Spatial expansion of EU and non-EU fishing fleets into the global ocean 1950 to the present

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Spatial expansion of EU and non-EU fishing fleets into the global ocean, 1950 to the present

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Abstract

The Concept of Primary Production Required (PPR), initially proposed by D. Pauly and V. Christensen (2001, *Nature,* 374:255-257) is recalled and used, jointly with annual maps of spatialized fisheries landings, to describe the geographic expansion of fisheries from 1950 to 2006, separately for EU, non-EU and all global fleets. The results, maps of threshold levels of PPR (reaching and then exceeding 10, 20 and 30% PPR), clearly show the spatial expansion of fisheries that went along with catch increase from 1950 to the late 1980, followed by a stagnation, then decline of landings. These trends suggest that overall, global fishery resources have not been sustainably exploited.

Introduction

Given that overfishing is a threat to human well-being and economic progress on a large scale (Srinivasan et al. 2010), it is important to ask how limited our global marine resources are and how much fishing can be supported. Clearly, fish production is limited in various ways, of which arguably the most important is the solar energy that ocean ecosystems receive and which drive their productivity (Pauly and Christensen 1995). The upper limits proposed for sustainable marine fisheries landing have ranged from 100 to 140 million tonnes per year, estimated using a variety of methods (Pauly 1996, Grainger and Garcia 1996; Chassot et al. 2010). Total reported landings have, however, stagnate at 80 million tonnes for several years now (Watson and Pauly 2001), with perhaps another 20 million tonnes of additional illegal catch (Agnew et al. 2009). Unfortunately, catches have not been capped by conservative management (Mora et al. 2009; Alder et al. 2010), as illustrated by the fact that fishing intensity, as expressed by the power of fishing vessels has continued to increase (Anticamara et al. 2011). In addition , fishing vessels and their equipment (fishing gear, onboard electronics, etc.) are becoming steadily more efficient, so that fishing effort has increased its effectiveness year after year (Pauly and Palomares 2010).

The expansion of global fishing fleets, driven by declining inshore catches, aided by improved technology and supported by subsidies (Sumaila 2010a, 2010b), has meant that few resources are now unfished (Swartz et al. 2010), and fishing now proceed even at great depths (Pauly et al. 2003; Morato et al. 2006; Norse et al. 2011). The expansion went along with the decline of fisheries on a grand scale (Christensen et al. 2003), and distant water fleets account for a large proportion of global fisheries landings (Bonfil et al. 1998). European and other fleets from developed nations now rely on resources from the developing world, such as West and East Africa (Alder and Sumaila 2004; Atta-Mills et al. 2004; Le Manach et al. 2012). The share of global productivity diverted by fisheries is considerable (Pauly and Christensen 1995) and this is arguably one of the best measures of aggregate level of fisheries exploitation (see also National Geographic, Oct. 2010 edition, and http://www.seaaroundus.org/national_geographic/). With the development of mapped global catch databases (Watson et al. 2004, 2005) it is now possible to track, through the Primary Production Required (PPR), how much primary productivity is captured by global fisheries through time on a fine spatial scale. Thus, Swartz et al. (2010) showed how the PPR levels increased and high PPR levels spread globally.

Here, we have recalculated PPR threshold levels using the latest available data on fisheries landings (currently only spatially disaggregated up to 2006) and trophic levels for the European, non-European and global fleets. This involved the production of annual maps of PPR levels from 1950 to 2006, which allows the underlying expansion to be better appreciated by managers, scientists and the public.

Methods

The analysis, which covers the period from 1950 to 2006, defines fisheries exploitation based on the primary production that is required to generate the catches of marine fisheries. The Primary Production Required (PPR), as proposed by Pauly and Christensen (1995) is computed from:

$$PPR = \sum_{i=1}^{n} \frac{C_i}{CR} \times \left(\frac{1}{TE}\right)^{(TL_i - 1)}$$

Where C_i is the catch of species *i*, *CR* is the conversion rate of wet weight to carbon, *TE* is the transfer efficiency between trophic levels, TL_i is the trophic level of species *i*, and *n* is the number of species caught in a given area. We applied a 9:1 ratio for *CR* and 10% for *TE* (Pauly and Christensen, 1995). Species-specific trophic levels, usually derived from diet composition, i.e., stomach content data, were taken from FishBase (*www.fishbase.org*) for fishes and SeaLifeBase (*www.sealifebase.org*) for invertebrates. Annual catch data were taken from the spatially disaggregated global catch database of the *Sea Around Us* project (Watson et al. 2004). This online database (*www.seaaroundus.org*) is derived mainly from corrected FAO global fisheries catch statistics (*www.fao.org/fishery/statistics/en*), complemented by the statistics of various international and national agencies, and reconstructed datasets (Zeller and Pauly 2007). These statistics, after harmonization, are disaggregated into a spatial grid system that breaks down the world's ocean into 180,000 cells (0.5° latitude by 0.5° longitude) based on the geographical distribution of over 1,500 commercially exploited fish and invertebrate taxa, and using ancillary data such as the fishing agreements regulating foreign access to the Exclusive Economic Zones (EEZs) of maritime countries. Here, landings data were not adjusted to account for discarded by-catch on the global estimates (Zeller and Pauly 2005); hence, our results will be very conservative.

Primary production estimates were derived using the model described by Platt and Sathyendranath (1998) which computes depth-integrated primary production based on chlorophyll pigment concentration based on SeaWiFS (www.seawifs.gsfc.nasa.gov) and photosynthetically active radiation as calculated in Bouvet et al. (2002). The primary production estimates presented here pertain to an average value for the period 1985-2009 inclusive, which, for the purpose of our analysis, was assumed to be representative of the entire period.

Using the primary production estimates and the equation above, we estimated for each year the proportion of primary production exploited in each of the 0.5° latitude/longitude ocean cells, defined as 'exploited' when the proportion of primary production exploited exceed a threshold level. We used three threshold levels: 10%, 20% and 30%, of average primary production in a 'ratchet-like' fashion. Thus, once the threshold is surpassed, the exploitation level is fixed until a higher level is obtained. Once an area has passed a threshold level, it cannot return to a lower level. See Swartz et al. (2010) for further details on the method.

Results and Discussion

Maps were prepared separately for the 27 EU countries' fleets (EU-27), non-EU and all global fleets for each year from 1950 to 2006 inclusive. The exploitation rates were expressed as threshold levels of the ratio of primary production taken through landings (PPR) to local average primary production and colour-coded to show intensity (Figure 1).

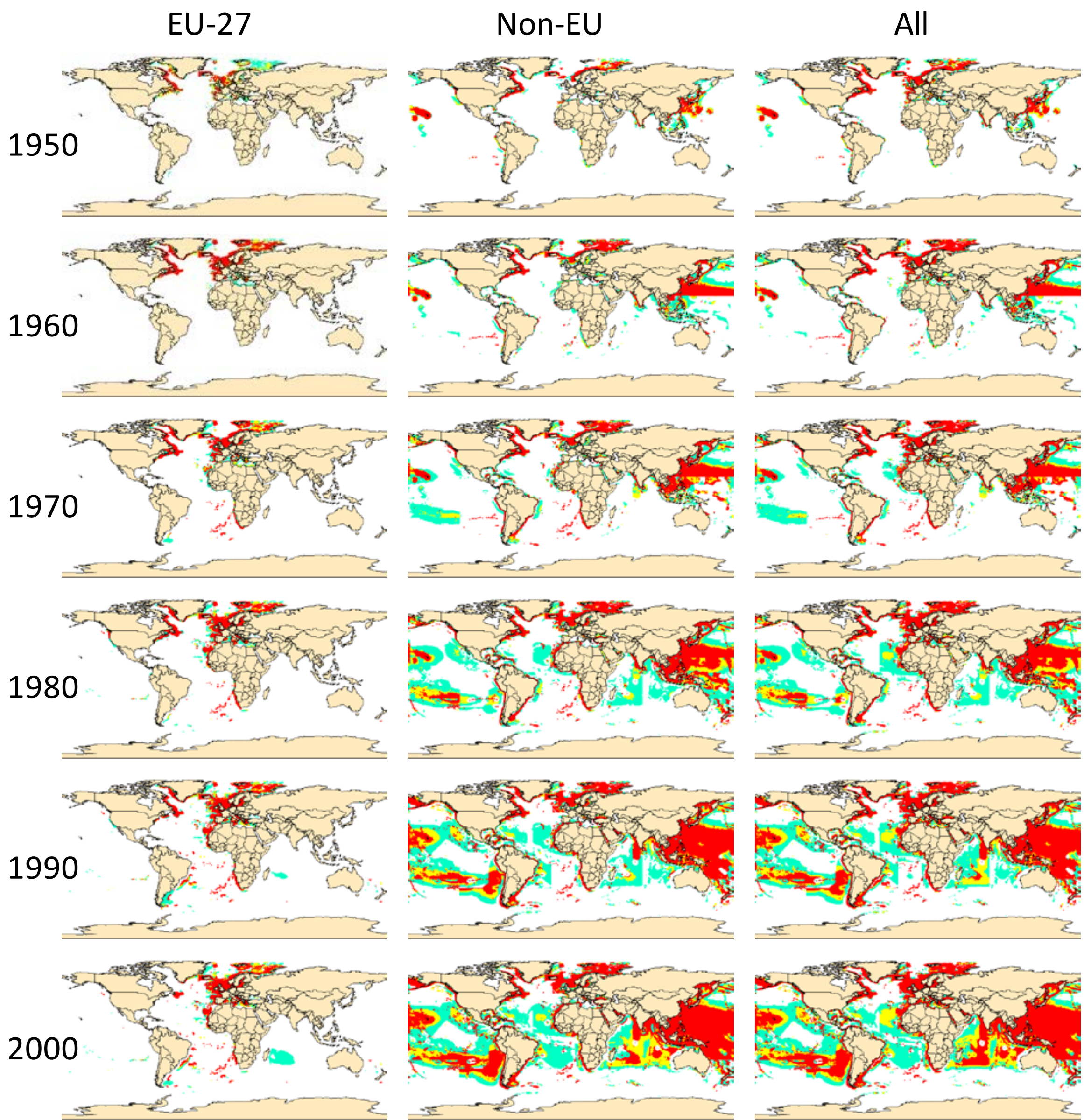

Figure 1: Proportion of primary production taken through landings by EU (EU-27), non-EU and all fishing fleets in 1950, 1960, 1970, 1980, 1990 and 2000. Threshold PPR levels are white (0%); green (≥ 10%); yellow (≥ 20%) and red (≥ 30%).

Figure 1 shows the development and expansion of global fisheries exploitation. Not surprisingly, in 1950 (when FAO began publishing annual global fisheries landing data), although most of the maps were white, i.e., the ratio of PPR to local primary productivity <10%, there were already many areas where exploitation was such that this ratio exceeded 30% (red in Figure 1). Thus, fishing in many parts of the world began long before the 1950s and was already intense by 1950. Since then, the spatial expansion of fishing fleets was necessitated by declining inshore fish populations, and made possible through improved technology (greater speed, endurance, safety and better navigation) and government subsides (Sumaila et al. 2010a, 2010b). Even on the small maps in Figure 1 (better visible in the visualizations), we can see the expansion to and intensification of EU fishing in areas of NW Africa in the 1970s and 1980s (Alder and Sumaila 2004; Atta-Mills et al. 2004; Watson 2005). In general, all global fleets moved to exploit more distant waters, increasingly in the waters of the southern hemisphere (Swartz et al. 2010).

Here we present the ratio of PPR to local primary production (Figure 1) as three threshold ratio levels to demonstrate the levels of exploitation in a manner easier to interpret. Pauly and Christensen (1995) found that the shelf areas in heavily exploited seas reached or exceeded 30% PPR which was starting to approach the 40% levels found in agriculture and other forms of land-based primary production appropriation, e.g., road and house construction, etc. (Vitousek et al. 1986). That is 40% of incident energy in local primary production is taken for our needs. Though there is no direct connection yet published between PPR threshold levels and fisheries sustainability, we believe that 30% should be considered a 'high level' of appropriation and hence exploitation. For convenience we have also shown the more arbitrary 10% and 20% intermediate levels so that the trend in PPR ratios can be better appreciated. Chassot et al (2010) found a strong relationship between available primary productivity and fisheries landings. They also confirmed that PPR levels have been rising. They also suggest a link to sustainability and used the probability of sustainability (Coll et al. 2008) as a measure of fishing pressure in Large Marine Ecosystems (LME). Notwithstanding that life-history traits have been shown to affect the response of fish stocks to fisheries exploitation, and that there is considerable variation in primary productivity available from area to area, and from year to year, their model found that current total fisheries catch could exceed sustainable reference levels, compared to LME areas where fishing is considered sustainable. LMEs are by definition coastal areas, and they found that in 2000-2004, depending on the level of certainty employed, fishing in many LMEs was not sustainable given current primary production levels. Further, they argued that with climate change, future levels of primary production may decline in some areas and further imperil many fisheries.

Interestingly, the primary production required (PPR) by European fleets appears to have declined after the 1970s, which is in contrast to the trend shown for all global fleets (Figure 2). This reduction in PPR by European fleets could have two causes. The first is simply a reduction in landings and the second is a reduction in the trophic level of the species landed.

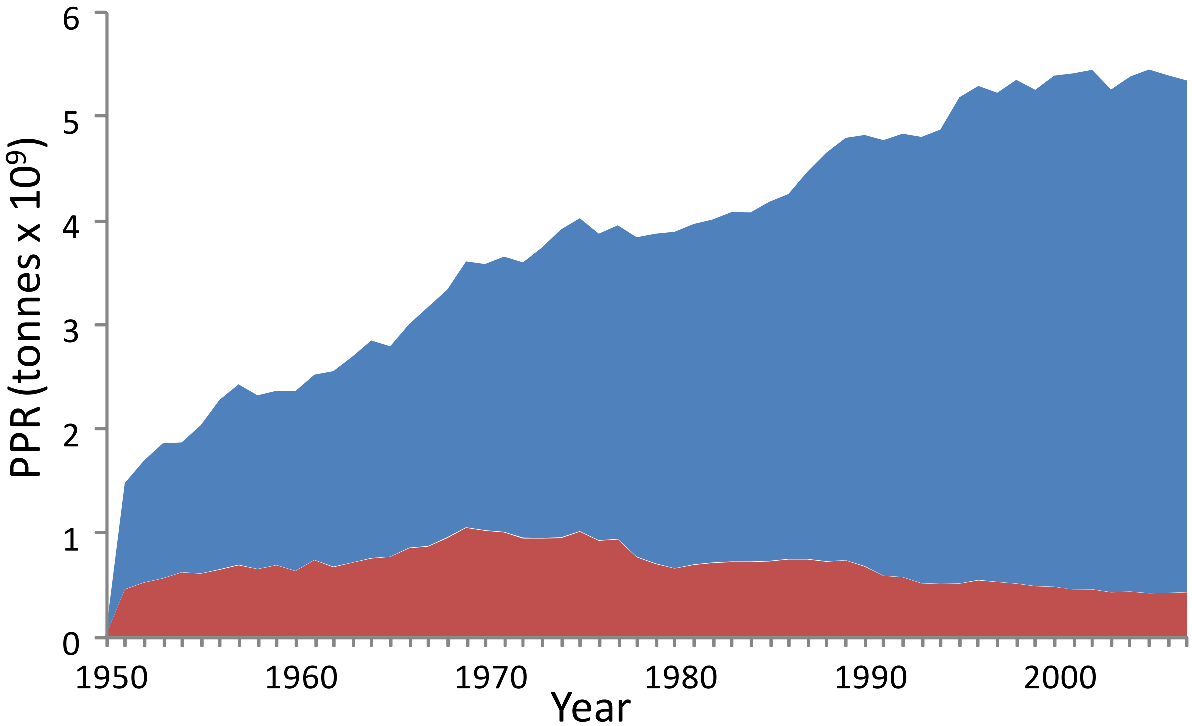

Figure 2: Global annual PPR by European (red) and other global fleets (blue) annually.

More detailed examination of the EU fleet data suggests that both total reported landings and the trophic level of these landings have declined (Figure 3). Less is taken, and what is taken is from a lower trophic level. However, note the increasing TL trend for the last few years of the data series in Figure (3). It remains to be seen if this signals a trend reversal. The declines in both these parameters explain the reduced PPR trend in European fleets compared to all global fleets (Figure 1). The reduction of trophic levels of commercial landings, particularly those in the seas close to Europe has been well documented (Pauly et al. 1998, Pauly and Watson 2005).

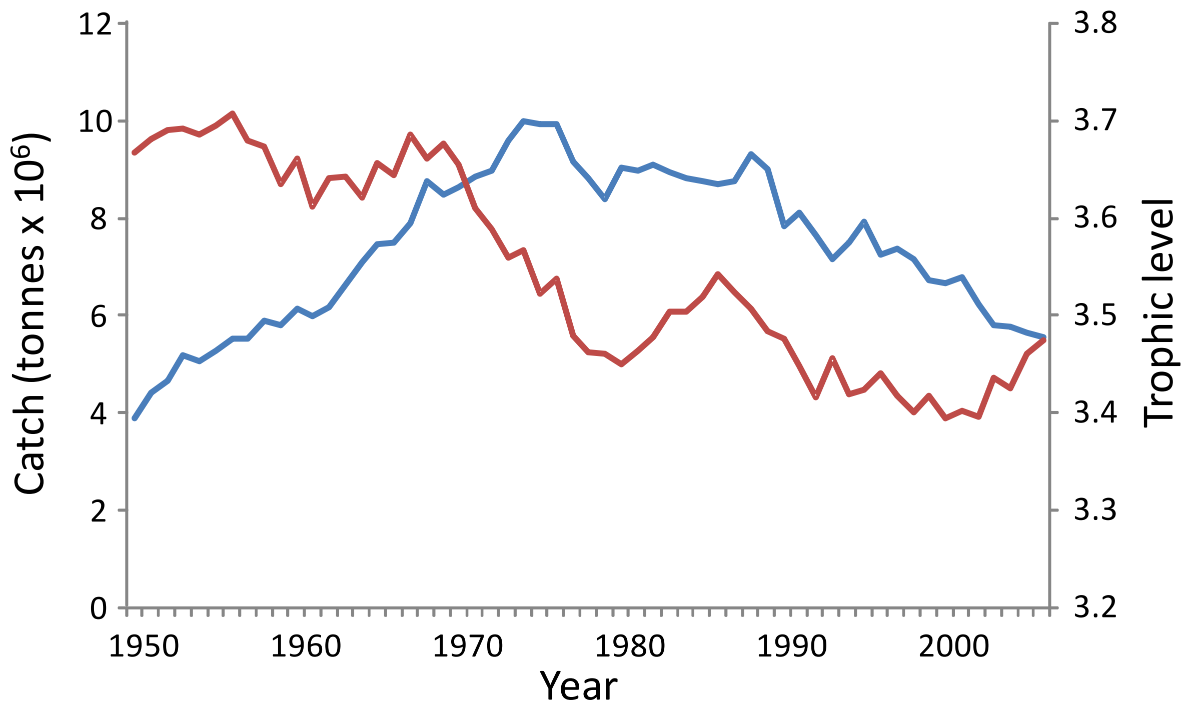

Figure 3: Global annual reported landings by European fleets (blue) and the catch-weighted mean trophic level of these landings (red). Note 'fishing down' by European fleets, which reduce PPR (see text).

The expansion and PPR trends of global fishing fleets were well documented by Swartz et al. (2010) and here we focus on European fleets (Figure 4A). Generally the area fished by all global fleets separated by PPR threshold categories increased since 1950, as illustrated by the area fished separated by the PPR ratio threshold levels of the fishing locations (Figure 4A). Note that, as per Swartz et al. (2010) 'threshold' level implies that once an area has reach a given threshold, it remains in that category until a higher threshold level is reached. This expansion and PPR trends of global fleets were described by Swartz et al. (2010). Figure (4) shows the area fished, separated by the PPR ratio threshold levels of the fishing location. However, the global pattern contrasts with the patterns for European fleets, especially in recent decades (Figure 4B). Unlike global fleets, the European fleets seemed to appropriate less primary production after the 1980s. Note that here we are considering areas whose threshold levels are defined by the combined demands of all fleets fishing in each area. Thus, European fleets, compared to global fleets, appear to fish increasingly in less-fished areas. Global fleets increased fishing in all situations and notably in areas with PPR threshold ratios that have exceeded 30% - that is those most heavily fished already. It is likely that European fleets are more mobile and fish newer areas more frequently. These are likely to be waters within the EEZ of other countries where access arrangements have been negotiated.

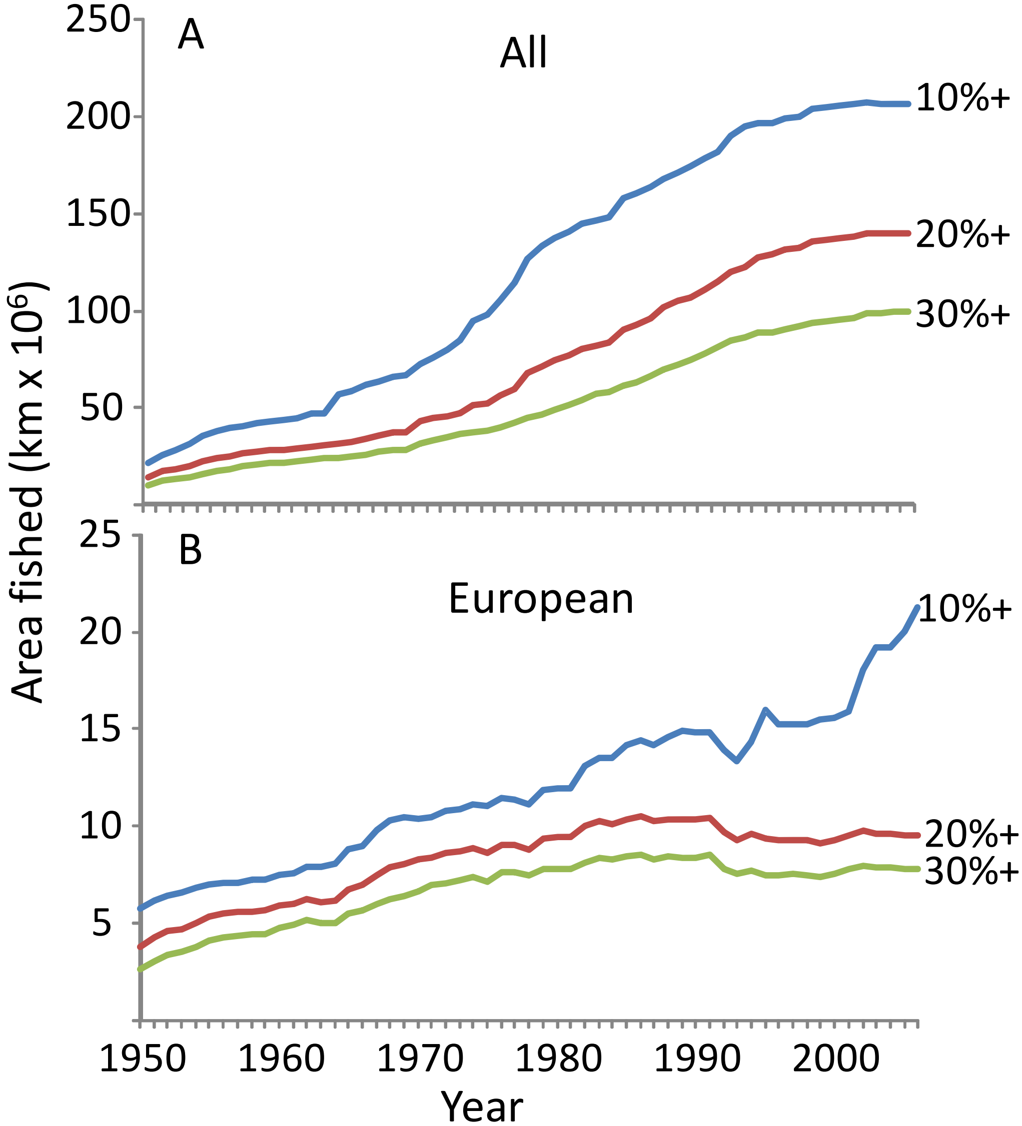

Figure 4: The area (km x 10^6) fished by A) all global fleets and B) European fleets separated by the threshold categories defined by the ratio of local PPR to local Primary Production (1998-2007 average) in the year fished. The threshold categories are set by ratios ever having exceeded: ≥ 10% (blue), ≥ 20% (red) and ≥ 30% (green). Note that lines are not additive in each year, as each category is a threshold, hence each higher category includes lower PPR thresholds.

Examining the most recent available EU fleet pattern (2006, Figure 5) suggests that the more lightly fished grounds (PPR threshold >10%) used by European fleets includes the remote edges of more exploited areas in the Atlantic, some areas in the Mediterranean and along the outer shelf of South America and a large area in the Indian Ocean.

These figures, combined with the maps in Figure (1), suggest that unlike most global fleets, those of Europe have moved to new, more lightly exploited fishing grounds post 1980. However, there is also some evidence that in recent times these areas are becoming more exploited. Unless European fleets could expand to further, relatively unexploited fisheries it is likely that they will be fishing areas that are more heavily exploited in the future, in a similar manner to most global fleets. The general pattern suggests that, until very recently, European fleets have been more mobile than most global fleets and better able to be the first to exploit new areas. Access arrangements negotiated for European fleets since the declaration of EEZ areas in coastal waters in the 1970s may have facilitated this (e.g., Le Manach et al. 2012). As for most global fleets, however, finding relatively un-fished areas is becoming increasingly difficult (Figure 1).

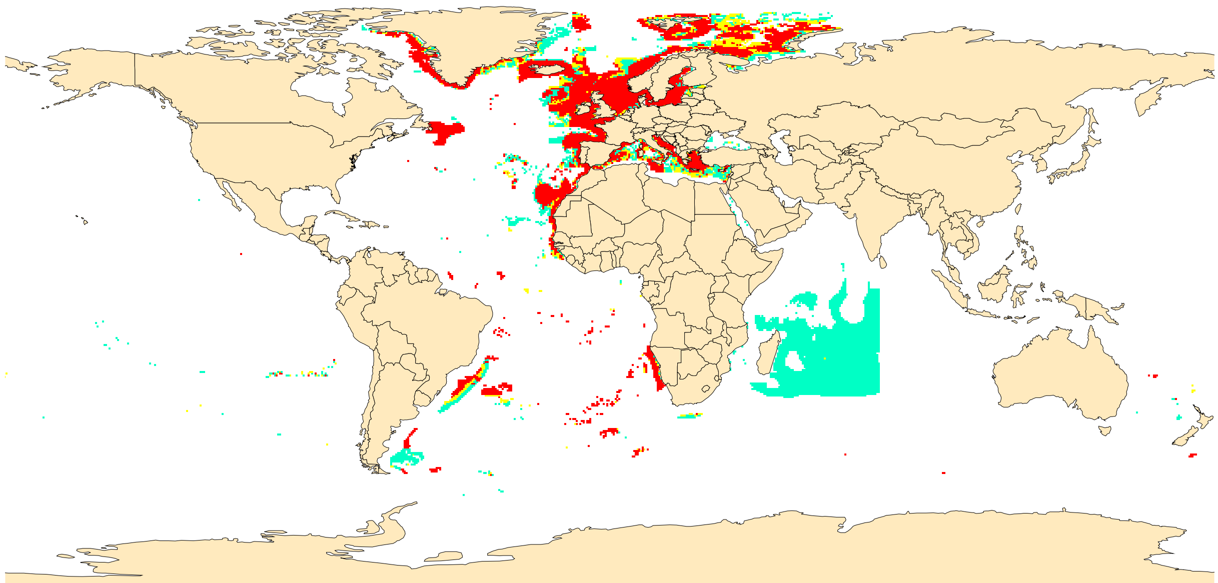

Figure 5: Fishing by European fleets in 2006 classified by the PPR threshold ratios of: ≥ 10% (blue), ≥ 20% (yellow) and ≥ 30% (red).

Examining the breakdown of PPR by European fleets by decade for the major FAO statistical reporting areas shows where those most exploited (purple) were taken from areas where the threshold of PPR to local primary productivity has exceeded 30% (Figure 6). Note the expansion of European fishing to a more diverse range of global oceans since 1950 and that some of the new areas are from lightly exploited areas (<10% PPR, coloured blue, Figure 6).

Though the declaration of Exclusive Economic Zones starting in the 1970s imposed restrictions on distant water fleets, in many cases, access arrangements were negotiated, and/or companies sought arrangements whereby fleets were effectively reflagged to appear as national fleets of the EEZcountry (Bonfil et al. 1998). Reflagging causes additional difficulties in tracking the activities of fleets. This is particularly so for vessels from European countries where this appears to be poorly documented.

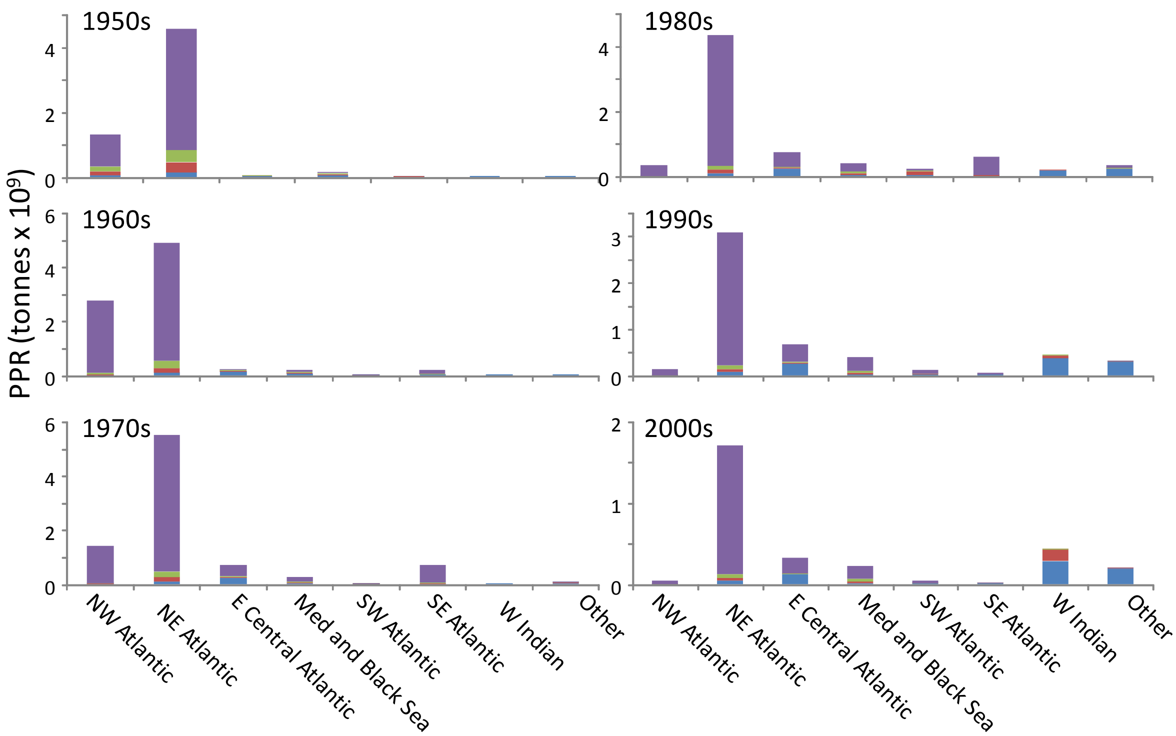

Figure 6: PPR of European fleets by decade by major FAO statistical reporting areas classified by the threshold PPR of the area fished <10% (blue), ≥ 10% (red), ≥ 20% (green) and ≥ 30% (purple).

As fleets expand their ranges, they experience increased costs; notably, travelling time is increased, as is fuel use. Fuel costs are already significant for global fishing fleets (Tyedmers et al. 2005) and might ultimately restrict their scope (Pauly et al. 2003) if it were not for huge subsides (Sumaila et al. 2010a, 2010b) which allow non-profitable operations to persist.

The expansion and intensification of exploitation levels are not only of concern to the future supply of marine-sourced protein and industry profitability (Srinivasan et al. in press, Tremblay-Boyer et al. in press), but to global marine biodiversity (Butchart et al. 2010; Andersen et al. 2011; Mouillot et al. 2011) and impacts on all aspects of the marine environment, ranging from critical habitats such as coral reefs to vulnerable populations of marine mammals and seabirds. Particularly vulnerable are the deeper, less productive areas, which are often outside of currently managed areas and EEZ claims (Pitcher et al. 2010; Norse et al. 2011). The High Seas fisheries also include the tunas and billfishes, whose life-strategy makes them very vulnerable to over-exploitation (Collette et al. 2011). Last, but not least, climate change will introduce additional challenges, bringing benefits to some but reductions in ocean productivity to other areas (Cheung et al. 2010).

The expansion of European fleets to new fishing areas over the last 60 years has provided landings from comparatively lightly exploited areas (often below a 10% PPR threshold). It is, however, expected that these areas will also attract greater interest from other global fleets. Some of these areas are on the high seas and have comparatively weak protection from overexploitation. Changes in effective management (Mora et al. 2009), particularly on the high seas will be essential if the expansion of global fleets is to avoid putting future fisheries and the marine environments supporting them in jeopardy.

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