California MLPA Master Plan Science Advisory Team
Digestible Modeling Work Group
Spatially Explicit Models to Support Evaluation and Revision of Draft Marine Protected Area Proposals

Revised February 13, 2008

Introduction

For marine protected areas (MPAs) to function effectively as a network in satisfying various goals of the Marine Life Protection Act (MLPA), they must (1) provide adequate protection from harvest to the portion of a species (adult) population resident in the MPA, and (2) capture a sufficient fraction of the populations' total larval production for populations to persist. The scientific guidelines for MPA design in the *California Marine Life Protection Act Master Plan for Marine Protected Areas* (master plan) support general evaluation of the efficacy of MPAs as refugia[1] and connectivity within the network[2], but do so without calculating potential population effects or accounting for conditions outside the MPA network, the actual spatial structure of the seascape, and variability of fishing pressure on different species.

Spatially explicit population models may support further evaluation of the consequences of MPA design on a proposed network's ability to satisfy various goals of the MLPA. These models go beyond the scope of the master plan science guidelines to calculate whether populations will persist and how the MPAs will affect fishery yield. They include, for example, potential contributions from MPAs that do not satisfy the guidelines, the status of populations outside of MPAs (which depends on fishery management), and the potential costs, in terms of fishery yield, associated with achieving a desired conservation outcome.

This document is intended to provide the MLPA Blue Ribbon Task Force and regional stakeholder group with a general synthesis of insights and results from application of two models to recently revised MPA proposals in the MLPA North Central California Study Region and offer advice on how the models could be used to complement evaluation based solely on the master plan guidelines.

Description of Models

Members of the MLPA Master Plan Science Advisory Team (SAT) developed two models to quantify the effects of an MPA network over a simplified representation of the habitat landscape along the California Coast. The Davis Spatial Sustainability and Yield model (UCD model) is a population dynamic model that estimates the effects on fish populations and fisheries of not fishing in designated areas (MPAs). The Equilibrium Delay-Difference Optimization Model (EDOM) similarly uses spatial data on habitat, MPA locations, and fleet dynamics to predict spatial equilibrium biomass, yield, and fisheries profits of multiple fish

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[1] For an objective of protecting adult populations, based on adult neighborhood sizes and movement patterns, MPAs should have an alongshore span of 5-10 kolometers (3-6 miles or 2.5-5.4 nautical miles) of coastline, and preferably 10-20 kilometers (6-12.5 miles or 5.4-11 nautical miles).

[2] For an objective of facilitating dispersal and connectedness of important bottom-dwelling fish and invertebrate groups among MPAs, based on currently known scales of larval dispersal, MPAs should be placed within 50-100 kilometers (31-62 miles or 27-54 nautical miles) of each other.

species. Importantly, both models incorporate the population consequences of dynamic to spatial fishing regulations.

The two models differ in details regarding, for example, how specifically populations' dynamics are modeled, how the steady-state impacts of fisheries outside of protected areas are parameterized, and what units are used to express conservation and economic values. Although they differ in these details, the two models are structurally similar. Both are "equilibrium models", in that they predict the state of the system over the long term rather than its dynamics over time[3].

Each model includes more or less the same structural elements: (a) larval dispersal distances, (b) larval settlement regulated by species density in available habitat, (c) growth and survival dynamics of the resident (adult) population, (d) reproductive output increasing with adult size, (e) adult movement (e.g., home ranges), and (f) harvest in areas outside of MPAs. The models necessarily make assumptions regarding each of the above elements (see Appendix 1).

Model Results

The two models produce similar outputs that can be described by two basic concepts: a measure of *conservation value* (e.g., increases in biomass or population sustainability), and a measure of *economic return* (e.g., yield). Conservation value is essentially a measure of MLPA goals 1, 2, and 6[4] while economic return is a potential cost of implementing MPAs. Because the models differ in various details of their structure, the exact forms of the measures produced by each model also differ. Nevertheless, both models yield some common, general insights on MPA proposals.

Generally, the two models found the following:

1. Increasing the size or decreasing the spacing of MPAs generally leads to an increase in the conservation value of the network. (The converse is also generally true).

2. The relationship between how measures of conservation value and economic return respond to changes in MPA configuration depends critically on what is happening outside of MPAs.

   When fishing effort outside MPAs is so high that populations become unsustainable, the stock is overfished and MPAs can produce a win-win situation in which both conservation value and economic return are increased.

   In contrast, when fishing effort outside of MPAs is maintained to achieve sustainable levels of harvest, a trade-off emerges between conservation value and economic return,

[3] Note that equilibrium models do not account for the costs incurred during the time required to reach steady state.
[4] Subsections 2853(b)(1), (b)(2), and (b)(6), California Fish and Game Code.

increasing one reduces the other. Optimizing effort outside MPAs, through other fisheries management actions, can substantially reduce the potential economic consequences of MPAs.

Evaluating MPA proposals therefore requires information regarding the future state of the populations outside of the MPAs (i.e., How sustainable will fishing be for populations outside MPAs when the MPA network reaches a steady state corresponding to the model predictions?). This requires an assumption regarding the future consequences of current and future fishery management policies, a projection that includes substantial uncertainty.

3. The effect of MPAs on species-specific conservation value and economic return depends strongly on larval dispersal distance and adult home range size (or other movement behavior).

   Whether proposed MPAs can convey any conservation value to individual species depends on whether the proposed MPAs satisfy the requirements of providing adequate refuge and allowing sufficient connectivity for populations to persist and for the marine ecosystems to function naturally. Networks with small MPAs can fail to sustain species with large home ranges (by exposing adults to take) or long larval dispersal ranges (by failing to retain sufficient offspring within protected areas). The fate of such species is also affected by management outside of MPAs.

   Likewise, the economic return associated with proposed MPAs depends on movement of individual species, as this determines whether the proposed MPAs sustain populations, and the degree to which proposed MPAs effectively augment the harvestable portion of the populations.

Guiding Evaluation and Revision of MPA Proposals

The models can be used by stakeholder groups, the SAT and the task force to evaluate and revise proposals because they predict the conservation value and economic return expected after implementing proposed MPAs. The models can make such predictions for varying habitats under any of a wide range of biological and management conditions. In doing so, they can predict potential responses to MPA configurations that equally meet or not meet the master plan science guidelines and thus complement evaluations based solely on those guidelines. Evaluations based on the master plan science guidelines compare only the conservation value of an MPA proposal based on individual MPA sizes and habitat spacing and inclusion and maximum potential immediate economic impacts without accounting for how populations may change. The models integrate the two analyses and consider the effects of outside management along with marine population changes over time.

While different proposals may meet the master plan science guidelines, comparing model results can reveal more subtle differences and tradeoffs. When the size or spacing (or presence) of an MPA differs across proposals, the model reveals which configuration leads to higher biomass or more sustainable populations (conservation value) and/or which lead to higher yield (economic return). Moreover, spatially explicit predictions of where biomass and yield are concentrated or lacking provide a basis for considering how to adjust MPA proposals to achieve desired conservation or economic results.

Evaluation of Current Draft Proposals

When looking at fin-fish species[5], the models show similar results. Figures 1 and 2 are sets of graphs from the UC Davis and EDOM models respectively. In each, the upper left graphs represent the relative level of conservation value (sustainability - in terms of the proportion of habitat in which production exceeds a critical fraction of lifetime egg production- or biomass) of each draft proposal for various levels of FUTURE stock status (sustainable, moderately overfished, or heavily overfished). Higher conservation values are farther to the right hand side of the graph. The lower right graphs represent the relative economic return (fisheries yield or total catch with respect to maximum sustainable yield) of each draft proposal for the same levels of future stock status. Higher economic returns are towards the top of this graph.

The lower left graphs combine conservation value and economic return from the other two graphs. Thus they represent the “tradeoffs”, if any, between conservation value and economic return. Results in these graphs tend to group by level of future stock status. For example, the squares (heavily overfished future stock status) tend to group together, the triangles (overfished) tend to group together, and the diamonds (sustainably fished) tend to be together. In all of these figures the changes in conservation value and economic return that can be expected for each proposal can be determined by comparing the value given to “no action” *within that same level of future stock status.* For each model, especially for future stock status that is either moderately or heavily overfished, some proposals allow for both increased biological and economic success, while others do not. The proposals that stand out from groupings within the same future stock status (e.g., no action for heavily overfished) are labeled for ease of interpretation.

[5] Mean results for cabezon, black rockfish, lingcod, canary rockfish, and California halibut, as these are the five species for which both models were run.

Figure 1. Results of UC Davis Model for each proposal in respect to conservation value (upper left), economic return (lower right), and tradeoffs between the two (lower left) when run for finfish species. Proposals that stand out in terms of tradeoffs are noted with arrows.

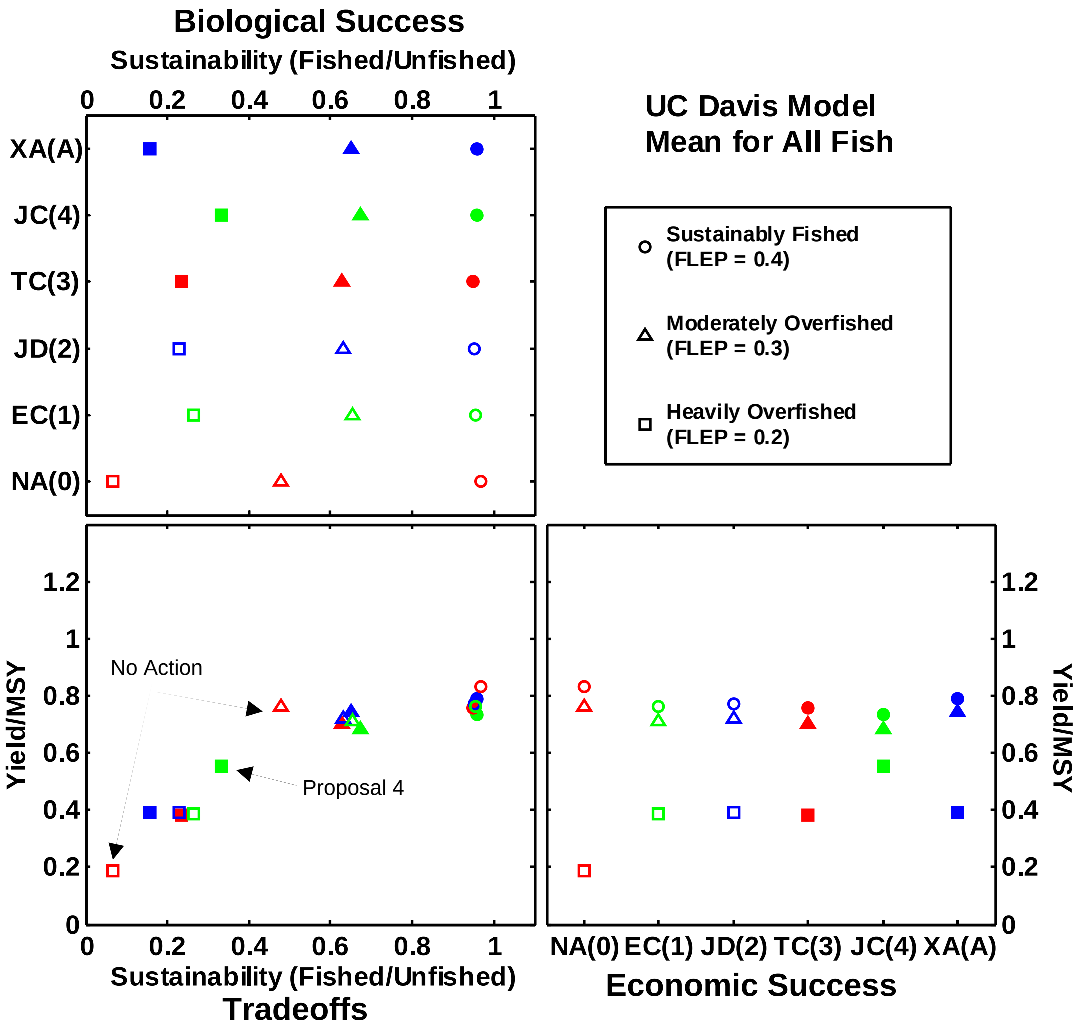
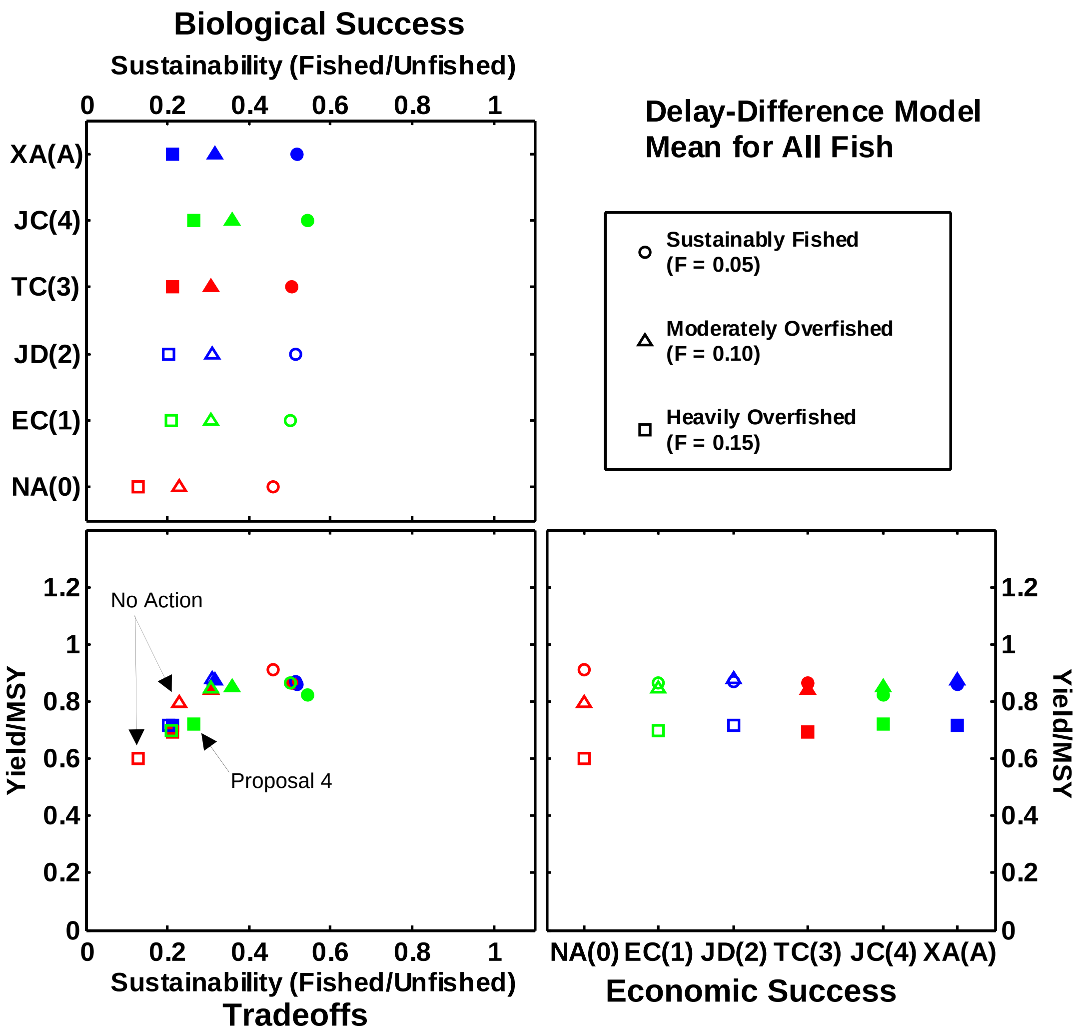
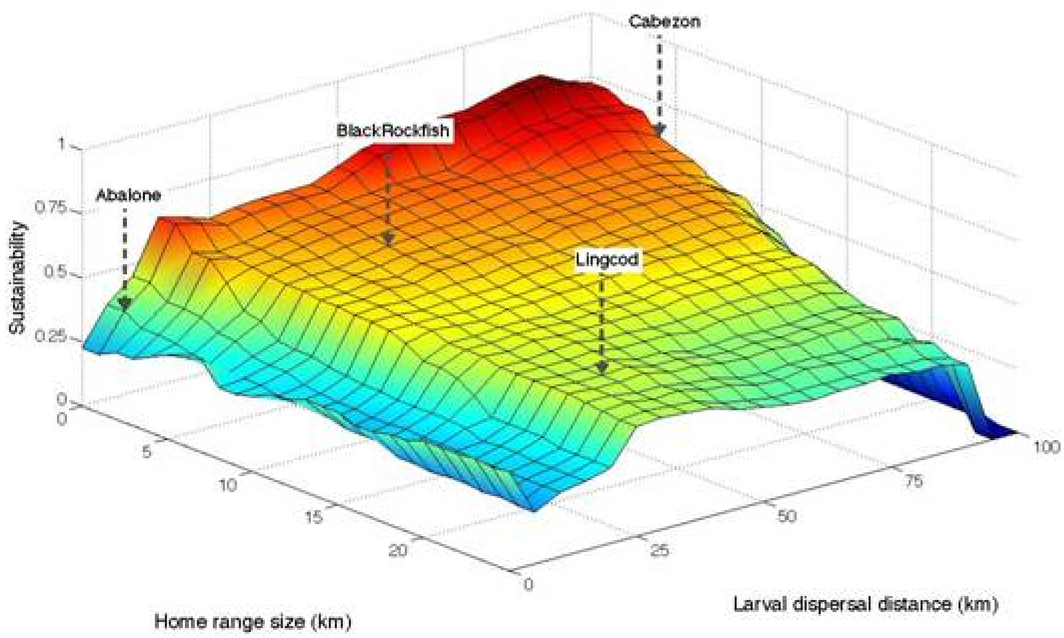


Figure 2. Results of EDOM Model for each proposal in respect to conservation value (upper left), economic return (lower right), and tradeoffs between the two (lower left) when run for finfish species. Proposals that stand out in terms of tradeoffs are noted with arrows.



Figures 1 and 2 are for all modeled species combined (see footnote 5). While not all species are modeled, the models can provide information on non-modeled species. Figure 3 compares the conservation value for a hypothetical proposal across a variety of species home ranges and larval dispersal distances, with some modeled species identified. This figure demonstrates that different species will receive different conservation values from any given proposal and that the modeled species represent the range of potential life history combinations. Detailed model results can be examined on a species-by-species basis.

Figure 3. Comparison of relative sustainability of species with different life history traits (larval dispersal distance and home range size) under the same MPA proposal. Different species will receive varying benefits in terms of sustainability depending on their life history traits.



Other analyses have shown that while relative benefit to an individual species does vary, the relative ranking of different proposals is essentially insensitive to either home range or larval dispersal distance. As either of these life history traits changes, the relative biological and economic success of any individual proposal does not change. This remains true regardless of whether individual species are compared or whether they are grouped together as in Figures 1 and 2. Figures 4 and 5 demonstrate the relative rating of each proposal at varying home range and larval dispersal distances respectively.

Figure 4. Relative ranking of proposals for conservation value (composite biomass) and economic return (fishery value) success at varying home range sizes.

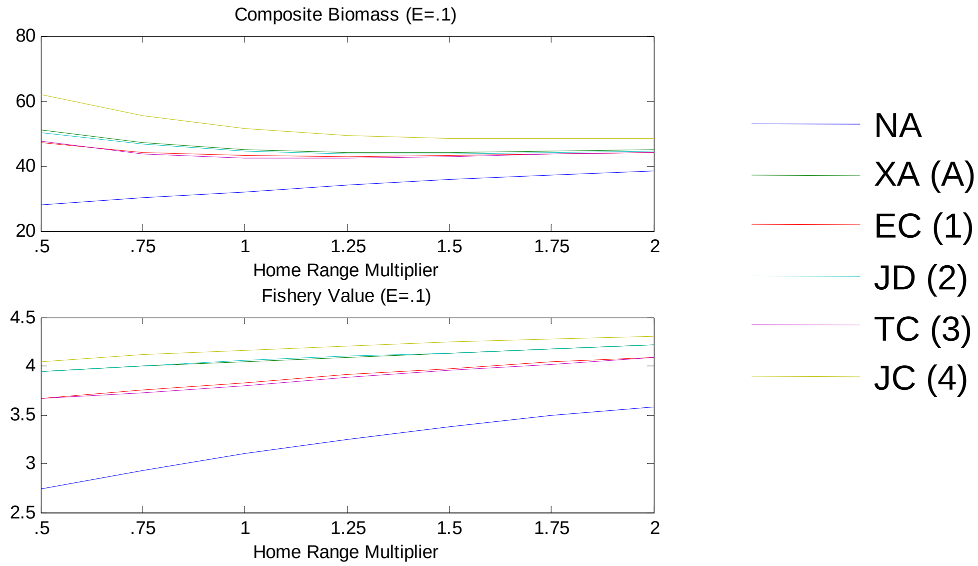
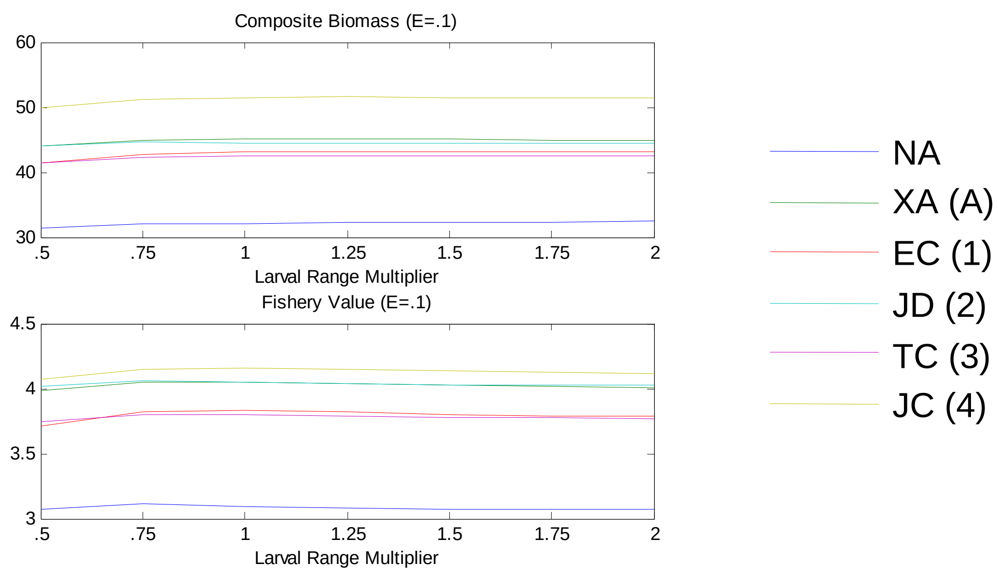


Figure 5. Relative ranking of proposals for conservation value (composite biomass) and economic return (fishery value) success at varying larval dispersal distances.



Summary of Evaluations

If conservation value is the only objective, regardless of economic return, Proposal 4 is projected to be more successful under all possibilities of future stock status.

Economic losses (in terms of lower economic return than no action) found in sustainable fisheries turn to gains when species status is assumed to be heavily overfished in the future:

- Sustainable stocks: All proposals result in some degree of economic loss (lower economic return than no action), consistent with predictions from other methods (e.g., Ecotrust evaluations).
- Moderately overfished: Some increases in economic return may be realized for certain fisheries while others may still experience modest losses.
- Heavily overfished: Large increases in economic return result from all proposals (Proposal 4 provides the largest benefit)

If tradeoffs are considered, good proposals depend on fishing assumption outside:

- Sustainable stocks: Proposals 2 and A stand out in terms of potentially increasing both fishery and biological success.
- Heavily Overfished: All proposals fare better than no action in both dimensions and proposal 4 ranks highest.

Ranking of proposals (by individual species or composite) is insensitive to home range and larval dispersal. While exact values may change, the overall rank of each proposal remains the same regardless of how these traits are modeled. Some very short distance dispersers (e.g., abalone) will still have conservation values increase, though their economic returns may decrease relative to no action, even if heavily overfished and regardless of which proposal is evaluated.

If value to recreational sector is measured by equilibrium effort, all proposals increase benefits to that sector.

Appendix 1. Model assumptions for key structural elements in the UD Davis and EDOM models.

UCD Model Assumptions	EDOM Assumptions
Larval Dispersal: Larvae disperse over a range of distances, but settlement declines the farther an individual is from its parent. Only larvae that find suitable habitat survive. A maximum number of larvae settling in any location survive to enter the adult population.	**Larval Dispersal:** For each species, larvae are distributed along the coast using a bell-shaped settlement curve. Successful survival of these larvae may be limited by larval settlement or availability of nursery habitat.
Spillover: Adults move within home ranges. Individuals with home ranges spanning MPA boundaries experience fishing pressure in proportion to the amount of their home range that is outside the MPA. This creates a spillover effect for adults with home ranges centered just inside MPAs.	**Spillover:** Two types of movement are modeled: irreversible movement of fish to seek new home ranges, and movement within home ranges. Irreversible movements are assumed to be relatively rare, but home ranges can be quite large (10-20km alongshore). Movement within home ranges creates an “exploitable biomass” that is a sum of contributions from surrounding nursery or spawning areas, hence representing “spillover” effects near MPA boundaries.
Growth and Reproduction: Growth, survival, and egg production are based on published data. In general, individuals grow to a maximum length, their weight is proportional to length cubed, and egg production is proportional to weight. Thus old, large individuals produce more eggs than young small individuals. Survival is constant with age except for species for which more precise data are available.	**Growth and Reproduction:** Growth and survival follow a previously published growth curve and survival is independent of fish age. Egg production is assumed proportional to total weight of older fish.
Fishing Pressure: Harvest of each species is modeled separately. Fishing regulations follow those set forth in each draft proposal, and both recreational and commercial fishing are considered. Fishing effort can be modeled in any of several ways: 1) effort is equal across space and implementing MPAs does not change effort outside MPAs, 2) effort is equal across space but total effort is redistributed and increases outside of MPAs, and 3) effort is proportional to fish biomass (the ‘gravity model’ in which fishing is concentrated where there are more fish).	**Fishing Pressure:** Effort for each gear type is assumed to take all species in each cell. When effort distributions are predicted (rather than optimized) using gravity model, effort is proportional to total fish biomass outside MPAs (summed over species and ages) and weighted by relative fish prices.