LETTER

Reply to Szuwalski and Hilborn: Forage fish require an ecosystem approach

In response to our recent paper (1), Szuwalski and Hilborn (2) make several points about the timing of recruitment failures, the effect of fishing on productivity, and our choice of using biomass, not recruitment, as the indicator for collapses. We address these points here to show that not only do they not affect our conclusions, but that we are largely in agreement regarding the biological processes and the implications for fisheries and conservation.

Szuwalski and Hilborn (2) show the timing of recruitment failures that have led to many of the forage fish collapses we identify in our study. We agree that the process of recruitment failure initiates a cascade of positive feedback, whereby fishing rates inadvertently increase during declines in population biomass, and that fishing does not directly incite these recruitment declines. As our title indicates, we show that when forage fish undergo natural population fluctuations (i.e., recruitment declines), fishing acts to amplify the extent of collapse. That is, fishing deepens the troughs of population cycles. We do not claim that fishing causes collapses or that it precipitates declines in productivity, only that fishing does affect the biomass of forage fish in the system, which can have repercussions throughout the food web.

Additionally, Szuwalski and Hilborn (2) note that our threshold of collapse does not correspond to a level of biomass causing recruitment limitation. Their definition of "collapse" is relevant for conventional "single species" management of forage fish, where management seeks to avoid depleting stocks below levels at which recruitment is impaired. However, forage fish management requires an ecosystem approach where the consequences of fishing on other valued components of the food web must be considered. In this context, biomass thresholds that correspond to predators' sensitivity are most relevant. Multiple studies have shown that predators are most sensitive to forage fish depletion at low forage fish biomass and that these effects are highly nonlinear (3, 4). Therefore, fishing strategies need to avoid, to whatever extent possible, depleting stocks below critical ecological thresholds. Identifying these thresholds remains an important priority for forage fish fisheries management.

Furthermore, we agree with Szuwalski and Hilborn (2) that management should respond to declines in recruitment as an early indicator of decreased productivity. In some cases where stocks are frequently monitored and environmental conditions that govern recruitment are well understood, it is possible to anticipate these recruitment failures and adjust fishing accordingly. Our paper (1) shows that, unfortunately, this has not commonly been the case. Therefore, it is important to put safeguards in place to avoid inadvertent ramping up of fishing rates when stock productivity and abundance is in rapid decline.

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1 Essington TE, et al. (2015) Fishing amplifies forage fish population collapses. *Proc Natl Acad Sci USA* 112(21):6648–6652.
2 Szuwalski CS, Hilborn R (2015) Environment drives forage fish productivity. *Proc Natl Acad Sci USA* 112:E3314–E3315.
3 Cury PM, et al. (2011) Global seabird response to forage fish depletion—One-third for the birds. *Science* 334(6063):1703–1706.
4 Robinson WML, Butterworth DS, Plagányi ÉE (2015) Quantifying the projected impact of the South African sardine fishery on the Robben Island penguin colony. *ICES J Mar Sci*, 10.1093/icesjms.fsv035.

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