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Short communication

Fishing down the deep: Accounting for within-species changes in depth of fishing

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ABSTRACT

New estimates of the global mean depth of fishing, which consider both the between and within species changes over time, showed a stronger shift to deeper water than estimated previously based only on between-species changes. The new estimates show a linear increase in the mean depth of fishing of 62.5 m decade^{-1}, corresponding to an increase of about 350 m for the period since 1950. These values are about 5 times higher than those obtained by using between-species change in catch composition over time, suggesting that deep water species and habitats are under a more serious threat from fishing than hitherto assumed.

1. Introduction

Deep sea fisheries, with very few exceptions, have been considered unsustainable (Norse et al., 2012). They operate at depths down to 1600 m and may have their impacts significantly extended further deep (Bailey et al., 2009). Deep sea fisheries mainly target low productivity fish populations that generally show long lifespans, slow growth and late maturity (Morato et al., 2006b), which explains the rapid stock declines (Devine et al., 2006) and slow recovery after stock collapses (Baker et al., 2009). These fisheries mostly operate nonselective trawl gears in an economic context that favor fish population "liquidation" (Sumaila et al., 2010). The increased importance of deep-water fisheries in global landings was demonstrated by Morato et al. (2006a), who showed that the depths at which marine fisheries operate has been increasing since the 1950s. However, the reported 42-m increase in the mean depth of the catch in the last 50 years has been questioned and thought to be unrealistically low. Morato et al. (2006a) results were based on the relative increase in the global catch of species (or higher taxa) known to occur in deeper waters. It was thus based on a between-species process and the shift of depth occurring within species was not taken into account. Thus, it did not include the consideration that fisheries increasingly exploit the deeper part of the range of commercial species. In this study, we re-estimate the global trend in mean depth of fishing by considering both between- and within-species changes.

2. Methods

The global catch data used for this study were provided by the *Sea Around Us* project of the University of British Columbia (Watson et al., 2004), which harmonize catch data originating from a wide range of sources (see http://www.seaaroundus.org/doc/saup_manual.htm#13) including the Food and Agriculture Organization of the UN (FAO) and its regional bodies, the International Council for the Exploration of the Sea (ICES), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the Northwest Atlantic Fisheries Organization (NAFO), and several reconstructed national datasets (Zeller and Pauly, 2007). Using additional databases of fishing access arrangements and/or observed national fleet fishing patterns, and extensive information on the distribution and harvest patterns of commercial marine species developed by the *Sea Around Us* project, the spatially coarse fisheries landings data records from 1950 to 2004 were assigned to a grid of 30-min latitude × 30-min longitude spatial cells.

The spatial allocation of fisheries landings was also based on revised depth distribution ranges for commercial bottom species in global fisheries statistics (Close et al., 2006). Fisheries catch was allocated independently for each demersal species and FAO statistical area. Moreover, we assumed, for each species, that the initial period of lower catches corresponded to an exploitation limited to the inshore part of the distribution range of that species. The exploited part of the range was then expanded offshore in a

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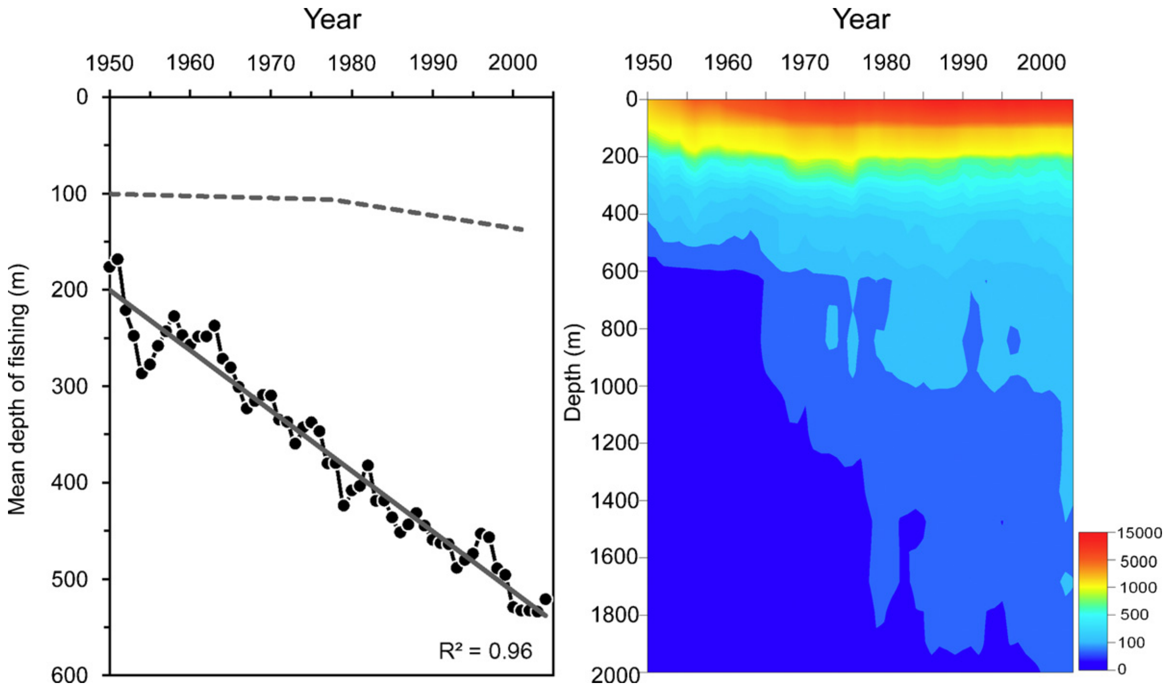

Fig. 1. Depth of world marine bottom fisheries catches, 1950–2004. (a) Trend line (solid line), fitted using a simple linear regression model and taking account both within- and between-species changes in mean depth; dashed line shows the trend line from Morato et al. (2006a), accounting only for between-species effects; (b) time series of world marine bottom fisheries catches by depth strata. Catch are in million tonnes.

ratchet-like manner, in proportion to the annual level of catch, until the year of maximum annual catch when it was assumed that the entire distributional range (though not necessarily all depths within that range) was being fished.

There is considerable evidence for the spatial expansion of fisheries on various scales globally though much is in the greyer literature. The offshore expansion of recreational fisheries has been well documented in Western Australia (Sumner et al., 2009) and as fisheries here are well monitored, similar patterns have been observed for other fisheries (Hall and Wise, 2011). The fishery for sea cucumber in the Seychelles was monitored by logbooks and expanded offshore (Koike et al., 2012), as indeed have all invertebrate fisheries globally (Anderson et al., 2011). Fisheries have expanded offshore and to more remote locations as seen with Atlantic cod in Newfoundland (Cadigan and Hutchings, 2001a,b; Gray, 2005) and in Sweden (Poulsen, 2007). The expansion of the northern shrimp fishery in the NE Atlantic (Guijarro, 2007) followed the same trend. This happens in tropical fisheries, especially as fishermen struggle to find new grounds because of reduced catches inshore or coastal development, such as oil production facilities. This is the case for the artisanal fisheries in Congo (Tati, 2008). It has happened in coastal fisheries in India since the 1950s (Bhathal, 2005). It also occurs through the movement of fisheries into the waters of other nations (illegal or otherwise) as it did in northern Australia (Field et al., 2009). In general, the expansion of fisheries offshore and into more remote areas has been well documented (Swartz et al., 2010). Thus it would be a poor assumption that in the 1950s, for example, that Atlantic cod fisheries covered the entire biological range of this species, but rather that even in this long-existing fisheries, the offshore extent was limited by the logistics, expense and the danger of fishing any further from ports then was absolutely necessary. As these fisheries developed, however, they expanded offshore through necessity supported by better logistics and vessel endurance (Cadigan and Hutchings, 2001a,b; Gray, 2005; Poulsen, 2007).

With fisheries expansion there is therefore a tendency for the catch of recent years to originate from the deeper part of each species distribution. It is further assumed that the entire distribution range of a species continued to be fished from the year of maximum catch onward. The rationale for the latter is that overexploited and collapsed stocks usually continue to be exploited as by-catch of other fisheries, especially so for demersal species.

After all catches for 1950–2004 were allocated, we calculated the mean depth of the bottom fisheries catch by year as the shallowest depth of each spatial cell weighted by the total catch in that cell. We used the minimum depth of each cell in order to have a conservative estimate of the depth of fishing. Note that our approach for allocating catches to spatial cells does not incorporate changes in depth (see Watson et al., 2004), and hence we avoid circularity when reporting such changes.

3. Results and discussion

This new approach was applied to catch time series covering 1950–2004 for over 1200 taxa (mainly at species level, the rest being at generic, family or higher level) and showed a much stronger shift to deeper water than was estimated before. The new estimates show that, for bottom dwelling marine fishes, the overall trend over the past 50 years has been a 350 m increase in the mean depth of the catch, from about 170 m in the early 1950s to 520 m in 2004 (Fig. 1a). The linear regression model ($r^2 = 0.96$) suggests a marked increase in the mean depth of fishing at a rate of 62.5 m decade^{-1}. These new estimates are about 5 times greater than those obtained by using only between-species change in catch composition over time (Morato et al., 2006a). In general, our analyses show that the mean depth of fishing started increasing mainly in the late 1960s, corresponding to the expansion of the fisheries catch into deeper waters below 600 m (Fig. 1b). By early 1980s, fisheries operations occurred down to 1500 m depth and close to 2000 m by 2004 as described in Rogers and Gianni (2010).

The new approach to estimating mean depth of fishing is less sensitive to changes in catch statistics reporting or their taxonomic resolution, but is very much dependent on the catch allocation algorithm. The expansion offshore (and hence into deeper waters) is ratchet-like, so the fishery range described by catch distribution never contracts even if, in some years, the catch does. Therefore, when the year of maximum catch occurs in a given FAO area for a given species, our approach assumes that the range of fishing has expanded offshore to the entire range of a species. The inshore areas are still fished as the harvest expands offshore and usually account for most of the catch. Although this approach has not been verified by detailed case studies, it mimics well the observed expansion in deeper waters described in the literature (Hopper, 1995; Devine et al., 2006; Bailey et al., 2009).

The new estimates suggest that deep water species and habitats may be under a more serious threat from fishing than hitherto assumed. If Bailey's et al. (2009) theory is correct, fish communities below the fishing range are also impacted, thus extending the footprint of these fisheries well below the fishing range, though, fortunately in individual cases. There is hope that management can interview to stabilize abundances (Neat and Burns, 2010). Scientific trawling at depths seldom fished commercially has shown that even our work may actually underestimate the impacts on the deepest stocks (Priede et al., 2010, 2011). Morato et al. (2006a) suggested that fisheries expansion to deeper waters is exploiting the last refugees for most fish species and targeting generally slow-growing and hence highly vulnerable species (Cheung et al., 2007) with little resilience to overexploitation (Baker et al., 2009). Moreover, the impact of fishing gears (mainly bottom trawling) on deep-water habitats may be more widespread than previously thought. Watson et al. (2006) showed how expansive global trawled areas are and how these have expanded since the 1950s when more than 40% of reported catch was already associated with trawl gear. Mapping fisheries impacts will remain vital to developing effect management, especially on the high seas, and this contribution highlights why.

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