California Marine Life Protection Act Initiative
Methods Used to Evaluate Draft Marine Protected Area Proposals in the MLPA South Coast Study Region (Draft)
Section 10.0 – Bio-Economic Modeling

Draft revised January 15, 2009

10.0 BIO-ECONOMIC MODELING

Introduction

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 scientific 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 the proposed MPA networks, but do not evaluate potential population effects or account for several variables, including conditions outside the MPA network (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 proposed network's ability to satisfy various goals of the MLPA. Spatially explicit models developed for evaluation of proposed MPA networks 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 proposed MPA networks. We also describe 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 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 MPA network 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 time[2].

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:

1. Larval dispersal kernel – we now use output from Regional Ocean Modeling System (ROMS)-based oceanographic models[3] to predict connectivity, rather than assuming homogeneous Gaussian kernels along the coastline.
2. Spatial dimension – we represent the coastline as a two-dimensional map (in contrast to the previous one-dimensional representation). This permits more realistic modeling of complex habitat patterns and offshore islands in the Southern California Bight. We will use a 1 kilometer x 1 kilometer grid for our patches.
3. Fleet dynamics – we will parameterize our fleet model with data from Ecotrust's surveys of commercial fisheries in Southern California, rather than assuming the fleet responds only to changes in fish density.

[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 North Central Coast Study Region. Both the UCSB and UCD models contain important advances over the versions used in the NCCSR 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 Section 8 – Spacing for additional information on the ROMS model.

4. Species – with help from the MLPA Master Plan Science Advisory Team (SAT), we have assembled a list of species that cover a wide range of life history and fishery traits that are relevant in Southern California.
5. Variability in larval dispersal – we will evaluate MPA networks in a variable (rather than static) environment.

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 1). 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 is more realistic than the spatially homogenous pattern of connectivity implicitly assumed by the size and spacing guidelines, yet the ROMS model has limitations in its ability to resolve nearshore circulation (see Section 8 - Spacing for more information on the ROMS model).

Model Outputs

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 or fishery profitability). Both conservation value and economic return can be described system wide or can be made spatially explicit. Conservation value is essentially a measure of the effectiveness of a proposed network of MPAs at meeting MLPA goals 1, 2, and 6[4] while economic return is a potential cost of implementing MPAs. Specifically, each model will output:

1. Conservation Value
    a. [UCD] Biomass and larval supply (a proxy measure of population sustainability) of 10 or so representative species, across space, under each MPA network proposal (including “No Action”).
    b. [UCSB] Biomass of 10 or so representative species, across space, under each MPA network 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 representative species, across space, for each MPA network proposal.

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

   b. [UCSB] Fish yield and Fisheries Profit for the 10 or so representative species, across space, for each MPA network 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.

SAT Recommendations for Evaluation Using Models

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 MPA network 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 a proposed MPA network. In doing so, the models extend the scope of the evaluation of MPA network 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.

Specifically, the SAT proposes that each proposed network of MPAs be evaluated by compiling the following summaries:

1. Spatial effects on Conservation Value (as percentage changes versus No Action, presented as a spatial map and averages for each bioregion)
   a. For each model species
   b. For a weighted average of all model species (SAT to determine weights)
2. Region-Wide effects on Conservation Value
   a. For each model species
   b. For 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 bioregion)
   a. For each model species
   b. For 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 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 a weighted average of all model species (SAT to determine weights)
6. Spatial fishing intensity
   a. For each model species
   b. For 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 intensity, adult home range size, etc. (See Appendix 1).

Figure 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. [This map is a draft and may be altered for the final document.]

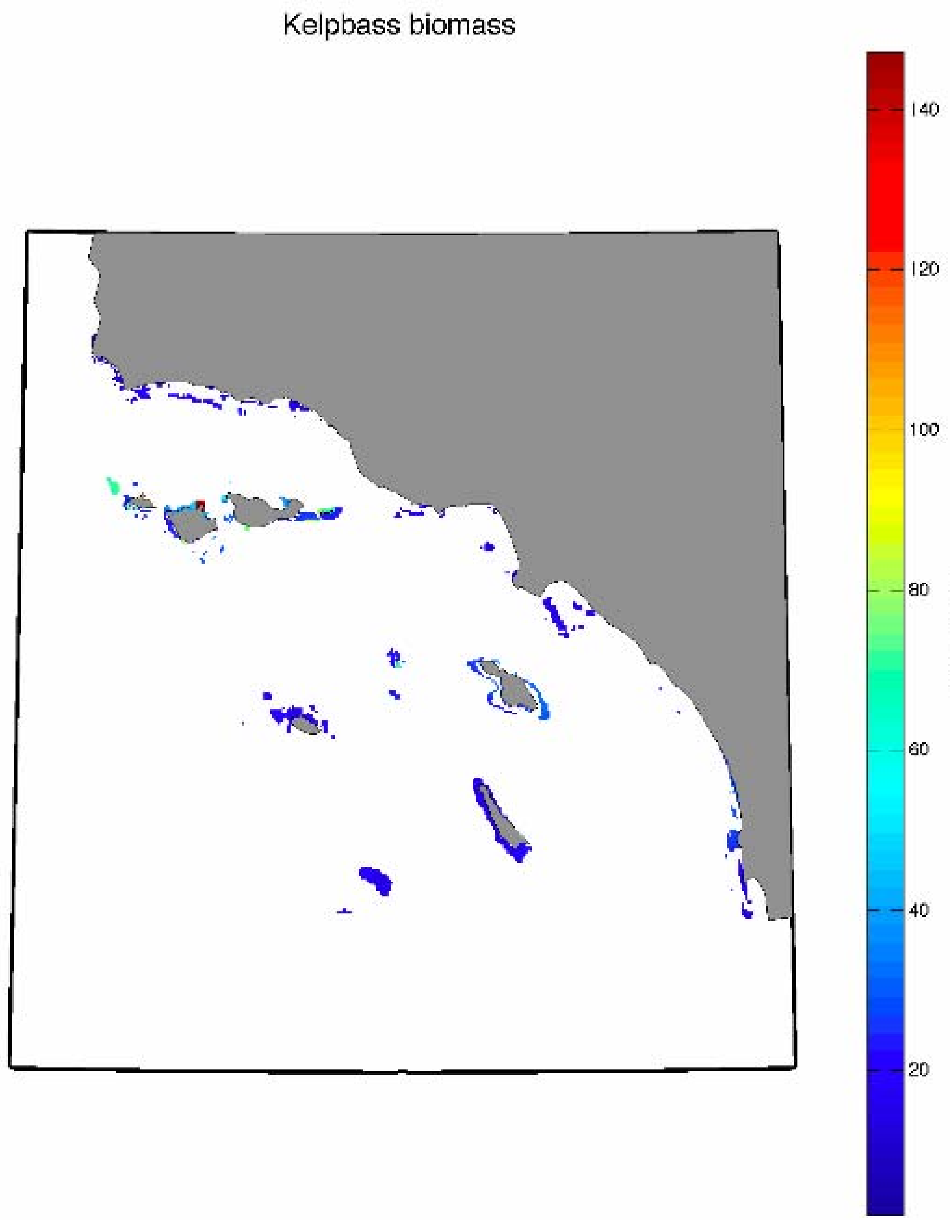


Figure 2. Example of spatial map of Economic Return generated by UCD model. The map shows the equilibrium yield for one species (kelp bass) in each model cell. [This map is a draft and may be altered for the final document.]

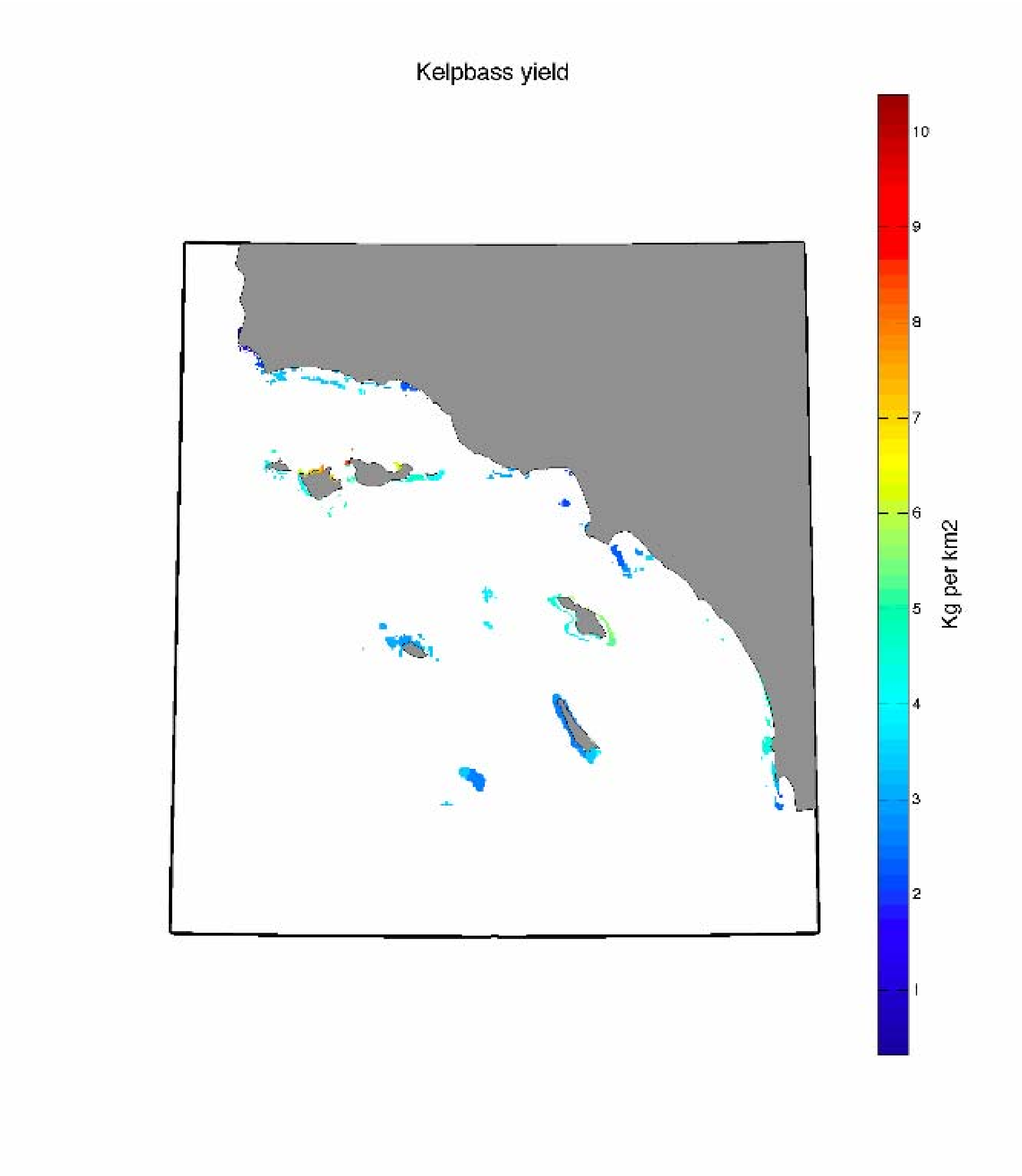


Figure 3. Example of spatial map of Recruitment generated by UCD model. The map shows the equilibrium larval recruitment for one species (kelp bass) in each model cell. [Map to be generated]

Figure 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. [Map to be generated]

Figure 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 Section 8 for description). [This is a draft; a revised version with more geographical landmarks denoted is forthcoming.]

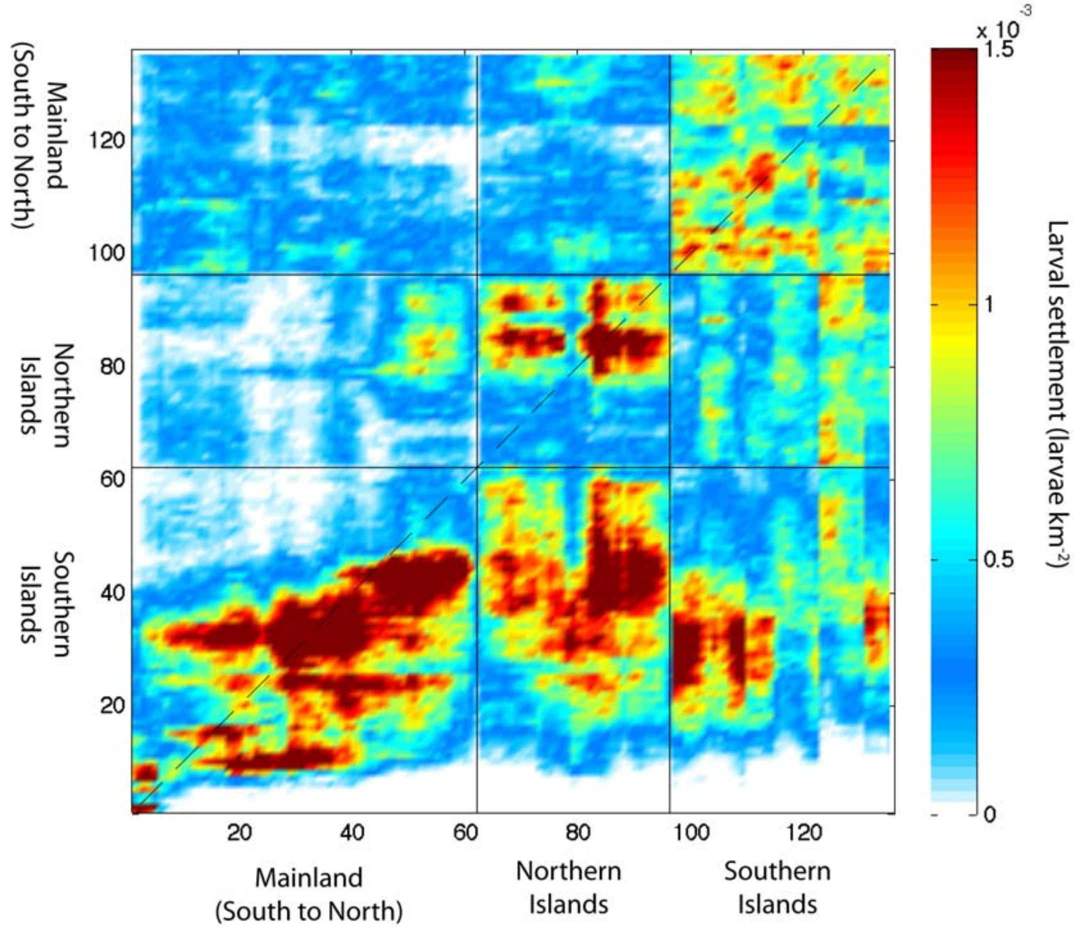
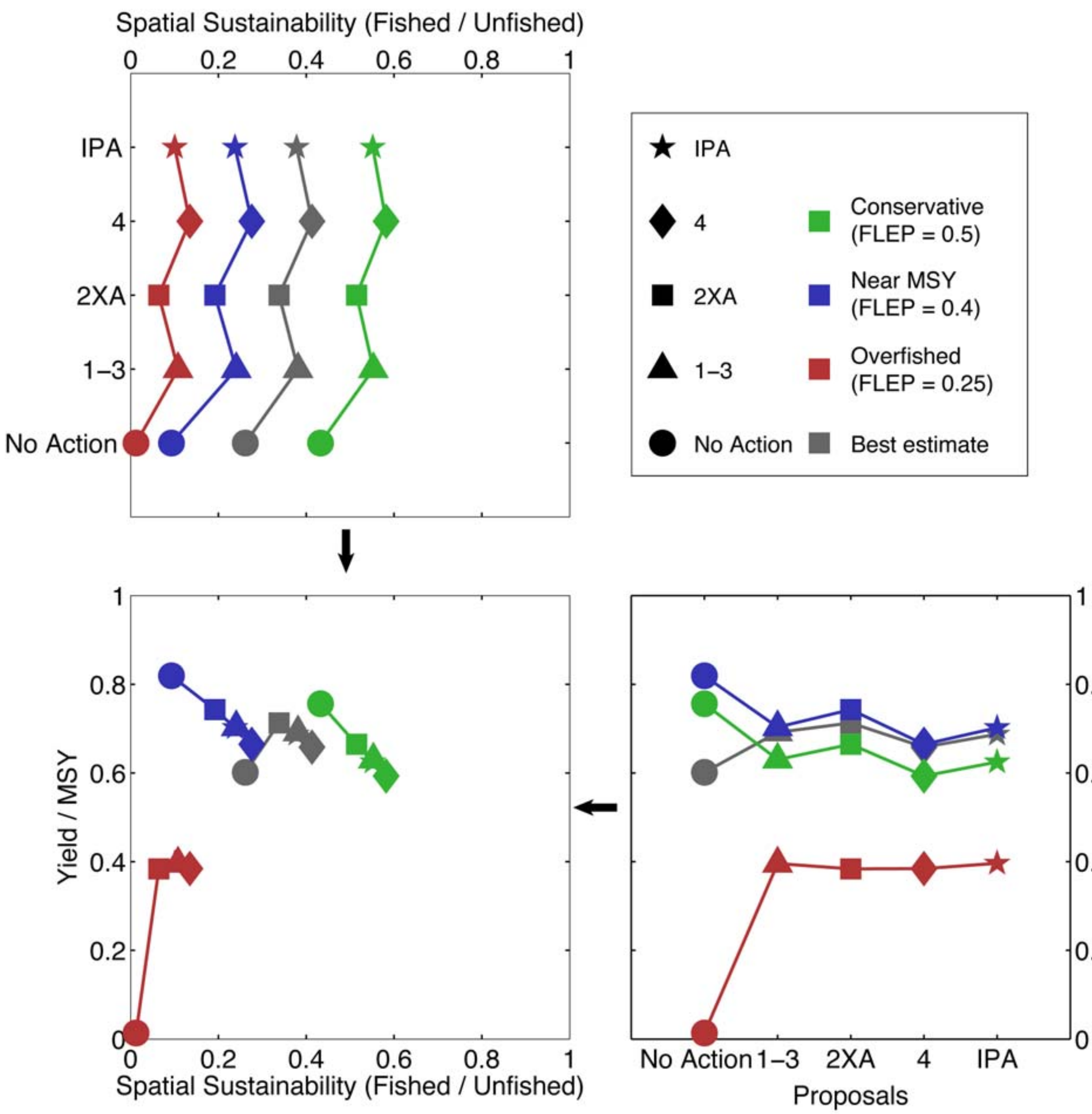


Figure 6. Example of tradeoff curve produced by models. This example shows a comparison of four MPA proposals and the No Action alternative from the North Central Coast Study Region. [An example using data from the South Coast Study Region is forthcoming.] The top left panel shows the Conservation Value metric ('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 3 different assumptions about the future success of fishery management outside of MPAs and 1 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.



Appendix 1. Model assumptions for key structural elements in the UCD and UCSB models.

UCD Model Assumptions	UCSB Model Assumptions
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 7 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 5 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.	**Larval Dispersal:** Same as UCD model.
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.	**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.
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 more eggs than young small individuals. Survival is constant with age except for species for which more precise data are available.	**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 to be proportional to the total weight of adult fish.
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.	**Adult Movement:** 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.
Fishing Pressure: Fishing regulations follow those set forth in each draft proposal, and both recreational and	**Fishing Pressure:** We assume that fishers are acting to maximize their own profits. Assuming a large number

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.	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. We 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.