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Coastal catch transects as a tool for studying global fisheries

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Abstract

We present a new, intuitive approach for the representation of fisheries catches within profiles perpendicular to coast of the Exclusive Economic Zones (EEZ) of countries, or of Large Marine Ecosystems (LME). These 'catch transects' show where catch is extracted in the water column and near the sea bottom on plots of log-bathymetry versus log-distance offshore and thus allow for representation of the catch density of pelagic and benthic fisheries. Hence, they also allow direct visual comparison of the intensity of fishing through time and space. The California Current, North Sea and the South China Sea LMEs and the EEZs of Australia, Canada, Chile, China, India and Thailand are presented as examples, revealing the general intensification and extension of fishing offshore and into the depths over the decades from the 1950s. Catch transects reveal how these trends have accelerated in some areas, but surprisingly have reversed themselves in some others. It is proposed that these catch transects will be particularly useful for communicating the results of large-scale fisheries studies to a wide spectrum of groups ranging from the fishing industry to the general public.

Keywords Coastal, cross-sectional transects, exclusive economic zones, global fisheries, large marine ecosystems

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Introduction

Humans have forever longed to see what occurs in the ocean's depths, sometimes out of curiosity or to anticipate dangers, but most often to better locate its resources (Cushing 1973; Brunner 2011). Our bodies are not well adapted to penetrate into the ocean's depth, and our eyes lack clear underwater vision, but our technologies have been progressively refined to compensate for our landlubbers' biology, and thus we have explored the marine world in increasingly sophisticated ways ranging from submersibles and remotely operated vehicles to ship-born hydroacoustics and networks of tethered sensors. Fisheries have particularly benefited from these developments and especially from the transfer of military technology, particularly those for antisubmarine warfare (Cushing 1973; Pauly *et al.* 2002).

Along with direct scientific surveys (Walsh 1996), these technologies provide a sense of the relative location and abundance of the marine resources of an area (see e.g. contributions in Forget *et al.* 2009). Unfortunately, they can prove limited in providing the spatial scale of information necessary to deal with wider resource allocation issues or studies of the interaction of fishing on other resources or habitats. Sensing from satellites, which allows coverage of extensive areas of global oceans, is often limited to bathymetry and ocean colours, the latter has allowed inferences about primary productivity (Dulvy *et al.* 2009). But, looking at the distribution of fisheries resources at depth from satellites is not yet possible.

Just as the global diversity of marine species is essentially a function of latitude (Gaston 2000), as also noted by Charles Darwin, who wrote that 'latitude is more important than longitude' (Pauly 2004), their productivity and abundance is largely a function of depth and distance from the coast, notably because coastal lands are major source of marine nutrients (Heincke 1913; Zeller and Pauly 2001). Thus, plotting fisheries catch on bivariate graphs with (log) depth and (log) distance from the coast should provide a context for their interpretation in terms of other variables, such as the historic development of fishing capacity. Here, we attempt to do that by combining existing detailed global catch mapping data (Watson *et al.* 2004) with information on the depth distributions of the fished organisms (Zeller and Pauly 2001; Morato *et al.* 2006; Pauly *et al.* 2008; Watson and Morato 2013). The 'catch transects' of LMEs and EEZs thus obtained, which are reminiscent of the cross-sectional catch maps in FAO (1972), can facilitate scientific comparisons between regions, and periods in the same region, guide decision-making with regard to overlaps with sensitive habitats and endangered resources and also help educate a wide spectrum of the public about the origins of our sea food.

Methods

Transects

Creating a catch transect requires working with mapped global catch data. The global catch data we used were previously assigned to a grid of spatial cells 30-min latitude by 30 min of longitude (see details below). We needed to construct representative transects or cross sections upon which catch could be mapped for each of the designated areas (Large Marine Ecosystems or Exclusive Economic Zones). We started by finding for each designated area, the average ocean depth within fixed ranges of distances perpendicular to the shore. We decided that $\log_{10}$ distances (km) and $\log_{10}$ depths (m) would be more useful, as most activity of interest occurs comparatively close to shore and at shallow depths, with change being relatively slower as distance from the coast and depth increases. Here, we are only concerned with coastal waters, that is, the waters within large marine ecosystem (LME) boundaries (Sherman *et al.* 1990) or the Exclusive Economic Zones (EEZ) of countries (usually 200 nautical miles). These areas also roughly correspond to the inshore biogeochemical provinces described by Longhurst (1998; see also Watson *et al.* 2003).

For depths, we used the NOAA ETOPO1 data set (Amante and Eakins 2009), which provided a grid of ocean depths with a resolution of one minute in latitude and longitude. This data set has more than 233 million points representing approximately 1.85-km spacing over the world's oceans. The computational challenge was to estimate, for each of these points, the distance from substantial land masses, while ignoring smaller islands. This was accomplished using a Microsoft VB.net routine which first calculated offshore differences starting immediately adjacent to the coast, then moved its focus to points progressively further offshore in a way that made use of all previous established distances, greatly reducing computing times.

Given a fine grid of points associated with both depth and perpendicular distance from shore, it is then possible to construct a representative transect for any coastal area of interest. The procedure used here assigns relevant points to a series of distances offshore of 0, 0.2, 0.4…2.2 $\log_{10}$ km. The transects presented here extend 160 km offshore, which should encompass the productive core area of both LMEs and EEZs. For each point on the transect, we calculated the average depth from the detailed bathymetry. If there were insufficient data (which occurred most frequently at the shoreward end of transects – where $\log_{10}$ distances perpendicular to shore meant that actual distances were very short), a geometric increase in depth was assumed.

Global catch

Annual catch data plotted in transects was taken from the spatially disaggregated global catch database of the *Sea Around Us* project (Watson *et al.* 2004). This online database (www.seaaroundus.org accessed 5 December 2012) is derived mainly from global fisheries catch statistics assembled by the Food and Agriculture Organization of the United Nations (FAO) from submission by its member countries (FAO 2009), complemented by the statistics of various international and national agencies and reconstructed data sets (Watson and Pauly 2001; Watson *et al.* 2004; Zeller and Pauly 2007). Reconstructed data sets are those prepared by experts working with the Sea Around Us project which augment those currently available in the public domain. These statistics, after harmonization, were 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 1500 commercially exploited fish and invertebrate taxa, using ancillary data such as the fishing agreements regulating foreign access to the EEZs of maritime countries. These data are not strictly 'catches' but largely represent 'landings' (what was retained and reported), although we adjusted these to account for illegal and unreported catch on the global estimates (Agnew *et al.* 2009). That latter consisted of using the 5-year averages (for 1980–2003) reported for most of the 18 FAO statistical reporting areas. We assigned the average global value for groups not included in Agnew *et al.* (2009), and values before 1980 were assigned the 1980–1984 average value. Agnew *et al.* (2009) reported a general decline in these unreported catch categories in recent years, as did Zeller and Pauly (2005). We used the average value from Agnew *et al.* (2009) for estimates of years after 2003. As Agnew *et al.* (2009) also showed that illegal and unreported catch varies with taxonomic group, it was decided to assign a value of only 5% to all landings of large tuna (Scombridae) and billfish (Istiophoridae), rather than the higher and less representative area averages.

The bathymetric distribution of each reported species or group of commercial fish or invertebrate was determined based on knowledge of their habits, as described in FishBase (www.fishbase.org accessed 5 December 2012) for fishes and SeaLifeBase (www.sealifebase.org accessed 5 December 2012) for invertebrates. Here, we were most concerned with broad brush estimates for where the taxa were caught and not with their fine-grained biological distribution. The resulting groupings of taxa with similar depth distribution are here called 'bathymetric groups'. For non-demersal species, we assumed a triangular distribution (Table 1) – which is a continuous probability distribution with lower limit a, upper limit b and mode c, where $a < b$ and $a \le c \le b$. Demersal species were assumed to be taken in close proximity to the bottom (usually by trawl gear).

Mapping catch onto transects

For each transect, a 600 × 400 resolution grid (pixels in a bitmap) was constructed to represent a representative cross section although the water column to 10 000 m in depth (4 in $\log_{10}$ of depth) by approximately 160 km in length (distance offshore) for the selected EEZ or LME. Then, the catch ($\log_{10}$) was plotted onto this bathymetric transect, with colour representing the density of catch taken from each representative depth and distance offshore grid cell. The continuous vertical distributions for species (Table 1) were discretized into the 400-pixel *y*-resolution of the transect bitmap figures. Pelagic and demersal catches were scaled by colour differently to allow greater detail to be seen (when they overlap, the highest density for each group was represented by the colour coding). The figures were finished with batch processing in R (Ihaka and Gentleman 1996).

Table 1 Bathymetric groups used for global commercial species and their modelled location in the water column. Some groups were closely associated with the bottom (labelled as bottom), and others were distributed according to a triangular distribution with the maximum (range) shown below.

Group	Depth range	Includes
Small pelagics	50 (1–200)	Peruvian anchoveta (*Engraulis ringens*, Engraulidae), South American pilchard (*Sardinops sagax*, Clupeidae), Atlantic herring (*Clupea harengus*, Clupeidae), chub mackerel (*Scomber japonicus*, Scombridae), Inca scad (*Trachurus murphyi*, Carangidae), etc
Large pelagics	100 (10–300)	Large tunas and mackerels (Scombridae), North Pacific hake (*Merluccius productus*, Merlucciidae), swordfish, large pelagic sharks
Squid and krill	100 (1–200)	Squid and krill
Demersal fishes	Bottom	Alaska Pollack (*Theragra chalcogramma*, Gadidae), Atlantic cod (*Gadus morhua*, Gadidae), largehead hairtail (*Trichiurus lepturus*, Trichiuridae), blue whiting (*Micromesistius poutassou*, Gadidae), sandlances (Ammodytidae), saithe (*Pollachius virens*, Gadidae), haddock (*Melanogrammus aeglefinus*, Gadidae), etc
Shrimp	Bottom	Shrimp
Lobster and crab	Bottom	Lobster and crabs
Other demersal invertebrates	Bottom	Oysters, mussels, octopus, clams, scallops, etc

Areas represented by transects

Three LMEs (California Current, North Sea and South China Sea) and six EEZs (Australia, Canada, Chile, China, India and Thailand) were selected as representative catch transects (Fig. 1). These represent large areas, jointly accounting for 30% of all global catch since 2000.

Results

Fisheries around the world vary; some are dominated by rich nutrient upwellings supporting strong but often variable pelagic fisheries (such as off Chile; Yáñez *et al.* 2001), whereas others are a mixture of fisheries for both demersal and pelagic resources. Fishing in coastal regions has changed since the late1940s to early 1950s, when the first global data sets became available (Watson *et al.* 2004) (Table 2). Here, we illustrate how finely mapped global catch data can be combined with information on where in the water column commercial species are taken to provide representative catch transects through both LMEs and EEZs around the world in such manner as to make visible interdecadal changes in fishing practices and fished resource status.

Table 2 Breakdown of global catch by decade by bathymetric groups (million tonnes followed by the percentage this forms of decadal total).

Group	1950s	1960s	1970s	1980s	1990s	2000s
Small pelagics	107 (46)	242 (56)	303 (52)	388 (54)	426 (53)	287 (51)
Large pelagics	8.8 (4)	15.5 (4)	24.3 (4)	35.9 (5)	52.5 (7)	44.6 (8)
Pelagic inverts	5.8 (3)	8.0 (2)	11.4 (2)	20.8 (3)	28.7 (4)	23.5 (4)
Demersal fishes	88.6 (38)	136 (31)	200 (34)	218 (30)	215 (27)	147 (26)
Shrimps	7.4 (3)	10.6 (2)	17.3 (3)	22.7 (3)	31.9 (4)	24.6 (4)
Crabs and lobster	2.7 (1)	4.6 (1)	6.3 (1)	8.2 (1)	12.0 (1)	9.6 (2)
Other demersal invertebrates	11.1 (5)	16.8 (4)	22.1 (4)	28.8 (4)	33.4 (4)	23.2 (4)
Total	231.6	433.6	584.2	722.0	800.0	559.4

2000s represents only 2000–2006 inclusive.

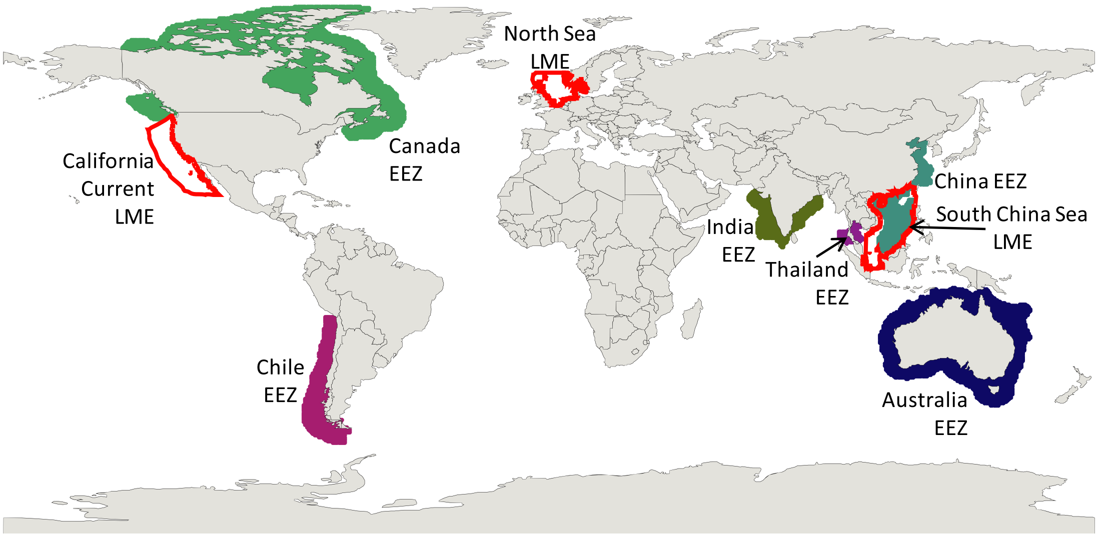

Figure 1 Large Marine Ecosystems (LMEs) and Exclusive Economic Zone (EEZs) areas (outlined areas) represented by catch transects.

Large Marine Ecosystems (LME)

We examined three significant LME areas. The California Current (Fig. 2) located along the coast of California (located in Fig. 1) includes both pelagic and demersal fisheries. Here, the intensification and offshore extension of fisheries from the 1950s to the 2000s can be clearly seen. Note the thin blue area on the bottom representing where demersal stocks were taken and how this also extends offshore and to deeper waters with time. Perhaps, nowhere is this expansion trend more obvious than in the LME area for the South China Sea (Fig. 2). Already intense in the 1950s by global standards, fisheries in this area further intensified and gradually extended to cover the entire LME (Cheung and Pitcher 2008). In contrast to these and other fisheries, those within the North Sea LME (Fig. 2) became slightly less intense during this same time scale, reflecting efforts to rebuild some of the pelagic (Zimmermann 2002) and demersal stocks (Froese and Proelß 2010).

Comparing all three figures, it is notable that except for fisheries on demersal stocks (which may extent to nearly 1000 m in depth), the fisheries targeting pelagic fish tend to operate in waters between 50 and 100 m below the surface. In the North Sea, however, which is relatively shallow, most of the water column is fished and has been for over a century (Froese and Pauly 2003).

Exclusive Economic Zones (EEZ)

The immense area claimed by China as its EEZ has experienced intensive fishing pressure since the 1950s, which increased further with every passing decade (Fig. 3). Pelagic and demersal stocks in this area are exploited at levels that are comparable to the highest anywhere, even those far offshore. However, the offshore expansion of fisheries can be seen even more clearly in the EEZ areas of Chile and India (Fig. 3). The offshore expansion of demersal fisheries within the Indian EEZ area is particularly visible, with the outer shelf, barely impacted in the 1950, being fully exploited by the 1990s, the fisheries then expanding to cover the whole shelf area (Bhathal and Pauly 2008). Note that the demersal fisheries around India (particularly on its west coast) have been generally limited to shelf areas as the dissolved oxygen in deeper waters is usually too low for most bottom fishes (Banse 1968; Pauly 2010).

Fisheries within Canadian waters (Fig. 4) showed an intensification of pelagic fisheries in the 1970s and 1980s, but atypically, this was reduced in later decades. During this period, however, the pressure on demersal stocks continued to build and moved deeper and further offshore, with catastrophic results (Walters and Maguire 1996). The fisheries in the Australian EEZ have also intensified, with those in offshore areas building in intensity, while the fisheries in the EEZ of Thailand are

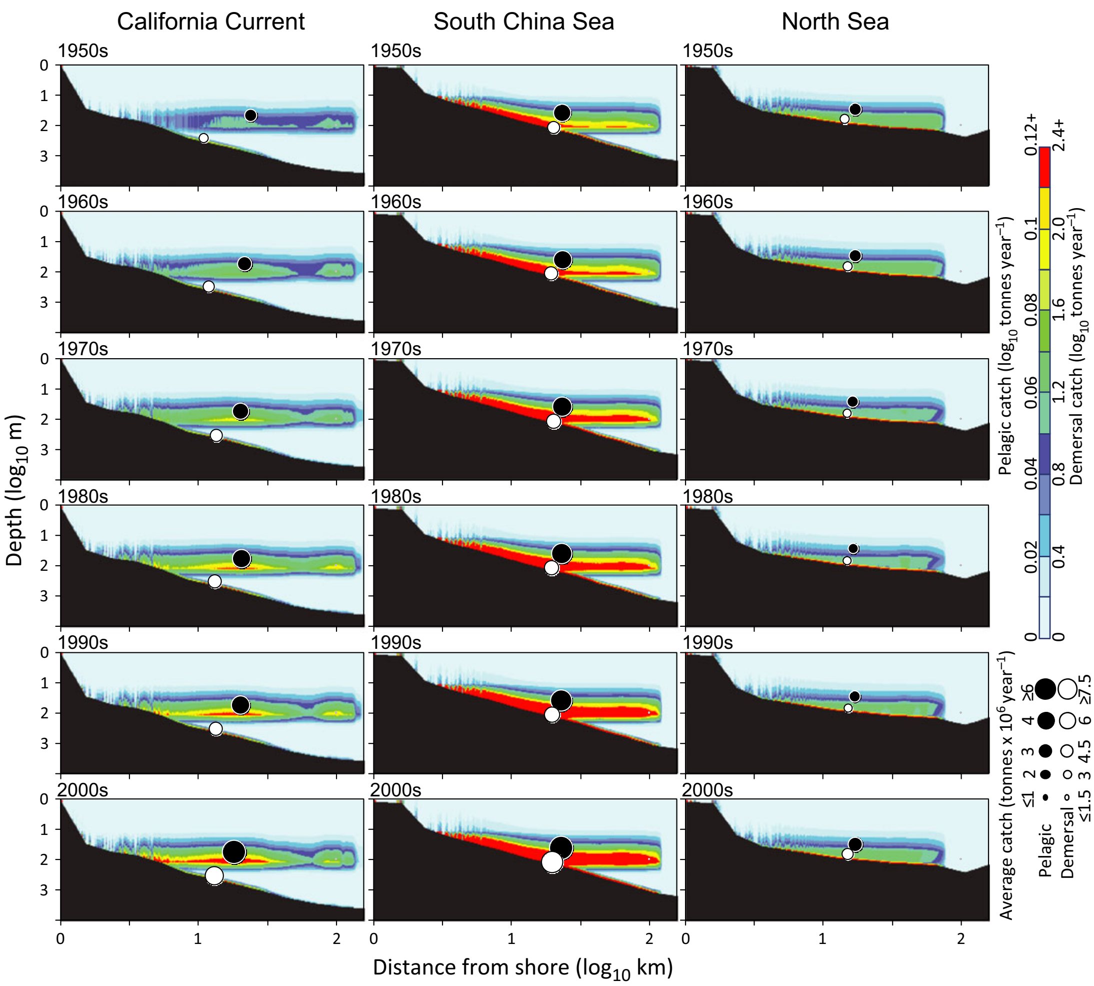

Figure 2 Catch transects for the California Current, South China Sea and the North Sea Large Marine Ecosystems. Catch densities ($\log_{10}$ tonnes year^{-1}) are scaled by colour (see legend). Demersal catches are scaled differently from pelagic catches. Locations of LME areas represented are shown in Fig. 1.

mostly intensive trawl fisheries, or other fisheries operating in shallow waters, where differentiating between demersal and pelagic fishes is difficult (Longhurst and Pauly 1987).

Discussion

We have demonstrated how the mapping of virtual transects can provide comparable snapshots of fisheries by area, allowing spatial and temporal comparisons. The California Current LME (CCMLE) shown in Fig. 2 has a significant history of fisheries collapse. The once great small pelagic fisheries here had all but collapsed by the 1950s (Aquarone and Adams 2009a). In recent years, fisheries there have focused on salmons [Chinook (*Oncorhynchus tshawytscha*, Salmonidae), coho (*Oncorhynchus kisutch*, Salmonidae), sockeye (*Oncorhynchus nerka*, Salmonidae), pink (*Oncorhynchus gorbuscha*, Salmonidae), chum (*Oncorhynchus keta*, Salmonidae)], pelagic fisheries, groundfish and invertebrates. Salmon abundance has fluctuated. Small pelagics still form a large part of fisheries there and include northern anchovy (*Engraulis mordax*, Engraulidae), jack mackerel (*Trachurus symmetricus*, Carangidae), chub mackerel (*Scomber japonicus*, Scombridae) and South American pilchard (*Sardinops sagax*, Clupeidae). Anchovy and mackerel fluctuate enormously in abundance. Although this area generally has a low productivity, it does have seasonal upwellings of cold nutrient-rich water that generate localized areas of high primary productivity (Aquarone and Adams 2009a). Squid are now important to fisheries there.

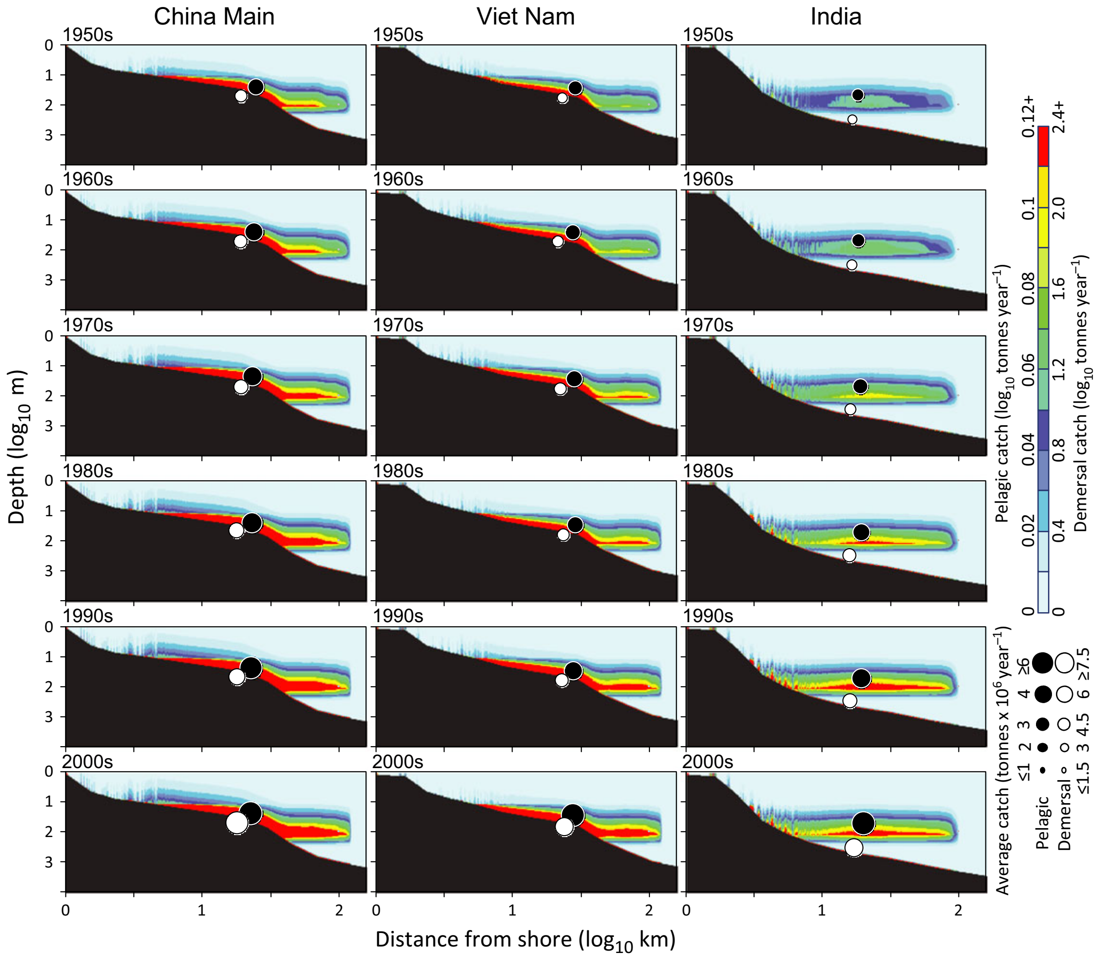

Figure 3 Catch transects for the Exclusive Economic Zones of China (Mainland), Chile and India. Catch densities ($\log_{10}$ tonnes year^{-1}) are scaled by colour (see legend). Demersal catches are scaled differently from pelagic catches. Locations of EEZ areas represented are shown in Fig. 1.

Some albacore tuna (*Thunnus alalunga*, Scombridae) are also caught in this area.

Our data series starts in the 1950s about the time that the huge fisheries for small pelagics had largely collapsed in the CCLME. The intensification we observed in transect plots (Fig. 2) reflects strong catches of North Pacific hake (*Merluccius productus*, Merlucciidae), South American pilchard and squid. The fisheries of this area have also diversified over recent decades, allowing for fisheries expansion and intensification. Here, as in many of the world's fisheries, fishing now extents further offshore and into deeper waters (Morato *et al.* 2006; Swartz *et al.* 2010; Watson and Morato 2013). If we compare the fishing intensity there to that of the South China Sea LME (Fig. 2), however, we see that fishing in the California Current LME is of relatively moderate intensity.

Fisheries are supported by the ecosystems they are embedded in (Worm *et al.* 2006). Primary productivity in each area is dependent on many factors, including incident solar radiation and nutrient availability. Fisheries take a portion of the energy or carbon flow up the food web from its primary productivity base. Fisheries are constrained usually by local primary production (Chassot *et al.* 2010). The portion of primary productivity required to support fisheries in an area – that is the ratio between the total average primary production and that which is encapsulated through trophic transfer to those fish species/products that are removed through fishing – is called the Primary Production Required (PPR). For the fisheries in the CCLME, on average over recent years, this is about 10–20% (Watson *et al.* 2013).

By contrast, the fisheries of the South China Sea LME (Fig. 2) are intense and have increased stea-

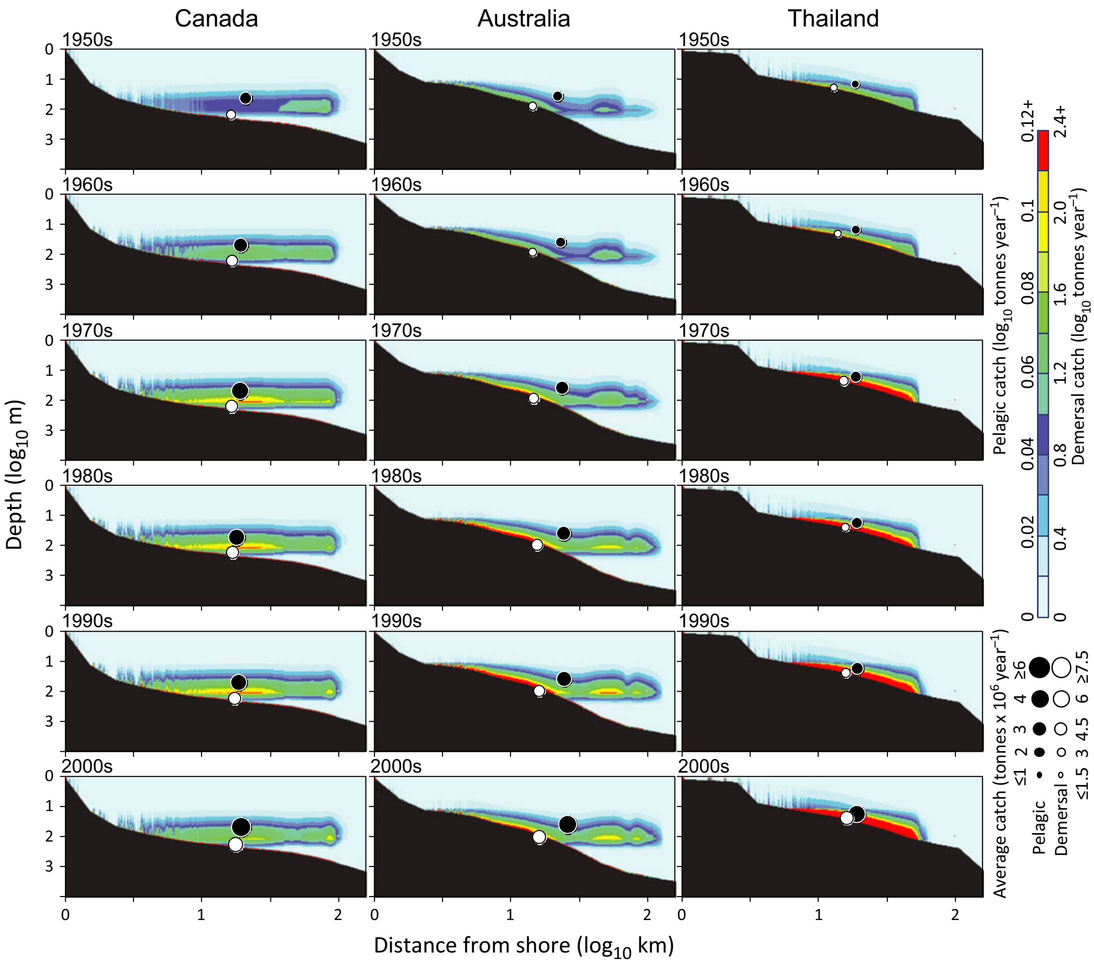

Figure 4 Catch transects for the Exclusive Economic Zones of Canada, Australia and Thailand. Catch densities ($\log_{10}$ tonnes year^{-1}) are scaled by colour (see legend). Demersal catches are scaled differently from pelagic catches. Locations of EEZ areas represented are shown in Fig. 1.

dily for many years (Watson *et al.* 2013). This area is biologically diverse, tropical, moderately productive – but has many overlapping fisheries claims (Heileman 2009) and enormous and rapidly increasing fishing capacity (Anticamara *et al.* 2011; Watson *et al.* 2012). PPR here is now approaching 250% (Watson *et al.* 2013). This level of intensive extraction requires food web contributions to be imported through currents or upwellings from outside the fished area but, regardless, it is unlikely that this level of fishing intensity can continue to be supported. Reductions in returns on investment motivates fishing fleets to redouble their efforts and to expand their range of operations (Watson *et al.* 2012). Because further expansion here is difficult, fleets from Asia are now fishing more broadly including the Atlantic coast of Africa and elsewhere (Pauly *et al.* 2012). The illustrative transects we present in Fig. 2 provide a means to observe these changes and to contrast them to fisheries in other areas.

The North Sea LME contrasts with the South China Sea LME because it has actually reduced its fishing intensity (Fig. 2) and, through strong management, has decreased PPR to 70% from a peak of 240% in the 1970s. Although only moderately productive, this area has been fished since recorded history and, moreover, quite intensely by world standards (Aquarone and Adams 2009b). The fleets of the European Union have been unable to expand further here in the last few decades and have instead extended their presence elsewhere in the world's oceans including north-western Africa (Watson *et al.* 2013), causing problems for local fisheries (Bonfil *et al.* 1998; Kaczynski and Fluharty 2002; Atta-Mills *et al.* 2004). Fortunately, the trend we observe in the North Sea LME is towards more sustainable levels of exploitation (Zimmermann 2002; Froese and Proelß 2010) although, arguably, this comes about through the export of fishing capacity to other areas with its inherent problems.

Examination of our newly proposed catch transects confirms with a glance that global fisheries have, with rare exceptions, intensified and extended into deeper depths and further offshore, as previously reported by Morato *et al.* (2006), Watson and Morato (2013). While our current methodologies already allow areas such as a country's EEZs to be compared with other areas and examined through time, we believe that this approach is only in its infancy. It will soon be possible to explore, using a similar approach, representations of where different (and sometimes destructive) fishing gear is deployed, where the valuable stocks are located, and where fishing and sensitive habitats overlap. Mapping large-scale threats in the marine environment is important (Halpern *et al.* 2008), notably because it helps galvanize public opinion and foreign collective policy. This will be increasingly important as we consider potential climate change impacts (Cheung *et al.* 2010).

Insights into how global fisheries operate in time and space are difficult to achieve (Worm *et al.* 2009). To map global fisheries requires that you first have data sets that represent their catch (Watson *et al.* 2004) and/or fishing effort (Watson *et al.* 2012, 2013). These data sets were compiled from a range of sources such as the FAO and augmented by expert reconstructions where possible (Zeller and Pauly 2007). Catch data so compiled are then usually only available by relatively large statistical reporting areas, sometimes covering entire ocean basins. To map these into finer spatial grids, this is a requirement to use auxiliary data such as databases of international fishing agreements (fishing fleet access) and detailed information about the ranges of the commercial species being fished (where fished taxa are found). Maps prepared in this way have captured the imagination of scientists, managers and the staff of environmental NGOs for more than a decade now (Watson *et al.* 2005). When trying to explore how fisheries have intensified and extended further offshore (Swartz *et al.* 2010) and into the depths (Morato *et al.* 2006), it has been difficult to represent the process in a way that provides quick insights and yet is available for the many political and biological divisions of the world's ocean such as LMEs and EEZs (Watson *et al.* 2003). Here, we have combined what is known about the fished distributions of the commercial taxa with fine-scale globally mapped data. This has been overlain on generalized profiles generated from 1-min bathymetric data, so that representative but generalized catch profiles or cross sections can be prepared for any area, regardless of their variability or scale. Until advances in the underlying data and computing processes, this was not achievable. We believe that these catch transect profiles will prove useful to a wide range of professionals and the general public trying to visualize fisheries and their potential impacts.

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References

Agnew, D.J., Pearce, J., Pramod, G. *et al.* (2009) Estimating the worldwide extent of illegal fishing. *PLoS ONE* **4** (2 e4570), 1–3.

Amante, C. and Eakins, B.W. (2009) ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. *NOAA Technical Memorandum* NESDIS NGDC-24, 19pp.

Anticamara, J., Watson, R., Gelchu, A., Beblow, J. and Pauly, D. (2011) Global fishing effort (1950–2010): trends, gaps, and implications. *Fisheries Research* **107**, 131–136.

Aquarone, M.C. and Adams, S. (2009a) California current LME.593-604. In: *The UNEP Large Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas* (eds K. Sherman and G. Hempel). UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme, Nairobi, Kenya, pp. 593–604.

Aquarone, M.C. and Adams, S. (2009b) North Sea LME.573-580. In: *The UNEP Large Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas* (eds K. Sherman and G. Hempel). UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme, Nairobi, Kenya, pp. 573–580.

Atta-Mills, J., Alder, J. and Sumaila, U.R. (2004) The decline of a regional fishing nation: the case of Ghana and West Africa. *Natural Resources Forum* **28**, 13–21.

Bhathal, B. and Pauly, D. (2008) 'Fishing down marine food webs' and spatial expansion of coastal fisheries in India, 1950-2000. *Fisheries Research* **91**, 26–34.

Banse, C. (1968) Hydrography of the Arabian Sea shelf of India and Pakistan and effects on demersal fishes. *Deep-Sea Research* **15**, 45–79.

Bonfil, R., Munro, G., Sumaila, U.R. *et al.* (1998) Impacts of distant water fleets: an ecological, economic and social assessment. In: *The Footprint of Distant Water Fleet on World Fisheries. Endangered Seas Campaign* (ed. D. Pauly). WWF International, Godalming, Surrey, pp. 11–111.

Brunner, B. (2011) *The Ocean at Home: An Illustrated History of the Aquarium*. Translated from German by Ashley Marc Slapp. Reaktion Books, London, 144pp.

Chassot, E., Bonhommeau, S., Dulvy, N.K. *et al.* (2010) Global Marine primary production constrains fisheries catches. *Ecology Letters* **13**, 495–505.

Cheung, W.W.L. and Pitcher, T.J. (2008) Evaluating the status of exploited taxa in the northern South China Sea using intrinsic vulnerability and spatially explicit catch-per-unit-effort data. *Fisheries Research* **92**, 28–40.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L. *et al.* (2010) Large-scale distribution of maximum catch potential in the global ocean under climate change. *Global Change Biology* **16**, 24–35.

Cushing, D.H. (1973) *The Detection of Fish*. Pergamon Press, Oxford, UK, 200pp.

Dulvy, N.K., Chassot, E., Heymans, S.J.J. *et al.* (2009) Climate change, ecosystem variability and fisheries productivity, Chapter 2. In: *Remote Sensing in Fisheries and Aquaculture* (eds M.-H. Forget, V. Stuart and T. Platt). International Ocean-Colour Coordinating Group, Report No. 8, Dartmouth, Canada, pp. 11–28.

FAO. (1972) *Atlas of the Living Resources of the Sea*. Department of Fisheries, Food and Agriculture Organization of the United Nations, Rome.

FAO. (2009) *The State of World Fisheries and Aquaculture 2008*. FAO, Rome.

Forget, M.-H., Stuart, V. and Platt, T. (eds) (2009) *Remote Sensing in Fisheries and Aquaculture*. International Ocean-Colour Coordinating Group, Report No. 8, Dartmouth, Canada.

Froese, R. and Pauly, D. (2003) Dynamik der Überfischung. In: *Warnsignale aus Nordsee und Wattenmeer – eine aktuelle Umweltbilanz* (eds J.L. Lozán, E. Rachor, K. Reise, J. Sündermann and H. von Westernhagen). GEO, Hamburg, pp. 288–295.

Froese, R. and Proelß, A. (2010) Rebuilding fish stocks no later than 2015: will Europe meet the deadline? *Fish and Fisheries* **11**, 194–202.

Gaston, K.J. (2000) Global patterns in biodiversity. *Nature* **405**, 220–227.

Halpern, B.S., Walbridge, S., Selkoe, K.A. *et al.* (2008) Mapping the impact of human threats to global marine ecosystems. *Science* **319**, 948–952.

Heileman, S. (2009). South China Sea LME. In: *The UNEP Large Marine Ecosystem Report: A Perspective on Changing Conditions in LMEs of the World's Regional Seas* (K. Sherman and G. Hempel). UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme, Nairobi, Kenya, pp. 297–308.

Heincke, F. (1913) Investigation on the plaice. General Rapport I. Plaice fishery and protective regulation. Part I. *Rapports P.-V. Réunion du Conseil International pour l'Exploration de la Mer* **17A**, 1–153.

Ihaka, R. and Gentleman, R. (1996) R: a language for data analysis and graphics. *Journal of Computational and Graphical Statistics* **5**, 299–314.

Kaczynski, V.M. and Fluharty, D.L. (2002) European policies in West Africa: who benefits from fisheries agreements? *Marine Policy* **26**, 75–93.

Longhurst, A.R. (1998) *Ecological Geography of the Sea*. Academic Press, San Diego, CA. 398pp.

Longhurst, A. and Pauly, D. (1987) *Ecology of Tropical Oceans*. Academic Press, San Diego, CA. 407pp.

Morato, T., Watson, R., Pitcher, T. and Pauly, D. (2006) Fishing down the deep. *Fish and Fisheries* **7**, 24–34.

Pauly, D. (2010) *Gasping Fish and Panting Squids: Oxygen, Temperature and the Growth of Water-Breathing Animals*. Excellence in Ecology (22), International Ecology Institute, Oldendorf/Luhe, Germany, xxviii + 216pp.

Pauly, D., Christensen, V., Guénette, S. *et al.* (2002) Towards sustainability in world fisheries. *Nature* **418**, 689–695.

Pauly, D., Cheung, W.W.L., Close, C., Hodgson, S., Lam, V.W.Y. and Watson, R. (2008) Asymmetry in latitudinal, longitudinal and bathymetric distribution of marine fishes and invertebrates. In: *Modelling Present and Climate-shifted Distribution of Marine Fishes and Invertebrates* (eds W.W.L. Cheung, V.W.Y. Lam and D. Pauly). Fisheries Centre Research Report **16** (3). Fisheries Centre, University of British Columbia, pp. 63–72.

Pauly, D., Belhabib, D., Cheung, W. *et al.* (2012) Catches [of the Chinese distant- water fleet] pp. 21–29 & 81–85. In: *The Role of China in World Fisheries* (eds R. Blomeyer, I. Goulding, D. Pauly, A. Sanz and K. Stobberup). European Parliament, Directorate General for Internal Policies, Policy Department B: Structural and Cohesion Policies – Fisheries. Brussels, 97 p.

Sherman, K., Alexander, L.M. and Gold, B.D., (eds) (1990) *Large Marine Ecosystem: Patterns, Processes and Yields*. American Association for the Advancement of Science, Washington, DC, 242pp.

Swartz, W., Sala, E., Tracey, S., Watson, R. and Pauly, D. (2010) The spatial expansion and ecological footprint of fisheries (1950 to present). *PLoS ONE* **5**, 1–6.

Walsh, S.J. (1996) Efficiency of bottom sampling trawls in deriving survey abundance indices. *NAFO Scientific Council Studies* **28**, 9–24.

Walters, C. and Maguire, J.J. (1996) Lessons for stock assessments from the Northern cod collapse. *Review of Fish Biology and Fisheries* **6**, 125–137.

Watson, R. and Morato, T. (2013) Fishing down the deep: accounting for within-species changes in depth of fishing. *Fisheries Research* **140**, 63–65.

Watson, R. and Pauly, D. (2001) Systematic distortions in world fisheries catch trends. *Nature* **414**, 534–536.

Watson, R., Christensen, V., Froese, R. *et al.* (2003) Mapping fisheries onto marine ecosystems for regional, oceanic and global integrations. In: *Trends in Exploitation, Protection, and Research* (eds G. Hempel and K. Sherman). Elsevier Science, Amsterdam, 12, pp. 375–395.

Watson, R., Kitchingman, A., Gelchu, A. and Pauly, D. (2004) Mapping global fisheries: sharpening our focus. *Fish and Fisheries* **5**, 168–177.

Watson, R., Alder, J., Kitchingman, A. and Pauly, D. (2005) Catching some needed attention. *Marine Policy* **29**, 281–284.

Watson, R., Cheung, W., Anticamara, J., Sumaila, R.U., Zeller, D. and Pauly, D. (2012) Global marine yield halved as fishing intensity redoubles. *Fish and Fisheries*, doi:10.1111/j.1467-2979.2012.00483.x.

Watson, R., Zeller, D. and Pauly, D. (2013) Primary productivity demands of global fishing fleets. *Fish and Fisheries*, doi: 10.1111/faf.12013.

Worm, B., Barbier, E.B., Beaumont, N. *et al.* (2006) Impacts of biodiversity loss on ocean ecosystem services. *Science* **314**, 787–790.

Worm, B., Hilborn, R., Baum, J.K. *et al.* (2009) Rebuilding global fisheries. *Science* **325**, 578–585.

Yáñez, E., Barbieri, M.A., Silva, C., Nieto, K. and Espíndola, F. (2001) Climate variability and pelagic fisheries in northern Chile. *Progress in Oceanography* **49**, 581–596.

Zeller, D. and Pauly, D. (2001) Visualisation of standardized life history patterns. *Fish and Fisheries* **2**, 344–355.

Zeller, D. and Pauly, D. (2005) Good news, bad news: global fisheries discards are declining, but so are total catches. *Fish and Fisheries* **6**, 156–159.

Zeller, D.and Pauly, D. (2007) Reconstruction of marine fisheries catches for key countries and regions (1950–2005). Fisheries Centre Research Reports **15**(2). Fisheries Centre, University of British Columbia.

Zimmermann, C. (2002) The north sea herring: a case study for single species fisheries management. In: *Oceans 2020: Science for Future Needs* (eds J.G. Field, G. Hempel and C.P. Summerhayes). Island Press, Washington, DC, pp. 123–125.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Exclusive Economic Zone areas.

Figure S2. Large Marine Ecosystems areas.