

California Marine Life Protection Act Initiative
Draft Methods Used to Evaluate Marine Protected Area Proposals in the
MLPA South Coast Study Region
Section 8.0 and Appendix B - Bioeconomic Modeling
Revised September 25, 2009

8. Bioeconomic Modeling

Status of this chapter: The SAT has approved the general approach to the modeling evaluation methods. Refinements to the models and this chapter will continue to be made (Revised by modeling work group ~~March 18~~ September 1, 2009).

For marine protected areas (MPAs) to function effectively as a network that satisfies 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) include a sufficient fraction of the populations' total larval production for populations to persist. The science guidelines for MPA design in the *California Marine Life Protection Act Master Plan for Marine Protected Areas* support general evaluation of the efficacy of MPAs as refugia and connectivity within alternative MPA proposals, but do not evaluate potential population effects or account for several variables, including conditions outside the MPA proposal (i.e., harvest), spatial structure of the seascape, realistic connectivity across space, and fishing pressure on different species.

Spatially explicit population models account for these factors and facilitate more comprehensive and spatially explicit evaluation of the consequences of MPA design for a proposal's ability to satisfy various goals of the MLPA. Spatially explicit models developed for evaluation of alternative MPA proposals go beyond the current scope of the master plan guidelines to calculate whether populations will persist and how the proposed MPAs will affect fishery yield and profit. The models include, for example, potential contributions from MPAs that do not satisfy all scientific 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. Further, the models allow us to detect potential situations in which MPAs are sited efficiently, so conservation comes at minimal cost (or perhaps even a benefit) to consumptive users.

This document briefly describes the key inputs and outputs of two models well-suited for analysis of alternative MPA proposals. Also described are the evaluations that will be performed by these models.

Description of Models

In the MLPA North Central Coast Study Region process of the MLPA Initiative, two models were developed, vetted, and utilized to evaluate alternative MPA proposals. Those models are currently being extended for use in the MLPA South Coast Study Region. Both models utilize spatial data on habitat, fishery effort, and proposed MPA locations and regulations to simulate the population dynamics of fished species and generate predicted spatial distributions of species abundances, yields, and (in one case) profits for each alternative MPA proposal. The UC Davis "Spatial Sustainability and Yield" model (UCD model) considers each fished species

separately, and focuses on sustainability of fished populations under each MPA proposal, using current estimates of fishery stock status to help predict future management success. The UC Santa Barbara “Flow, Fish, and Fishing” model (UCSB model) focuses on the tradeoffs between fisheries performance (profits) and fish abundance.¹ Importantly, both models incorporate the population dynamic consequences of spatially explicit 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 models have the ability to be run dynamically or to equilibrium, though running dynamically requires data on the starting stock, across space, of multiple species. In equilibrium mode, they predict the state of the system over the long term rather than its dynamics over time².

Each model includes more or less the same structural elements: (a) larval connectivity across patches driven by ocean currents, pelagic larval duration, and spawning season, (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.

Key Changes to Models

Both models have been enhanced since they were used in the north central coast. Some of these enhancements are driven by differences in biogeography between the two regions (e.g., more heterogeneous flow patterns in southern California), and some are driven by new methods or data (e.g., the desire to integrate data on fisherman behavior into the models). The key changes in the models are:

- Larval dispersal kernel—they now use output from Regional Ocean Modeling System (ROMS)-based oceanographic models³ to predict connectivity, rather than assuming homogeneous Gaussian kernels along the coastline.
- Spatial dimension—they represent the coastline as a two-dimensional map (in contrast to the previous one-dimensional representation). This permits more realistic modeling of

¹ The UCSB model adopts many of the key assumptions of the Equilibrium Delay Difference Optimization Model (EDOM), developed by Walters, Hilborn, and Costello in the MPA North Central Coast Study Region. Both the UCSB and UCD models contain important advances over the versions used in the north central coast to accommodate a more complex biogeography and spatial data on fishing effort in southern California.

² Note that equilibrium models do not account for the costs incurred during the time required to reach steady state.

³ The ROMS model has been developed by oceanographic investigators at UCLA and UCSB who have provided model outputs for use by the spatially explicit population models described in this document. See Chapter 7 – Spacing for additional information on the ROMS model.

complex habitat patterns and offshore islands in the Southern California Bight. A one kilometer by one kilometer grid is used for the patches.

- Fleet dynamics—the fleet model is parameterized with data from Ecotrust’s surveys of commercial fisheries in southern California, rather than assuming the fleet responds only to changes in fish density. The details of the fleet model are given in Appendix B2.
- Species—with help from the MLPA Master Plan Science Advisory Team (SAT), a list of species has been assembled that covers a wide range of life history and fishery traits that are relevant in southern California (Appendix B3).
- ~~Variability in larval dispersal—alternative MPA proposals will be evaluated in a variable (rather than static) environment. Larval dispersal matrices will vary among larval years to reflect the interannual variability present in the existing set of ROMS model outputs (years 1996-2002).~~

Caveats Associated with Model Interpretation

All models necessarily make simplifying assumptions about the nature of real-world processes. Both the UCD and UCSB models rely upon a series of key assumptions about the structural elements ~~(a-f) listed above~~ (Appendix B1). As such, model results should be interpreted with awareness of the assumptions, although these actually are less restrictive than those required by the verbal and mathematical models that form the basis of the size and spacing guidelines in the master plan. For example, the ROMS model used to estimate larval dispersal patterns in the models has limitations in its ability to resolve nearshore circulation, yet is more realistic than the spatially homogenous pattern of connectivity implicitly assumed by the size and spacing guidelines (see Chapter 7 - Spacing for more information on the ROMS model).

Model outputs also depend on the particular parameter values chosen for each species, so the predictions of the models will be most accurate when appropriate parameter values are known. Both modeling teams have undertaken a search of the biological literature for the best estimates of the necessary life history parameters for each model species. In Appendix B3, both modeling teams have detailed the parameter values and literature source for each estimate. This document ~~will be~~ has been circulated among SAT members and outside experts to ensure that the best parameter estimates have been used, and that these consensus parameter values ~~will be~~ have been standardized between the two models.

The spatial distributions of larval settlement and adult biomass predicted by the model are driven by two sets of assumptions: 1) larval dispersal is driven by oceanography as predicted by the ROMS model, and 2) the suitability of a particular location for the settlement and growth of a species is determined by the presence of habitat appropriate for that species. Habitat is derived from the regional habitat map developed by DFG and R. Kvitek and is represented in a binary fashion; that is, habitat is either hard- or soft-bottom. Using a rasterized version of these maps, the models consider the fraction of the one square kilometer cell which is suitable habitat (either hard or soft substrate of the appropriate depth, depending on species) to be a continuous measure of habitat availability in the cell. The maximum density of individuals in a cell (carrying capacity) is proportional to this measure of habitat availability.

A limitation to this approach is that it assumes that all locations with the appropriate substrate can support each species, whereas many species in the MLPA South Coast Study Region, including some of those being modeled, have range limits within the study region, and therefore are not found on suitable substrates outside those limits. For example, kelp bass are not found in great numbers, if at all, in the westernmost Channel Islands, despite the abundance of suitable substrate there. The precise mechanisms creating these boundaries are generally unknown and likely reflect a complex combination of factors (e.g., temperature, habitat quality, and the abundance of prey, among others) that are beyond the scope of the current modeling effort. As a consequence, the models sometimes misrepresent abundances outside of these range limits (e.g., the ocean circulation model predicts that kelp bass larvae will settle on San Miguel Island, where no adult kelp bass are actually found). To handle this potential artifact, the models assume that there is no suitable habitat for larval settlement outside of the known range of the species. Larvae arriving in those excluded locations are assumed to die, regardless of the substrate type.

At present, range limits are estimated using existing survey data on species abundances around the study region to estimate range limits primarily the 2004 CRANE survey data combined with feedback from a panel of Southern California fish experts, including several SAT members. ~~Additional range limit data could be incorporated if provided by the SAT.~~ Note that with this approach, the representation of suitable habitat remains binary: either a location is suitable habitat for a species, or not. Survey data are used to characterize the presence or absence of a species in a location, not actual population densities, which would not be well represented by a single year of survey data. Additionally, the modeling groups ~~are currently exploring the use of satellite-derived sea surface temperature data (from AVHRR satellite images) as an additional measure of habitat suitability in order to represent the north-south trends in abundance of many of the species.~~

A final caveat is that model results are highly sensitive to the level of fishing outside of MPAs. Because the models are intended to predict a future equilibrium state, it is necessary to predict future fishing levels, an area of high uncertainty. Moreover, the performance of a species under a certain level of fishing is also highly sensitive to the shape of the settler-recruitment relationship (see Table B1 in Appendix B1), which is itself highly uncertain. The precise relationship between fishing effort and the shape of the settler-recruit curve is complex and not perfectly understood, especially in models such as these with considerable spatial complexity. In general, however, it is possible to represent the joint uncertainty in the shape of the settler-recruit curve (biological uncertainty) and in future harvest scenarios (management uncertainty) relative to each other. Specifically, the models describe the shape of the settler-recruit curve in terms of a compensation ratio or critical replacement threshold (CRT), and harvest is described in terms of its effect on the lifetime egg production (LEP) of a species.

For a given value of the CRT, the model results depend roughly on the relative values of CRT and LEP rather than on the particular CRT chosen. In general, the management scenario depends on whether harvest causes lifetime egg production to exceed or fall short of the critical replacement threshold set by the settler-recruit relationship. Expressing the effects of harvest in terms of lifetime egg production also reduces some of the dependence of model

results on uncertainty about adult life-history parameters. Therefore, it is possible to represent both biological and management uncertainty by choosing a particular value for the CRT for each species and then simulating population dynamics under several different harvest regimes relative to that CRT. The models will simulate harvest regimes that will approximate poorly managed, MSY-like management, and conservatively managed scenarios, given that CRT. Thus the model results can illustrate a range of possible performance for each species. For concise interpretation (i.e., coming up with several summary results for each alternative MPA proposal) it may be desirable to weight results across species or possibly weight the probability of different future management outcomes.

SAT Recommendations for Using Models to Compare Alternative MPA Proposals

Because the models are built on the best available science, the SAT recommends that these models be among the principal modes of evaluation for each alternative MPA proposal in the MLPA South Coast Study Region. In making this recommendation, the SAT emphasizes that the models' conceptual principles are consistent with those upon which existing MPA size and spacing guidelines are based, and yield similar general conclusions: MPA size relative to adult movement strongly determines MPA effectiveness, and MPA spacing relative to larval dispersal distance strongly determines the ability of MPAs to function as a network. Spatially explicit modeling is more comprehensive in that it integrates the effects of MPA size and spacing, habitat distribution, level of fishing, and adult and larval movement to quantify the effectiveness of an alternative MPA proposal. In doing so, the models extend the scope of the evaluation of alternative MPA proposals currently addressed by the size and spacing guidelines. Moreover, spatially explicit models are not susceptible to threshold-related sensitivity that can arise from evaluation based on the size and spacing guidelines (i.e., that specific sizes and spacing (or ranges of these) are adequate, but others are not). Rather they estimate the conservation and economic consequences of each proposed spatial configuration of MPAs, so that they can be evaluated directly.

The UCD and UCSB models produce similar outputs that can be used to evaluate these conservation and economic consequences. Both models produce a measure of *conservation value* (e.g. increases in biomass or population sustainability), and a measure of *economic return* (e.g. yield or fishery profitability). Both conservation value and economic return can be described study-region wide or can be made spatially explicit. The models calculate each output at three spatial scales: individual one kilometer by one kilometer cells, the entire study region, and four sub-areas (the mainland south of Long Beach Harbor, the mainland north of Long Beach Harbor, the northern islands [San Miguel, Santa Rosa, Santa Cruz, Anacapa, Santa Barbara] and the southern islands [San Nicolas, San Clemente, Santa Catalina]). Conservation value is essentially a measure of the effectiveness of an alternative MPA proposal at meeting MLPA goals 1, 2, and 6⁴, while economic return reflects the expected changes to fishing yields of implementing MPAs. Specifically, each model will output:

1. Conservation Value

⁴ Subsections 2853(b)(1), (b)(2), and (b)(6), Fish and Game Code.

- a. [UCD] Biomass and larval supply (a proxy measure of population sustainability) of ~~10 or so~~ 8 representative species, across space, under each alternative MPA proposal (including “No Action”).
 - b. [UCSB] Biomass and larval supply of ~~10 or so~~ 8 representative species, across space, under each alternative MPA proposal (including “No Action”).
 - c. If A=Conservation Value under Proposal X, and B=Biomass under No Action, then the quotient: $(A-B)/B$ provides a measure of the percentage increase in conservation value compared with No Action.
2. Economic Return
- a. [UCD] Fish yield of ~~10 or so~~ 8 representative species, across space, for each alternative MPA proposal
 - b. [UCSB] Fish yield and Fisheries Profit for the ~~10 or so~~ 8 representative species, across space, for each alternative MPA proposal
 - c. Again, by comparing to “No Action”, one can generate a measure of the percentage increase or decrease in economic return from the proposal.

The SAT proposes that each alternative MPA proposal be evaluated by compiling the following outputs:

1. Spatial effects on Conservation Value (as percentage changes versus No Action, presented as a spatial map and averages for each sub-area)
 - a. For each model species
 - b. For an weighted average of all model species (~~SAT to determine weights~~)
2. Region-Wide effects on Conservation Value
 - a. For each model species
 - b. For an average of all model species ~~a weighted average of all model species~~ (~~SAT to determine weights~~)
3. Spatial effects on Economic Return (presented as a spatial map and averages for each sub-area)
 - a. For each model species
 - b. For an average of all model species ~~a weighted average of all model species~~ (~~SAT to determine weights~~)
4. Region-Wide effects on Economic Return
 - a. For each model species
 - b. For an average of all model species ~~a weighted average of all model species~~ (~~SAT to determine weights~~)
5. Spatial effects on Recruitment (presented as a spatial map and averages for each bioregion)
 - a. For each model species
 - b. For an average of all model species ~~a weighted average of all model species~~ (~~SAT to determine weights~~)

6. Spatial fishing intensity
 - a. For each model species
 - b. For an average of all model species ~~a weighted average of all model species~~
 (~~SAT to determine weights~~)
7. Connectivity diagrams: the larval dispersal kernel that shows the intensity of connections from all source to all destination locations.
8. Tradeoff Curves: plot Conservation Value against Economic Return for each MPA proposal

All analyses will take place over a range of ~~assumptions, e.g. with respect to fishing intensities~~
~~adult home range size, etc. (See Appendix B1).~~

Using Model Outputs to Improve Each MPA Network Proposal

In addition to the outputs being used to compare alternative MPA proposals, both models also produce outputs which can be used to evaluate the strengths and weaknesses of each design. These outputs are intended provide feedback during the iterative design process so that proposals can be adjusted to improve their performance in terms of conservation value and (if desired) economic value.

~~Three~~ Four kinds of feedback are provided for each species:

- The models calculate changes in conservation and economic value on sub-area scales. These data can be used to evaluate how the effects of alternative MPA proposals varies over space, and if necessary to revise the proposals to correct spatial imbalances in effects. The sub-areas used are the southern mainland (Long Beach harbor south to the Mexican border), northern mainland (Long Beach harbor north to Pt. Conception) northern islands (San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara) and southern islands (San Nicolas, Santa Catalina and San Clemente). In each sub-area, conservation value is calculated by comparing biomass in the sub-area with the MPA proposal to biomass in the sub-area without fishing. In each sub-area, economic value is calculated by comparing profit (or yield) in the sub-area with the MPA proposal to profit (or yield) in the sub-area with no new reserves. Examples of these outputs as produced by the UCSB model are given in Figures B4.1 and B4.2 of Appendix B4.
- The models calculate how much biomass is in each MPA, what fraction of the larvae arriving in that MPA were produced within the MPA (self-recruitment), and to what degree the MPA is self-sustaining (self-persistence). The first metric will allow a determination of which MPAs are in locations that support large populations of the target species and which are poorly placed to protect that species. The second metric (self-recruitment) allows a determination of to what extent each MPA is seeded with larvae originating elsewhere, as opposed to being replenished primarily by larvae spawned within that MPA. The third metric (self-persistence) is related and determines whether the MPA would persist in isolation; this is subtly different from self-recruitment, in that an MPA may receive a huge influx of larvae from other sources (low fraction of self-recruitment) but might nonetheless persist on its own. Conversely, an MPA may be

highly self-recruiting, but if the total number of self-produced larvae is very low, the population in the MPA may not be persistent. Examples of these outputs as produced by the UCSB model are given in Figures B4.3 and B4.4 of Appendix B4.

- The models also calculate how conservation value and economic value would vary for an alternative MPA proposal if one of the proposed MPAs was not implemented. That is, the model is run for a particular alternative MPA proposal, which contains m individual MPAs. Then m additional model runs are made. In each run, one of the MPAs is 'deleted' from the proposal. The outcome of these deletion runs is then compared to the run with the full proposal. By comparing the performance of the proposal with and without each individual MPA, the relative importance of each MPA can then be determined. If the proposal with a particular MPA removed performs similarly to the whole, intact proposal, then the given MPA is not contributing greatly to various MLPA goals, and could be altered to improve its effectiveness at meeting those goals. Alternatively, if removing an MPA causes a sharp decrease in overall performance, then that MPA is performing well at meeting those goals and should probably not be reduced in size or repositioned. Examples of these outputs as produced by the UCSB model are given in Figures B4.5 and B4.6 of Appendix B4.
- The models calculate the change in larval supply to each spatial cell under each alternative MPA proposal. This value is calculated as the percentage change in larvae settling in a cell in a given proposal, relative to the number of larvae settling in that cell under Proposal 0 (existing MPAs). This statistic reveals which portions of the study region should experience an increase (or decrease) in larval replenishment as a result of MPA implementation. Additionally, the model results also display the locations where those additional larval settlers were spawned; i.e., the locations where MPAs increase the production of successful larvae ("successful" larvae are those that actually disperse to another cell within the study region). This statistic quantifies the degree to which a given MPA actually increases the replenishment of itself, other MPAs, and the fished areas outside of MPA boundaries. This statistic can be compared across MPA proposals to determine which MPA configurations lead to the greatest increase in successful larval production. Examples of these outputs as produced by the UCD model are given in Figure B4.7 of Appendix B4.

In interpreting these feedback outputs, it is important to recognize that the performance of an alternative MPA proposal or a particular MPA within that proposal is determined by the interplay of multiple factors, often in nonlinear ways. Therefore "improving" the performance of a particular MPA could be accomplished by varying any one of a number of factors (including size, shape, coverage of habitat in the vicinity, distance to neighboring MPAs, position relative to oceanographic retention zones, etc.). However, lessons drawn from simpler models of population dynamics within MPAs (e.g., Crowder et al. 2000, Botsford et al. 2001, 2009, Gaines et al. 2003, Kaplan and Botsford 2005, Kaplan 2006, Moffitt et al. 2009) do suggest the consequences of adjusting different MPA features. In general, MPAs will afford better protection to a species if it is made larger relative to the home range radius of that species. An MPA is more likely to be self-sustaining and independently persistent if it is larger (so that a greater fraction of larvae produced within that MPA return to replenish the population within the

MPA) and if it is positioned in a location with higher oceanographic retention (larger values on the diagonal of the larval connectivity matrix). MPAs may also support large populations if they are situated such that they receive large inputs of larvae from 'upstream' locations, although then the performance of the 'downstream' MPA is tied to the persistence of the population in the 'upstream' location. Similarly, it may be advantageous to locate MPAs such that they export many larvae to 'downstream' locations (determined by looking at the off-diagonal elements of the connectivity matrix in the horizontal rows corresponding to that MPA as a larval origin). However, the successful export of larvae will still depend on whether the 'source' MPA maintains a large, persistent population.

Figure 8-1. Example of Spatial Map of Conservation Value Generated by UCD Model

The map shows the equilibrium biomass for one species (kelp bass) in each model cell.

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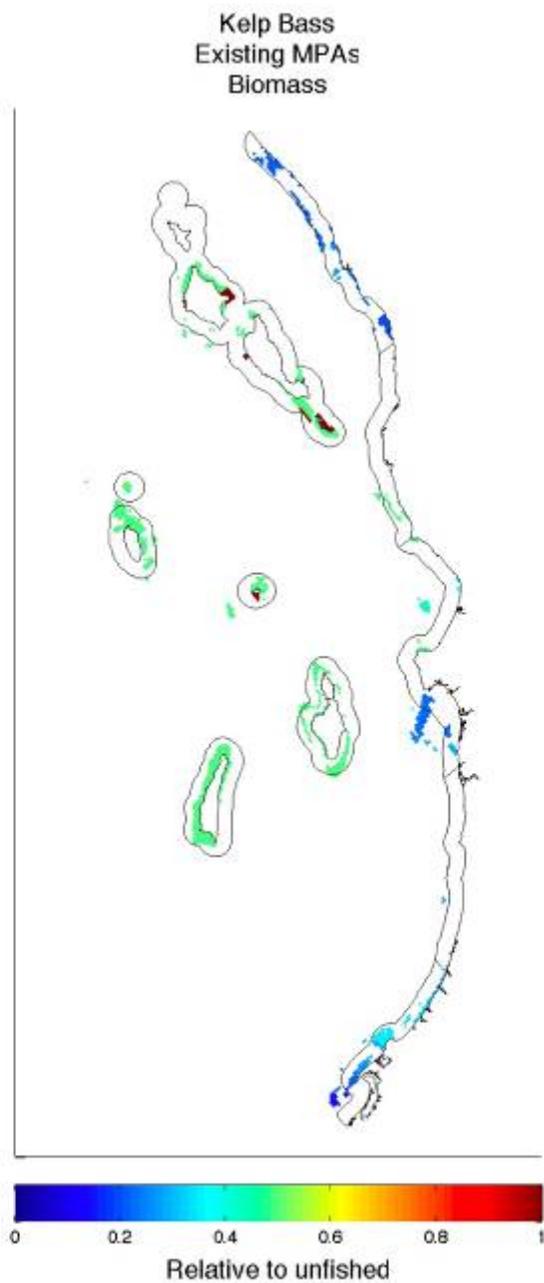


Figure 8-2. Example of Spatial Map of Economic Return Generated by UCD Model

The map shows the equilibrium yield for one species (kelp bass) in each model cell. [This map is a draft and may be altered for the final document.]

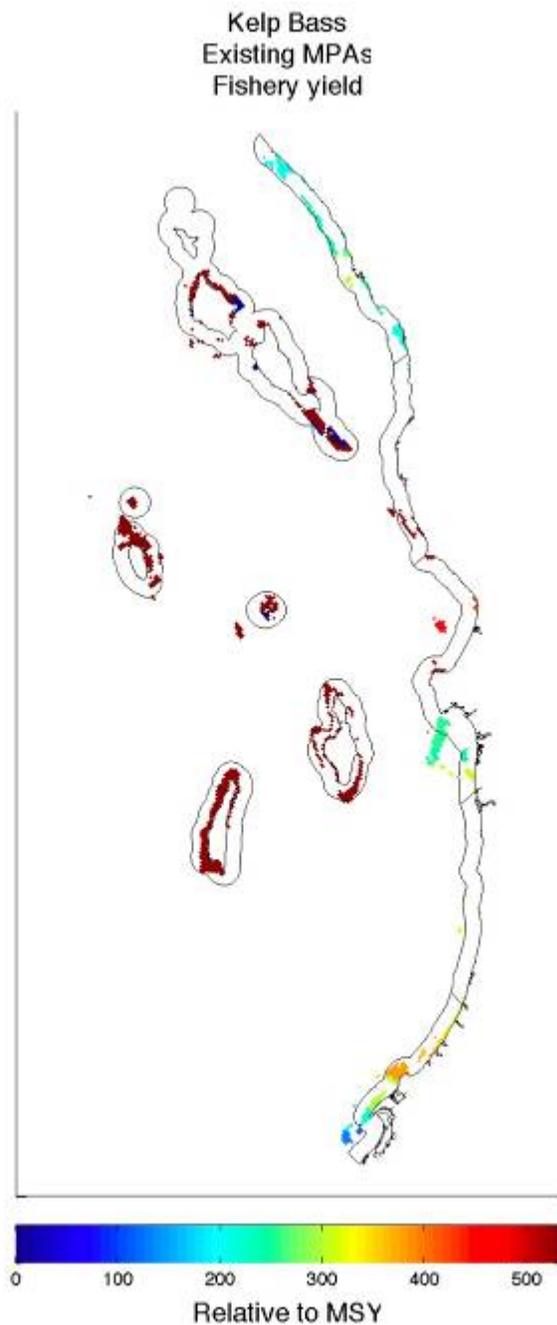


Figure 8-3. Example of Spatial Map of Recruitment Generated by UCD Model

The map shows the equilibrium larval recruitment for one species (kelp bass) in each model cell.

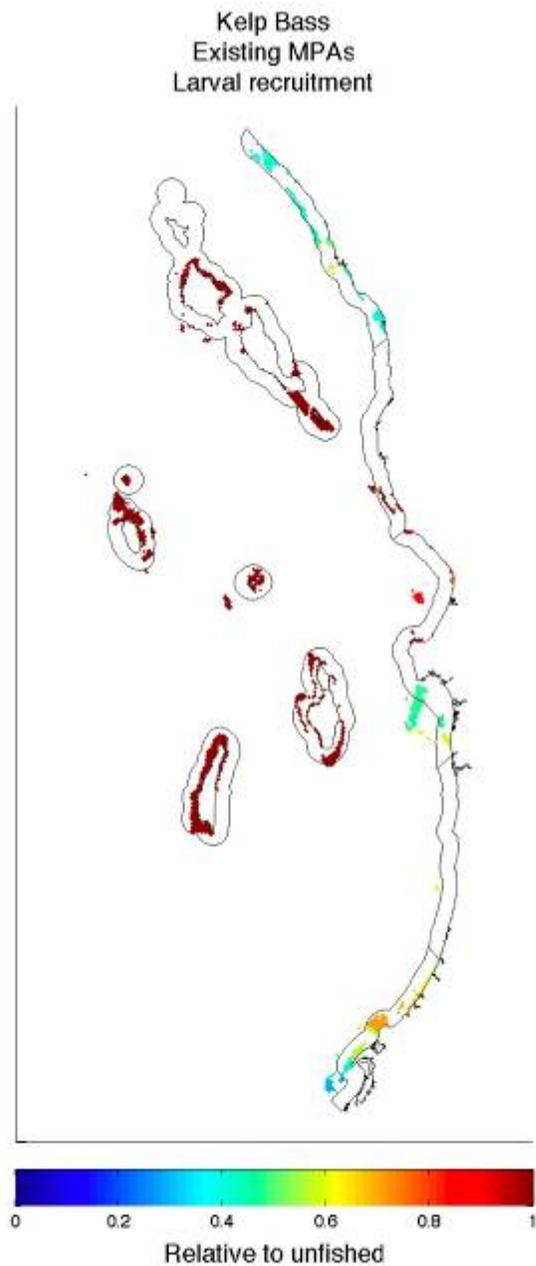


Figure 8-4. Example of Spatial Map of Fishing Generated by UCD Model

The map shows the equilibrium fishing rate for one species (kelp bass) in each model cell.

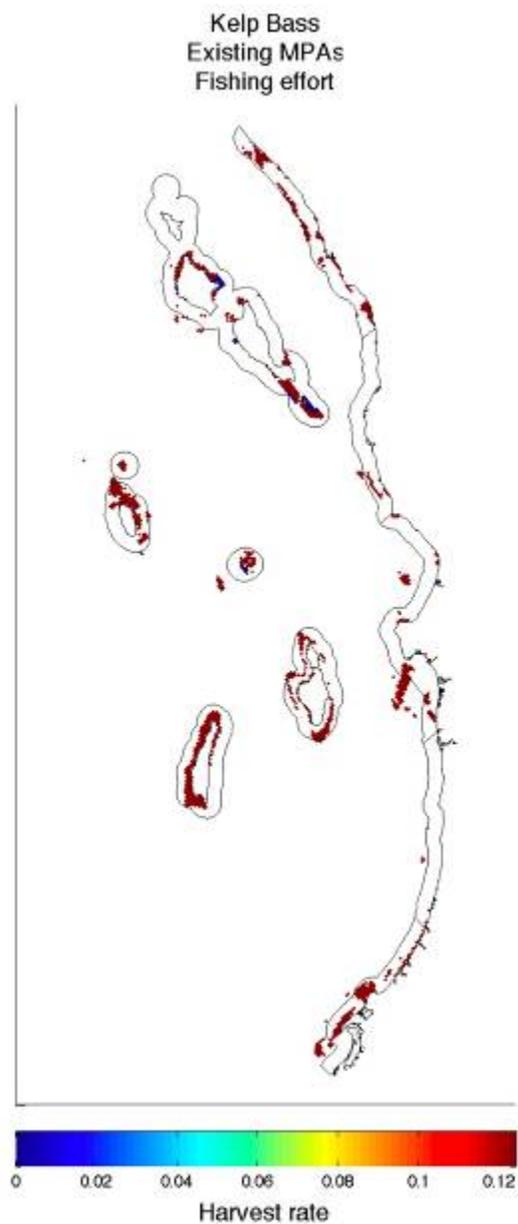


Figure 8-5. Example of Connectivity Matrix Used by Models

Color intensity at each point shows the probability of dispersal of kelp bass larvae from an origin patch (along vertical axis) to a destination patch (along horizontal axis). Points are grouped by geographical region (see Chapter 8 for description). [This is a draft; a revised version with more geographical landmarks denoted is forthcoming.]

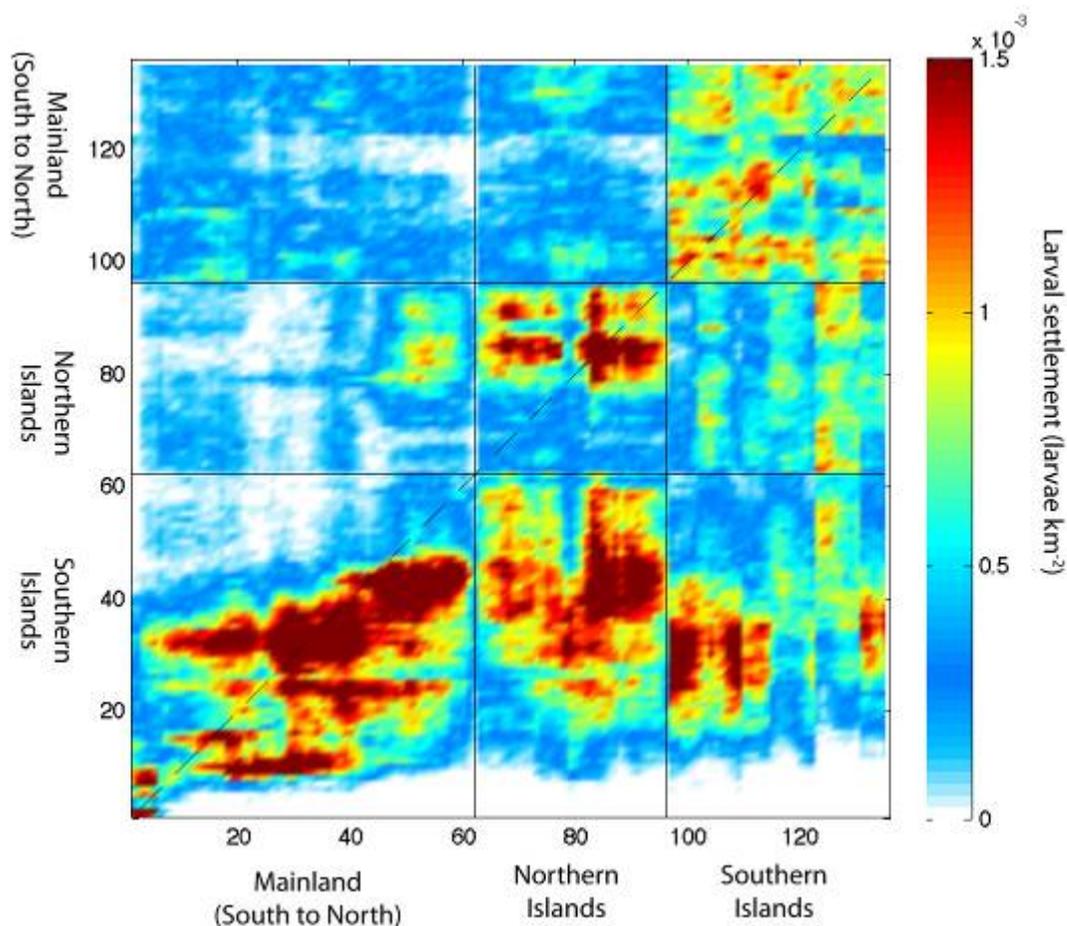
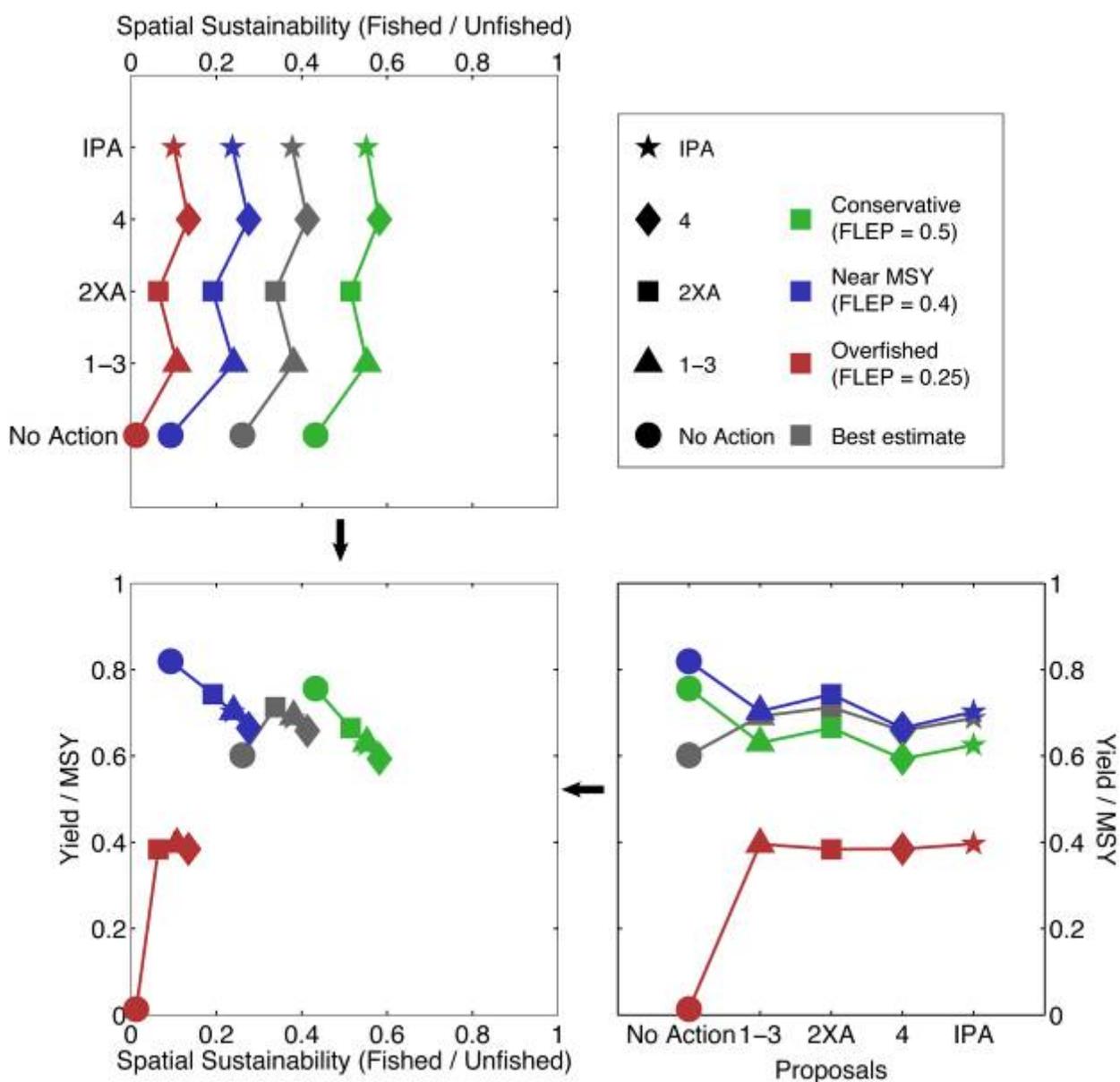


Figure 8-6. Example of Tradeoff Curve Produced by Models

This example shows a comparison of four MPA proposals and the no action alternative (Proposal 0) from the MLPA South Coast Study Region. [An example using data from the MLPA South Coast Study Region is forthcoming.] The top left panel shows the Conservation Value metric (total biomass as a proportion of biomass in a scenario without fishing) ('spatial sustainability,' a measure of population persistence estimated by the NCCSR UCD model) for each proposal; the bottom right panel shows the Economic Value metric (yield as a proportion of maximum sustainable yield) for each proposal, and the bottom left panel shows the tradeoff curve for both metrics for each proposal. Model results were generated using three different assumptions about the future success of fishery management outside of MPAs: conservative management, MSY-type management, and unsuccessful management, and one scenario in which past management success was used to predict future success ("best estimate"), these different scenarios are indicated by different colors in the figure.



Chapter 8 References

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Appendix B. Bioeconomic Modeling

B1. Model Assumptions for Key Structural Elements in Spatially Explicit Bioeconomic Models

Table B1-1. Assumptions of the UCD and UCSB Bioeconomic Models

UCD Model Assumptions	UCSB Model Assumptions
<p>Larval Dispersal: Adults of representative species in each 1 km x 1 km habitat cell throughout the study region spawn larvae that are randomly distributed within that cell. The probability of larvae moving from that cell to any other in the study region is calculated using output from the ROMS model, for which larvae are assumed to behave as passive, neutrally buoyant particles. Dispersal pathways are calculated by averaging across seven years of ROMS circulation output (1996-2002). This is may be modified, as needed, pending analysis of the sensitivity of model results to time-varying dispersal kernels. For each species, dispersal pathways are calculated using known spawning seasons and pelagic larval durations for the species. ROMS dispersal probabilities are calculated for five km radius circles distributed along the coastline of the study region; these data are mapped onto the 1 km x 1 km habitat grid used in the population models. Successful settlement for larvae 'arriving' at each model cell is contingent on the presence of suitable habitat in that cell.</p>	<p>Larval Dispersal: Same as UCD model.</p>
<p>Larval Settlement: Settling larvae experience intra-cohort density-dependent mortality. That is, the mortality rate of settlers depends on the density (fish per square meter) of other settlers arriving at that location, reflecting competition for habitat and predator refuges that is typical of the species being modeled.</p>	<p>Larval Settlement: Settling larvae experience intra-cohort density-dependent mortality as in the UCD model. Because this density-dependence represents competition for habitat and refuges, its strength depends on the proportion of the cell that is suitable habitat. For a given number of settling larvae, more will survive to adulthood in a cell with abundant suitable habitat than will survive in a cell with mostly poor habitat.</p>
<p>Adult 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</p>	<p>Adult Growth and Reproduction: Growth for each species is based on previously published growth curves. Survival is independent of fish age and is based on published estimates of mortality in the absence of fishing. Egg production is assumed</p>

UCD Model Assumptions	UCSB Model Assumptions
more eggs than young small individuals. Survival is constant with age except for species for which more precise data are available.	to be proportional to the total weight of adult fish.
<p>Adult Movement: 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.</p>	<p>Adult Movement: <u>Each year a fraction of the fish of each age class in each cell leave the cell and are distributed evenly among all neighboring habitable cells (any cell adjacent at the sides or corners which contains appropriate habitat). We assume for each species that this fraction is proportional to the typical diameter of a home range</u> The model is reasonably insensitive to the scaling of this diffusive movement rate. Two types of movement are modeled: irreversible movement of fish into a new home range and movement within a fixed home range. Irreversible movements are assumed to be relatively rare, but sometimes quite large (10-20 km alongshore). Movement within home ranges means that the “exploitable biomass” within a cell is a sum of contributions from fish with home ranges centered in the cell and in surrounding areas.</p>
<p>Fishing Pressure: Fishing regulations follow those set forth in each draft proposal, and both recreational and commercial fishing are considered. Initially, in the absence of better information, fishing effort will be modeled assuming that effort is equal across space but total effort is redistributed and increases outside of MPAs after MPA implementation. Pending collaboration with UCSB and Ecotrust, fishing effort will vary over space depending on fish abundance and travel costs (distance from port) using a fleet model that is parameterized based on data from the southern California commercial fishing fleet.</p>	<p>Fishing Pressure: We assume that fishers are acting to maximize their own profits. Assuming a large number of fishers acting independently, this means that fishing effort will be distributed such that at the end of each season marginal profits are the same in all patches. The current calculation of profits accounts for the “stock effect” in which fish are cheaper to extract from large than from small populations. <u>We have also developed a version of the model that accounts for the</u> are working on incorporating costs of travel and weather into the model, which will reduce profits in more distant and less sheltered locations. We are collaborating with UCD and Ecotrust to parameterize the fleet model using data on fishing effort and profit, by location.</p>

B2. Summary of Methods for Parameterizing Fishing Fleet Component of Spatially Explicit Bioeconomic Models

Note: These methods are currently under development.

Both the economic and conservation outcomes of implementing an MPA network will depend on how areas outside of the MPAs are fished. The UCSB and UCD models therefore predict

not only how MPAs will change fish populations but also how fishing effort will be distributed throughout the region. Because of the broad spatial scale and the large number of fishers involved, the models do not seek to predict decisions made by individual fishers but instead to predict the aggregate distribution of fishing effort for each species.

The description of the spatial distribution of fishing effort in the bioeconomic models can take on several forms, of increasing complexity. The simplest description is a uniform distribution of effort (except in MPAs, where effort is restricted or prohibited). A somewhat more realistic description is to allow fishing effort to be redistributed across space as a function of profit. This approach is based on the expectation that effort on each species will be distributed across patches so that marginal profits from fishing the species are the same in all fished patches. If this were not the case, and one patch had higher marginal profits than another, fishers would be expected to reduce effort in the less profitable patch and allocate more effort to the more profitable patch. To calculate the level of fishing effort that equalizes marginal profits in each patch, the models need to know how profit in each patch varies as a function of fishing effort.

Profit in each patch is calculated as revenue less costs, where revenue is a function of fishing effort and fish biomass in the patch, and costs are a function of fishing effort in the patch, distance of the patch from the nearest port and typical weather conditions in the patch. A simple form is assumed for this relationship:

$$\text{Profit in patch } i = \bullet_1 f(E_i, B_{i0}) \bullet [\bullet_2 D_i + \bullet_3 W_i + \bullet_4] E_i$$

Where $f(E_i, B_{i0})$ gives yield as a function of effort and biomass in patch i , D_i is the distance of the patch from port, W_i reflects typical weather conditions in the patch, and the \bullet terms are unknown parameters giving the relative importance of the different factors.

The modeling team is collaborating with Ecotrust to determine the values of these \bullet parameters. For each species, the \bullet parameters are tuned to obtain the best match between the spatial distribution of fishing effort predicted by the model (assuming the current suite of existing MPAs) and the actual current distribution of fishing, documented by Ecotrust. ~~These best parameter values will then be used in evaluating alternative MPA proposals, and will allow the models to predict how fishing effort will be distributed under that proposal, and thus how fishing outside of MPAs will effect conservation and economic outcomes of the proposal.~~

At present, both modeling groups have calculated preliminary \bullet parameters, using slightly different approaches. Both groups estimated a single set of parameters using the four modeled species for which appropriate CPFV data were available in the Ecotrust dataset: Kelp bass, California sheephead, ocean whitefish, and California halibut. A best-fit set of parameters was obtained from the data for those four species, and those parameters were then applied to all modeled species, including those for which detailed Ecotrust data are not available, assuming that the factors affecting fishing effort decisions are similar across species.

The UCSB group fit parameters based on the profit-focused approach outlined above. There was a significant cost of distance for each of the four species, with patches further from any

port being fished less heavily than similar patches (i.e., patches with similar fish populations) closer to a port. This distance effect was incorporated into the revised fleet model for all species. By contrast, typical weather conditions were not found to have a significant effect on the distribution of fishing. Therefore a cost of weather was not included in the final model (effectively $\bullet_3 = \text{zero}$ in the equation above). The lack of an effect of weather may be due to the consistent weather patterns across the south coast study region, with the exception of some of the island locations such as San Miguel. Another possible cause of the lack of weather effect may be that fishers choose which days to go to each patch, so they could spend considerable time in a patch with bad weather on average, by visiting it only during fair weather periods.

The UCD group used a slightly different approach, modeling fishing effort as a probabilistic process, in which the relative probability of fishing in patch i is a function of both location and the catch per unit effort (CPUE, a proxy for profit in the UCD model) in that patch in the previous timestep of the model;

$$q_{i,t+1} = q1_i(\text{location})q2_{ij}(\text{CPUE}_{i,t})$$

where both $q1$ and $q2$ are logistic functions of several covariates:

$$q1 = (1 + \exp(-(a_1 + a_2D_i + a_3Lat_i + a_4Lat_i^2 + a_5Lon_i + a_6Lon_i^2)))^{-1}$$

$$q2 = (1 + \exp(-(a_7 + a_8CPUE_{i,t})))^{-1}$$

The Lat and Lon terms represent the latitude and longitude of grid cell i . Including these terms allows the model to capture geographic trends in total fishing effort that are evident in the Ecotrust dataset.

Given q , the overall probability p of fishing in patch i is calculated as q_i divided by the sum of q_j for all of the patches in the study region. This model and \bullet parameters are used for all species in the UCD model except red sea urchin, for which the latitude and longitude parameters are excluded; this reflects the unique geographical distribution of urchin fishing effort.

The model parameters were fit to the Ecotrust data by repeatedly running the entire population model using alternative parameter values. For each set of parameter values, the likelihood of the Ecotrust data given the model prediction was calculated assuming that q follows a Beta distribution. The posterior distribution of best parameter values was found using a Markov chain - Monte Carlo algorithm.

Both the UCD and UCSB models are run using the revised fleet model described here to generate predictions of how fishing effort will be distributed under each MPA proposal, and how fishing outside of MPAs will affect conservation and economic outcomes. At present, both the original and revised fleet models are used to generate overall evaluation statistics, but many of the detailed results (e.g., deletion analysis) are derived only from the original fleet model. Evaluations presented to the SAT, RSG and BRTF also focus on the original fleet model because the revised fleet model is under development and preliminary results were not available during initial rounds of proposal evaluation.

Note that while “profit” implies the sale of harvested resources, it is possible to calculate the relative benefit of recreational fishing in each location in an analogous manner because recreational fishermen place a value, though not necessarily monetary, on the fish they catch.

B3. Summary of Life History Parameters Used in Models

Life-history parameters for each modeled species were obtained by searching the published scientific literature, stock assessments, and the 2000 Pacific States Marine Fisheries Commission report prepared by G. Cailliet et al. These parameters have been vetted by the modeling group and by a panel of experts on southern California fish and kelp forest ecosystems, including many SAT members

~~At present this appendix describes parameters obtained and used by the UC Davis model; there is an ongoing collaboration between the UC Davis and UCSB groups to double check and revise (as necessary) these estimates. Some parameters are still tentative pending contact with various experts who may possess unpublished data. Furthermore, the modeling groups will circulate this document among appropriate scientific experts, including those on the SAT, to confirm the accuracy of these estimates. Therefore some values may be revised as the south coast process progresses.~~

Parameters Used

Movement: Because management with MPAs involves creating differences in conditions (i.e., fishing mortality rate) over space, the effects of individual movement have a critical effect on sustainability and yield. Two kinds of biological movement are important, dispersal during the larval stage and swimming movement during juvenile and adult stages.

Juvenile/Adult Swimming: Most of the species that will be protected and sustained by the MLPA either have very little adult movement, or move within a specified home range. For some of these species the sizes of the home ranges have been estimated using acoustic tags. This type of movement can be considered well known for species that have been studied in this way. In general, home range size is reported in terms of diameter, which facilitates implementation in a one-dimensional model. There is greater confidence in estimates derived from acoustic tagging studies than from simple tag-recapture studies.

Larval Dispersal: The models use estimates of larval dispersal derived from the ROMS-based Lagrangian particle-tracking model developed by UCLA and UCSB. In this approach, each species is characterized by pelagic larval duration (PLD) and spawning season.

Life History: Both reproduction and yield depend on the sizes of individuals, which depends on how fast they grow through life. Here size vs. age is presented in terms of the dependence of length on age in the most commonly used form, a von Bertalanffy growth function. The parameter L_{∞} represents the mean length for very old individuals, the parameter k represents the growth rate at young ages, and the parameter t_0 essentially describes the length of an individual at age 0. Size vs. age is also presented in terms of weight, which is calculated from size via an allometric relationship, $W = aL^b$. The values of a and b are given for each species.

Reproduction depends on the age of maturity and fecundity. Fecundity, f , the number of eggs produced by a female of a certain age or size in a year, is commonly assumed to be proportional to weight, but is sometimes also calculated from an allometric (or other) relationship with length.

Mortality consists of two components, fishing mortality and natural mortality. Here ~~are~~ we presented instantaneous natural mortality rates.

The size ranges that are available to be caught by the fishery are either specified by regulation or estimated from fishery or other data.

Compensation Ratio / Critical Replacement Threshold: Species persistence, and thus all model results, depend heavily on the shape of the settler-recruit relationship. This relationship describes the per-capita mortality of settlers as a function of settler density; settlers surviving this initial bout of post-settlement mortality are considered 'recruits' into the benthic population. This curve is generally described in terms of the slope at the origin; it is assumed that the curve has a Beverton-Holt functional form and that the asymptotic maximum density can be made nondimensional by scaling all model results to the baseline unfished case.

The settler-recruit curve is analogous to the stock-recruit curves utilized in nonspatial fishery models. The slope at the origin of the stock-recruit curve can be described as a nondimensional compensation ratio, which is the ratio of per-capita settler survival at very low densities (settlers = 0) to per-capita survival of settlers at the highest possible density in the unfished state. The inverse of this number ($1/CR$) is also referred to as the critical replacement threshold (CRT), because it is the fraction of lifetime egg production (FLEP) below which the population is not persistent. That is, if $CR = 5$, $CRT = 1/5 = 0.2$, and if fishing reduces lifetime egg production below 20% of its unfished maximum, the population will collapse. Estimates of the CR are generally difficult to obtain except for species that have been fished below the CRT and therefore collapsed. As a consequence the CR is known for only a few fished species. Dorn (2002) estimated a CR of approximately 3 for several collapsed species of north Pacific rockfishes. This CR is likely to be a conservative estimate, especially since some southern California species are likely to be somewhat more resilient than those rockfish species. Therefore, both models use a reasonable but nonetheless conservative estimate of $CR = 4$ ($CRT = 0.25$) for the settler-recruit curves for each species.

Although the choice of CR will affect the model results, by far the largest effect will be on the sensitivity of the population to fishing. This effect on sensitivity to fishing should largely be accounted for by the methods used to choose fishing effort outside of reserves. Because fishing effort in each of the future fishing scenarios is chosen as some constant fraction of CRT (or MSY, in the case of the UCSB model), the potential for the choice of CR to affect model outcomes should be much reduced.

Species Notes

At this time the The effects of alternative MPA proposals are evaluated for 8 species. The text and tables that follow provide both reported estimates of each parameter and, for those

parameters with different estimates or a range of values, an indication of the value chosen to use in the models. Unless otherwise noted, all distances are in kilometers, all organisms lengths are in centimeters, and all masses are in kilograms.

Kelp bass (*Paralabrax clathratus*)*

The estimate of home range size is based on acoustic telemetry studies (Lowe et al. 2003). The estimate of < 1 km actually encompasses some rare longer-distance movements, as most fish use home ranges smaller than this estimate.

California Sheephead (*Semicossyphus pulcher*)*

The estimate of home range size is based on acoustic telemetry studies (Topping et al. 2005, 2006). The same authors also suggests that sheephead prefer ecotone habitat that spans both sand and rocky reef.

Kelp rockfish (*Sebastes atrovirens*)*

The estimate of home range size is based on tag-recapture studies (Miller and Geibel 1973, Lea et al. 1999). Computer simulations suggest that home range diameter is approximately 70% of the mean recapture distance in tag-recapture studies.

Ocean Whitefish (*Caulolatilus princeps*)

The estimate of home range size is based on acoustic telemetry studies (Bellquist et al. 2008).

Fishing for ocean whitefish is primarily recreational, although there may be some bycatch in the live fish fishery (CDFG 2003). The status of the fishery is essentially unknown because it is widely assumed that larval fish settle in Mexico and eventually migrate to California waters as adults (CDFG 2003). However, coastal benthic trawl surveys in 1969-1999 found that whitefish recruitment does occur in California waters, primarily in warmer years (Bellquist et al. 2008).

Opaleye (*Girella nigricans*)

No home range data are available for non-tidepool individuals; still checking citations in Davis (2001). PLD is 2-4 months (Waples 1987 Evolution).

Black perch (*Embiotoca jacksoni*)

The estimate of home range size is based on tagging studies conducted by Hixon (1979, 1980).

No larval stage.

Red sea urchin (*Strongylocentrotus franciscanus*)*

There are several references for the duration of the larval stage of red sea urchin; the relatively low value of 49 days has been chosen. Red sea urchins move very little after settlement (less than 10 m).

Growth and mortality rates have been estimated from size distributions collected along the coast of northern California (Morgan, et al. 2000).

California halibut (*Paralichthys californicus*)

The estimate of home range size is based on a tag-recapture study by Domeier & Chun (1995). Based on computer simulations, the mean home range diameter is estimated to be 70% of the mean recapture distance.

California halibut is a soft-bottom species. Although some individuals recruit into estuaries, more recent information suggests that recruitment also occurs along the open coast, consistent with the assumptions of the ROMS larval dispersal modeling.

Table B3-1. Kelp bass (*Paralabrax clathratus*)

Parameter	Value	Source
Pelagic larval duration	30 d	Cordes & Allen 1997
Spawning season	May-Sept	Oda et al 1993
Biogeographic assemblage	Southern / San Diegan	Allen et al. 2006
Range limit	not north of Point Conception or at San Miguel	CRANE data, Allen et al. 2006
Home range diameter	65 m	Lowe et al 2003
Length-at-age (cm TL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Love et al 1996
L_{∞}	69.8	
k	0.06	
t_0	-3.5	
Weight-at-length (cm, kg)		
$W = aL^{\hat{a}}$		Young 1963
a	5.06×10^{-6}	
\hat{a}	3.27	
Maximum age	34 yr	Leet 2001
Age at maturity	3 yr	Love et al 1996
Natural mortality rate	0.29	Young 1967
Available to fishery	6 yr	CDFG Regulations

Table B3-2. Ocean Whitefish (*Caulolatilus princeps*)

Parameter	Value	Source
Pelagic larval duration	45 d	L. Bellquist, pers. comm.
Spawning season	Nov-March	Elorduy-Garay & Ramirez-Luna 1994, Dooley 1978
Biogeographic assemblage	Southern / San Diegan	Allen et al. 2006
Range limit	none	CRANE data, Allen et al. 2006
Home range diameter	161 m	Bellquist et al 2008
Length-at-age (cm TL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Cooksey 1980
L_{∞}	77.29	
k	0.23	
t_0	-0.016	
Weight-at-length (cm, kg)		
$W = aL^{\hat{a}}$		Cooksey 1980
a	2.83×10^{-6}	
\hat{a}	3.15	
Maximum age	13 yr	Love 1996
Age at maturity	3 yr	Cooksey 1980
Natural mortality rate	0.17	Elouardy-Garay 2005
Available to fishery	2 yr	DFG Marine Status report 2003*, Cooksey 1980

* www.dfg.ca.gov/marine/status/report2003/oceanwhitefish.pdf

Table B3-3. Black perch (*Embiotoca jacksoni*)

Parameter	Value	Source
Pelagic larval duration	0	Love 1996
Spawning season	March-May	Schmitt & Holbrook 1984, Isaacson & Isaacson 1966
Biogeographic assemblage	Cosmopolitan in CA	Allen et al. 2006
Range limit	none	CRANE data, Allen et al. 2006
Home range diameter	50 m	Hixon 1979, Hixon 1981
Length-at-age (cm SL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Froeschke et al 2007
L_{∞}	21.79	
k	0.3562	
t_0	-1.648	
Weight-at-length (cm, kg)		
$W = aL^{\hat{a}}$		Froeschke et al 2007
a	1.16×10^{-4}	
\hat{a}	2.8636	
Maximum age	9 yr	Love 1996
Age at maturity	1 yr	Love 1996, Froeschke et al 2007
Natural mortality rate	0.23	Hixon (1979), Schmitt and Holbrook (1990)
Available to fishery	1	

Table B3-4. Kelp rockfish (*Sebastes atrovirens*)

Parameter	Value reported	Source
Pelagic larval duration	60 d	Standish et al 2008
Spawning season	March-June	Love et al 2002
Biogeographic assemblage	Northern / Oregonian	Allen et al. 2006
Range limit	none	CRANE data, Allen et al. 2006
Home range diameter	8 km	Miller & Geibel 1973, Lea et al 1999, D. Hanan personal communication
Length-at-age (cm TL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Lea et al. 1999, 2000, 2001
L_{∞}	378	
k	0.23	
t_0	-0.7	
Weight-at-length (cm TL, kg)		
$W = aL^{\hat{a}}$		Lea et al 2002, 2003
a	9.37×10^{-6}	
\hat{a}	3.172	
Maximum age	25 yr	Love et al 2002
Age at maturity	4 yr	Love et al 2002
Natural mortality rate	0.2	Estimated from lifespan
Available to fishery	4	L. Allen and M. McCrae, pers. comm.

Table B3-5. Opaleye (*Girella nigricans*)

Parameter	Value reported	Source
Pelagic larval duration	90 d	Waples 1987
Spawning season	May April-July	Love 1996
Biogeographic assemblage	Southern / San Diegan	Allen et al. 2006
Range limit	none	CRANE data, Allen et al. 2006
Home range diameter	≤ 0.5 km	
Length-at-age (cm TL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Bredvik 2008
L_{∞}	28.36	
k	0.536	
t_0	-0.099	
Weight-at-length (cm TL, kg)		
$W = aL^{\hat{a}}$		Bredvik 2008
a	4.0×10^{-5}	
\hat{a}	2.95	
Maximum age	10 yr	Bredvik 2008
Age at maturity	4 yr	Bredvik 2008
Natural mortality rate	0.2	Estimated from lifespan
Available to fishery	2	L. Allen and M. McCrae, pers. comm.

Table B3-6. Sheephead (*Semicossyphus pulcher*)

Parameter	Value reported	Source
Pelagic larval duration	40 d	Waples 1987
Spawning season	May- July <u>October</u>	Cowen 1985, DeMartini et al. 1994
Biogeographic assemblage	Southern / San Diegan	Allen et al. 2006
Range limit	not north of Point Conception	CRANE data, Allen et al. 2006
Home range diameter	139 m	Topping et al. 2005, 2006
Length-at-age (cm TL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Alonzo et al. 2004
L_{∞}	83.86	
k	0.068	
t_0	0	
Weight-at-length (cm TL, kg)		
$W = aL^{\hat{a}}$		Alonzo et al. 2004
a	2.69×10^{-5}	
\hat{a}	2.857	
Maximum age	30 yr	Warner 1975, Alonzo et al. 2004
Age at maturity	4 yr	Warner 1975, Alonzo et al. 2004
Natural mortality rate	0.25	Estimated from Warner 1975, Cowen 1990
Available to fishery	7	CDFG Regulations

Table B3-7. Red Sea Urchin (*Strongylocentrotus franciscanus*)

Parameter	Value reported	Source
Pelagic larval duration	49 d	Leet 2001
Spawning season	Dec-March	Rogers-Bennett et al. 1995
Biogeographic assemblage	Cosmopolitan in CA	Leet 2001
Range limit	none	CRANE data, Allen et al. 2006
Home range diameter	0.01	
Length-at-age (test diameter, cm)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		Values reported in Kaplan et al. 2006
L	11	
k	0.22	
t_0	0	
Weight-at-length (cm, kg)		
$W = \hat{a}L^{\hat{a}}$		Values reported in Smith and Wilen 2003
\hat{a}	6.76×10^{-4}	
\hat{a}	2.68	
Maximum age	$50 \pm$ yr	Values reported in Kaplan et al. 2006
Age at maturity	4 yr	Values reported in Smith and Wilen 2003
Natural mortality rate	0.08	Values reported in Kaplan et al. 2006
Available to fishery	8	CDFG Regulations

Table B3-8. California halibut (*Paralichthys californicus*)

Parameter	Value reported	Source
Pelagic larval duration	25 d	Kucas and Hassler 1986, Moser and Watson 1990, Leet 2001, Love 1996
Spawning season	Year-round, peaks in Feb, July, Oct <u>December - May</u>	Moser and Watson 1990
Biogeographic assemblage	Cosmopolitan in CA	Allen et al. 2006
Range limit	none	CRANE data, Allen et al. 2006
Home range diameter	9 km	Domeier and Chun 1995
Length-at-age (cm TL)		
von Bertalanffy equation:		
$L(t) = L_{\infty} (1 - \exp(-k(t - t_0)))$		MacNair et al 2001
L	136.77	
k	0.08	
t_0	-1.2	
Weight-at-length (cm TL, g)		
$W = \acute{a}L^{\hat{a}}$		Reed and MacCall 1988
\acute{a}	8.70×10^{-6}	
\hat{a}	3.0496	
Maximum age	30 yr	Love 1996
Age at maturity	4 yr	Love and Brooks 1990
Natural mortality rate	0.15 <u>0.225</u>	Reed and MacCall 1988
Available to fishery	5	CDFG Regulations

B4. Examples of Bioeconomic Model Output to Be Used as Feedback on Individual MPA Performance

The following figures are examples of model outputs that will be provided to help improve alternative MPA proposals. These example results were produced by the UCSB model based on a proposal of three MPAs: MPA A - near San Diego, MPA B - near Santa Barbara and MPA C – at San Nicolas Island.

Figure B4-1. Conservation Value (Biomass as a Fraction of Unfished Biomass) for All Regions and for Each Subregion Separately

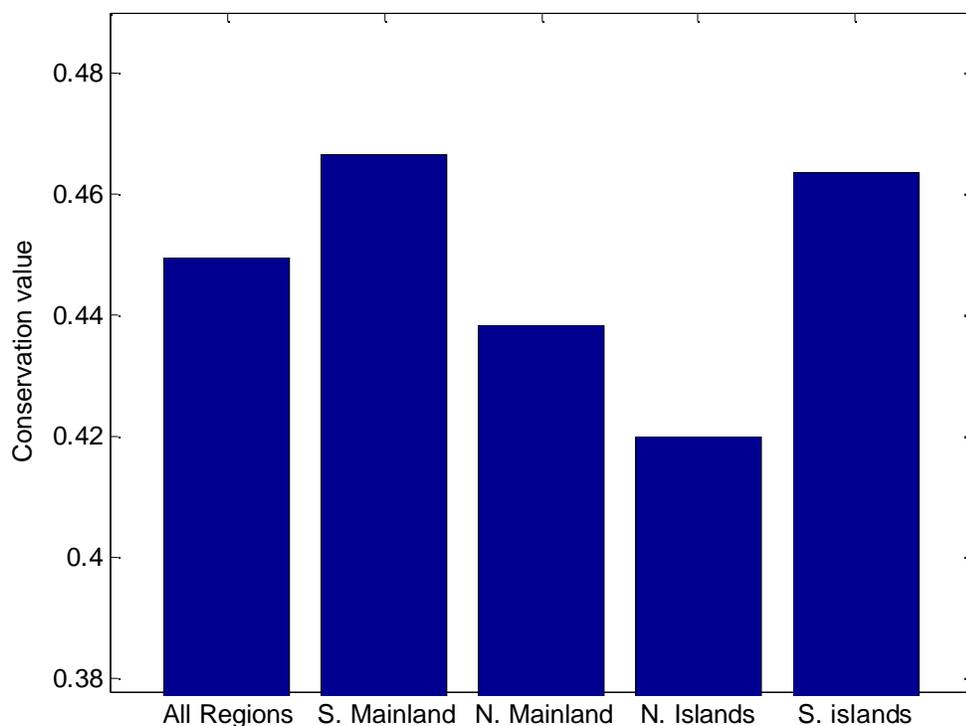


Figure B4-2. Economic Value (Profit with Reserves as a Fraction of Maximum Sustainable Profit without Reserves) for All Regions and for Each Subregion Separately.

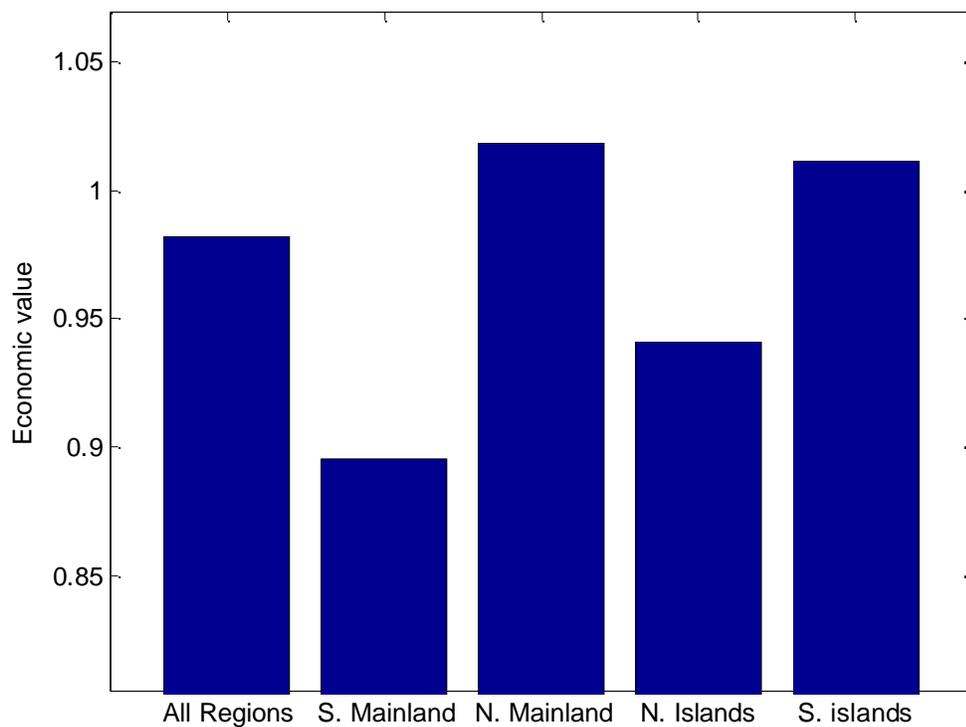


Figure B4-3. The Mass of Fish in Each Reserve, as a Fraction of the Total Mass of Fish in the Whole System

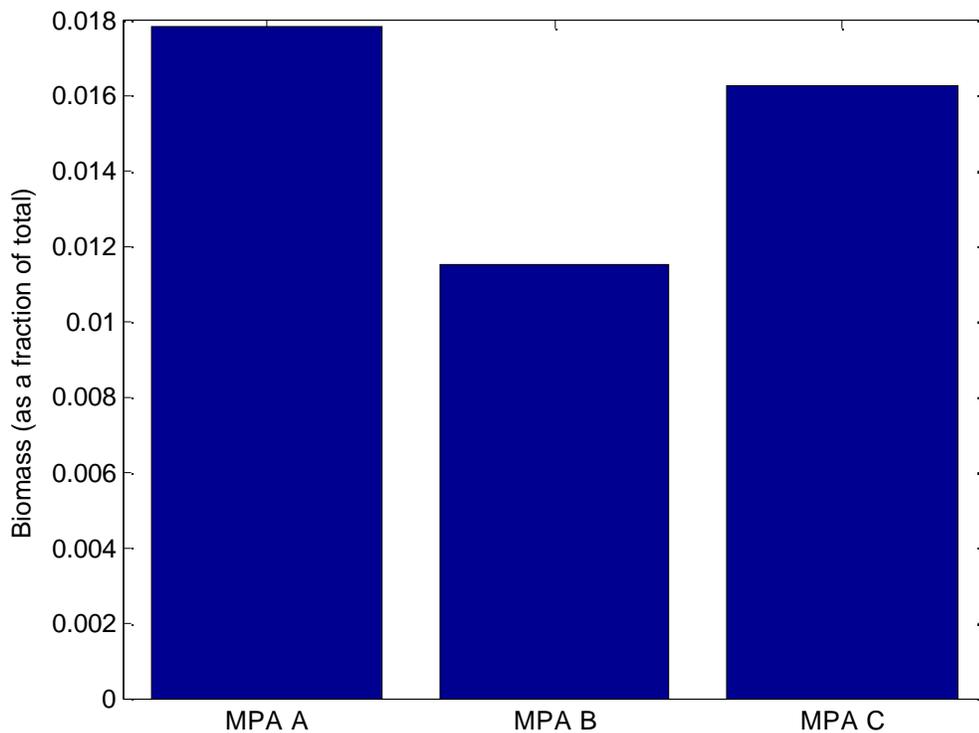


Figure B4-4. The Fraction of Larvae Arriving in Each Reserve which were Produced within the Reserve

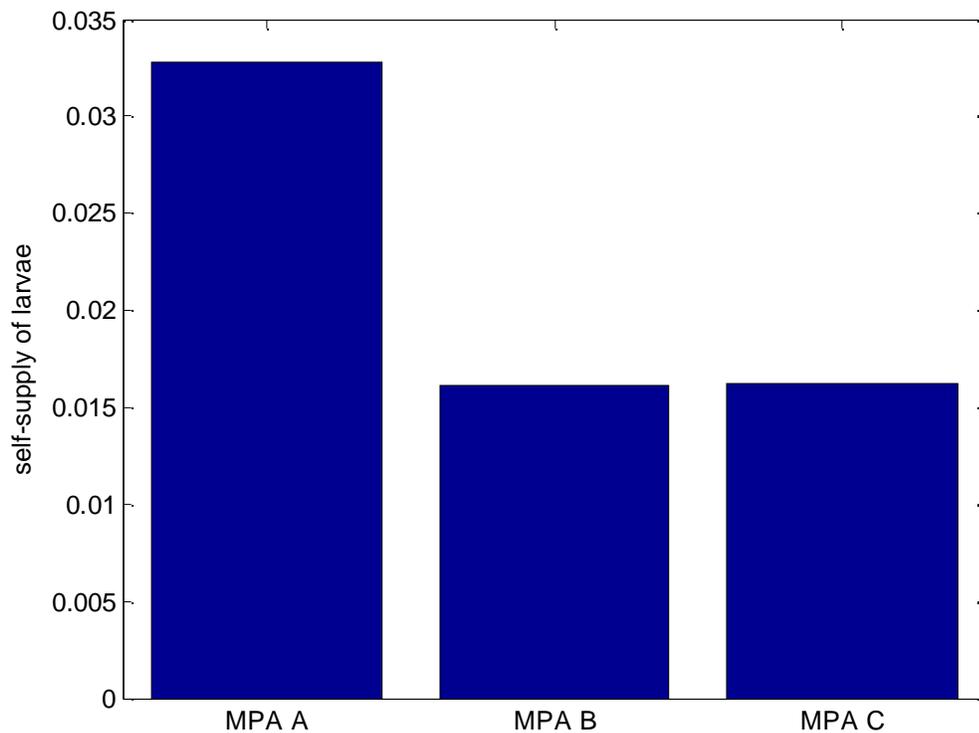


Figure B4-5. Conservation Value for the Whole System, for Subsets, and for No MPAs

Conservation Value (Biomass as a Fraction of Unfished Biomass) for the Whole System with All Reserves (i.e. the Whole MPA Proposal), as well as with All Reserves Except Reserve A, All Except Reserve B, All Except Reserve C and No MPAs

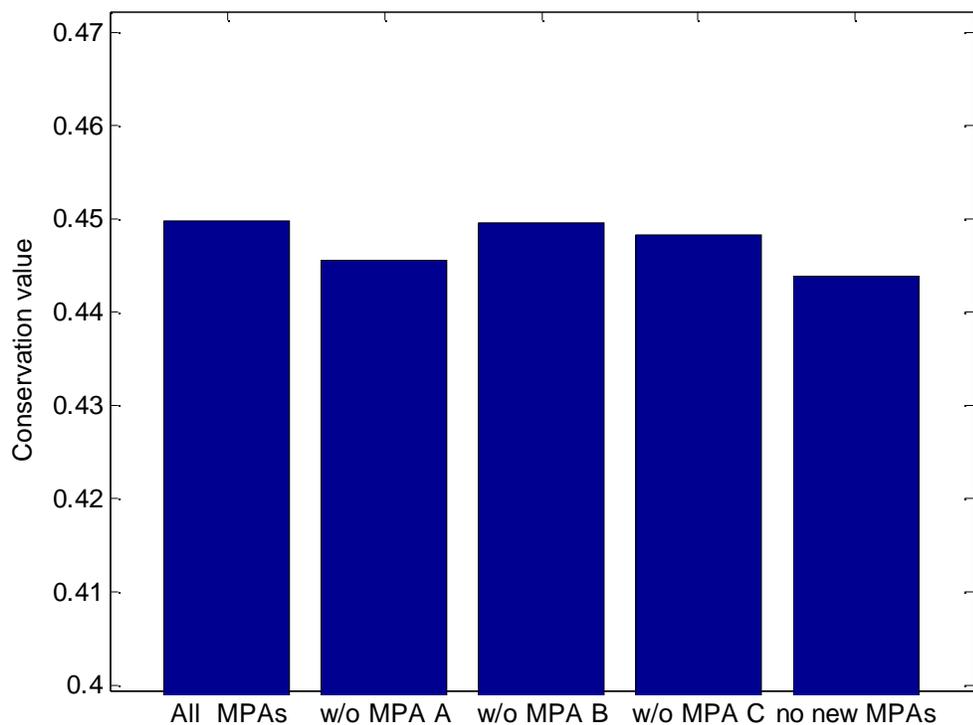


Figure B4-6. Economic Value for the Whole System, for Subsets, and for No MPAs

Economic Value (Profit with Reserves as a Fraction Maximum Sustainable Profit Without Reserves) for the Whole System with All Reserves (i.e. the Whole MPA Proposal), as well as with All Reserves Except Reserve A, All Except Reserve B, All Except Reserve C and No MPAs

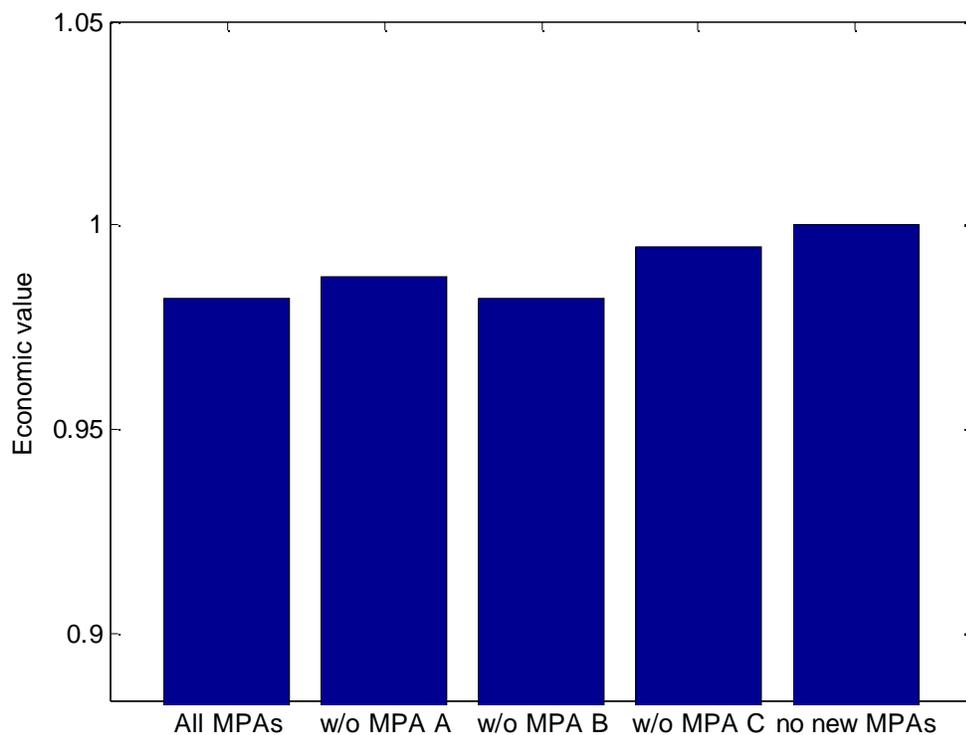


Figure B4-7. Change in larval production and larval supply for a hypothetical MPA proposal

Left panel: percent change in the production of successfully dispersing larvae, relative to Proposal 0 (both under unsuccessful fishery management scenario). Right panel: percent change in larval settlement, relative to Proposal 0. The successful larval settlers depicted in the right panel were produced at the locations depicted in the left panel.

