Matters arising

A path forward for analysing the impacts of marine protected areas

https://doi.org/10.1038/s41586-022-04775-1

Received: 1 February 2022

Accepted: 19 April 2022

Published online: 6 July 2022

Check for updates

Ray Hilborn[1] ✉ & Michel J. Kaiser[2]

ARISING FROM: E. Sala et al. *Nature* https://doi.org/10.1038/s41586-021-03371-z (2021)

Sala et al.[1] propose that a global network of marine protected areas (MPAs) could have positive impacts. Their analysis suggests that such a network could improve global biodiversity, reduce carbon released by trawling and increase yields from the world's fisheries. However, Sala et al.[1] made inconsistent assumptions about how fishing fleets would respond to closed areas, they did not have data on many important fish stocks and fishing efforts in South and Southeast Asia, and their models did not include the enormous uncertainty in the effects of trawling on CO_2 flux in sediments. We suggest that such an analysis should be done at regional scales for which good data are available, that it is recognized that when areas are closed, fishing effort moves but does not disappear, and that models should explicitly consider the wide range of uncertainties.

The proposals by Sala et al.[1], if true, would mean that they have found a single management strategy that would be a much-needed win–win–win situation for biodiversity conservation, CO_2 emissions reductions and food security. But as C. Sagan said, "extraordinary claims require extraordinary evidence"[2]. In this case, many claims are unsupported because of a number of weaknesses in the underpinning assumptions or presentation of the analyses. The objective of the paper is admirable, timely and the calculations complex. The objective of our Comment is to point the authors and future studies towards an analysis that is more robust and provides a basis for sound advice to fisheries managers and policy-makers.

The implementation of MPAs results in the closure of areas of the ocean to fishing. The paper by Sala et al.[1] addresses the effects of MPAs on: (1) fisheries harvest; (2) biodiversity and (3) carbon released by the disturbance of marine sediments by bottom trawling. The most important weakness in their analysis is the inconsistent accounting of what happens to the fishing effort once an MPA is established in their baseline scenario. Vessels fishing in the area that is implemented as an MPA can either stop fishing all together—thereby leading to a decrease in fishing effort—or they can move and fish outside the MPA, which is well documented[3–5] and would certainly be the logical default assumption. In their calculations of biodiversity conserved and CO_2 emissions reduced, the authors assume that fishing effort disappears, which would decrease the total harvest at the point when the MPAs are established. However, in the baseline scenario for the fisheries harvest section, the authors assume that fishing effort moves to areas open to fishing, keeping fishing harvests high. In supplementary figure 14 of ref. [1], a map is shown that allow for effort relocation for all three impacts, but this supplementary figure is only briefly referred to in the main text of the paper, and not discussed.

If effort does relocate, then the benefits to biodiversity and emissions would be less, completely nullified or worse. If the effects are simply shifted from the closed area to areas that are open, some of which may not have been fished previously and for which greater fishing activity may be required to achieve the same amount of harvest, the net effects could increase. Fishing effort generally goes to places with high catch rates, and if forced to fish elsewhere, more effort is required to achieve the same catch. For each topic in the baseline scenario, the authors have made assumptions about vessel movement that maximizes the benefits of MPAs, but they cannot have it both ways. To fully support their analysis, they must use the same assumption about effort displacement; either the effort disappears, or it does not.

The second weakness is the omission of one-third of the world's fish catch from the analysis[1], much of which comes from the Indian Ocean and Asia. This is because of the exclusion of data on fish landings reported at taxonomic groups above species level, which constitute one-third of the global catch and 84% of these landings are from the Indian Ocean and the rest of Asia. This means that their 'global' analysis is not truly global, but instead heavily focused on places for which fisheries data collection is most intense. Some of the largest trawl fisheries in the world are in South and Southeast Asia[6], yet for bottom trawling, Sala et al.[1] rely on satellite data from automatic identification systems to locate bottom trawlers, and there is little coverage by automatic identification systems in South and Southeast Asia. This is probably why their map showing proposed MPA networks that would have benefits for biodiversity conservation, CO_2 emissions reductions and food security shows few priority areas in South and Southeast Asia or the Indian Ocean; the areas of the world where there are major challenges and potential benefits of improvement management. Rather than attempting a global analysis when global data are not available, the authors should have done an analysis of the specific region or regions for which adequate data is available to support their models. There is no reason their approach needs to be global, when almost all fisheries problems can be addressed regionally, an approach we used previously[7].

Lastly, not only do the calculations of the carbon impact of bottom trawling made by Sala et al.[1] assume that fishing effort disappears when areas are closed, but also their methods use a single model and set of parameters in an area of science that is highly uncertain[8,9]. The authors acknowledge that this is a preliminary analysis, added after the paper was first submitted. Almost every assumption and parameter in their model is highly uncertain, and their estimates are often at odds with other studies that the authors do not cite[10], whereas the presentation of the results appears highly certain about the carbon benefits that MPAs could bring to world fisheries. Sala et al.[1] show results for highly specific parameter estimates and assumptions that undermine the multi-objective conclusions of their paper.

[1]School of Aquatic and Fishery Sciences and Center for Sustaining Seafood, University of Washington, Seattle, WA, USA. [2]The Lyell Centre, Institute of Life and Earth Sciences, Heriot-Watt University, Edinburgh, UK. ✉e-mail: hilbornr@gmail.com

Certainly, protection of the oceans is needed, but the paper by Sala et al.[1] suggests that protection can be achieved primarily by using no-take MPAs, and does not include a suite of strategies and tools that have proved to be effective. Almost all the large-scale successes in rebuilding fish stocks and protecting biodiversity have resulted from fisheries management measures such as limits on how many fish can be caught, restrictions of when and where fisheries can operate, and gear limitations[11], not from no-take MPAs. Put simply, sustainable fisheries are managed, informed by science and have enforcement. The same cannot be said for most of the world's MPAs.

Their overall approach certainly has merits and further work with this approach would be valuable if (1) effort displacement was included in all calculations; (2) the analysis was done regionally and highlighted potential differences between regions; and (3) the modelling included structural and parameter uncertainties in the calculations.

1. Sala, E. et al. Protecting the global ocean for biodiversity, food and climate. *Nature* **592**, 397–402 (2021).
2. Gillispie, C. C., Gratton-Guinness, I. & Fox, R. *Pierre-Simon Laplace, 1749-1827: A Life in Exact Science* (Princeton Univ. Press, 1999).
3. Dinmore, T. A., Duplisea, D. E., Rackham, B. D., Maxwell, D. L. & Jennings, S. Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities. *ICES J. Mar. Sci.* **60**, 371–380 (2003).
4. Hiddink, J. G., Hutton, T., Jennings, S. & Kaiser, M. J. Predicting the effects of area closures and fishing effort restrictions on the production, biomass, and species richness of benthic invertebrate communities. *ICES J. Mar. Sci.* **63**, 822–830 (2006).
5. Greenstreet, S. P. R., Fraser, H. M. & Piet, G. J. Using MPAs to address regional-scale ecological objectives in the North Sea: modelling the effects of fishing effort displacement. *ICES J. Mar. Sci.* **66**, 90–100 (2009).
6. Suuronen, P. et al. A path to a sustainable trawl fishery in Southeast Asia. *Rev. Fish. Sci. Aquac.* **28**, 499–517 (2020).
7. Amoroso, R. O. et al. Bottom trawl fishing footprints on the world's continental shelves. *Proc. Natl Acad. Sci. USA* **115**, E10275–E10282 (2018).
8. Atwood, T. B., Witt, A., Mayorga, J., Hammill, E. & Sala, E. Global patterns in marine sediment carbon stocks. *Front. Mar. Sci.* **7**, 165 (2020).
9. Smeaton, C., Hunt, C. A., Turrell, W. R. & Austin, W. E. N. Marine sedimentary carbon stocks of the United Kingdom's exclusive economic zone. *Front. Earth Sci.* **9**, 593324 (2021).
10. Legge, O. et al. Carbon on the northwest European shelf: contemporary budget and future influences. *Front. Mar. Sci.* **7**, 143 (2020).
11. Melnychuk, M. C. et al. Identifying management actions that promote sustainable fisheries. *Nat. Sustain.* **4**, 440–449 (2021).

Author contributions Both authors contributed to the ideas and writing of the paper.

Competing interests M.J.K. is currently funded by Natural Environmental Research Council (UKRI-GCRF), EDP Renewables, Fishmongers Company, Macduff Shellfish Ltd, Scottish Whitefish Producers Organisation, Sainsbury's Supermarkets Ltd, The Cooperative, CISCO and Defra Seafood Innovation Fund. Less than 1% of his current funding is from fishing organizations. R.H. receives research funding from many groups that have interests in fisheries outcomes including environmental nongovernmental organizations, foundations, governments and fishing industry groups.

Additional information
Correspondence and requests for materials should be addressed to Ray Hilborn.
Reprints and permissions information is available at http://www.nature.com/reprints.

Reply to: A path forward for analysing the impacts of marine protected areas

https://doi.org/10.1038/s41586-022-04776-0

Published online: 6 July 2022

Check for updates

Enric Sala[1✉], Juan Mayorga[1,2], Darcy Bradley[2], Reniel B. Cabral[2,3], Trisha B. Atwood[4], Arnaud Auber[5], William Cheung[6], Christopher Costello[2], Francesco Ferretti[7], Alan M. Friedlander[1,8], Steven D. Gaines[2], Cristina Garilao[9], Whitney Goodell[1,8], Benjamin S. Halpern[10], Audra Hinson[4], Kristin Kaschner[11], Kathleen Kesner-Reyes[12], Fabien Leprieur[13], Jane Lubchenco[14], Jennifer McGowan[15], Lance E. Morgan[16], David Mouillot[13], Juliano Palacios-Abrantes[6], Hugh P. Possingham[17], Kristin D. Rechberger[18] & Boris Worm[19]

REPLYING TO: R. Hilborn & M. J. Kaiser *Nature* https://doi.org/10.1038/s41586-022-04775-1 (2022)

We appreciate the recommendations from Hilborn and Kaiser to further our analysis[1], and although we agree with some of the suggestions in their Comment[2] as a basis for future work, they do oversimplify and mischaracterize several of our conclusions. First, Hilborn and Kaiser[2] comment on our assumptions about effort redistribution once marine protected areas (MPAs) are created. They suggest that we were inconsistent in our treatment of effort redistribution and that the benefits to biodiversity and carbon would be nullified under a full-effort transfer scenario; however, we disagree with this suggestion.

The objective of our analysis was to identify the most beneficial areas to place MPAs, which are a commonly used tool to conserve biodiversity, help to recover fish stocks and can mitigate climate change[3–7]. We tested how the location of the most beneficial places would change under two different assumptions of how fishing effort relocates outside the MPA after implementation: (1) no effort is relocated and (2) all effort is relocated. The first assumption implies an overall reduction in total fishing effort as areas of the ocean get protected and we applied it consistently across the three objectives. We find that under this assumption, protecting 24% of the ocean would maximize benefits across all objectives if biodiversity and food provision are set to be equally important (figure 3 and supplementary figures 10 and 13 of ref. [1]).

The alternative assumption implies that all fishing effort from inside the MPA gets displaced to the remaining fishable areas, so that total fishing effort remains constant. In this scenario, we assume that displaced effort redistributes to unprotected pixels in proportion to the effort before protection. Although we did not quantify the magnitude of the biodiversity and carbon impacts outside the MPA, our analysis does account for fishing effort displacement in the ranking of locations for MPA placement. Hilborn and Kaiser[2] suggest that the benefits to biodiversity and carbon would be nullified if these effects were quantified; our results provide a more nuanced picture in line with previous assessments of the ecological effects of effort displacement[8,9]. For biodiversity, the benefit curves in our prioritization analysis show steep gains after protecting the first pixels (see figures 1 and 2 of ref. [1]), suggesting that the top priority areas disproportionately contribute to species persistence. Therefore, we propose that a full redistribution of fishing effort would not considerably diminish the overall biodiversity conservation benefit of MPAs; the empirical magnitude of this effect would be interesting to explore in future studies. For carbon, we acknowledge that relocating bottom trawling effort would reduce potential benefits, particularly if relocated to areas with little or no previous trawling. Therefore, one of our conclusions was that, to achieve climate benefits from MPAs, effort displacement must be constrained, underscoring the importance of improved gear-specific fishery management.

Second, Hilborn and Kaiser[2] point out that because of current gaps in fisheries data, our analysis probably underestimated the benefits of future MPAs in Southeast Asia and the Indian Ocean. We agree that MPAs in those regions would probably generate more regional and global catches and carbon benefits than what we originally reported and that this could lead to more global priority areas in these regions.

Third, we agree with Hilborn and Kaiser[2] that there are assumptions and uncertain parameters in our models; as there are in any complex analysis. Although we attempted to use the most scientifically defensible estimates, surely other assumptions would lead to different conclusions, some with greater benefits than we estimated and some with smaller. We agree that further analyses that elucidate the implications and validity of alternative assumptions would be helpful and instructive.

Finally, we disagree with Hilborn and Kaiser's claim[2] that our original Article[1] assumes that the only form of protection is no-take MPAs. Like nearly every published paper on fishery science or conservation, our Article does not aim to assess the consequences of all possible strategies and interventions. Instead, we focus on a particular tool (MPAs in which fishing is banned) and evaluate its potential to deliver on the three objectives identified in our original Article[1].

[1]Pristine Seas, National Geographic Society, Washington, DC, USA. [2]Environmental Markets Lab, University of California, Santa Barbara, CA, USA. [3]College of Science and Engineering, James Cook University, Townsville, Queensland, Australia. [4]Department of Watershed Sciences and Ecology Center, Utah State University, Logan, UT, USA. [5]IFREMER, Unité Halieutique de Manche et mer du Nord, Boulogne-sur-Mer, France. [6]Changing Ocean Research Unit, Institute for the Oceans and Fisheries, The University of British Columbia, Vancouver, British Columbia, Canada. [7]Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA. [8]Hawai'i Institute of Marine Biology, Kaneohe, HI, USA. [9]GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany. [10]National Center for Ecological Analysis and Synthesis (NCEAS), University of California, Santa Barbara, CA, USA. [11]Evolutionary Biology and Ecology Laboratory, Albert Ludwigs University, Freiburg, Germany. [12]Quantitative Aquatics, Los Baños, The Philippines. [13]MARBEC, Université de Montpellier, Montpellier, France. [14]Oregon State University, Corvallis, OR, USA. [15]The Nature Conservancy, Arlington, VA, USA. [16]Marine Conservation Institute, Seattle, WA, USA. [17]Centre for Biodiversity and Conservation Science CBCS, The University of Queensland, Brisbane, Queensland, Australia. [18]Dynamic Planet, Washington, DC, USA. [19]Ocean Frontier Institute, Dalhousie University, Halifax, Nova Scotia, Canada. ✉e-mail: esala@ngs.org

To the extent that our study also enabled us to compare synergies between MPAs and fishery management interventions, we have noted the importance of pursuing both in concert. In fact, in quantifying the biodiversity effects of MPAs, we select only the species that can be influenced by MPAs and carefully categorize threats as abatable and unabatable by MPAs. For instance, we do not expect MPAs to solve pollution problems. However, our framework is general enough to accommodate other management tools that can address different biodiversity threats that can be examined by further research. Furthermore, fishing is only one use of the ocean, and in our Article we noted that "MPAs and responsible fisheries management are not mutually exclusive; rather, they are complementary". We firmly support the need for a broad suite of measures, including responsible fishery management and MPAs, to rebuild depleted stocks, protect biodiversity and help to mitigate climate change. We focused on fully protected MPAs, which have a track record in helping to achieve these goals[5–7,10] and we found that large efficiency gains can be achieved if global conservation efforts are carefully planned, coordinated and executed.

1. Sala, E. et al. Protecting the global ocean for biodiversity, food and climate. *Nature* **592**, 397–402 (2021).
2. Hilborn, R. & Kaiser, M. J. A path forward for analysing the impacts of marine protected areas. *Nature*https://doi.org/10.1038/s41586-022-04775-1 (2022).
3. Goñi, R., Badalamenti, F. & Tupper, M. H. In Marine Protected Areas: A Multidisciplinary Approach (ed. Claudet, J.) 72–98 (Cambridge Univ. Press, 2011).
4. Lester, S. et al. Biological effects within no-take marine reserves: a global synthesis. *Mar. Ecol. Progr. Ser.* **384**, 33–46 (2009).
5. Lynham, J., Nikolaev, A., Raynor, J., Vilela, T. & Villaseñor-Derbez, J. C. Impact of two of the world's largest protected areas on longline fishery catch rates. *Nat. Commun.* **11**, 979 (2020).
6. Roberts, C. M. et al. Marine reserves can mitigate and promote adaptation to climate change. *Proc. Natl Acad. Sci. USA* **114**, 6167–6175 (2017).
7. Sala, E. & Giakoumi, S. No-take marine reserves are the most effective protected areas in the ocean. *ICES J. Mar. Sci.* **75**, 1166–1168 (2018).
8. Bastardie, F. et al. Competition for marine space: modelling the Baltic Sea fisheries and effort displacement under spatial restrictions. *ICES J. Mar. Sci.* **72**, 824–840 (2015).
9. Greenstreet, S. P. R., Fraser, H. M. & Piet, G. J. Using MPAs to address regional-scale ecological objectives in the North Sea: modelling the effects of fishing effort displacement. *ICES J. Mar. Sci.* **66**, 90–100 (2009).
10. Harrison, H. B. et al. Larval export from marine reserves and the recruitment benefit for fish and fisheries. *Curr. Biol.* **22**, 1023–1028 (2012).

Author contributions All authors participated in the discussion and writing of this Reply.

Competing interests The authors declare no competing interests.

Additional information
Correspondence and requests for materials should be addressed to Enric Sala.
Reprints and permissions information is available at http://www.nature.com/reprints.
Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.