CIESM Workshop held in Kerkyra, Greece, 26-30 July, 2000. CIESM Workshop Series No 12, 99 p.
Pauly, D. Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D. and Wallace, S. 2001. Fishing down Canadian aquatic food webs. Can. J. Fish. Aquat. Sci. 58. 51-62.
Pauly, D., V. Christensen and C. Walters. 2000. Ecopath, Ecosim and Ecospace as tools for evaluating ecosystem impact of fisheries. ICES Journal of Marine Science 57: 697-706.
Pinnegar, J.K., Jennings, S., O'Brien, C.M. & Polunin, N.V.C. 2002. Long-term changes in the trophic level of the Celtic Sea fish community and fish market price distribution. Journal of Applied Ecology 39(3):377-390.
Stergiou, K.I. and M. Koulouris. 2000. Fishing down the marine food webs in the Hellenic seas. P. 73-78 In: F. Durand (ed.) Fishing down the Mediterranean food webs? Proceedings of a CIESM Workshop held in Kerkyra, Greece, 26-30 July, 2000. CIESM Workshop Series No 12, 99 p.
Valtysson, H.Þ. 2002. The sea around Icelanders: Catch history and

discards in Icelandic waters. In D. Zeller, R. Watson, T. Pitcher and D. Pauly (eds). Fisheries Impacts on North Atlantic Ecosystems: Catch, Effort and National/Regional Data Sets. Fisheries Centre Research Reports 9(3):52-87

Vasconcellos, M. and Gasalla, M.A. 2001. Fisheries catches and the carrying capacity of marine ecosystems in southern Brazil. Fisheries Research 50: 279-295