LETTER

Models of marine protected areas must explicitly address spatial dynamics

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We agree with three broad points raised by Cabral et al. (1): 1) Marine protected areas (MPAs) can play an important role in conservation and food security, 2) much of the high seas could be closed to fishing without substantially reducing global catch, and 3) much of the potential food security benefits of MPAs could be achieved by targeted protection in key places. We note an error in the business-as-usual (BAU) policy in their original manuscript which overestimated the food gains of MPAs and distorted the prioritization map, but which is being corrected by Cabral et al. However, beyond this issue, their model makes a series of assumptions that produce results inconsistent with best available knowledge of the state of global fisheries and marine ecology.

Cabral et al. (1) do not explicitly account for spatial structure of fish populations in their model, instead assuming that all unassessed [i.e., not in the RAM Legacy Stock Assessment Database (2)] stocks of the same species comprise a single perfectly interconnected population, based on probability of occurrence estimates from Aquamaps (3). This results in the median modeled geographic range of an unassessed stock being 17 times that of an assessed stock, which is not credible and distorts the optimal size of MPA networks. This lack of explicit spatial structure produces results such as MPAs placed in Australia providing equal benefits to areas as far apart as Indonesia and Mexico (Fig. 1*A*), and closures by the Americas benefiting species only caught near China (Fig. 1*B*). Based on the results in the paper, users cannot know whether the purported food benefits of MPAs in an area highlighted by Cabral et al. stem from these sorts of transoceanic connections.

The global MPA network for food production resulting from this distance-free model should give pause to MPA stakeholders of all kinds. Using the corrected BAU policy, Cabral et al.'s (1) food-maximizing MPA network would close 22% of the United States' exclusive economic zone (EEZ) to fishing, yet places only 2.5% of India's, 10% of Indonesia's, and 12% of China's EEZs in MPAs (Fig. 1*B*). Costello et al. (4) estimated that the median F/F_{MSY} (fishing mortality rate F relative to the fishing mortality rate producing maximum sustainable yield F_{MSY}) of fisheries in India, Indonesia, and China is nearly twice that of the United States, creating almost 5 times as much potential food upside from fishery reforms in those regions relative to the United States.

Any global model must make simplifying assumptions, but the assumptions made in Cabral et al. (1) are not necessary and produce misleading results. A global model of MPAs must consider biological constraints of movement and spatial heterogeneity of fishery institutions. Reducing the effective range of populations by following the same stock structure as Costello et al. (4) would be a start in this direction, but explicitly modeling the role that distance plays in ecological and economic responses to MPAs would be preferred. Either of these approaches would be computationally intensive but feasible and, we suspect, would produce markedly different results from the findings Cabral et al. currently report.

Data Availability. All materials needed to fully reproduce this letter, including data, are stored in or generated by code available at GitHub, https://github.com/DanOvando/FoodProvision2019-reply.

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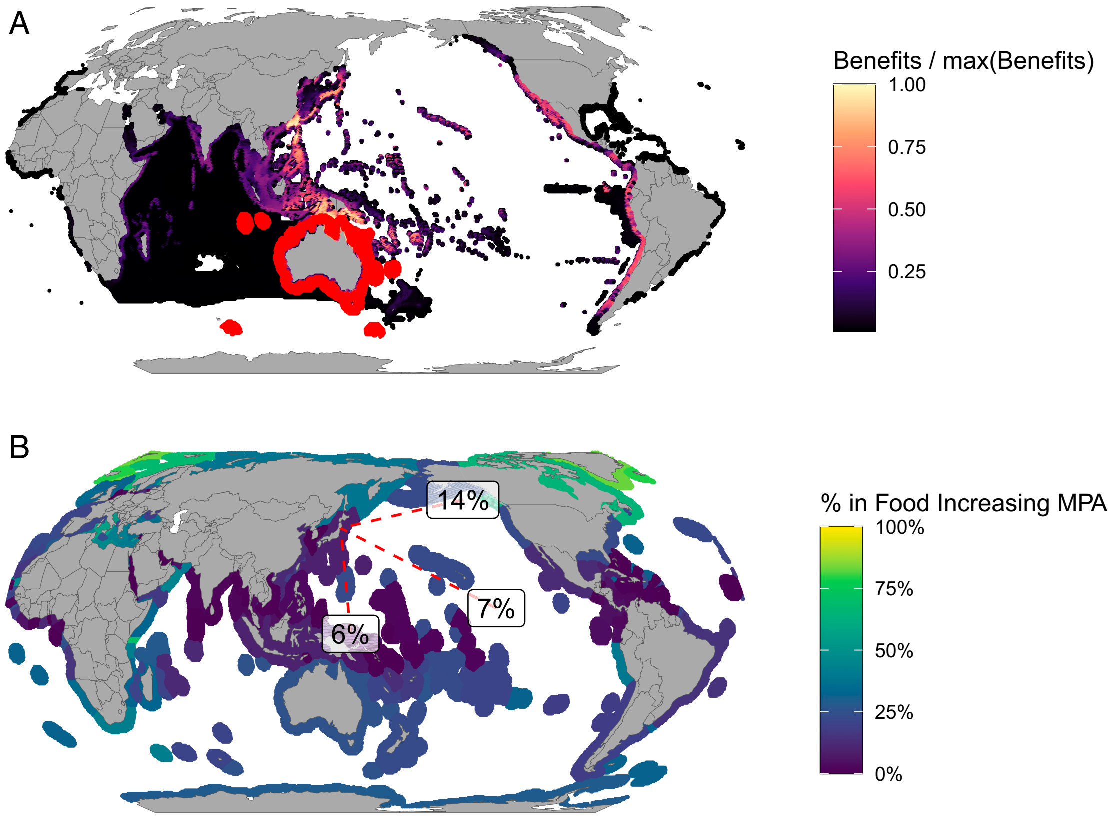

Fig. 1. **Omitting distance from MPA models produces results that are not credible. (*A*) The distribution of food increases, omitting tunas, generated by a network of MPAs covering Australia's EEZ according to the Cabral et al. (1) model, with MPAs shown in red, and color of individual non-MPA cells showing the predicted food benefits generated by the Australian MPAs in that cell, scaled by the maximum food benefits generated by these MPAs in any cell. White areas show cells with benefits divided by maximum benefits less than 0.01. (*B*) Percent of each country's EEZ protected under Cabral et al.'s food-maximizing MPA network under their BAU policy, applying the BAU correction for RAM stocks. Text percentages show percent of MPA-generated food benefits for overfished unassessed species caught nearly exclusively by China in the Pacific Northwest Food and Agriculture Organization of the United Nations (FAO) region originating from FAO regions outside the Pacific Northwest according to Cabral et al. White areas are outside of EEZs.**

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