The following supplements accompany the article

Trophic level-based indicators to track fishing impacts across marine ecosystems

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Supplement 1. Details of ecosystem case studies on which the paper is based. The paper centres on 9 ecosystem case studies (Fig. S1), which are detailed below

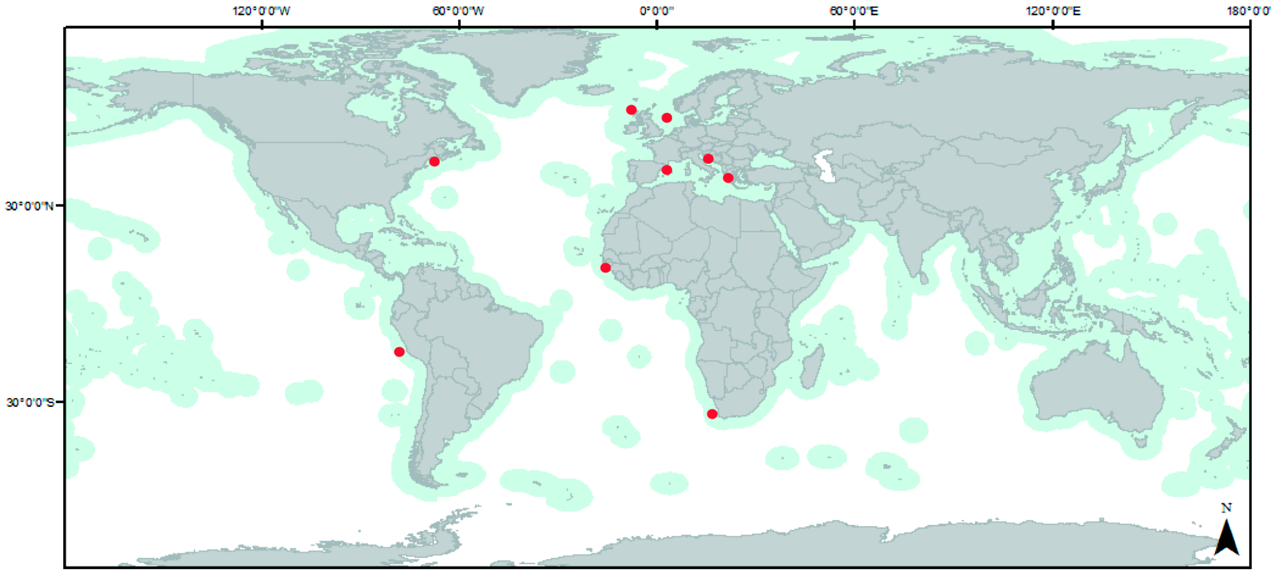

Fig. S1. Location of case studies. The economic exclusive zones are indicated in the map in green

Southern Benguela

The complex life cycles of many marine species off South Africa, which have spawning, nursery and feeding grounds in both the upwelling area off the west coast and on the Agulhas Bank or south coast at different times of the year, make it difficult to separate biological indicators and management strategies in the upwelling and bank areas; thus, the whole ecosystem off South Africa is considered as the Southern Benguela. During the 1980s, anchovy (*Engraulis encrasicolus*) was the dominant small pelagic fish in the southern Benguela sub-system. By the 1990s, anchovy biomass had declined and stocks of sardine (*Sardinops sagax*), redeye (*Etrumeus whiteheadi*), horse mackerel (*Trachurus capensis*) and both species of hake (*Merlucius capensis* and *M. paradoxus*) had increased in size (see Van der Lingen et al. 2006 for details). Sardine dominated the South African catch from 1950 to 1965, and anchovy from then until the mid-1990s. Sardine again began to recover in the late 1990s, and in the early 2000s, both anchovy and sardine were relatively abundant for a few years, after which anchovy returned to moderately high abundance levels and sardine declined. Total catches in the south-east Atlantic increased during the 1950s and 1960s, peaking at 3 million t in 1968, and fluctuating at around 2 million t thereafter (600 000 t in the Southern Benguela). The rapid increase in catches is attributed to the expansion of the purse seine fishery targeting pelagic fish. When these catches declined, there was an expansion of the demersal trawl fishery targeting hakes, and when hake catches decreased, horse mackerel were more heavily fished. Currently in the Southern Benguela, the most valuable commercial species are shallow- and deep-water hake. Cape Hake are caught in demersal trawls, and by the line and the longline fisheries. Catches of hake increased from the 1950s, had peaked by 1977 (when a 200 mile Fishing Zone was proclaimed by South Africa), and have since remained fairly stable. There is little room for expansion of the demersal fishery above present levels, particularly the hake fishery. Most linefish stocks were considered overexploited and subject to a moratorium on catches since 2002, with recent analyses suggesting recovery of several species (H. Winker & T. Booth pers. comm.). This recovery as well as the return to 'normal' small pelagic fish abundances explains the increase in proportion of predatory fish in surveys from 2003 onwards, following the low values for this indicator in the late 1990s. Mean length of all surveyed fish (pelagic and demersal) has declined in recent years, and mean maximum lifespan of surveyed fish declined in the early 2000s when small pelagic fish were unusually abundant, but has since returned to levels observed in the 1980s and 1990s.

A model of the Southern Benguela was fitted to catch and abundance time series for the period 1978 to 2003 (Shannon et al. 2008). The fitting procedure included assigning vulnerabilities to the 25 most sensitive predator-prey interactions in the model, incorporation of hypothetical (model-derived) environmental forcing functions applied to anchovy and its predators, sardine and its predators, and to phytoplankton production.

Interpreting TL indicators in the Southern Benguela

Overall, TL of the community and landings (TL_{SC} and TL_L) declined in the early 2000s and have subsequently increased, although not to previous levels despite declines in both fishing (EwE model) and fishing pressure (landings/biomass, data-based). By contrast, fishing effort (data- based, used to drive the model) has increased over time. TL_{MC} (1978–2003) closely matched TL_L, and also corresponded to TL_{SC} for the years for which survey data were available (see Table S4 in Supplement 4 for correlations). TL-based indicators using all 3 data sources (landings, surveys and model) tracked the increase in abundance of small pelagic fish in the early 2000s and the subsequent 'return to normal' abundance levels coupled with the start in recovery of several line fish stocks in recent years. $TL_{SC3.25}$ tracked the upsurge in small pelagics because the only fish species with TL below 3.25 was sardine, whereas anchovy, attaining higher biomass levels on average across the model time period, had TL around 3.5. This was not the case for $MTI_{3.25}$, since the contribution of low TL sardine to catches was important. For an upwelling system such as is included in the Southern Benguela ecosystem, $MTI_{3.25}$ misses the ecosystem variability inflicted by small pelagic fish, which play pivotal roles in ecosystems of this type. Thus, considering MTI alone in such an ecosystem would not be meaningful. Our results differ in absolute terms and in trends from those reported as mean trophic index in Branch et al. (2010), since the latter authors consider the full Benguela ecosystem in $MTI_{3.25}$ (whereas splitting the Southern and Northern Benguela ecosystems is more advisable; see reasons above) but consider the Agulhas system separately, and they only considered the demersal trawl survey data from west coast of South Africa in their ecosystem assessment to which they compare $MTI_{3.25}$. Assessing TLs across the full Southern Benguela ecosystem and across the full spectra of species (pelagic and demersal surveys, for example), independently from the differently functioning and managed Northern Benguela, provides a more balanced and fuller picture of how the TL-based indicators relate to one another in the offshore ecosystems of South Africa.

Taking into account observed trends in the various TL-based indicators, TL indicator trends when small pelagic fish are excluded (results not shown), and declines in mean length and mean maximum lifespan (Coll et al. unpubl. data) in the surveyed community (which, despite improving trends in the most recent decade, are still below long term means in all years from 2000 to 2010 apart from 2006 in the case of mean maximum lifespan), the Southern Benguela could be viewed as showing some of the signs of a system that has been 'fished down'. Signals from indicators are complicated by the high variability of small pelagic fish in this ecosystem, associated with large environmental variability.

Northern Humboldt

The Northern Humboldt Current Ecosystem (NHCE) is the most productive eastern boundary current system in the world in terms of fish (Wolff et al. 2003). In this area (0.8% of all the oceans) about 15% of total world's catch is produced (FAO 2005). The coastal area is characterized by cold and nutrient rich upwelled waters. Three subsystems (pelagic, demersal and coastal) are clearly differentiated, and species inhabiting each subsystem are exploited by a particular fleet. Pelagic fish are targeted by purse seiners and comprise 95% of the Peruvian catches, the most important being the neritic anchovy (*Engraulis ringens*), sardine (*Sardinops sagax*), the transzonal jack mackerel (*Trachurus murphyi*) and chub mackerel (*Scomber japonicus*). The anchovy population has been recognized as the largest single fishery stock ever recorded. The anchovy fishery has spanned 3 stages, the first from 1953 to 1972 with a maximum annual catch of 12 million t, the second from the stock collapse in 1973, followed by 20 yr of low anchovy biomass, and the third since 1992 to the present, with a recovery of catch levels and a maximum annual catch of ~10 million t in 1994. Demersal species are caught by bottom trawlers mainly for direct human consumption. Peruvian hake (*Merluccius gayi peruanus*) is the main target species. Peruvian rock seabass (*Paralabrax humeralis*), Peruvian banded croaker (*Paralonchurus peruanus*) and lumptail searobin (*Prionotus stephanophrys*) are caught as by-catches, but still important for human consumption. The coastal subsystem is restricted to 5 nautical miles parallel to the coastline. It is dominated not only by fish species but also a high diversity of benthic invertebrates, which are caught by a large artisanal fleet (around 5000 vessels) able to land almost 200000 t of fish and shellfish per year for direct human consumption (Valdivia & Arntz 1985). The most abundant coastal fishes are the South Pacific bream (*Seriolella violacea*), mullet (*Mugil cephalus*), South Pacific menhaden (*Ethmidium maculatum*) and drum (*Sciaena deliciosa*). Scallop (*Argopecten purpuratus*), mussel (*Aulacomya ater*) and snail (*Concholepas concholepas*) are the dominant invertebrates (Wolff et al. 2003). This ecosystem has been modelled by an Ecopath model representative of the 1995/96 period. The model extends from 3° S to 16° S and out to 60 nm, covering an area of approximately 165000 km^2. Further information about the model configuration is available in Tam et al. (2008) and Taylor et al. (2008). Thirty-one living functional groups and a detritus box are included in the model. Hake population is structured into 2 size groups (small and large) to account for diet changes between life stages. Diatoms and dinoflagellate biomass time series were used as environmental forcings. Mesopelagics biomass time series were also used as forcing during the fitting period. The Ecosim simulations were calibrated for the period 1995 to 2003 against observed catches and biomasses.

Interpreting TL-based indicators in the Northern Humboldt

TL of the landings was similar to $MTI_{3.25}$, because the only fish species with TL below 3.25 was *Normanichthys*, and these indicators increased as they tracked the dominance in landings of sardine (TL = 3.3) in the 1980s and the dominance in landings of anchovy (TL = 3.5) in the 1990s. $MTI_{4.0}$ and $TL_{SC4.0}$ tracked the increase of predators, such as hake in the 1990s and jumbo squid in the 2000s.

TL indicators based on catches showed different trends than TL indicators based on surveys, because while landings data were dominated by sardine and anchovy, other species such as Jack mackerel (TL = 3.9) and Pacific mackerel (TL = 3.7) contributed to biomasses data, mainly before 2000s. TL_{MC} had similar fluctuations as TL_{SC} for the years for which survey data were available (1995 to 2003), tracking the decrease of TLs after the El Niño of 1997-98 due to the biomass dominance of anchovy over Jack mackerel, despite the fact that fishing effort and fishing mortality (EwE model) have declined from the 2000s. In the Northern Humboldt, catch-based and survey-based TL indicators were necessary to track different trends in landings and biomass species composition.

During the period 1983 to 2009, the recovery of anchovy with a higher trophic level than sardine could be viewed as a ‘fishing up’ the food web process in the Northern Humboldt. In addition, the increase of predators such as hake and jumbo squid produced an increasing trend in $MTI_{4.0}$ and $TL_{SC4.0}$. However, the high environmental variability of upwelling systems, generating large fluctuations of landings and biomasses of a few dominant species, open the possibility of occurrence of other processes (e.g. ‘fishing through’ or ‘fishing down’) during other periods of study.

Inner Ionian Sea Archipelago (Eastern Mediterranean Sea)

The Inner Ionian Sea Archipelago is situated in the eastern Mediterranean Sea, in the western part of Greece. The area covers approximately 1021 km^2 of sea surface, is extremely oligotrophic with values of chlorophyll *a* (chl *a*), nutrients and particulate organic carbon among the lowest found in Mediterranean coastal waters. The European sardine (*Sardina pilcardus*) and anchovy (*Engraulis encrasicolus*) are the most important pelagic fish in terms of biomass in the area representing approximately 26% of the total Inner Ionian Sea Archipelago catch, while hake (*Merluccius merluccius*) dominate the demersal fish compartment. The area is an important spawning ground for European pilchard and hake. Also, of the 9 species of marine mammals occurring in the Mediterranean Sea, 3 regularly inhabit the area: the bottlenose dolphin (*Tursiops truncatus*), the critically endangered Mediterranean monk seal (*Monachus monachus*) and the endangered short-beaked common dolphin (*Delphinus delphis*). Unfortunately, in the last decades (in particular since the late 1960s), most of the commercial pelagic and demersal fish stocks have shown a remarkable decline. Such collapse was mainly caused by an intensive fishing effort by purse seiners and trawlers that increased until the end of the 1990s. As a consequence, trawl and purse seine catches have shown clear evidence of decline between 1996 and 2000. In addition, while most important pelagic and demersal stocks have clearly decreased through time, crustacean biomass has gradually increased, suggesting a cascading effect caused by predation release. A negative biomass trend was also observed for monk seal and short-beaked common dolphin biomass. In both cases the decline started after the 1970s as a consequence of direct and incidental killings caused by fishers and extent of intensive fishing pressure on these marine mammals' prey. Such changes in the structure of this marine ecosystem have been also observed in the ecological indicators examined: a step decline in proportion of predatory fish and in mean life span, respectively, from 1975 onwards and from the beginning of 1980, and a mean length of all fish (pelagic and demersal) that declined since the beginning of 1990.

A model of the Inner Ionian Sea Archipelago has been fitted to catch and biomass time series for the period 1964 to 2003 (Piroddi et al. 2010, 2011). The fitting procedure included searching for predator–prey vulnerabilities and looking at the impact of environmental factors on pelagic and demersal fish stocks by applying model-derived time series of nutrient loading as forcing function. In particular, the simulated changes in nutrient concentration in the water column directly impacted the primary production biomass, therefore affecting pelagic and demersal fish stocks.

Interpreting TL-based indicators in the Inner Ionian Sea

Overall, TL of the community and landings has increased through time, supporting the decrease of European pilchards and European anchovies in the catch and the increase of target species with higher trophic level. Both trends have shown an increase until the beginning of 2000 and a decline afterwards of TL and TL 3.25 and TL 3.24 and TL 4.0, respectively, for landings and survey community. In particular, the drops observed in the landings were mainly influenced by the decline of hake and several other pelagic and demersal species (e.g. picarel *Spicara smaris* and horse mackerels *Trachurus mediterraneus; Trachurus trachurus*; bogue *Boops boops* and mullidae *Mullus barbatus and Mullus surmuletus*; Piroddi et al. 2010) while the declines observed in the survey community were driven by the collapse of short-beaked common dolphins, swordfish and tuna species (Piroddi et al. 2010, 2011). Interestingly, landings of TL 4.0 have increased despite the decline in the area of swordfish and tuna species, suggesting a possible spatial expansion of purse seiners in deeper areas outside the studied ecosystem. As for TL of the modelled community (1964 to 2003), similar patterns were observed in comparison to the survey community (i.e. increase until 2000s) with the exception of TL 4.0 organisms, which markedly declined in the model after the year 2000, and TL of survey community, which increased after 2000 instead of decreasing in the modelled community. These differences were probably influenced by the presence in the modelled community of a greater number of functional groups (e.g. seabirds, turtles) that declined as well due to the reduction of marine resources. Effort and fishing mortality in the area have exponentially increased until the beginning of the year 2000 and slightly decreased afterwards due to stocks reduction; conversely, L/B showed a decline. One possible explanation could be related to underreporting of catch statistics that in the area has been recognized to be of major issue (landing data are unreliable, fishers may deliberately misreport their catches to avoid stricter regulations or higher taxation; Stergiou et al. 1997, Bearzi et al. 2006). To conclude, these indicators have clearly highlighted the deterioration of the Inner Ionian Sea ecosystem due to intensive overexploitation particularly in relation to small pelagic fishes, key species of this Mediterranean food web.

North Sea

While herring (*Clupea harengus*) form the most abundant stock in the North Sea, sandeels (*Ammodytes marinus*) support the greatest tonnage of landings. Pelagic fisheries target herring and mackerel (*Scomber scombrus*), while sandeels, Norway pout (*Trisopterus esmarkii*) and sprat (*Sprattus sprattus*) are targeted by industrial fisheries for meal. Demersal otter trawlers mainly target either *Nephrops* or a mix of roundfish, including cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*) and whiting (*Merlangius merlangus*) and saithe (*Pollachius virens*). The flatfish plaice (*Pleuronectes platessa*) and sole (*Solea solea*) are typically targeted by beam trawlers (Mackinson & Daskalov 2007). High levels of discarding of fish provide additional to prey to scavenging seabirds, and the North Sea is home to ~60% of the world's population of the great skua (*Catharacta skua*), and >70% of the world population of both northern gannet (*Morus bassanus*) and the subspecies *graellsii* of the lesser black-backed gull (*Larus fuscus*). Marine mammals are protected, and seals have risen in abundance over the past 2 decades (SCOS 2011). All stocks of roundfish and flatfish have at some time been exposed to high levels of fishing mortality for a long period. For most of these stocks, their lowest observed spawning stock size has been seen in recent years. This has resulted from excessive fishing effort, possibly combined with an effect of a climatic phase which is unfavourable to recruitment (ICES WGNSSK 2011).

The North Sea EwE model (Mackinson & Daskalov 2007) has been updated and calibrated by fitting to time-series data from 1991 to 2007 (Mackinson 2014). The calibration process included sensitivity analysis of parameters used in initializing and fitting model predictions to observations. Specifically, this involved the selection of initial vulnerability parameters, selection and weighting of time-series data used in fitting, and the parameterization of stock–recruitment dynamics. Sensitivity to the selection of data used in model fitting reveals that model performance is best when data on all functional groups in the ecosystem are included. When data on only selected important commercial species are included, the results conflict with empirical evidence. Results of analyses reported in Mackinson (2014) indicate strong empirical evidence for water temperature as being an important driver of bottom-up changes in the North Sea ecosystem; a finding that is supported by evidence from the model key run (SCOS 2011). However, fishing pressure overall peaked during the 1980s and has been reducing since. The last decade has seen fishing effort at very low levels and sustained recovery of numerous stocks is expected; some stocks such as cod are showing very preliminary signs of recovery.

Interpreting TL-based indicators in the North Sea

The small increase in $MTI_{4.0}$ during the late 1980s was due to a decline in sprat *Sprattus sprattus* (TL = 4.1) landings. A similar pattern during this period (increase in indicators) was seen in the 3 survey-based indicators, largely due to an increase in whiting *Merlangius merlangus* (TL = 4.9 and a predator of sprat) and a decrease in haddock *Melanogrammus aeglefinus* (TL = 3.6); sprat catch rates in the survey were low throughout.

$MTI_{4.0}$ decreased during the 1990s and early 2000s, in line with declining fishing effort and a reduction in landings of demersal fish (cod *Gadus morhua,* TL = 4.4; saithe *Pollachius virens,* TL = 4.1; whiting *Merlangius merlangus,* TL = 4.9; Fig. 2) enforced by restrictions in total allowable catch (ICES 2012). However, a different pattern is shown in both the TL_L and $MTI_{3.25}$ due to the inclusion in these indicators of sandeel (Ammodytidae) landings (the sandeel fishery is the greatest by far in terms of total weight of the catch) with low trophic level (TL = 3.35). Sandeel landings were also reduced through fisheries management during the early 2000s; however, the decrease was so great (from 850 kt in 2002 to 330 kt in 2003) that the proportion of landings by this species decreased markedly, resulting in an increase in the TL_L and $MTI_{3.25}$. A knock on effect of the bias in TL_L by the management of the sandeel fishery is the significant negative correlation between this indicator and $TL_{MC4.0}$. Notably however, $TL_{MC4.0}$ does correlate significantly with $MTI_{4.0}$ ($p < 0.01$), since the gradual decline in landings of demersal fish was a response to the clear gradual declines in the biomass of those species, and the group is well represented in both indicators. The catch-based indicators that include trophic levels <4 (TL_L and $MTI_{3.25}$) show different patterns to $MTI_{4.0}$. The fall in both indicators from 1980 to 1990 is a response to decreases in cod and sprat and increases in both sandeels and herring as the stock recovered from previous overexploitation. During the mid-2000s, the rise in these 2 indicators is due purely to the great drop in landings of sandeels (Ammodytidae) following management action.

The model-based indicators are quite stable, but nevertheless differences within the set are discernable. $TL_{MC3.25}$ shows a different pattern to TL_{MC} due solely to the dominance in TL_{MC} by a great biomass of zooplankton (2 groups: 'carnivorous zooplankton' and 'herbivorous and omnivorous zooplankton [copepods]'). $TL_{MC4.0}$ differs from $TL_{MC3.25}$ due to the high abundance of sandeels and herring in $TL_{MC3.25}$. A decline in sandeels (TL = 3.4) during 2001 to 2006 initially led to a rise in $TL_{MC3.25}$, but this was counteracted by a rise in herring of a similar low trophic level (TL = 3.5) and led to a decline in $TL_{MC3.25}$.

The survey-based indicators $TL_{SC3.25}$ and $TL_{SC4.0}$ generally show similar patterns to the $MTI_{4.0}$ as mentioned above. However, both indicators show a greater increase than catch-based indicators post-2005. This is attributable to the increase in whiting and decrease in herring catch-rates in the survey, which is not reflected in the catch due to the relatively small contribution of whiting to the total catch.

West coast of Scotland

The sea to the west of Scotland is described as ICES area VIa, and of that the shelf area encompassing 110000 km^2 was used in this study. It includes the Firth of Clyde, Firth of Lorne and the waters surrounding the Outer- and Inner Hebrides. The area has a comparatively smaller demersal fishery than that of the North Sea due to the rougher terrain and deeper waters (Bailey et al. 2011). Other fisheries that operate in the area are pelagic trawls, dredges, gillnets, longlines, creels and hand fishing for shellfish, with 2177 fishers on 975 vessels in 2010 (Scottish Government 2011). The main fishers use <10 m boats and focus on demersal such as cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*), and shellfish such as nephrops (*Nephrops norvegicus*) and scallops (*Pecten maximus*) (Scottish Government 2011). The area has been severely overfished (Thurstan & Roberts 2010), and the ecosystem altered (Heath & Speirs 2012, McIntyre et al. 2012). The ecosystem of the West Coast of Scotland has been fitted to time series of catches in Bailey et al. (2011) and updated to include more comprehensive fitting in Alexander (2012).

Interpreting TL-based indicators in in the WC Scotland

For the West Coast of Scotland (WC Scotland), the normalised TL of the catch (Fig. 2) shows a general decline from 1985 to 2002, with the top predators ($MTI_{4.0}$) showing the most severe decline during that time. The $MTI_{3.25}$ and total TL fluctuates more, with the $MTI_{3.25}$ showing some recovery in the late 1990s. However, the main recovery comes subsequent to 2002, when both the total TL and the $MTI_{4.0}$ show good recovery due to the good year class strengths of higher trophic level species such as whiting and haddock in the early 2000s (Bailey et al. 2011). There are also increased catches of blue whiting and sharks during this time (Alexander 2012). This is in contrast to the very low $MTI_{4.0}$ in the North Sea during the same period, where top predators seem to not be doing as well.

The trophic level of the survey community (Fig. 2) shows a very large increase in the top predators (and of the whole community) in the WC Scotland. This is due to the very large increase in mackerel (*Scomber scombrus*) biomass (TL = 3.3) and the increase in haddock (*Melanogrammus aeglefinus*) biomass (TL = 3.7) in the early 2000s. In contrast to the survey- and landings-based indicators, the modelled community TL indicators (Fig. 2) show an increased trend in TL over time, regardless of which TLs are taken into account. This is due to the fact that the biomass of large predators such as grey (*Halichoerus grypus*) and harbour (*Phoca vitulina*) seals, and other species such as monkfish (*Lophius piscatorius, L. budegassa*), flatfish (*Pleuronectes platessa, Lepidorhombus whiffiagonis, Psetta maxima,* halibut *Hippoglossus hippoglossus*, *Scophthalmus rhombus*, *Hippoglossoides platessoides*, *Limanda limanda*, *Glyptocephalus cynoglossus*, *Platichthys flesus*), rays (*Dipturus batis, Raja clavata, R. brachyura, R. montagui, R. naevus, Rostroraja alba, Leucoraja circularis, L. fullonica, Amblyraja radiate*), blue whiting *Micromesistius poutassou*, small demersals (*Argentina silus, A. sphyraena, Enchelyopus cimbrius, Trisopterus minutus, T. luscus, Gaidropsarus* spp., *Gaidropsarus vulgaris, Gadiculus argenteus, Raniceps raninus, Ciliata mustella, C. septentrionalis, Echiodon drummondii, Zoarces viviparous, Capros aper, Syngnathus acus, Entelurus aequerius, Myoxocephalus scorpius, Triglops murrayi, Taurulus bubalis, T. lilljeborgi, Agonus cataphractus, Liparis liparis, Mullus surmuletus, Ctenolabrus rupestris, Labrus bergylta, L. mixtus, Trachinus vipera, Blennius gattorugine, Chirolophis ascanii, Lumpenus lumpretaeformis, Pholis gunnellus, Callionymus lyra, C. maculatus, C. reticulatus,* Gobiidae, *Crystallogobius linearis, Pomatoschistus minutus, P. microps, Lesueurigobius friesii, Balistes carolinensis, Macroramphosus scolopax*) and large demersals (*Anguilla Anguilla, Conger conger, Salmo trutta, Brosme brosme, Phycis blennoides, Molva molva, Merluccius merluccius, Zeus faber, Gasterosteus aculeatus, Sebastes viviparous, Helicolenus dactylopterus, Cyclopterus lumpus, Pagellus bogaraveo, Cepola rubescens, Anarhichas lupus, Sebastes marinus*) have all increased both in CPUE and in modelled biomass (Alexander 2012). Thus, although the main commercial species such as cod and whiting have declined (Heath & Speirs 2012), the biomass (and therefore TL_{MC}) of non-commercially important species have increased—showing changes in the community structure of the ecosystem.

The changes in fishing mortality (FM) and landings/biomass on the WC Scotland (Fig. 4) show very similar trends, with a significant decline in FM over the time period (Table 5). This was mainly due to the introduction of the cod recovery plans in the early 2000s (Horwood et al. 2006), which was meant to reduce the FM in both the North Sea and the WC Scotland. Over the 25 yr of the time series in the WC Scotland, the fishery has changed from one dominated by cod, haddock (*Melanogrammus aeglefinus*) and Pollock (*Pollachius virens, P. pollachius*), to a fishery dominated by mackerel (*Scomber scomgrus*), blue whiting (*Micromesistius poutassou*) and Nephrops (*Nephrops norvegicus*) (Alexander 2012). While the biomass of the historically most important commercial species (cod, haddock, whiting) have declined over this time, the reduction in bottom trawling has caused an increase in monkfish, flatfish and rays (Alexander 2012), although the species that were to be protected by the cod recovery plan have not shown the increase expected.

The Western Scotian Shelf

The Western Scotian Shelf, including the Bay of Fundy, is located within the Northwest Atlantic Fisheries Organization (NAFO) Divisions 4X and 5Yb. The Western Scotian Shelf is a temperate, wide continental shelf influenced by the northerly Gulf Stream and cold water currents from Labrador and the Gulf of St. Lawrence. Compared to the eastern part of the LME, the Western Scotian Shelf is characterized by warmer waters (Zwanenburg et al. 2002) which has made it more resilient to change (Frank et al. 2007, Shackell & Frank 2007). Overall, water properties have large seasonal cycles, east-west and inshore-offshore gradients, and vary with depth (Petrie 1996). The defining characteristic of the Bay of Fundy is the magnitude of tides, which generate intense vertical mixing caused by bottom turbulence (Garrett et al. 1978) and generate high levels of marine productivity. The Western Scotian Shelf and Bay of Fundy have supported a wide range of fisheries for the last 500 yr for between 30 and 60 species, including groundfish species such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Pollock (*Pollachius virens*), white hake

(*Urophycis tenuis*), small pelagic species such as mackerel (*Scomber scombrus*) and herring (C*lupea harengus*), commercially valuable invertebrates such as lobster (*Homarus americanus*), crabs, clams and scallops, and large pelagic species such as sharks, swordfish (*Xiphias gladius*) and tunas. As a result of overfishing, biomass of many groundfish species and herring has decreased and fishing effort increased on species such as lobster, sea scallop (*Placopecten magellanicus*) and spiny dogfish (*Squalus acanthias*). As fish harvesters seek alternative species to exploit, a suite of new fisheries have recently emerged such as sea cucumber (*Cucumaria frondosa*), sea urchin (*Strongylocentrotus droebachiensis*), whelks (*Buccinum* sp.), red crab (*Geryon quinquedens*), rock crab (*Cancer irroratus*), Jonah crab (*C. borealis*), surf clams (*Spisula solidissima*) and hagfish (*Myxine glutinosa*). The pace of developing and emerging species, in the context of the recent decline in traditional fisheries, may be too rapid to ensure their sustainability (Anderson et al. 2008). There has been a long term reduction in the abundance of groundfish such as cod, pollock and haddock, large pelagics such as sharks and even the small pelagic herring (Araújo & Bundy 2012). The number of large fish has declined, as has the mean weight individual fish (Zwanenburg et al. 2002), and condition of 3 functional groups (large benthivores, medium benthivores, and piscivores) has decreased Shackell & Frank (2007).

Using multivariate analysis, Shackell et al. (2012) concluded that fishing has been the dominant driver of ecosystem response and that local climate regimes exacerbate the response. This was further explored using an EwE model of the Western Scotian Shelf/Bay of Fundy (WSS/BoF) (Araújo & Bundy 2011), which was able to reproduce the observed dynamics, such as major decadal trends in abundance and mortality for most groups. The relative strength within a triad of drivers (biophysical, exploitative, and trophodynamic) was explored and the results indicated that all 3 of the triad of drivers contribute to shaping the observed biological and ecological changes of the WSS/BoF. This has substantial implications for fisheries management and an ecosystem approach: (1) climate change (global warming) may negatively affect productivity at the species and ecosystem level; (2) these effects may be magnified due to the combined effects of trophic interactions and exploitation; and (3) fisheries assessments must account for environmental and climate change and the broader ecosystem, or at a minimum, be extremely cautious and manage well below the usual reference points.

Interpreting TL-based indicators in the Western Scotian Shelf

The 3 data sources and TL cut-off points produced 2 main trends in average trophic level of the Western Scotian Shelf: decreasing or increasing. The landings-based and model-based indicators were most consistent: trophic level of total landings, landings > TL 3.25, and all the modelled community TL indicators declined starting in the 1980s or early 1990s. This is due to large declines in the catches and biomass of traditional groundfish species such as cod, pollock and haddock, and also herring which has a relatively high TL (3.87) (Araújo & Bundy 2012). At the same time, there has been an increase in low trophic level invertebrates in the catch, from around 5% of the total catch in the mid-1980s to around 25% of the catch in the late 2000s. Both TL and TL_{MC} have increased since 2005, reflecting an increase in the biomass of some groundfish species such as halibut and haddock, and redfish (*Sebastes* sp.) in recent years. In contrast to this general decreasing trend, the trophic level of landings with TL > 4 has increased since the early 1990s, despite a declining total catch. In this case, as the traditional groundfish species noted above have declined, catches of non-traditional species such as spiny dogfish and large pelagics have increased, and the relative catches of other predators such as Atlantic halibut and the demersal piscivores have also increased. This increase is not observed in $TL_{SC4.0}$ and $TL_{MC4.0}$.

Somewhat surprisingly, given the noted declines in biomass of groundfish species on the Western Scotian Shelf, and in contrast to the landings and model based indicators, there is a general increase in TL_{SC} from the 1980s to the mid-2000s, regardless of cut-off point. This pattern is driven primarily by trends in the biomass of herring (TL = 3.87), which decreased, and spiny dogfish (TL = 4.45), which increased. The average trophic level from 1980 to 2010 is 3.95, so a decline in herring increases the TL, as does the increase in spiny dogfish. Masked are all the other species declines due to the large effect of herring in the earlier years, and the relatively large effect of spiny dogfish in the latter years, when the biomass of most other species is low. Although spiny dogfish are caught commercially, the catch does not reflect their abundance, so it is not surprising that this indicator using survey estimates of biomass is different from the catch-derived indicators. The difference between the survey and model results is due to the difference in relative biomass of herring and spiny dogfish: the relative biomass of spiny dogfish is lower in the model data therefore it does not have the same positive effect on mean TL, and the relative biomass of herring is higher.

Spiny dogfish are poorly sampled by the fisheries-independent research survey, and trends in catches do not represent trends in abundance (DFO 2007). Arguably, the model estimates of spiny dogfish are the most representative since they take into account catch, trophic interaction and broader information about the status of the stock (Araújo et al. 2011). Given that herring and spiny dogfish have such a large influence on the TL indicators on the Western Scotian Shelf, the landings and model-based trophic level indicators are more representative of the status of the system. The landings indicators have a marked change in trend around 2000, when TL_L and $MTI_{3.25}$ level off and $MTI_{4.0}$ increases. This is picked up by the model indicators around 2005 when all indicators increase. TL_{MC} and $TL_{MC3.25}$ likely increase as a result of reductions in fishing drivers and landings which began in the early 2000s. Overall, taking into account observed trends in the landings- and model-based TL indicators together with declines in mean length, the status of the Western Scotian Shelf is poor. Proportion of predatory fish has increased, but this is due to an increase in spiny dogfish and a decrease in herring, a major forage species in the area. Recent signs indicate that the ecosystem deterioration may have been stalled in response to the reduced fishing drivers since the 2000s, but the ecosystem is still considerably changed since the 1970s and 1980s.

Gulf of Guinea (Guinean EEZ)

The Guinean EEZ ecosystem is characterised by a strong and rapid expansion of the fishery over the studied period. Fishing pressure remained relatively low, at least for coastal species, until the mid-1980s. Between 1985 and 2005, the number of industrial vessels registered in the EEZ increased from 50 to more than 150, while the number of artisanal skiffs increased from 1000 to 3600. Given the increase in fishing powers, the realised fishing effort was estimated to be multiplied by about 7 over the last 20 yr.

During that time, catches tripled, reaching 130 000 t in recent years and resulting mainly from the artisanal sector. Artisanal catches are dominated by bonga shad (*Ethmalosa fimbriata*), followed by fish from the sciaenid community (bobo croaker *Pseudotolithus pseudotolithus*), croakers (*Pseudotolithus* spp.), and sea catfishes (*Arius* spp.). Industrial catches are dominated by sardinella (*Sardinella aurita*), horse mackerel (*Trachurus* spp.), cephalopods (*Octopus vulgaris*) and demersal fish. Overall, the fisheries target a large variety of fish species while crustaceans and cephalopods landings remain moderate.

The total biomass of demersal fish, estimated from demersal surveys, decreased from 500 000 t to 200 000 t between 1985 and 2005. The decline affected most groups but is especially strong for croakers, giant African threadfin (*Polydactylus quadrifilis*), grunts (*Pomadasis* spp.), and reached a 10-fold decrease for bobo croakers. Thus, in less than 25 yr, exploitation resulted in the over-exploitation of several stocks, especially among those of the coastal scianids communities.

Two Ecopath models of the Guinean continental shelf were built, for the years 1985 and 2004 (Gascuel et al. 2009). In addition, the 1985 model was adjusted using Ecosim and time series of biomass and catches for the period 1985 to 2004. The model functional group structure was defined from an updated list of 333 species grouped based on ecological similarities and the availability of fisheries data, and the correspondence of commercial fish categories with ecological groups. The resulting structure is composed of 35 functional groups, of which 24 are fish groups.

The comparison of the 1985 and 2004 models clearly show the changes that occurred in the ecosystem. The reduction in biomass not only affects demersal fish but most of the components of the ecosystem. Trophic spectral analysis shows that the decrease in biomass was more accentuated for high trophic level groups (–25% for TL = 3.0 and –50% for TL ≥3.5). In the same way, ecosystem indices (mean trophic level, ascendancy, Finn recycling index) confirm the degradation of the ecosystem.

The fitting of the Ecosim model to biomass and catch time series show that fishing mortality was sufficient to explain the observed trends. Furthermore, Ecosim simulations for the period 2005 to 2015 show that most groups are already overexploited and suggest that global biomass should decrease in the future even under a freeze of fishing effort.

Interpreting TL-based indicators in the Guinean EEZ ecosystem

All fisheries developed over the period and an increase in landings was observed for almost all species. Thus, landings at TLs 2.5, 3.5 and 4.5 increased at the same rate (Fig. 3a). As a result, catch-based TL indicators remained almost stable over the period, slightly decreasing during the first decade (due to a stronger increase in catch of low TL species such as bonga shad, sardinella or mullets) and increasing over the last years (notably due to an increase in landings of large pelagics) (Fig. 2). Surveyed biomass, referring to demersal finfish, decreased sharply over the whole period. The decline affected most groups but was especially strong for high TLs. $Biomass_{SC2.5}$, mainly referring to bonga shad, fluctuated with no clear trend, while $Biomass_{SC3.5\&4.5}$ significantly decreased (Fig. 3). Survey-based TL indicators TL_{SC} and $TL_{SC3.25}$ decreased accordingly, while $TL_{SC4.0}$ remained almost stable (Fig. 2) suggesting that all the highest TLs decreased in the same proportion. The same trend was observed regarding the model-based indicators, with no clear trends for $TL_{MC4.0}$ and a sharp decrease observed for TL_{MC} and $TL_{MC3.25}$. This result suggests that in ecosystems like Guinea, where the biomass of TLs higher that 4.0 is very limited, indicators based on a TL 4.0 cut-off are not able to capture the signal related to changes occurring for apex predators. Lastly, it should be noted that in such a case of fishery expansion and decreasing biomass, the 2 indicators of the width of the trophic spectrum (TL corresponding to the 95 percentile of distribution, and width of the trophic spectrum between $TL_{5\%}$ and $TL_{95\%}$; see Fig. 3b) exhibit a clear pattern when calculated from model. The decreasing trend observed there confirms that trophic diversity has been affected in the Guinean EEZ ecosystem.

North-Central Adriatic Sea – Central Mediterranean

The North-Central Adriatic Sea constitutes the widest continental shelf in the Mediterranean (Pinardi et al. 2006) and is of great value for fishing within the Italian and the European context. The area is characterized by high diversity of environmental conditions that is translated into high biodiversity (Ott 1992). Several studies have highlighted the important relationship between environmental factors and primary and secondary production dynamics in the area (e.g. Agostini & Bakun 2002, Santojanni et al. 2006), such as wind mixing, river runoff, eutrophication and increase in water temperature. Some proliferation of jellyfish species in the Adriatic since the 1980s has been related to climatic events and eutrophication (Mills 2001). In recent times, a decrease of primary production in the basin has been described, with consequences for the whole food-web (Steenbeek et al. 2013). Environmental factors have been related with biomass fluctuations of anchovy and sardine as well (Azzali et al. 2002, Santojanni et al. 2003, 2006).

Mass-balance ecosystem models developed to represent the North-Central Adriatic Sea during the mid- to late 1990s enabled the structure and functioning of the ecosystem to be characterized, integrating a notable amount of the ecological and biological information available (Coll et al. 2007). The models highlighted important coupling between pelagic-benthic production of plankton, benthic invertebrates and detritus. Organisms located at low and medium trophic levels (i.e. benthic invertebrates, zooplankton and small pelagic fish, as well as dolphins, *Tursiops truncatus*), were identified as keystone groups of the ecosystem. Jellyfish were found to be an important element in terms of consumption and production of trophic flows within the modelled ecosystem. A model fitted to data and comparison of models from 1975 and the 1990s highlighted important changes in main marine resources of the region and food-web structure and functioning (Coll et al. 2009). Ecological models have also been used to explore alternative scenarios of fishing management (Fouzai et al. 2012).

Small pelagic fish, mainly sardine (*Sardina pilchardus*) and anchovy (*Engraulis encrasicolus*), constitute the principal component of the catches from the North-Central Adriatic Sea and are mainly caught by purse seiners and mid water trawlers. The demersal fishery mainly comprises juveniles of several target species, e.g. hake (*Merluccius merluccius*) and red mullet (*Mullus* spp.), principally caught by the bottom trawling and the beam trawling fleets. Invertebrates (cephalopods, crabs and scallops) also constitute an important proportion of the catch.

Important changes in landings have been recorded in the North-Central Adriatic from mid-1970s to the present, with a dramatic increase in catches from the mid-1970s to the mid-1980s mainly due to the increase of small pelagic fish in the catch (Coll et al. 2007, 2009, 2010a). This was followed by marked fluctuations in landings until catches progressively declined from late 1980s to the present, primarily because of the decrease in small pelagic fish, especially anchovy and sardine (Azzali et al. 2002, Santojanni et al. 2003, 2006). Total official landings from 2000 were lower than those attained in the late 1970s. Existing data show a significant decrease in fish landings with time, coupled with a non-significant increase in invertebrate landings. In general, fishing effort has increased overall, although nominal effort has declined.

Interpreting TL-based indicators in the North-Central Adriatic Sea

In the Adriatic Sea, all TL indicators except the TL_L show first a decline with time, suggesting depletion and a fishing down the food web (Coll et al. 2009, 2010a), and then an increase with time after 2000, suggesting a high exploitation of small pelagic fish and invertebrate species (Coll et al. 2010b). This is mainly due to a degradation of the ecosystem and a depletion of small pelagic fish and invertebrate species that have now been depleted, and fisheries are catching much less, but are catching species from higher trophic levels, which have not recovered. So this increase is not related to an increase of biomass of high trophic levels, but to a further depletion of low trophic level species.

The TL_L first increases until the mid-1990s, then decreases to early 2000 and afterwards it increased again. These fluctuations are mainly related to the population dynamics of small pelagic fish species, especially anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*). These 2 species are abundant in the area, however a notable decrease in anchovy was described during the late 1980s (coinciding with the increase in the TL_L), followed by a recovery (coinciding with the decline in the TL_L). A decline in sardine biomass has been described from the early 1990s (coinciding with the increase in the TL_L), still without a clear recovery.

Southern Catalan Sea – North-Western Mediterranean

The Southern Catalan Sea is located in the North-Western Mediterranean Sea, in the Catalano-Balearic basin. It is associated with a wide continental shelf influenced by the Ebro River Delta, where soft bottom sediments predominate, with mainly mud and mud-sandy areas. It is mostly described as oligotrophic area, but temporal enrichment occurs due to regional environmental events, mainly related to wind conditions, the existence of a temporal thermocline and a shelf-slope current and river discharges (Estrada 1996). These factors greatly influence the productivity and fishing activity of the area, which yields almost half of the total landings of the Catalan coast and is especially relevant for the reproduction of small pelagic fish, mainly the European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) (Palomera et al. 2007).

Several studies have highlighted the relation between environmental factors and primary and secondary production dynamics in the area (e.g. Estrada 1996). In the Catalan Sea, the wind mixing index has been positively related with recruitment of various demersal species, most likely due to enhanced fertilization and local planktonic production (Lloret et al. 2001). This is also the case for sardine landed in the Ebro River Delta area during the sardine spawning season (November to March). River runoffs from the Rhône and Ebro have been positively related with recruitment of demersal species (Lloret et al. 2001), as well as with anchovy landings during the anchovy spawning season (April to August) in the Southern Catalan Sea (Lloret et al. 2004). The progressive increase in water temperature in the Mediterranean Sea has been positively related with an increase of sardinella (*Sardinella aurita*) landings and its expansion to northern NW Mediterranean areas (Sabatés et al. 2006).

In 1983, 7802 ha of the terrestrial domain of the Ebro Delta River was protected as a National Park due to its international importance for its flora and fauna (mostly birds). Thus, the Southern Catalan Sea is a strategic area for marine vertebrate conservation, sheltering three quarters of the world's breeding population of the Mediterranean endemic Audouin's gull (*Larus audouinii*) and important colonies of other terns and gulls (Zotier et al. 1999). Various species of resident or migratory marine mammals as well as important populations of marine turtles occur in the ecosystem.

Mass-balance ecosystem models developed to represent the Southern Catalan Sea in different time periods (late 1970s, mid-1990s and early 2000s) (Coll et al. 2006, 2008, 2009) facilitated characterisation of the structure and functioning of this ecosystem by integrating most of the ecological and biological information available. The models represented the continental shelf and upper slope area associated with the Ebro River Delta and showed that from the 1970s, the ecosystem was dominated by the pelagic food web. Small pelagic fish were identified as important components of the ecosystem, dominating the pelagic fraction in terms of biomasses and catches. European hake (*Merluccius merluccius*) and medium-sized pelagic fish (horse mackerel *Trachurus* spp. and mackerel *Scomber* spp.) also played important ecological roles in terms of biomasses and trophic interactions.

The Southern Catalan Sea study area includes 7 fishing harbours from Tarragona to Les Cases d'Alcanar. Trawling, purse seine, and long line and troll bait are the most important fisheries in terms of catches, while an important artisanal fleet is still present (with 195 boats in 2006). Small pelagic fish (overcoat sardine and anchovy) constitute the principal component of the catches in terms of biomass and are mainly caught in purse seines and by bottom trawlers. The demersal fishery comprises mainly juveniles of several target species, e.g. hake, red mullet (*Mullus barbatus*), anglerfish (*Lophius* spp.) and blue whiting (*Micromesistius poutassou*), caught principally by the trawling fleet. Large demersal fish (e.g. adult hake) and large pelagic fish are caught by long line and troll bait fleets.

Historical official landings from the Catalan Sea increased dramatically from the beginning of the 19th century to the 1960s and from then to 1990s, mainly due to the expansion of the fishery and public incentives to the fishing sector. Marked fluctuations in landings occurred from the 1970s until they underwent a progressive decrease, beginning in 1994. More recent data from the Southern Catalan Sea showed similar patterns, while nominal fishing effort progressively increased to mid-1990s (Bas et al. 2003). From 1994 to 2003, total official landings declined by 55% and in 2003, were similar to those attained in the late 1970s. This reduction was mainly due to the pelagic fraction, which also exhibited marked inter-annual fluctuations and underwent a reduction of 70.2% in the case of anchovy official landings, and a reduction of 70% in the case of sardine landings. Demersal landings have been maintained at similar levels since 1983, with a reduction of 18% in landings, and underwent smaller fluctuations over the period of decline in the pelagic fraction. Discards, by-catch and illegal, unregulated or unreported (IUU) landings are important in the Southern Catalan Sea.

The scientific general assessment suggests that several demersal stocks are now fully exploited or overexploited, while some pelagic stocks also show signs of overexploitation. There is increasing concern about recruitment overfishing of North-Western Mediterranean anchovy stocks (Palomera et al. 2007), while growth overfishing affects some demersal resources because for many species the sizes at first catch are very similar to those at which the fish recruit. Moreover, the introduction of new fishing procedures such as modern long lines (e.g. for adult hake) has eliminated the spawning refuge of some species and has led to increasing concern about recruitment overfishing of some demersal stocks.

The area has been highly impacted by fishing activity since the 1970s (Coll et al. 2006, 2008, 2009) and presently there are high probabilities of ecosystem overfishing (Coll et al. 2009). Fishing technology, overcapitalization and the increasing market demand is placing intensive pressure on exploited resources of the Mediterranean (Bas et al. 2003). Recent analysis of biodiversity patterns and threats in the Mediterranean Sea identified the coastal areas of the Western Mediterranean Sea as areas hosting a high degree of marine biodiversity but highly threatened by numerous human activities (Coll et al. 2012). In general, and due to technological improvements and fisheries expansion, the catch increased greatly from the 1900s until late 1930s when it decreased during the Spanish Civil War. After the war, catches increased again due to public incentives to the fishing sector. From 1994 onward, landings showed marked fluctuations and a progressive decrease. It is now recognized that there is a depletion of marine resources, and management actions are not applied strongly enough to reverse the situation.

Interpreting TL-based indicators in the South Catalan Sea

The Catalan Sea trends are somewhat different from the North-Central Adriatic Sea, as in the area there has been an expansion of fisheries to deeper and further areas to fish (Coll et al. 2006, 2008). In addition, new species have been incorporated in the fishery as the highly commercial ones have been depleted. So there has been a degradation of the system, but the expansion of fisheries is masking the pattern of some indicators. This is not as evident in the Adriatic since this is a closed area, and the case study here is only from the Adriatic and international waters, so does not include the expansion of fisheries in the eastern part of the Adriatic from the 2000s. Therefore, TL-based indicators in the South Catalan Sea show this expansion and depletion process. From mid-2000s the trophic level of landings has increased. This is due to the depletion of small pelagic fish (mainly sardine and anchovy) and not due to a recovery of the ecosystem. The TL-based indicators from surveyed data show the shift of the community to smaller-sized individuals.

Table S1. Details of the Ecopath with Ecosim models for the 9 ecosystem case studies examined

Ecosystem	Time period for which EwE model was fitted	Publication(s) documenting model fit
North-Central Adriatic Sea	1975–2002	Coll et al. (2009)
Gulf of Guinea	1984–2010	Gascuel et al. (2009)
Inner Ionian Sea Archipelago	1964–2003	Piroddi et al. (2010, 2011)
Northern Humboldt	1995–2003	Tam et al. (2008), Taylor et al. (2008)
North Sea	1991–2007	Mackinson & Daskalov (2007)
Southern Benguela	1978–2003	Shannon et al. (2004, 2008), Smith et al. (2011)
South Catalan Sea	1978–2010	Coll et al. (2008, 2013)
West Coast of Scotland	1985–2008	Bailey et al. (2011), Alexander (2012)
Western Scotian Shelf	1970–2009	Araújo & Bundy (2012)

Supplement 2. Trophic levels used per group/species for calculating TL-based indicators in each of the nice case studies

Table S2. Trophic levels used per group/species surveyed

NC ADRIATIC	
Engraulis encrasicolus	3.04
Sardina pilchardus	2.97
Nephrops norvegicus	3.72
Squilla mantis	3.27
Octopus sp. & *Eledone* s	3.23
Merluccius merluccius	4.02
Mullus sp.	3.22
Conger conger	4.08
Lophius sp.	4.44
Raja sp.	3.99
Trachurus sp.	3.43
Scomber sp.	3.31
Scophthalmus rhombus	4.05
Spicara smaris	3.67
Sprattus sprattus	3.24
Ilex sp. & *Loligo* sp.	4.08
Chlamys opercularis	2.00

SOUTHERN BENGUELA	
Argyrosomus hololepidotus	3.80
Argyrozona argyrozona	3.50
Arnoglossus capensis	3.60
Austroglossus microlepis	3.50
Austroglossus pectoralis	4.00
Bassanago albescens	3.50
Brama raii = B. brama	4.10
Caelorinchus braueri	3.60
Caelorinchus simorhynchus	3.30
Callanthias legras	3.40
Callorhinchus capensis	3.50
Champsodon capensis	4.20
Cheilodactylus fasciatus	3.42
Chelidonichthyes queketti	3.40
Chelidonichthys capensis	4.20
Chirodactylus grandis	3.30
Congiopodus spinifer	3.30
Congiopodus torvus	3.40
Cruriraja parcomaculata	3.64
Cynoglossus zanzibarensis	3.60
Dasyatis chrysonota	3.80
Emmelichthys nitidus	3.60
Galeichthys feliceps	3.47
Galeorhinus galeus	4.20
Genypterus capensis	4.40
Gonorhynchus gonorhynchus	3.30
Halaelurus natalensis	4.21
Haploblepharus edwardsii	3.80
Helicolenus dactylopterus	3.80
Holohalaelurus regani	4.16
Hoplostethus mediterraneus	3.50
Lampanyctodes hectoris	3.60
Lepidopus caudatus	3.90
Loligo vulgaris	3.80
Lolliguncula mercatoris	3.80
Lophius vomerinus	4.50
Lucigadus ori	3.45
Malacocephalus laevis	4.20
Maurolicus walvisensis	3.10
Merluccius capensis	4.20
Merluccius paradoxus	4.20
Mustelus mustelus	3.83
Mustelus palumbes	3.54
Myliobatis aquila	3.61
Octopus dofleini=magnifica	3.80
Pagellus bellottii natalensis	3.34
Paracallionymus costatus	3.03
Photichthys argenteus	4.00
Physiculus capensis	3.03
Pliotrema warreni	4.20
Pomatomus saltatri	4.50
Pterogymnus laniarius	3.70
Raja alba	4.40
Raja clavata	3.80
Raja leopardus	3.90
Raja miraletus	3.80
Raja pullopunctata	4.10
Raja straeleni	4.00
Raja wallacei	3.90
Rhabdosargus globiceps	2.87
Rhinobatos annulatus	3.35
Rossia enigmatica	3.80
Scomber japonicus	3.80
Scombrops boops	4.47
Scyliorhinus capensis	4.00
Sepia australis	3.80
Sepia hieronis	3.80
Sepia papillata	3.80
Sepia simoniana	3.80
Sphoeroides pachygaster	4.20
Sphyrna zygaena	4.50
Spicara axillaris	3.00
Spondyliosoma emarginatum	2.76
Squalus acanthias	4.30
Squalus megalops - mixed	4.30
Squalus mitsukurii	4.50
Sufflogobius bibarbatus	2.80
Synogrops japonicus	3.40
Thyrsites atun	3.70
Todarodes angolensis - unsexed	3.80
Todaropsis eblanae - male	3.80
Todaropsis eblanae - unsexed	3.80
Torpedo fuscomaculata	4.50
Trachurus trachurus - all	3.70
Tripterophysis gilchristi	3.40
Umbrina canariensis	3.40
Zeus capensis	4.50
Engraulis encrasicolus	3.50
Sardinops sagax	3.00
Etrumeus whiteheadi	3.60

S CATALAN SEA	
Mullus sp.	3.16
Lophius sp.	4.56
Pleuronectiformes	3.25
Merluccius merluccius	3.88
Galeus melastomus	3.66
Engraulis encrasicolus	3.05
Sardina pilchardus	2.97
Trachurus sp.	3.15
Scomber sp.	3.49
Thunnus thynnus	4.03
Xiphias gladius	4.17
Octopus sp.	3.08
Loligo sp.	3.64
Trisopterus minutus	3.36
Micromesistius poutassou	3.29
Conger conger	4.22

GUINEAN EEZ	
Rays	4.00
Bobo croaker	3.94
Other croakers	3.97
Lesser Afr, threadfin	3.88
Giant Afr, threadfin	4.11
Royal threadfin	3.96
Seabream	3.62
Sea catfish	3.70
Mullets	2.33
Grunts	3.60
Soles	3.30
Large demersal, predators eaters	4.00
Medium demersal predatators eaters	3.57
Medium demersal invertebrates eaters	3.30
Small demersal invertebrates eaters	3.32

INNER IONIAN SEA	
Common dolphins	4.02
Bottlenose dolphins	4.41
Monk seals	4.23
Sardines ALL	2.89
Anchovies	3.11
Tuna	4.08
Swordfish	4.08
Hake	3.73
Other pelagics	3.10
Other demersal	3.16
Cephalopods	3.50
Crustaceans	3.11

NORTHERN HUMBOLDT	
Engraulis ringens	3.50
Sardinops sagax sagax	3.30
Trachurus murphyi	3.90
Scomber japonicus	3.70
Dosidicus gigas	4.20
Anchoa nasus	3.30
Normanichthys crokeri	3.00
Galeichthys peruvianus	3.70
Merluccius gayi peruanus	4.00
Prionotus stephanophrys	3.60

NORTH SEA	
Ammodytes tobianus	3.11
Anarhichas lupus	3.24
Aspitrigla cuculus	3.76
Clupea harengus	3.79
Dicentrarchus labrax	4.53
Eutrigla gurnardus	3.64
Gadus morhua	4.35
Glyptocephalus cynoglossus	3.88
Hippoglossus hippoglossus	4.53
Lepidorhombus whiffiagonis	3.56
Limanda limanda	4.20
Lophius piscatorius	4.09
Melanogrammus aeglefinus	3.59
Merlangius merlangus	4.94
Merluccius merluccius	3.85
Micromesistius poutassou	3.14
Microstomus kitt	3.67
Mullus surmuletus	4.38
Platichthys flesus	3.85
Pleuronectes platessa	3.67
Pollachius virens	4.11
Psetta maxima	3.96
Scomber scombrus	3.61
Scophthalmus rhombus	3.79
Solea solea	4.17
Sprattus sprattus	4.09
Trachurus trachurus	3.94
Trigla lucerna	3.65
Trisopterus esmarkii	3.91
Zeus faber	4.20

W COAST SCOTLAND	
Cod mature	3.96
Cod immature	3.15
Haddock mature	3.70
Haddock immature	2.95
Whiting mature	4.18
Whiting immature	3.05
Pollock	3.94
Gurnards	3.66
Flatfish	3.51
Rays	3.88
Sharks	4.07
Large demersals	4.33
Other small fish	3.28
Mackerel	3.34
Horse Mackerel	3.17
Blue Whiting	3.67
Herring	3.16
Norway pout	3.30
Poor cod	3.60
Sandeel	3.19
Monkfish	4.38
Sprat	3.19
Nephrops	3.25
Crustaceans	2.74
Cephalopods	3.24

W SCOTIAN SHELF	
American plaice < 26 cm	3.58
American plaice >= 26 cm	3.35
Cod 0 years	3.66
Cod 1-3years	4.08
Cod 4-6 years	4.47
Cod 7+ years	4.47
Spiny dogfish < 73 cm	4.45
Spiny dogfish >= 73 cm	4.45
Demersal pisciviores < 40 cm	4.33
Demersal pisciviores >= 40 cm	4.60
Flounders < 30 cm	3.23
Flounders >= 30 cm	3.21
Haddock < 33 cm	3.38
Haddock >= 33 cm	3.43
Halibuts < 46 cm	3.86
Halibuts 46-81 cm	4.65
Halibuts >= 82 cm	4.65
Herring < 4 years	3.87
Herring>= 4 years	3.87
Large benthivores<41 cm	3.78
Large benthivores >= 41 cm	3.55
Longhorn sculpin < 25 cm	3.74
Longhorn sculpin >= 25 cm	3.77
Mackerel	3.77
Mesopelagics	3.37
Otherpelagic	3.59
Pollock<49	3.91
Pollock49+	4.25
Redfish<22	3.88
Redfish22+	3.90
Silver hake < 25 cm	3.92
Silver hake 25 - 31 cm	4.01
Silver hake >= 32 cm	4.75
Skates<49	3.63
Skates49+	3.91
Small-Medium Benthivores	3.58
Squids	3.98

Table S3. Trophic levels used per group/species reported in the catch

NC ADRIATIC	
Bivalves	2.00
Benthic invertebrates	2.00
Shrimps	3.03
Nephrops norvegicus	3.69
Squilla mantis	3.26
Crabs	2.95
Benthic cephalopods	3.25
Benthopelagic cephalopods	4.13
Merluccius merluccius (vulnerable)	3.99
Merluccius merluccius (non-vulnerable)	4.11
Gadiformes	3.32
Mullus spp.	3.13
Conger conger	4.16
Lophius spp.	4.49
Flatfish	3.77
Turbot and Brill	4.12
Demersal sharks	4.00
Demersal skates	4.10
Demersal fish (1)*	3.30
Demersal fish (2)*	3.64
Demersal fish (3)*	3.74
Engraulis encrasicolus	3.05
Sardina pilchardus	2.98
Other small pelagic fish	3.26
Trachurus spp.	3.49
Scomber spp.	3.29
Sarda sarda	4.05
Thunnus thynnus & *Xiphias gladius*	4.23
*Coll et al. 2007	

SOUTHERN BENGUELA	
Large pelagic fish	4.50
Benthic-feeding demersal fish	3.40
Pelagic-feeding demersal fish	4.90
Cephalopods	3.80
Engraulis encrasicolus	3.50
Sardinops sagax	3.00
Merluccius capensis and *M. paradoxus*	4.20
Thursites atun	4.50
Trachurus capensis	3.70
Etrumeus whiteheadi	3.60
Scomber japonicus	3.80
Lampanyctodes hectoris	3.60
Other small pelagoc fish	3.50
Benthic-feeding chondrichthyans	3.70
Pelagic-feeding chondrichthyans	4.90
Unidentified chondrichthyans	3.90
Apex chondrichthyans	5.20

S CATALAN SEA	
Natantia	2.98
Reptantia	2.89
Nephrops norvegicus	2.82
Other invertebrates	2.02
Octopus sp.	3.10
Loligo sp.	3.67
Mullus sp.	3.16
Conger conger	4.22
Lophius sp.	4.39
Pleuronectiformes	3.20
Trisopterus minutus	3.31
Merluccius merluccius	3.45
Merluccius merluccius	4.10
Micromesistius poutassou	3.40
Other demersal (mixed)	3.08
Other demersal (invert. Feeders)	3.01
Other demersal (pisc)	3.96
Galeus melastomus	3.68
Benthopelagics	3.49
Engraulis encrasicolus	3.05
Sardina pilchardus	2.97
Other small pelagic fish	3.00
Trachurus sp.	3.19
Scomber sp.	3.55
Sarda sarda	4.06
Thunnus thynnus & *Xiphias gladius*	4.19

GUINEAN EEZ	
Rays	4.10
Sharks	4.38
Large pelagics	4.26
Barracudas	4.13
Carangids	4.17
Horse mackerels	3.13
Ethmalosa	2.53
Sardinella	2.85
Bobo croaker	3.95
Other croakers	3.97
Lesser African threadfin	3.88
Giant African threadfin	4.11
Royal threadfin	3.96
Seabreams	3.64
Sea catfish	3.75
Mullets	2.33
Grunts	3.61
Soles	3.30
Large demersal, predators eaters	4.11
Medium demersal predatators eaters	3.56
Medium demersal invertebrates eaters	3.30
Small demersal invertebrates eaters	3.32
Bathy-demersal predators eaters	3.79
Bathy-demersal invertebrates eaters	3.55
Crustacea	3.03
Cephalopods	3.60

INNER IONIAN SEA	
Sardines	2.89
Anchovies	3.11
Tuna	4.08
Swordfish	4.08
Hake	3.73
Other pelagics	3.10
Other demersals	3.16
Cephalopods	3.50
Crustaceans	3.11

NORTHERN HUMBOLDT	
Engraulis ringens	3.50
Sardinops sagax sagax	3.30
Trachurus murphyi	3.90
Scomber japonicus	3.70
Dosidicus gigas	4.20
Anchoa nasus	3.30
Normanichthys crokeri	3.00
Galeichthys peruvianus	3.70
Merluccius gayi peruanus	4.00
Prionotus stephanophrys	3.60
Paralabrax humeralis	3.70
Paralonchurus peruanus	3.60
Sarda chilensis	3.70

NORTH SEA	
Ammodytes tobianus	3.11
Anarhichas lupus	3.24
Aspitrigla cuculus	3.76
Clupea harengus	3.79
Dicentrarchus labrax	4.53
Eutrigla gurnardus	3.64
Gadus morhua	4.35
Glyptocephalus cynoglossus	3.88
Hippoglossus hippoglossus	4.53
Lepidorhombus whiffiagonis	3.56
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Microstomus kitt	3.67
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Psetta maxima	3.96
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Scophthalmus rhombus	3.79
Solea solea	4.17
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W COAST SCOTLAND	
Cod mature	3.96
Cod immature	3.15
Haddock mature	3.70
Haddock immature	2.95
Whiting mature	4.18
Whiting immature	3.05
Pollock	3.94
Gurnards	3.66
Flatfish	3.51
Rays	3.88
Sharks	4.07
Large demersals	4.33
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Poor cod	3.60
Sandeel	3.19
Monkfish	4.38
Sprat	3.19
Nephrops	3.25
Crustaceans	2.74
Cephalopods	3.24

W SCOTIAN SHELF	
Albacore tuna	4.82
Alewife	3.59
American angler	4.47
American eel	3.58
American lobster	3.10
American plaice	3.35
American shad	3.59
Argentines (ns)	3.59
Atlantic blue marlin	4.82
Atlantic butterfish	3.59
Atlantic cod	4.34
Atlantic hagefish	3.58
Atlantic halibut	4.65
Atlantic herring	3.87
Atlantic mackerel	3.77
Atlantic redfishes (ns)	3.90
Atlantic rock crab	3.18
Atlantic white marlin	4.82
Bigeye tuna	4.82
Capelin	3.59
Clams (ns)	2.10
Cusk (tusk)	4.60
Dogfishes (ns)	4.45
Flatfishes (ns)	3.21
Great blue shark	4.81
Greenland halibut	4.65
Haddock	3.43
Jonah crab	2.64
Large sharks (ns)	4.82
Lumpfish (lumpsucker)	3.55
Mahi mahi (dolphin)	4.82
Marine crabs (ns)	2.64
Northern bluefin tuna	4.82
Pelagic fishes (ns)	3.59
Periwinkles (ns)	2.81
Pink (=pandalid) shrimps	2.61
Pollock (saithe)	4.25
Porbeagle	4.81
Queen crab	3.18
Red crab	3.18
Red hake	3.55
Roundnose grenadier	3.55
Sculpins (ns)	4.27
Sea cucumber	2.06
Sea scallop	2.05
Sea urchin	2.06
Silver hake	4.22
Skates (ns)	3.91
Skipjack tuna	4.82
Squids (ns)	3.98
Stone king crab	2.64
Summer flounder	3.21
Swordfish	4.82
Tilefish	3.67
Tunas (ns)	4.82
White hake	4.60
Winter flounder	3.21
Witch flounder	3.21
Wolffishes (ns)	3.67
Yellowfin tuna	3.59
Yellowtail flounder	3.21

Supplement 3. Comparing effects on TL-based indicators of different ways of allocating TL to species groups (see discussion in 'Methods: Implications of estimating TLs using different methods')

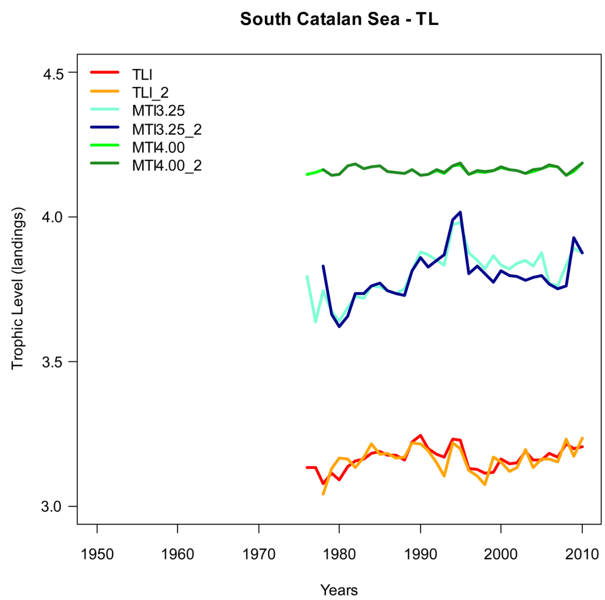

Fig. S2. Plots of TL of landed catch, MTI, TL of the surveyed community, and TL of the surveyed community when a TL > 3.25 cut-off was adopted (as for MTI) when model-generated annual TLs are used, compared to a single TL per species applied across the full time series (denoted as series 2 of each indicator in question) for the South Catalan Sea case study

Fig. S3. Plot of TL of landed catch, and MTI (TL of landed catch with cut-off TL 3.25) in the Southern Benguela, for species-disaggregated TLs (modelled TL used for key, well described species, FishBase TLs for species falling into aggregated model groups) versus when an average TL was used for feeding guilds comprised of demersal fish and chondrichthyans other than deep- and shallow-water Cape hake and snoek. This comparison was made to verify usage of TL of the landed catch from 1950 onwards, since species-disaggregated data were not readily available until 2003

Supplement 4. Correlations results per ecosystem

Table S4. Correlating each TL indicator with time and with every other TL-based indicator examined. ADRIATIC = North-Central Adriatic Sea; S BENG = Southern Benguela; S CATALAN = South Catalan Sea; GUINEA = Gulf of Guinea; HUMB = Northern Humboldt; IONIAN = Inner Ionian Sea Archipelago; N SEA = North Sea; SCOTLAND = West Coast of Scotland; W SCOTIAN = Western Scotian Shelf. Values are correlation coefficients. **Bold** values in shaded cells indicate significant ($p < 0.05$) correlations: dark grey = positive, light grey = negative

ADRIATIC	Year	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Year	1	-0.163	-0.5313	0.089133	-0.3513	-0.46623	-0.54545	-0.17391	0.112648	0
TL_L	-0.163	1	0.206087	0.162393	0.250435	0.198701	0.241558	-0.03557	0.098814	-0.07806
$MTI_{3.25}$	-0.5313	0.206087	1	0.225217	0.67476	0.25614	0.366667	0.555336	0.064229	-0.22628
$MTI_{4.0}$	0.089133	0.162393	0.225217	1	0.649565	-0.3	0.458442	0.229249	-0.28458	0.011858
TL_{SC}	-0.3513	0.250435	0.67476	0.649565	1	0.249351	0.494805	0.272727	-0.06883	-0.15065
$TL_{SC3.25}$	-0.46623	0.198701	0.25614	-0.3	0.249351	1	-0.02727	-0.22394	0.091847	-0.31063
$TL_{SC4.0}$	-0.54545	0.241558	0.366667	0.458442	0.494805	-0.02727	1	0.407637	-0.1063	-0.06708
TL_{MC}	-0.17391	-0.03557	0.555336	0.229249	0.272727	-0.22394	0.407637	1	-0.20059	-0.27767
$TL_{MC3.25}$	0.112648	0.098814	0.064229	-0.28458	-0.06883	0.091847	-0.1063	-0.20059	1	0.33004
$TL_{MC4.0}$	0	-0.07806	-0.22628	0.011858	-0.15065	-0.31063	-0.06708	-0.27767	0.33004	1

S BENG	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	-0.69113	0.380645	-0.34032	-0.5614	-0.42632	0.307018	-0.86435	-0.24435	-0.19652
TL_L	-0.69113	1	0.083468	0.365323	0.803509	0.677193	-0.36842	0.528696	0.266957	0.368696
$MTI_{3.25}$	0.380645	0.083468	1	-0.16653	0.350877	0.561404	-0.47018	-0.43217	0.109565	0.037391
$MTI_{4.0}$	-0.34032	0.365323	-0.16653	1	0.508772	0.250877	-0.14386	0.30087	-0.05478	-0.18
TL_{SC}	-0.5614	0.803509	0.350877	0.508772	1	0.808772	-0.37018	0.678322	0.363636	0.293706
$TL_{SC3.25}$	-0.42632	0.677193	0.561404	0.250877	0.808772	1	-0.55088	0.328671	0.321678	-0.02797
$TL_{SC4.0}$	0.307018	-0.36842	-0.47018	-0.14386	-0.37018	-0.55088	1	-0.1049	-0.1049	-0.34266
TL_{MC}	-0.86435	0.528696	-0.43217	0.30087	0.678322	0.328671	-0.1049	1	0.590435	0.370435
$TL_{MC3.25}$	-0.24435	0.266957	0.109565	-0.05478	0.363636	0.321678	-0.1049	0.590435	1	0.464348
$TL_{MC4.0}$	-0.19652	0.368696	0.037391	-0.18	0.293706	-0.02797	-0.34266	0.370435	0.464348	1

S CATALAN	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	-0.18347	0.564516	0.0125	-0.29073	0.633871	0.407661	-0.92339	0.30121	0.039113
TL_L	-0.18347	1	0.253629	0.037097	0.552419	0.199194	-0.11492	0.358468	-0.1496	-0.12702
$MTI_{3.25}$	0.564516	0.253629	1	-0.09556	0.38871	0.640323	-0.08992	-0.47944	0.183468	0.010484
$MTI_{4.0}$	0.0125	0.037097	-0.09556	1	-0.2504	-0.12661	0.503629	0.076613	-0.08952	-0.03831
TL_{SC}	-0.29073	0.552419	0.38871	-0.2504	1	0.266532	-0.51129	0.368952	-0.05161	0.039113
$TL_{SC3.25}$	0.633871	0.199194	0.640323	-0.12661	0.266532	1	0.356452	-0.47823	0.088306	0.042742
$TL_{SC4.0}$	0.407661	-0.11492	-0.08992	0.503629	-0.51129	0.356452	1	-0.27903	-0.04073	-0.01976
TL_{MC}	-0.92339	0.358468	-0.47944	0.076613	0.368952	-0.47823	-0.27903	1	-0.29315	-0.05524
$TL_{MC3.25}$	0.30121	-0.1496	0.183468	-0.08952	-0.05161	0.088306	-0.04073	-0.29315	1	-0.24677
$TL_{MC4.0}$	0.039113	-0.12702	0.010484	-0.03831	0.039113	0.042742	-0.01976	-0.05524	-0.24677	1

GUINEA	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	0.015038	0.168421	-0.55489	-0.52967	-0.27033	-0.5033	-0.99817	-0.99817	-0.51221
TL_L	0.015038	1	0.700752	0.458647	0.043956	-0.06044	0.043956	-0.01504	-0.01504	0.222556
$MTI_{3.25}$	0.168421	0.700752	1	0.532331	0.153846	0.104396	0.027473	-0.16842	-0.16842	0.17594
$MTI_{4.0}$	-0.55489	0.458647	0.532331	1	0.752747	0.406593	0.230769	0.554887	0.554887	0.682707
TL_{SC}	-0.52967	0.043956	0.153846	0.752747	1	0.89011	0.243956	0.52967	0.52967	0.494505
$TL_{SC3.25}$	-0.27033	-0.06044	0.104396	0.406593	0.89011	1	0.112088	0.27033	0.27033	0.191209
$TL_{SC4.0}$	-0.5033	0.043956	0.027473	0.230769	0.243956	0.112088	1	0.503297	0.503297	0.397802
TL_{MC}	-0.99817	-0.01504	-0.16842	0.554887	0.52967	0.27033	0.503297	1	1	0.514042
$TL_{MC3.25}$	-0.99817	-0.01504	-0.16842	0.554887	0.52967	0.27033	0.503297	1	1	0.514042
$TL_{MC4.0}$	-0.51221	0.222556	0.17594	0.682707	0.494505	0.191209	0.397802	0.514042	0.514042	1

HUMB	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	0.953602	0.952381	0.896825	-0.69475	-0.37607	0.882641	-0.53333	0.566667	0.7
TL_L	0.953602	1	0.999389	0.870574	-0.63309	-0.29182	0.838406	-0.28333	0.366667	0.45
$MTI_{3.25}$	0.952381	0.999389	1	0.869353	-0.63553	-0.28938	0.839092	-0.28333	0.366667	0.45
$MTI_{4.0}$	0.896825	0.870574	0.869353	1	-0.62149	-0.23871	0.875783	-0.81667	0.25	0.483333
TL_{SC}	-0.69475	-0.63309	-0.63553	-0.62149	1	0.758852	-0.7129	0.666667	0.016667	-0.51667
$TL_{SC3.25}$	-0.37607	-0.29182	-0.28938	-0.23871	0.758852	1	-0.30827	0.166667	-0.03333	-0.65
$TL_{SC4.0}$	0.882641	0.838406	0.839092	0.875783	-0.7129	-0.30827	1	-0.73113	0.522233	0.652791
TL_{MC}	-0.53333	-0.28333	-0.28333	-0.81667	0.666667	0.166667	-0.73113	1	-0.13333	-0.45
$TL_{MC3.25}$	0.566667	0.366667	0.366667	0.25	0.016667	-0.03333	0.522233	-0.13333	1	0.283333
$TL_{MC4.0}$	0.7	0.45	0.45	0.483333	-0.51667	-0.65	0.652791	-0.45	0.283333	1

IONIAN	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	0.534209	-0.44992	0.64751	0.644225	-0.22715	0.730159	0.761357	0.664477	0.573618
TL_L	0.534209	1	-0.04433	0.404488	0.415982	0.334428	0.490969	0.342091	0.262178	0.529283
$MTI_{3.25}$	-0.44992	-0.04433	1	-0.21675	-0.15928	0.796935	-0.23864	-0.45758	-0.56596	-0.17734
$MTI_{4.0}$	0.64751	0.404488	-0.21675	1	0.526546	-0.17953	0.550629	0.515052	0.650246	0.365079
TL_{SC}	0.644225	0.415982	-0.15928	0.526546	1	0.031746	0.512315	0.338259	0.47017	0.083744
$TL_{SC3.25}$	-0.22715	0.334428	0.796935	-0.17953	0.031746	1	0.126437	-0.35468	-0.30816	0.007115
$TL_{SC4.0}$	0.730159	0.490969	-0.23864	0.550629	0.512315	0.126437	1	0.418172	0.621237	0.350301
TL_{MC}	0.761357	0.342091	-0.45758	0.515052	0.338259	-0.35468	0.418172	1	0.510673	0.701697
$TL_{MC3.25}$	0.664477	0.262178	-0.56596	0.650246	0.47017	-0.30816	0.621237	0.510673	1	0.335523
$TL_{MC4.0}$	0.573618	0.529283	-0.17734	0.365079	0.083744	0.007115	0.350301	0.701697	0.335523	1

N SEA	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	-0.41694	-0.35444	-0.81774	-0.48878	-0.47345	-0.44171	-0.48039	-0.13235	-0.64706
TL_L	-0.41694	1	0.992742	0.109677	-0.13957	-0.15326	-0.42091	-0.14706	-0.17402	-0.48284
$MTI_{3.25}$	-0.35444	0.992742	1	0.037097	-0.19814	-0.21237	-0.46415	-0.17647	-0.18382	-0.53431
$MTI_{4.0}$	-0.81774	0.109677	0.037097	1	0.697318	0.694581	0.612479	0.54902	0.105392	0.661765
TL_{SC}	-0.48878	-0.13957	-0.19814	0.697318	1	0.995074	0.686918	0.377451	0.257353	0.544118
$TL_{SC3.25}$	-0.47345	-0.15326	-0.21237	0.694581	0.995074	1	0.686918	0.392157	0.272059	0.578431
$TL_{SC4.0}$	-0.44171	-0.42091	-0.46415	0.612479	0.686918	0.686918	1	0.115196	0.387255	0.335784
TL_{MC}	-0.48039	-0.14706	-0.17647	0.54902	0.377451	0.392157	0.115196	1	-0.27941	0.779412
$TL_{MC3.25}$	-0.13235	-0.17402	-0.18382	0.105392	0.257353	0.272059	0.387255	-0.27941	1	0.061275
$TL_{MC4.0}$	-0.64706	-0.48284	-0.53431	0.661765	0.544118	0.578431	0.335784	0.779412	0.061275	1

SCOTLAND	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	-0.26783	-0.75565	-0.43478	-0.50395	-0.62253	0.802372	0.924348	0.838261	0.825217
TL_L	-0.26783	1	0.613913	0.129565	0.18083	0.143281	-0.13933	-0.24957	-0.28087	-0.24
$MTI_{3.25}$	-0.75565	0.613913	1	0.144348	0.563241	0.495059	-0.42984	-0.64348	-0.60783	-0.52
$MTI_{4.0}$	-0.43478	0.129565	0.144348	1	-0.05929	-0.07115	-0.21344	-0.33391	-0.43565	-0.37826
TL_{SC}	-0.50395	0.18083	0.563241	-0.05929	1	0.563241	-0.30534	-0.34486	-0.31522	-0.37451
$TL_{SC3.25}$	-0.62253	0.143281	0.495059	-0.07115	0.563241	1	-0.51976	-0.50692	-0.22925	-0.32213
$TL_{SC4.0}$	0.802372	-0.13933	-0.42984	-0.21344	-0.30534	-0.51976	1	0.807312	0.69664	0.799407
TL_{MC}	0.924348	-0.24957	-0.64348	-0.33391	-0.34486	-0.50692	0.807312	1	0.84087	0.890435
$TL_{MC3.25}$	0.838261	-0.28087	-0.60783	-0.43565	-0.31522	-0.22925	0.69664	0.84087	1	0.906087
$TL_{MC4.0}$	0.825217	-0.24	-0.52	-0.37826	-0.37451	-0.32213	0.799407	0.890435	0.906087	1

W SCOTIAN	Years	TL_L	$MTI_{3.25}$	$MTI_{4.0}$	TL_{SC}	$TL_{SC3.25}$	$TL_{SC4.0}$	TL_{MC}	$TL_{MC3.25}$	$TL_{MC4.0}$
Years	1	-0.83589	-0.69637	0.774597	0.390726	0.305242	0.136694	-0.44778	-0.46749	-0.9069
TL_L	-0.83589	1	0.653226	-0.79355	-0.37218	-0.29113	-0.04395	0.483744	0.470936	0.855665
$MTI_{3.25}$	-0.69637	0.653226	1	-0.61895	-0.06129	0.024597	-0.17097	0.248276	0.380788	0.695074
$MTI_{4.0}$	0.774597	-0.79355	-0.61895	1	0.408871	0.343952	0.170565	-0.28867	-0.30099	-0.69113
TL_{SC}	0.390726	-0.37218	-0.06129	0.408871	1	0.984677	0.487903	-0.30493	-0.07488	-0.51281
$TL_{SC3.25}$	0.305242	-0.29113	0.024597	0.343952	0.984677	1	0.481048	-0.30493	-0.03005	-0.44778
$TL_{SC4.0}$	0.136694	-0.04395	-0.17097	0.170565	0.487903	0.481048	1	0.137438	-0.06305	-0.20936
TL_{MC}	-0.44778	0.483744	0.248276	-0.28867	-0.30493	-0.30493	0.137438	1	0.629064	0.494581
$TL_{MC3.25}$	-0.46749	0.470936	0.380788	-0.30099	-0.07488	-0.03005	-0.06305	0.629064	1	0.575862
$TL_{MC4.0}$	-0.9069	0.855665	0.695074	-0.69113	-0.51281	-0.44778	-0.20936	0.494581	0.575862	1

Supplement 5. Additional results from analysis of trophic spectra

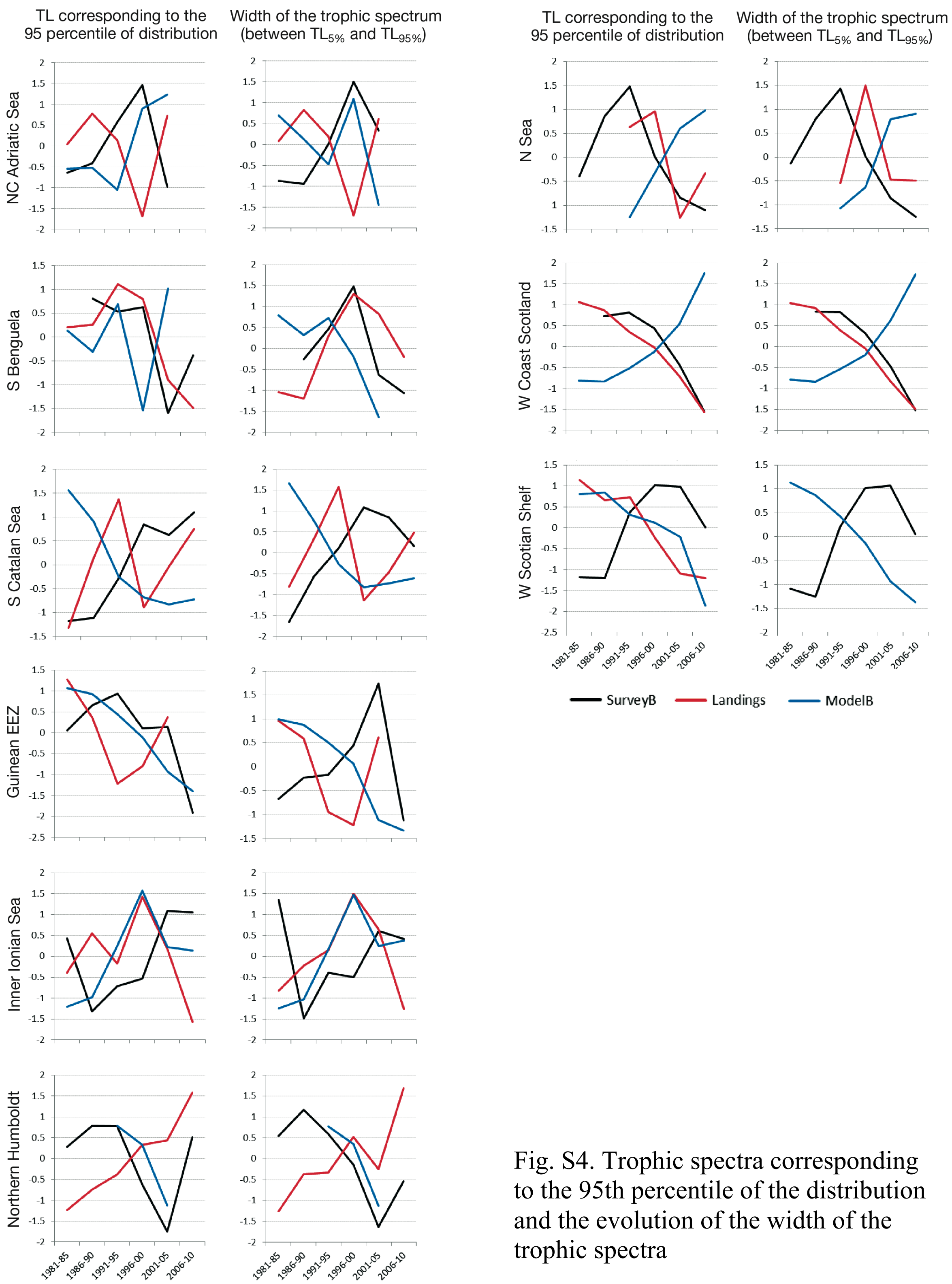

Fig. S4. Trophic spectra corresponding to the 95th percentile of the distribution and the evolution of the width of the trophic spectra

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