# Response to Comment on "A Global Map of Human Impact on Marine Ecosystems"

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Our results provide an important first step toward a full assessment of how human activities act cumulatively to affect the condition of the oceans. Fisheries (and climate change) impacts are some of the hardest to map and measure accurately. Consequently, species-specific considerations and fine-scale analyses should be left to more nuanced regional-scale replicates of our mapping framework.

Halpern *et al*. (*1*) used a quantitative method to assess the cumulative impact of human activities across 20 ocean ecosystems. We agree with Heath (*2*) that the impacts of activities can fall outside the bounds of their footprints of occurrence, but we contend that in most cases, the majority of the impact at the ecosystem-level is concentrated at the site of the activity's footprint. Although increased accuracy in representing the true spatial distribution and scale of impacts is an important task, it is probably a less urgent priority for the marine science community than improving global ecosystem distribution data, especially for intertidal and nearshore ecosystems, and developing high-resolution maps of many human activities poorly captured by our cumulative impact map (*1*), such as illegal fishing, historical fishing, and sewage input.

Using mackerel as an example, Heath (*2*) demonstrates that the consequences of catching migratory species will be felt beyond the site of capture (e.g., spawning grounds, feeding grounds, and inshore nursery areas/juvenile habitats). We have three points of clarification on this issue: First, the large scale of the commercial fisheries data (half-degree reporting blocks) may partially account for impacts of the activity beyond its direct footprint, although not in an informed way. Second, at least in the case of mackerel, details of our methodology actually account for a more even distribution of impact compared with the spatial unevenness in catch rates shown in figure 1 in (*2*). We log-transformed each driver data set, which flattened the distribution of fishing intensity, and normalized each point against the global maximum, which, for mackerel, likely produced a fairly even impact across the species' range because there is at least some level of catch across the entire range. A similar situation likely exists for many other migratory fish species in the fisheries data sets we used. Without a formal analysis of exactly where the ecological effects of mackerel fishing are greatest, it is hard to argue for a further manipulation of the distribution of fishing impact. Third, the "pelagic, low-bycatch fishing" driver category to which most mackerel catch and ~90 other taxa belong shows a broad footprint across the globe [figure S2A in (*1*)]. Large swaths of maximum value in the North Atlantic, Baltic, and tropical eastern Pacific occur at scales matching the range of mackerel and other migratory taxa, which suggests that little would change if details on migration patterns of a few species were added.

Heath also suggested that our use of productivity to adjust the impact of catch rates does not account for the patterns of species movement addressed above and focuses on a scale that is likely smaller than what is relevant to ecological impacts of catch. Although this treatment is perhaps inadequate for many fisheries-specific analyses, as one of 17 data layers in a global scale analysis, it adequately captures the fact, we feel, that the ecological impact of catch level partly depends on local productivity. Bottom-up linkages between primary productivity and fisheries catch have been demonstrated around the world at various scales, as reviewed in (*3*). The spatial scale at which annual mean primary productivity varies is larger than the half-degree scale of the fishing blocks, often by several times (*4*). We used a 5-year mean of productivity, averaged within a moving window, to smooth local variability even more and avoid "spatial artifact."

Highly migratory species highlight the challenge of representing cumulative impacts on the most appropriate scale, because that scale will differ for various components of the ecosystem. Heath (*2*) rightly points out that just because activities can be mapped on a 1-km$^2$ scale does not mean that impact varies at 1 km$^2$. We agree, but also note that mapping impact at 1 km$^2$ does not force it to vary at 1 km$^2$; in most cases, the intensity of human activities, ecosystems, and impact vary at larger scales (*5*). We intended the fine scale of our maps to provide spatial detail to managers and policymakers on where boundaries between ecosystems, vulnerability, and activities occur.

As we originally noted (*1*), the global map is best used for broad comparisons among regions and global priority setting. The type of detailed data on variation in species' habitat uses, the influence of productivity on catches, and cascading impacts that Heath mentions would be better suited to local and regional-scale analyses that apply our framework to a tailored list of relevant drivers, vulnerability weights, and higher-resolution and/or higher-quality data on drivers and habitats (*6*). In the meantime, those using the global results to assess impacts on a region should not overlook activities located outside the region's boundaries that may affect important high dispersal or migratory species.

Visualizing the patterns of overlap in human activities allows us to find ways of using our oceans and its resources more effectively and efficiently by minimizing new impact where it is already greatest and protecting the few areas that are still relatively unused. Lessons learned at smaller spatial scales about the need for streamlining and integrating multiple, disparate, and noninteracting management institutions (*7*, *8*) to confront the cumulative impacts and consider all sources of stress to a management region are further supported at the global scale. We are grateful to Heath for this opportunity to clarify our work.

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### References and Notes

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