MARINE PROTECTED AREAS

Elevated trawling inside protected areas undermines conservation outcomes in a global fishing hot spot

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Marine protected areas (MPAs) are increasingly used as a primary tool to conserve biodiversity. This is particularly relevant in heavily exploited fisheries hot spots such as Europe, where MPAs now cover 29% of territorial waters, with unknown effects on fishing pressure and conservation outcomes. We investigated industrial trawl fishing and sensitive indicator species in and around 727 MPAs designated by the European Union. We found that 59% of MPAs are commercially trawled, and average trawling intensity across MPAs is at least 1.4-fold higher as compared with nonprotected areas. Abundance of sensitive species (sharks, rays, and skates) decreased by 69% in heavily trawled areas. The widespread industrial exploitation of MPAs undermines global biodiversity conservation targets, elevating recent concerns about growing human pressures on protected areas worldwide.

In light of mounting anthropogenic pressures, spatial protection of sensitive habitats and species has emerged as a leading strategy to halt ongoing biodiversity loss, both on land and in the sea (*1*). However, it has been shown recently that about one-third of terrestrial protected areas experience intense human pressure, potentially undermining global conservation targets and sustainable development goals (*2*). We asked to which extent this conflict may also occur in the ocean, using newly available satellite sensors that allow fine-scale, real-time quantification of industrial fishing effort from space (*3*). We focused on Europe, which is both a global hot spot of industrial fishing (*3*) and features extensive marine protected area (MPA) networks that cover 29% of European Union (EU) territorial waters (*4*).

According to International Union for the Conservation of Nature (IUCN) guidelines, MPAs should be managed primarily for biodiversity conservation objectives (*5*) and exclude environmentally damaging industrial activities in any of their six protected-area categories (table S1) (*6*). With respect to commercial fisheries in MPAs, recent IUCN guidelines clarify that "any fishing gear used should be demonstrated to not significantly impact other species or other ecological values" (*7*). In the EU, a variety of different MPA types exist; although they may or may not adhere to nonbinding IUCN criteria (table S1), all feature biodiversity protection as a cross-cutting objective (table S2) and contribute toward international conservation targets (*8*). Yet, many MPA types do not address commercial fisheries, which are often regulated under the EU Common Fisheries Policy (table S2).

By far the most common industrial fishing method in Europe is trawling (*3*), which targets mainly bottom-associated fishes, often with a high rate of unwanted bycatch (fig. S1). This fishing technique has been identified as a threat to many endangered species in Europe, including most elasmobranchs (sharks, rays, and skates) (*9*), and has well-documented impacts on seafloor biodiversity (*10*), sensitive habitats, and indicator species (*11*). We directly quantified the extent of commercial trawling in the EU with respect to MPAs. We investigated associated changes in biodiversity using elasmobranchs as indicator species because they are particularly vulnerable to industrial exploitation and bycatch (*12*, *13*), have one of the highest extinction risk among marine fishes in Europe (*13*, *14*), and are generally not targeted by EU MPAs (table S2).

We quantified commercial trawling effort in the EU from automatic identification system (AIS) vessel tracking data at grid cells of 0.01° by 0.01° resolution for the year 2017, using a neural network algorithm with 98% precision when run on test data (*3*). AIS is legally required for all EU industrial fishing vessels larger than 15 m, accounting for 94% of commercial trawling effort in our data. AIS data may miss some fraction of smaller artisanal boats, rendering our estimates of trawling effort conservative. All 727 MPAs included in our study were classified as 100% marine (no terrestrial components), were designated before 2017, and are registered in the World Database on Protected Areas, thus counting toward international biodiversity conservation targets.

We found that trawling efforts concentrated along coastlines of continental Europe and the United Kingdom (Fig. 1A), a pattern that is consistent with other data sources (*15*–*17*). Aggregate commercial effort exceeded 1 million hours of trawling in 2017, with more than 225,000 hours occurring inside MPAs (Table 1). Trawling intensity (hours per square kilometer) across the entire MPA network was 38% higher inside MPAs compared with unprotected areas (Fig. 1A and Table 1) and 46% higher inside MPAs when comparing trawling intensity per trawled area (Table 1). This suggests that MPAs do not reduce fishing pressure under current management.

Elevated trawling intensity inside MPAs was especially pronounced in large-scale EU-wide MPA types, whereas untrawled MPAs were often small and designated by individual countries (Fig. 1, C and D, and fig. S2). Of all 727 MPAs, 489 were located in territorial waters (inside 12 nautical miles, 67%).

The MPAs with highest commercial trawling effort were typically located along the continental coastline (fig. S3), were recently designated, and in IUCN categories II or V (fig. S4). No trawling effort was detected in 295 of the 727 MPAs considered in this study, implying that at least 59% of MPAs experienced commercial trawling. Of these 295 MPAs, 171 were located in territorial waters. MPAs with no commercial trawling were generally smaller and older and had some IUCN category assigned, yet only 40% had management plans, compared with 60% of commercially trawled MPAs (table S3).

We addressed the cited IUCN criterion regarding fishing impacts on other species and ecological values (*7*) by assessing elasmobranchs inside and outside of MPAs and over time. We used randomized scientific trawl surveys by the International Council for the Exploration of the Sea (ICES) to estimate relative abundance for 20 elasmobranch species (table S4) from 1997 to 2016. Only surveys with gear types and depth appropriate to catch these species were considered. Data were normalized to avoid any one species dominating aggregate indices.

Elasmobranchs were generally rare across the study area, particularly in heavily trawled areas (Fig. 1B). The primary aggregations west and south of the British Isles are in agreement with previously described hot spots (*18*), and British MPAs also had the highest abundance of elasmobranchs (Fig. 1E and fig. S5). Elasmobranchs were caught in 141 (79%) of the 178 MPAs scientifically surveyed by ICES. Total elasmobranch catch per research haul was 2.3-fold higher outside MPAs than inside (Fig. 1B and Table 1), and a normalized multispecies abundance index was 24% higher outside of MPAs (Table 1). This conservation paradox was especially pronounced for endangered and critically endangered species, which were all ≥5-fold more abundant outside MPAs (Fig. 2).

Size, age, and management attributes of MPAs are all thought to drive conservation outcomes (*19*). Yet under current fishing pressure, only MPA size showed a positive trend with relative elasmobranch abundance in our study area (fig. S6). No clear pattern emerged between elasmobranch abundance and the age of the MPA, whether it was classified according to the IUCN categories or had a management plan (fig. S7). Of the 178 MPAs

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scientifically surveyed, only 24 (or 13%) had no commercial trawling present, and in 10 of those MPAs, elasmobranchs have been reported. These untrawled MPAs had indeed higher average elasmobranch abundance as compared with those of commercially trawled MPAs (fig. S8). Overall, elasmobranch abundance decreased with increasing trawling intensity both inside (fig. S9) and outside MPAs (fig. S10).

After controlling for spatial autocorrelation and potentially confounding effects of habitat and climate, we found that commercial trawling was the strongest predictor of elasmobranch relative abundance across the study area ($P < 0.001$) (Fig. 3A and table S5), with an average decrease of 69% across the observed gradient of trawling intensity (0 to 6.4 hours km^{-2}). Analyzing this relationship over time, we detected no trend in relative elasmobranch abundance in areas with high trawling intensity but detected higher and increasing abundance in areas with low trawling

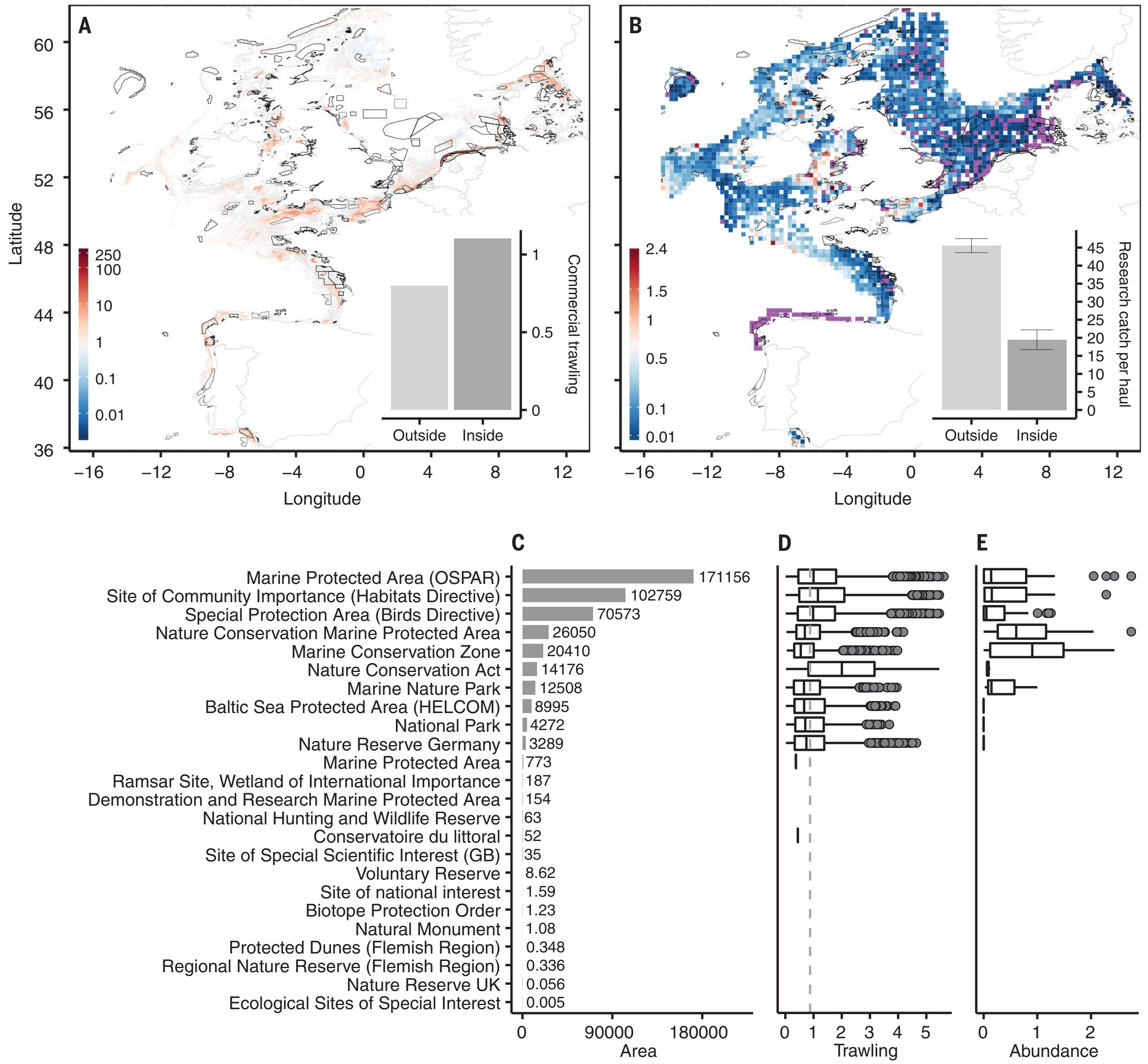

Fig. 1. Spatial distribution of marine protected areas, commercial trawling, and elasmobranchs in the European Union. (**A**) Commercial trawl fishing hours per 0.01° × 0.01° grid cell in 2017 (log_{10} color scale). Existing MPAs as of 2016 are outlined with black borders. (Inset) Aggregate commercial trawling intensity (hours per square kilometer) across MPAs versus unprotected areas. (**B**) Elasmobranchs scientific survey abundance expressed as normalized multispecies catch per unit effort per 0.25° × 0.25° grid cell (square-root transformed color scale). Grid cells in purple were surveyed, but no elasmobranchs were present. (Inset) The total elasmobranch research catch per haul inside versus outside MPAs, with 95% confidence limits. (**C**) MPA area (square kilometers), (**D**) commercial trawling intensity per trawled area (log_e hours per square kilometer trawled), and (**E**) elasmobranch abundance index for each MPA type. The gray dotted line in (D) indicates the median commercial trawling intensity in nonprotected areas for reference. No data in (E) indicates MPA types that were not scientifically surveyed.

intensity (Fig. 3B). These results further support the notion that elevated trawling effort in MPAs negatively affects sensitive species and ecological values and is thus conflicting with IUCN criteria.

These data demonstrate that simply designating areas as MPAs has little benefit for those species that require protection the most. That most major EU MPA types exhibit high trawling intensity (Fig. 1D and fig. S2) and do not address industrial fishing (table S2) leaves protected zones vulnerable to fishing effort aggregation and associated biodiversity impacts documented here. Our finding that 59% of studied MPAs are fished industrially exceeds recently documented shortfalls on land, where 33% of protected areas are exposed to undue human pressures (*2*). A sectoral approach in which marine conservation measures are implemented by EU member states, but fisheries are managed by a Common Fisheries Policy, may drive this apparent disconnect. Last, the lack of transparent international MPA standards may further exacerbate this; we found that of 727 EU MPAs studied here, >50% do not report a management plan, >90% are not classified according to IUCN criteria, and >99% have no information on no-take areas, according to the World Database on Protected Areas. We suggest that better reporting and independent vetting of MPA standards is needed to assess the true value of the world's increasing MPA coverage.

Our results suggest that much of the EU's spatially impressive MPA network is being affected more heavily than nonprotected areas by industrial fishing and, as such, provides a false sense of security about positive conservation actions being taken. This is not an isolated occurrence, as data from terrestrial protected areas (*2*) and marine case studies from elsewhere suggest (*20*, *21*). Hence, internationally agreed-upon conservation targets under the Convention on Biological Diversity might be undermined by increasing human pressure, both on land and in the sea. Considerable work remains to be done to improve MPA policy, to develop and enforce minimum standards for MPA designation and classification, and to make MPA regulations and management stronger and more transparent.

Table 1. Commercial trawling effort and elasmobranch catch from research surveys inside and outside of MPAs. Commercial trawling is given in hours for the year 2017. Grid cells encompass 0.01° longitude by 0.01° latitude. Research catch from scientific surveys is given for the years 1997 to 2016 in total number of elasmobranch specimens per 60-min haul duration. The abundance index is given as normalized total multispecies catch per unit effort (msCPUE). Area (square kilometers) and commercial trawling hours for MPAs were calculated by subtracting the nonprotected area or hours from the total study area or hours, to avoid multiple counts for MPA types whose areas overlap.

	Outside MPAs	Inside MPAs	Total study area
Commercial trawling hours	848,703	227,718	1,0764,21
Area (km^2)	1,063,533	206,674	1,270,207
Number of 0.01° cells commercially trawled	335,167	57,085	392,252
Commercially trawled area (km^2)	252,886	43,812	296,698
Commercial trawling (hour km^{-2})	0.80	1.10	0.85
Commercial trawling (hour 0.01° $cell^{-1}$)	2.53	3.99	2.74
Commercial trawling (hour km^{-2} trawled area)	3.56	5.20	3.63
Research catch (number of elasmobranchs)	1,142,533	94,419	1,236,952
Research effort (number of hauls)	25,092	4,850	29,942
Total research catch per haul	45.53	19.47	41.31
Abundance index (msCPUE)	15.76	12.70	28.46

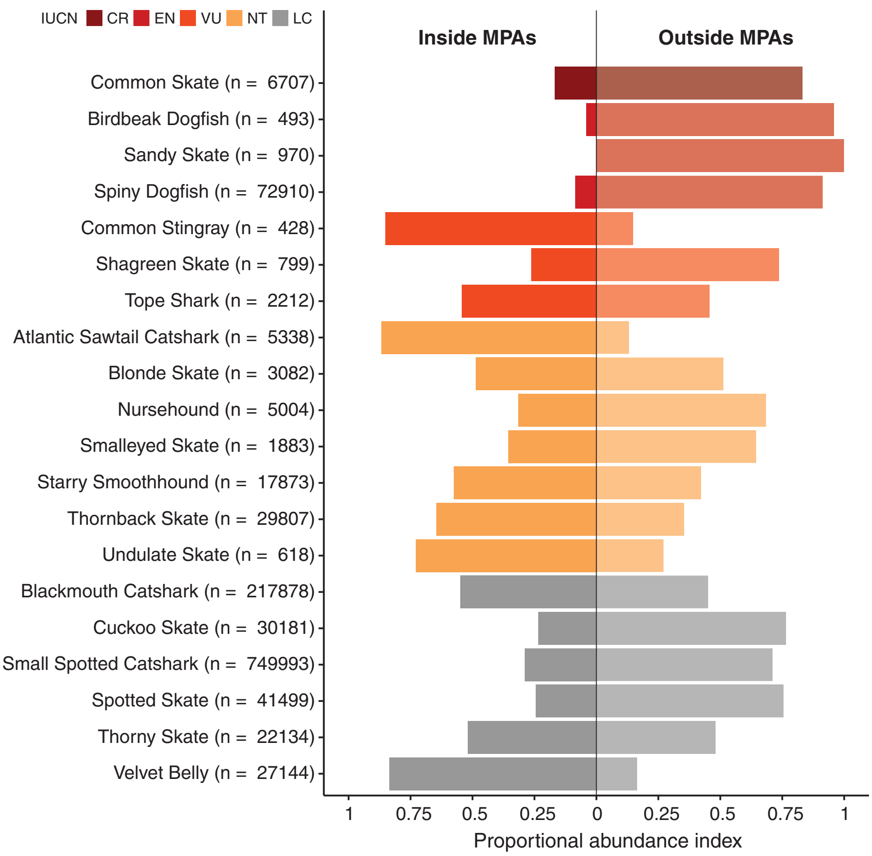

Fig. 2. Abundance of threatened species in relation to MPAs. Proportional scientific survey catch per unit effort is given for each elasmobranch species inside versus outside MPAs. The sample size for each species is given in brackets. Colors represent the IUCN Red List status per species. CR, critically endangered; EN, endangered; VU, vulnerable; NT, near threatened; LC, least concern.

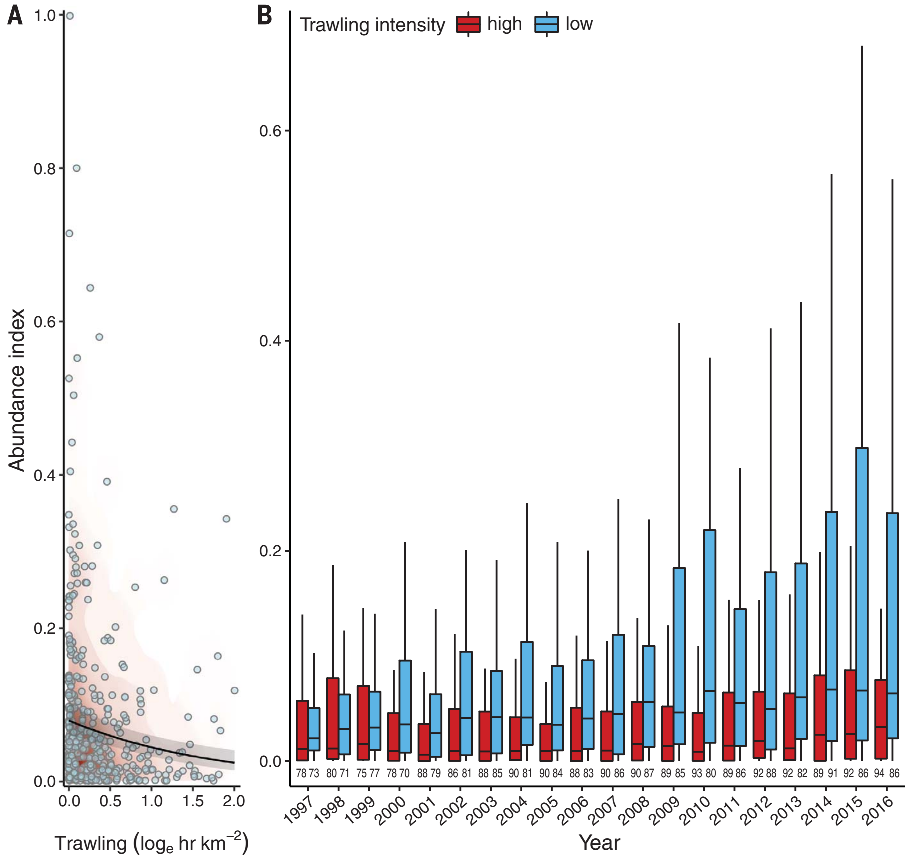

Fig. 3. Relationship between elasmobranch abundance and commercial trawling. (**A**) Elasmobranch abundance index (scaled multispecies catch per unit effort) versus commercial trawling intensity (log$_e$ +1 hour km^{-2}) for all 392 ICES statistical management areas scientifically surveyed over the study area. The black line shows the predicted relationship of relative abundance and commercial trawling intensity for the average temperature and depth across management areas, with 95% confidence limits in gray (table S5). Red shading visualizes the density distribution of data points. (**B**) The temporal trend of elasmobranch mutispecies catch per unit effort is shown in ICES statistical management areas, with high (upper quartile, ≥0.616 hours km^{-2}) versus low (lower quartile, ≤0.037 hours km^{-2}) commercial trawling intensity. Sample size of ICES statistical areas for each year is indicated below.

This would help to ensure that international targets for increased protected area coverage translate into tangible benefits for biodiversity conservation and the recovery of threatened marine wildlife.

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/362/6421/1403/suppl/DC1
Materials and Methods
Figs. S1 to S32
Tables S1 to S6
References (*22*–*33*)

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Not as advertised

Marine protected areas (MPAs) have increasingly designated globally, with an associated advertised percentage of area protected. However, recent research has made it clear that many MPAs are not actually protecting marine biodiversity. Dureuil *et al.* focused on European MPAs and found that trawling, one of the most damaging types of fishing, occurs widely in these areas. Furthermore, using sharks and rays as indicator species, they found that many MPAs are failing to protect vulnerable species.

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