MPA News
Interview with Loo Botsford and Will White on the subject of reserve effects
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MPA News: The following questions are in light of recent studies like Cudney-Bueno et al. (http://www.plosone.org/article/info:doi%2F10.1371%2Fjournal.pone.0004140) and Robin Pelc's study of mollusks (http://depts.washington.edu/mpanews/MPA108.htm#IMPAC2):

> Question 1. If we define the reserve effect on fisheries as the ability of marine reserves to benefit adjacent fished populations via larval export and/or spillover of adults, would you say that the reserve effect is now settled science? If so, what is your evidence for that? If not, what do we still need to know?
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> Question 2. If you were a marine reserve planner, under what conditions would you feel comfortable promising increased catches over time for nearby fishers as a result of the reserve?

Loo Botsford and Will White: We presume Pelc's presentation referred to work described in her recent publication, so we include that here.

While both of these efforts (Cudney, et al. and Pelc, et al.) contribute to answering the question you pose, neither settles the scientific issue of whether reserves will benefit fisheries. There is scientific consensus that larvae disperse over space; the open question is what fraction of those larvae leaving each location successfully settle at each other location. Both of the sources you cite seek to answer the question of whether larvae disperse from one specific location to another. Scientists are trying to answer that question through a variety of approaches (Botsford, et al. 2009). Cudney-Bueno, et al. (2009) have answered it for several locations in the northern Gulf of California, Pelc, et al. (2009) answers it for several locations in South Africa, and Pelc's presentation describes the advantages of using mollusks to study the question, a taxon for which one is likely to be successful because it disperses short distances. We agree generally with the comments in the abstract and the introduction of Cudney-Bueno, et al. (2009) regarding the contribution of their paper and its role as a call for future research. As noted in the comments by Robin Pelc, this is a difficult problem, and we think both of these studies contribute to its solution. We will briefly explain where we think we stand on this issue to give you and the readers some idea of what we still need to know.

In order for a fishery to benefit from MPAs, there (a) must be a persistent population inside the MPA, and (b) a certain fraction of larvae reproduced from that population must reach the fished location. Population persistence, both inside and outside of the MPA depends on how much fishing is occurring outside the MPAs (and inside the MPA, if there is poaching), the spatial

configuration of the MPAs, and spatial scales of larval and adult movement. Empirical evidence based on inside/outside comparisons for a large number of existing MPAs indicates that most, but not all, MPAs improve population persistence within their borders: 90 percent of reviewed cases had increased biomass inside MPAs, and 63 percent of reviewed cases had increased density inside MPAs (Halpern 2003). In our experience using models to combine the above factors to estimate the effects of MPAs, the projected increase in persistence and abundance can range from zero to large (White, et al. 2009). There is not space here to describe how all of the above factors affect persistence and abundance, but briefly stated the increase will be greater for species that were heavily fished prior to the MPA and move little.

Persistence of populations inside the MPAs depends on the amount of fishing outside MPAs because population persistence depends on population density over the spatial scale of larval dispersal (Botsford, et al. 2001, Hastings and Botsford 2006, White, et al. 2009). The spatial distribution of fishing outside the MPAs is a consequence of what the fishermen displaced from inside the MPAs decide to do after MPAs are implemented. They could stop fishing, but most likely they would continue to fish, fishing outside the MPAs. This information is being obtained empirically by characterizing fishermen's behavior and modeling their responses to population changes (e.g., Smith and Wilen 2004).

The information being gathered by Cudney-Bueno, et al. (2009) and Pelc, et al. (2009) is needed to answer both the persistence question (a above) and the consequent larval spillover question (b above). Cudney-Bueno, et al. have shown that there is likely transport between locations, but what we need to know to answer the persistence question and the fishery benefit question is the dispersal matrix for the general area: i.e., what fraction of larvae released at every location survive to settle at every other location. This information can be obtained from a variety of approaches, including the two taken in the papers referred to: circulation modeling with empirical verification of results by Cudney-Bueno, et al. (2009), and direct observation of larval dispersal by Pelc (other approaches are reviewed in Botsford, et al. 2009).

It is important to realize that both Pelc et al. and Cudney-Bueno et al. address these questions for specific locations and species. However, one cannot conclude from those two studies that every MPA will produce a so-called "reserve effect" for every species and every system of MPAs. In fact, one of the three MPAs examined by Pelc et al. did not produce a reserve effect, because larval production was similar inside and outside of the reserve. The lack of a reserve effect in that case is consistent with model predictions (e.g., White et al. 2009), and it illustrates why the reserve effect is not "settled science".

We would say that the set of interacting factors (and associated parameters) that determine whether there will or will not be a reserve effect *is* settled science. But one must examine the specific combination of those factors (i.e., parameter values) in a specific MPA to determine whether there will be a reserve effect in each case.

There are several other factors relevant to the interpretation of the Cudney-Bueno and Pelc publications that MPA scientists and decision-makers should be aware of.

First, the overall effect of the MPAs on population distribution and abundance will be seen only after the ecosystem has gone to equilibrium. The current level of recruitment as reported in Cudney-Bueno, et al. (2009) likely depends on increased reproduction from individuals recruited before the MPAs existed. In the future it will depend on how MPAs affect recruitment at the source location, which in turn will depend on the dispersal matrix (i.e., the fraction of larvae leaving each location that settles successfully at each other location) and the future distribution of fishing effort.

Another implication of the question of whether MPAs will have the ability to *benefit* adjacent fished populations is whether they increase overall yield in the fishery. Does the increase in yield over the local (still fished) area outweigh the loss of fishing due to the closed area within the MPAs? Modeling results to date indicate that MPAs are more likely to provide a direct benefit if the population was heavily fished (or overfished) prior to MPAs (Holland and Brazee 1996, Mangel 1998, Hastings and Botsford 1999, White, et al. 2009). This is the rationale underlying the point made by Pelc, et al. that there was not a detectable increase in recruitment outside the MPA, where the fishery was well managed. Related to this point, another important question regarding benefit is whether the implementation of MPAs is the best approach of those possible. For example, in some cases reducing fishing could provide the same benefits at less cost.

Finally, another extant aspect of the question of fishery benefit that makes it difficult is the multi-species aspect of MPAs. When designing or evaluating MPAs one must consider the effects on a variety of species, and they will all have different movement rates and levels of fishing. Because of these differences they will have different responses to MPAs, i.e., an increase in MPAs beyond some point may increase yield for one species but decrease yield in another (White, et al. 2009). Thus, the implementation of MPAs could increase yield in some while decreasing yield in others. And of course species that are not fished will likely see no response to MPA implementation, as Pelc, et al. demonstrate with the barnacle species they used as a comparison to the fished mussel species.

To answer your second question (2. above), we would probably not use the word "promise"; rather we would say "the best available science indicates". We would then make the kind of calculations that underlie the above discussion of persistence and yield. Fortunately, we can point to examples of calculations our research group has made for proposed MPAs in the decision-making process for the implementation of California's Marine Life Protection Act (Kaplan, et al. 2009, Moffitt, et al. 2009, White, et al. 2009). The most recent of these calculates the contributions of proposed MPAs to persistence and yield using simple diffusion results for larval dispersal, and home range behavior for adult movement of fish. It uses decision analysis to account for the uncertainty in fishing rate, and it averages over the differing results for the six species whose responses are evaluated.

To summarize, the results to which you referred do not settle the general scientific issue, but would provide important parts of the answer for specific locations. We would still need to know how the fishing effort will be redistributed, and the dispersal matrix for the region of interest to settle the question for the specific locations. The question of benefits to a fishery requires consideration of overall net yield benefits, as well as consideration of alternative tools, and it will be complicated by differences in response among the multiplicity of species of interest.

One might fairly question whether we will ever be able to deal with the needed amount of information and the levels of complexity and uncertainty implied by these considerations. The results from implementation of MPAs in California (Kaplan, et al. 2009, Moffitt, et al. 2009, White, et al. 2009) provide an example of having enough information to make the basic calculations, while accounting for the remaining uncertainties. We hope that approach, along with a sound monitoring program and future adaptive management, will provide the information on which to base general answer to the question posed regarding the benefits of MPAs to fisheries. The alternative is to continue implementing MPAs without the modeling and data needed to predict results, and rely on observations of changes in yield and catch-per-unit effort. We agree with Pelc who notes "that such studies have trouble differentiating effects of larval export from the effects of changes in management policies and fishing practices that may occur at the same time as reserve protection." In a similar vein, Cudney-Bueno, et al. (2009) cite a basic maxim of adaptive management: "without explicit model predictions of patterns of enhanced recruitment, assumptions of reserve effects can neither be supported nor falsified by empirical results."

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