PEER REVIEW

CALIFORNIA MARINE LIFE PROTECTION ACT (MLPA) SCIENCE ADVICE AND MPA NETWORK PROPOSALS

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FOREWORD

Introduction

In 1999 Governor Gray Davis signed the Marine Life Protection Act into California law. Legislative declarations (**2851. Legislative Findings and Declarations)** found, in part, that (c) "coastal development, pollution and other human activities threaten the health of marine habitat and the biological diversity of California's ocean waters." (f)"Marine life reserves are an essential element of an MPA system because they protect habitat and ecosystems, conserve biological diversity, provide a sanctuary for fish and other sea life, enhance recreational and educational opportunities, provide a reference point against which scientists can measure changes elsewhere in the marine environment, and may help rebuild depleted fisheries." Further, (d)"fish are a sustainable resource and fishing is an important community asset. MPAs and sound fishery management are complementary components of a comprehensive effort to sustain marine habitats and fisheries."
[Therefore], (h) "it is necessary to modify the existing collection of MPAs to ensure that they are designed and managed according to clear, conservation-based goals and guidelines that take full advantage of the multiple benefits that can be derived from the establishment of marine life reserves."

The intent of the MLPA was to implement a Marine Life Protection Program, including a statewide network of marine protected areas (MPAs). The MLPA identified a set of goals for the Marine Life Protection Program including:
conservation of biological diversity and the health of marine ecosystems; recovery of wildlife populations; improving recreational and educational opportunities consistent with biodiversity conservation; protection of representative and unique habitats for their intrinsic value; ensuring that MPAs have defined objectives, effective management and enforcement, and are designed on sound science; and ensuring that MPAs are managed, to the extent possible, as a network. The MLPA required an "improved marine life reserve component; provisions for monitoring and adaptive management; and a process for the establishment, modification or abolishment of existing or future new MPAs. Further, the MLPA called for the use of "best readily available science" in designing and managing MPAs.

In August 2004, the California Resources Agency, California Department of Fish and Game (DFG) and Resources Legacy Fund Foundation (RLFF) launched an unprecedented public-private partnership to implement the MLPA, after two earlier attempts had failed, the last attempt curtailed by DFG budget cuts. In this renewed effort, called the MLPA Initiative, RLFF-contracted staff created a master plan framework to guide the public process, including specific scientific guidelines on MPA design; established a Science Advisory Team (SAT) to develop the science advice, based on the MLPA; convened a Blue Ribbon Task Force to provide policy advice; and appointed a regional stakeholder group to develop alternative MPA proposals, beginning with an initial central coast study region.

Rationale for this Peer Review

As noted above, the MLPA declares that MPAs and sound fishery management are "complementary components" of comprehensive efforts to sustain marine habitats and fisheries. The MLPA also requires the use of "best readily available science" in designing and managing MPAs. However, the science advice provided in the MLPA master plan framework was deficient in at least three major aspects:

- It failed to consider other impacts to marine resources besides fishing (i.e. climatic variability, non-point source pollution, coastal development impacts on habitat etc.), and instead focused only on restricting fisheries.
- It failed to consider the ecosystem benefits of existing fishery management and failed to integrate existing fishery regulations and restrictions into its MPA size and spacing guidelines and analysis of MPA proposals.
- Moreover, CFC members with practical at-sea experience had serious doubts about "scorched earth" larval transport theory, as well as the assumption that fishery management was non-existent (or ineffective) outside MPAs, and desired that the science advice be given independent scientific scrutiny.

In light of those omissions, and because the MPA network proposals developed through the MLPA Initiative process pose potentially ruinous socio-economic impacts to central coast fisheries, ocean harvesters and coastal communities, the California Fisheries Coalition (CFC), a group of more than 20 ocean-dependent associations and businesses representing thousands of fishermen, seafood processors, abalone aquaculturists and allied industries, sponsored this peer review of the MLPA science advice.

The purpose of this review is to evaluate the science advice in relationship to the goals and provisions of the MLPA, with specific consideration of the ecosystem contributions of existing fishery management, as well as MLPA requirements for monitoring and adaptive management. In short, the objective of this peer review is to couple MPA science to adaptive fishery management.

The peer reviewers were contracted to perform the following tasks:

[1] Review master plan framework science advice relative to its assumptions, best available science and Marine Life Protection Act goals:

An MPA network covering all habitats must include both State and Federal waters. Assess habitats expected to achieve functioning MPA networks if only State waters are involved.

[2] Review existing state and federal fishery management regulations relative to achieving MLPA goals

Fishery management review shall include the following:

- a. The relative lifetime fecundity (LTF) that is used by both the Council and the SAT. This will allow a comparison of the Councils standards of 40-65% of lifetime fecundity to the 0-35% used by the SAT.
- b. The historical and recent fishing gear limitations, including existing closed areas (examples: seasonal and year-round Rockfish Conservation Area, Cowcod Conservation Area, Essential Fish Habitat area designations; no-trawl zones, no gillnet areas etc.) should be described for several habitats and species groups, with emphasis on the expected lifetime fecundity that would be expected in important species groups given present fishery management. *(This would probably be done by showing LTFs that occurred during the decline of key species (selected to show a range of habitats) vs. those that are expected with current management.)*

[3] Review SAT modeling and analysis to assess the effects of larval dispersal and juvenile and adult movement on the expected performance of MPAs in maintaining populations inside and outside of MPAs. This concept should be developed and used to demonstrate the strengths and weaknesses of MPAs for maintaining populations of exploited species and healthy ecosystems inside and outside of MPAs.

[4] Review SAT analysis of Package 1, 2R and 3R network proposals relative to meeting science advice and achieving goals and objectives of MLPA and central coast study region.

[5] Review the SAT size, spacing and protection levels relative to maintaining the diversity and abundance of marine organisms.

This review addresses the following questions:

- How well validated are the SAT assumptions and is there broad scientific consensus that these assumptions are reasonable - or "best available science"
- What is the degree of uncertainty in the assumptions
- Are there other explanations that address the same purpose?
- What is the appropriate mix of MPAs necessary to achieve the goals of the MLPA, considering existing fishery management in California.
- Assess whether the goals of MLPA are more effectively achievable, with lesser socio-economic impact, through MPAs or traditional or new fishery management tools.

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PEER REVIEW OF

CALIFORNIA MARINE LIFE PROTECTION ACT (MLPA) SCIENCE ADVICE AND MPA NETWORK PROPOSALS

1. EXECUTIVE SUMMARY

As reviewers of the science advice developed from the goals and requirements of the Marine Life Protection Act (MLPA), and given the additional task to review and comment on the contributions of fishery management toward maintaining marine populations, ecosystem function and biological diversity, we take our primary role, objective and potential benefit to the process to provide advice on the best available science, integrating (largely theoretical) MPA science into existing fishery management. In that context we view ourselves as troubleshooters of possible pitfalls and gaps in the process, and how adaptive management plans could be improved to deal with those pitfalls.

Summary comments on the goals of the MLPA

The first potential pitfall is the "fuzzy" language of the MLPA itself. The MLPA simply mandates protecting marine biodiversity and ecosystem function; ensuring that MPAs are designed on sound science; and ensuring that MPAs are managed, to the extent possible, as a network. The MLPA also specifies that the Marine Life Protection Program shall include, in addition: provisions for monitoring, research, and evaluation at selected sites to facilitate adaptive management of MPAs and ensure that the system meets the program's stated goals; and a process for the establishment, modification, or abolishment of existing MPAs or new MPAs established pursuant to this program. The dichotomy between reserves to protect biodiversity and the mandate for adaptive management was reflected in the master plan framework statement, noting the distinction between fishery management closures, which function as "de facto" MPAs, and designated MPAs: the former could be reduced or abolished based on recovery of marine species, while the latter would be "permanent", abolished only if they failed to achieve biodiversity and habitat protection. In reality, a cornerstone of adaptive management is change.

The MLPA statute provided no explicit guidance to address the "SLOSS" (single large or several small) MPA debate, but suggested that decisions on size and placement be made by a master plan team and regulatory agencies, with the involvement of stakeholders. The science guidance provided by the MLPA Initiative Science Advisory Team (SAT) clearly favored the SS (several small) approach in its interpretation of the law. The SAT advice produced a very extensive network of MPAs in each of the MPA network proposals, with a heavy emphasis on nearshore rocky habitat protected in marine reserves.

MPA proponents have commented that marine reserves, and in this case the MLPA, are largely intended to protect intact ecosystem functions and biodiversity, and are "not about fishery management." However, MPAs and MPA networks certainly affect and are affected by fisheries and fisheries management. In fact, "de facto" MPAs such as the Rockfish Conservation Area have been utilized successfully in fishery management and also achieve MLPA goals such as restoring stocks of concern and protecting benthic habitat. Resulting from precautionary "ecosystem-based" fishery regulations enforced by both State and Federal fishery management agencies in recent years, there is now no evidence that current fishing practices upset the "natural" biological diversity of the marine ecosystem.

Further, the perception that rocky bottom fishes are presently overfished is incorrect. The SAT apparently did not consider or seriously underestimated the conservation benefits afforded by areas protected by measures other than restrictive MPAs, or marine reserves. For many species, especially those with wide dispersal patterns, the other forms of protection (e.g. existing fishery management measures) are much more effective than MPA status. For example, the enactment of MPAs will have little effect on the annual take or abundance of most groundfishes because their management includes the use of annual quotas. Therefore the annual take for these species will be the same with or without MPAs; but MPAs will determine where the fish are taken.

Summary comments on the MLPA science advice

The MLPA master plan framework science advice can be divided into discrete components:

1. Types of habitat to include in MPAs
    - The SAT advice greatly expanded specified MLPA habitat types, developing 20 habitats, and further required three to five replicates of each habitat in reserve. This increase undoubtedly contributed to the large number of MPAs (29-31) in each of the network packages.
    - The extensive use of headlands in Package 2R and 3R, in an attempt to capture upwelling centers, could be counterproductive for species with larval stages exceeding 10-15 days because these areas have extensive offshore jets that entrain larvae far offshore as a result of the Ekman spiral.

2. Size and distance between MPAs
    - The MLPA science advice recommended a collection of quantitative prescriptions about size and spacing of MPAs. It appears to us that those prescriptions were pulled out of the air, based on intuitive reasoning about larval transport and adult movement distances.
    - Relying on intuitive assessments is inappropriate when the mathematical machinery is readily available to integrate key population dynamics factors. We used mathematical models to calculate the consequences of the size and spacing and found that all proposed patterns of MPAs generally have little impact because of their small size and the relatively high mobility of adults.

3. Levels of protection provided by different types of MPAs
    - Late in the stakeholder process, the SAT devised protection levels to evaluate protection benefits of MPA proposals. This classification system resulted in four protection levels: "no take" SMR; SMCA-high; SMCA-moderate, and SMCA-low. No-trawl zones, such as the RCA and groundfish EFH areas, were graded as "SMCA-low" and not analyzed.
    - To the contrary, no-trawl areas offer protection to benthic habitat and species, the reason why hundreds of square miles in State waters and hundreds of thousands of square miles in Federal waters have been designated as "no-trawl" zones and groundfish essential fish habitat.
    - The SAT did not quantify the protection provided by different types of MPAs.

4. Evaluation of MPA proposals against criteria established in the preceding three steps
   - We found no evidence that any such evaluation was conducted, beyond simple calculations of percentage of area protected. Such calculations cannot be used as direct predictors of population and community responses over highly variable life histories.

5. Species to benefit list
   - As mandated by the MLPA, the SAT developed two lists of species thought to benefit from MPAs. The value of these lists is minimal because there was no attempt to quantify potential benefits to individual species.

We found it impossible to evaluate MPA design criteria without a quantitative evaluation of adult and larval movement and population dynamics. We built two models of these dynamics and used them in our evaluations.

Our primary finding regarding the SAT size and spacing guidelines is that the scale of adult dispersal compared to the recommended MPA placement formula is such that only species that are highly sedentary as adults will see significant increases in abundance inside MPAs. Even movements of a mile or two per year preclude development of much higher biomasses inside of reserves.

Further, we found the SAT assumption that the proposed networks would be biologically connected by larval dispersal to be illusory; only a small fraction of larvae leaving one reserve would arrive in another reserve in reserves of this size and spacing. MLPA findings speak to correcting the illusion of protection provided by the existing statewide system of MPAs. Yet the science guidance adopted as “best readily available science” appears to recommend moving from one illusion to another.

It appears the SAT implicitly assumed that there will be no fish outside of reserves, i.e. no effective management besides that offered by the reserve network. We believe this assumption is deeply incorrect; the primary determinant of the status of fish stocks and the health of the marine ecosystems will be the catch regulations imposed by State and Federal agencies, particularly in relation to biological diversity and marine ecosystem function, which depend substantially on species too mobile to be protected by reserves. The current pattern of State and Federal closures, gear restrictions, limited entry and catch reductions imposed along the California coast will be far more important than any of the proposed MPA plans.

Conclusions

We compared the MPA network packages by employing population dynamics models that account for spatial organization in recruitment, dispersal and harvest impacts, using population parameters for a range of species with different movement patterns. Based on this quantitative analysis we concluded:

1. Packages 1, 2R and 3R provide very similar results for most species;
2. Anything close to "natural" abundances inside MPAs would only be achieved for highly sedentary species (like abalone);
3. For all but the most sedentary species, positive impacts of the MPAs will be trivial compared to impacts expected from current management measures aimed at meeting low target fishing mortality rates.

For all the model tests, we found the most critical parameters *not* to be larval dispersal distances, but rather (1) adult movement rates, since these create dispersal imbalances that can extend well into MPAs, even for low movement distances on the order of one mile per year; and (2) compensatory changes in post-settlement juvenile survival rates, which determine the larval settlement necessary for adequate recruitment to both MPAs and areas still open to fishing.

We found that all of the proposed MPA network designs will have similar benefits with respect to stock status, cultural protection and recreational and educational opportunities, as well as protection of unique habitats such as estuaries and kelp beds. However, the packages differed significantly in their economic impacts, with Package 1 having the lowest impact, Package 2R the highest, and Package 3R closest to Package 2R.

Ecosystem-based management, a stated goal of California's marine protection policies ostensibly including the MLPA, requires a provision for adaptive management (AM), but to date this MLPA process has not heeded past lessons from AM planning. It is well understood that direct input, thorough socio-economic evaluation and support from affected stakeholders are essential to insure the success of MPA programs. The SAT's failure to consider displaced fishing effort, in addition to the absence of a thorough socio-economic assessment of impacts to fishing communities, are examples of the MLPA Initiative's failure to achieve ecosystem-based management through this MPA program.

It is important to understand that there is little empirical evidence in the northern hemisphere to verify that marine reserves are the panacea that many have claimed. Such research is needed, and we recommend that the Fish and Game Department and Commission:

1. Implement a phased MPA network designed with a variety of MPA sizes and with an adequate long-term monitoring plan and sufficient resources to test MPA theories.

2. The fact that the baselines at long-established MPAs have not been reassessed after they had been in place for 12 years should stand out as a caution for this attempt to establish a monitoring program for the 29-31 MPAs proposed in the MLPA Initiative stakeholder packages. At a minimum, the Big Creek (and Punta Gorda) baseline should be resurveyed before any permanent monitoring program is designed.

3. Incorporate our AM and monitoring recommendations in the Adaptive Management and Monitoring and Evaluation Framework and adopt this framework as the overarching monitoring / AM policy for all MPAs in California, including the Channel Islands as well as future MPA networks on the mainland coast. *(See Section 4.)*

4. Recognize that there is little chance that State-implemented MPAs will contribute significantly to the maintenance of marine ecosystem function; the function of these ecosystems is largely determined by highly mobile species that will be totally unaffected by MPAs. Only widespread, effective fisheries management will insure maintenance and restoration of ecosystem function.

We concur with other reviewers who recommend that marine reserves and other protected areas should be integrated with existing and emerging management measures as part of a coherent ecosystem-based approach to management of commercial and recreational fisheries, and should not simply be layered on top of existing regulations. As other reviewers have found, the size and placement of MPAs are ultimately a policy decision.

The last word

The MLPA declares that MPAs and sound fishery management are "complementary components" of comprehensive efforts to sustain marine habitats and fisheries. The MLPA also requires the use of "best readily available science" in designing and managing MPAs. Our analyses demonstrate that the MLPA science advice fails to meet both requirements. It cannot be stated that the best readily available science was utilized when no quantitative evaluation of the impact of both adult and larval movement on population dynamics was done. Further, the SAT did not consider or evaluate existing fishery management, nor the contribution of fishery management to achieve ecosystem protection and fulfill biodiversity goals of the MLPA.

2. Introduction

This review was commissioned by the California Fisheries Coalition to provide an independent evaluation of the science guidance of the Marine Life Protection Act. Our process was initially for each of us to independently review the primary documents associated with the master plan framework and the Science Advisory Team (SAT) advice (Appendix C). After this initial review it became clear that it would be impossible to evaluate either the science advice or the consequences of alternative plans on the table without a quantitative model of the system. Two of us (Walters and Hilborn) independently developed population dynamics models of the central California coastline, using the standard fisheries models commonly used in the published literature on MPAs but with particular emphasis on accounting for dispersal movements of older animals and applying fishing mortality rates based on current fishery management regulations. These models will provide much of the basis for our comments below.

3. The nature of the "Science Advice"

To understand the science advice we must first refer back to the goals of the Marine Life Protection Act.

3.1. Goals of the MLPA

From the MLPA statute, the goals of the MLPA are:

1. To protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems.
2. To help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted.
3. To improve recreational, educational, and study opportunities provided by marine ecosystems that are subject to minimal human disturbance, and to manage these uses in a manner consistent with protecting biodiversity.
4. To protect marine natural heritage, including protection of representative and unique marine life habitats in California waters for their intrinsic value.
5. To ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines.
6. To ensure that the state's MPAs are designed and managed, to the extent possible, as a network.

Measurable objectives for each of these goals were developed by regional stakeholders and adopted by a Blue Ribbon Task Force.

3.2. Elements of the science advice

The MLPA process has been long and complex, as has the interaction between legislation, various committees and task forces. There is no single document that provides the sum total of the science advice. Much of the initial science advice was incorporated into the master plan framework adopted by the Fish and Game Commission; however, further changes to the science advice developed during evaluation of network packages. These additions, such as protection levels within conservation areas, are now proposed for adoption into the master plan framework.

The MLPA statute mandated that the best "readily available science" be employed and provided guidance as follows:

> Sec. 2856 (a)(2)
> (2) The master plan shall include all of the following components:
> (A) Recommendations for the extent and types of habitat that should be represented in the MPA system and in marine life reserves. Habitat types described on maps shall include, to the extent possible using existing information, rocky reefs, intertidal zones, sandy or soft ocean bottoms, underwater pinnacles, sea mounts, kelp forests, submarine canyons, and seagrass beds.
>
> Sec. 2857 (c)
> (c) The preferred siting alternative shall include MPA networks with an improved marine life reserve component, and shall be designed according to each of the following guidelines:
> (1) Each MPA shall have identified goals and objectives. Individual MPAs may serve varied primary purposes while collectively achieving the overall goals and guidelines of this chapter.
> (2) Marine life reserves in each bioregion shall encompass a representative variety of marine habitat types and communities, across a range of depths and environmental conditions.
> (3) Similar types of marine habitats and communities shall be replicated, to the extent possible, in more than one marine life reserve in each biogeographical region.
> (4) Marine life reserves shall be designed, to the extent practicable, to ensure that activities that upset the natural ecological functions of the area are avoided.
> (5) The MPA network and individual MPAs shall be of adequate size, number, type of protection, and location to ensure that each MPA meets its objectives and that the network as a whole meets the goals and guidelines of this chapter.

The science advice can be broken into discrete components:

Science Advice #1: specification of the types of habitat to be protected.

Science Advice #2: specification of the appropriate size and distance between protected areas

Science Advice #3: evaluating of the levels of protection provided by alternative types of protected areas

Science Advice #4: evaluation of each of the proposed "plans" against the criteria established in the preceding three steps

Science Advice #5: evaluation of the species to benefit list developed by the SAT.

Our evaluation will look at each of these types of science advice.

4. Specific analysis of science advice

4.1. Science Advice #1: specification of the types of habitat to include in protected areas

The MLPA identified eight habitat types: rocky reefs, intertidal zones, sandy or soft bottoms, underwater pinnacles, seamounts, kelp forests, submarine canyons and seagrass beds. The SAT interpreted the MLPA specification of habitats in an expansive manner, developing 20 habitat types from the eight types itemized in statute. The SAT removed the seamount habitat because none occur in state waters. Five of the alongshore habitats were measured in linear miles and the remaining 15 habitats were measured in area (i.e. sq. mi.)

The MLPA specified that similar types of marine habitats shall be replicated in more than one marine life reserve in each biogeographical region. Based on recommendations from the Blue Ribbon Task Force and Department of Fish and Game, it was established that the northern bioregion extends from Point Conception to the Oregon border.

The large increase in habitat types undoubtedly contributed to the large number of MPAs in each of the packages, as replicates were required for each habitat type, and the spacing guidelines were applied to each replicate habitat type. Midway through the MLPA Initiative process, the SAT realized that the spacing guidelines could not be applied to the six deepwater habitats due to the fact that the shelf break seldom occurs within state waters. In addition, for part of the stakeholder MPA negotiations, three oceanographic-based habitats were included on the habitat list: freshwater plumes, larval retention areas and upwelling centers. The first two were quickly dropped by the SAT, but upwelling centers remained a major consideration until nearly the end of the process.

Recent analyses describe four upwelling centers in the California region (one extending southward from each of the region's major promontories: Cape Mendocino, Point Arena, Point Sur and Point Arguello (Pickett and Schwing in Press, Pickett and Paduan, 2003). Due to the documented large scale, upwelling centers were finally dropped from the habitat list. However, this did not occur until two of the three final MPA packages had already sited most of the MPAs at major and minor headlands, where upwelling centers were originally considered to occur.

The entire central California region is within the California Current's region of maximum upwelling (Parrish, Nelson and Bakun 1981); therefore, offshore dispersal and loss of pelagic larvae is of particular importance for benthic species. We note that the extensive use of major headland areas (i.e. Point Sur) for MPAs could be counterproductive for species with pelagic larval stages exceeding 10-15 days because these areas have extensive offshore jets which entrain nearshore waters far offshore.

One way to achieve a balanced network would be to include roughly equal percentages of common habitats; rather than take this approach the SAT favored placing MPAs in shallow rocky bottom habitats. The stated reasons included the idea that these habitats have high species diversity, high productivity and because fishes that live in these habitats were considered by some to be more susceptible to overexploitation. The impression that some habitats are more deserving of protection, and the fact that no numerical guidelines (or empirical data) were available to determine how much area in reserve is enough, resulted in the stakeholders placing 30-100% of many habitats in MPAs. Alterations of this magnitude will cause severe changes in the distribution of fishing effort. If such an extensive MPA system were implemented, it is likely that fisheries would not be sustainable on the reduced habitat area unless additional corrective fishery management actions were taken.

4.2. Science Advice #2: specification of the appropriate size and distance between protected areas

The SAT made specific recommendations regarding the size and spacing of reserves. This advice was based on two guiding principles. First, reserves must be large enough to encompass the normal movement of adult individuals, so that there is a true "reserve" effect. If reserves are too small, then there will be little build up of abundance within the reserves. Secondly the distance between reserves will be determined by larval dispersal distances. If reserves are too far apart then larvae from one reserve will rarely disperse far enough to "network" with the closest other reserves.

As the SAT noted, any specific MPA design will be a compromise for a range of different species. For the species of interest, some will have very sedentary adults and larvae, others will be reasonably sedentary as adults but have highly dispersive larvae, and some will have both adults and larvae with large amounts of movement.

The SAT provided guidelines on both size and distance based on literature about adult movement and larval dispersal distances. Evidently no quantitative population dynamics models were used in that evaluation, since the construction of such models leads immediately to strong concern about issues like compensatory mortality of post-settlement juveniles. These issues were not highlighted as critical uncertainties in the SAT discussions. It is our understanding that Dr. Loo Botsford had worked on such a model, but the model was not used in the final SAT advice, nor in the SAT analysis of MPA proposals.

In an effort to help us understand the consequences of alternative MPA designs, and to understand the SAT MPA design criteria, we constructed two models, described in Appendices A and B. These models make very standard assumptions about fisheries life history and dispersal, and we understand these are broadly similar to the model Dr. Botsford was constructing. The models differ in complexity: Appendix A model predicts only abundance; Appendix B is fully age-structured so as to account explicitly for effects of fishing on factors such as mean fecundity. These models allow us to determine what predictions are robust to particular model assumptions.

MLPA planning documents, specifically the science advice incorporated in the MLPA master plan framework, have recommended a collection of quantitative prescriptions about how large MPAs need to be and how they should be spaced along the coast. It appears to us that those prescriptions were pulled out of the air, based on intuitive reasoning about larval transport and adult movement distances of various organisms. Considering the substantial economic and social costs posed by MPA establishment, relying on such intuitive assessments is not appropriate when the mathematical machinery is readily available to integrate key population dynamics factors and processes into models that will give at least some feeling for likely quantitative consequences of various dynamic rate processes acting together. The best readily available science is the use of quantitative models.

The models described in Appendices A and B illustrate some of the pitfalls and problems of MPA design discussed below, such as dispersal imbalance effects on density patterns in MPAs and increased fishing impacts outside the MPAs when fishing effort is displaced. One of these models (Appendix A) is relatively simple, examining only changes in total numbers of animals. The second (Appendix B) is a much more detailed age-structured accounting system, allowing evaluation of age-related management policies such as changes in size limits. Both models are implemented in spreadsheets that should be relatively easy for various California stakeholders to use for broad comparisons of how alternative MPA plans might impact species with different life histories. By comparing results from simple versus detailed models, it is relatively easy to see what predictions are robust to the details of model formulation.

From the results of our modeling, and indeed almost all other MPA models that have been published, we find very little basis for the specific MPA size and distance criteria the SAT developed. Worse, the modeling results indicate a strong possibility of a "win-lose" outcome for non-consumptive versus consumptive users, due to reduced fishery yields compared to what could be obtained with effective fishery management.

As our models show, given the average distances moved by adults, "tagging studies indicate that net movements of many of California's nearshore bottom-dwelling fish species, particularly reef-associated species, are on the order of 5-20 km (3-12.5 m or 2.5-11 nm) or less over the course of a year (MLPA master plan framework page 40)", the SAT has greatly overestimated the amount of build up of adults within reserves of the size they recommended. For a species that moves, on average, two miles per year, with a 15% natural mortality rate (not particularly long lived), we expect to see very little adult build-up within reserves. The situation for shelf and slope fishes, with higher adult movement rates than the nearshore fishes, would be expected to be even less. The implications in the SAT advice that these reserves will produce large, nearly unfished population sizes is not supported by any quantitative analysis. The reserves would have to be very much larger to achieve significant increases in abundance within the reserves; this concern was in fact recognized by the SAT in their discussions about the SLOSS (single large versus several small) debate in MPA design, but the size and spacing recommendations favored the SS side of the equation.

SAT advice regarding the impact of different spacing levels is similarly not supported by quantitative analysis. If the average larval dispersal distance is on the order of 40-100 km, then only a very small fraction of the larvae dispersing from one MPA will randomly land in another MPA. The vast majority will land outside of other MPAs, thus these MPAs will not be well connected in any biological sense. It is certainly true that if the MPAs are too far apart there will be almost no larval connection, but the quantitative modelling shows that there is almost no population level impact of connection. If there is truly no larval production outside of MPAs, then each MPA will effectively be an island, and those larvae that do land in other reserves will represent a small fraction of the total dispersal, and will not result in natural levels of recruitment within the MPA unless there is a very strong compensatory increase in juvenile survival rates after larval settlement.

Fortunately, under current conditions, the majority of larval production will come from outside of MPAs. Even for stocks that are currently fished down to 10% of virgin biomass, the larval production that will come into MPAs would represent perhaps a minimum of 20% of the maximum possible larval production (using the spawner recruit assumptions in the NOAA stock assessments), so even if 20% of the total area was protected, and stocks rebuilt to virgin abundance in those areas, the larval production from outside the reserves would equal the larval production from inside the reserves.

The exceptions to the above case would occur in very limited habitats where all of the Packages placed almost the entire habitat in MPAs (i.e. eelgrass), and limited habitats where a majority of the area was placed in MPAs (i.e. coastal marsh, estuary and tide flats). In addition, Packages 2R and 3R exceeded the SAT guidelines by placing 30-49% of several nearshore habitats in MPAs (i.e. rocky shoreline, surfgrass, average kelp, persistent kelp and 0-30 m hard bottom).

Most stocks of interest are far above 10% of virgin biomass, and under PFMC rebuilding plans these stocks are all rebuilding toward 40%. Thus the fundamental theory of the SAT, that larval connection between MPAs is essential to meet the objectives of the MLPA, is flawed both because the SAT's advice on distance does not provide for real connection, and such connection is unnecessary because there is significant larval production outside of reserves.

The entire theoretical basis of "networking" disappears when one resolves to manage fish stocks outside the reserves to maintain an adequate level of larval production, and thus the question reverts to a SLOSS debate from the pure conservation perspective.

There are two issues with respect to conservation:

1. How much area to put in reserves?

2. Where to site them?

Given that the objectives of the reserves are largely for protection of biodiversity, more is obviously better, but there is a general trade off of more reserve area negatively impacting long-term sustainable extraction, and thus there is really no right answer, it depends on the societal trade-off between harvesting and large protected populations.

It is obviously important to have significant portions of representative habitats protected, as in wilderness reserves, but some types of habitats may be "fully utilized", that is someone is fishing them. This is where the true conflict occurs, and we suggest the following:

First: accept that the amount of area protected in the "fully utilized" habitats will be less than the overall average; it may be possible to get 50-80% of the habitats that are never fished protected, but accept that only 5-10% of fully utilized habitats are protected.

Second: identify where the lowest conflict areas will be: obviously remote and hard to access sites will cause the lowest conflict, so select those for protection.

Regarding reference sites, the purpose of reference sites is to provide an idea of the abundance of fish in the absence of fishing and to provide "controls" on recruitment trends. Given the estimated larval dispersal rates of tens of kilometers, and the fact that in practice we are not going to see any reserves that are much larger than the dispersal rate of larvae, we doubt that any reserve design will provide controls on recruitment trends; there is too much larval mixing. So again there is really no role for networking with reference to this goal. It also means that the main purposes of reference sites are simply to get an idea of abundance in the absence of fishing and potentially as controls on changes in adult mortality.

A final serious flaw in the SAT advice on this point is that for most species, the MPAs in state waters will protect only a small fraction of the spawning stock biomass. Achievement of the goals of the MLPA will be largely determined by fisheries regulations in federal waters, yet the SAT advice regarding size and spacing of reserves took no account of existing, pending and future fisheries regulation.

4.3. Science Advice #3: evaluating of the levels of protection provided by alternative types of protected areas

Three different classes of MPAs were used in the MLPA process: marine reserves (SMR) where no take is allowed, marine parks (SMP) where some or all recreational take is allowed but commercial take is prohibited, and marine conservation areas (SMCA), where some or all recreational and some commercial take is allowed. The MLPA, the master plan framework and the SAT provide virtually no guidance regarding the situations where these different types of MPAs should be used, and the SAT did not indicate how the several types of MPAs should be evaluated under the SAT guidelines at the beginning of the MPA design process. Late in the stakeholder process, the SAT devised three protection levels for marine parks and conservation areas to assist in evaluating of the relative protection to sedentary benthic species provided by marine parks and conservation areas with differing allowed take. Particular emphasis was placed on harvest of pelagic species in waters deeper and shallower than 50 meters, trap fisheries for crab and spot prawn, different harvest methods for kelp and power plant intakes and discharges.

This classification system resulted in four protection levels (SMR, SMCA-high, SMCA-moderate and SMCA-low); however, other than simple bar graphs of the percentage area in the differing protection levels, the SAT did not provide any quantitative descriptions of the protection provided by areas with differing protection levels. For example they could have defined high, moderate and low protection as having all species at 90%, 70% and 50% of their unfished levels. They did not describe how many species have to be taken at a given level to reduce the protection level classification. This failure to quantify the reduction in protection to sedentary benthic species caused by fisheries directed at other species makes it impossible to compare the several packages whose differences to a large degree are based on different protection levels. In addition, the SAT made no attempt to quantify the percentage of an MPA that was impacted by the protection level. For example, an MPA might have a very low percentage kelp habitat; however, if kelp harvest was allowed in this small area, the whole MPA out to three miles was assigned the same reduced protection level. As a result, the number of MPAs was increased without any increase in protection. For example, the several Point Buchon configurations have a reserve near shore and a conservation area that allows fishing for salmon, and in some cases albacore, offshore. This is the same protection that would occur with a single conservation area that allowed fishing for salmon (and albacore) offshore of some depth or longitude line. However, due to the undocumented SAT constraint, the stakeholders were prevented from using the simpler MPA configuration to avoid assigning the lower protection level to the entire MPA. Another constraint was the statute requirement for replicate (more than one) reserves for each specified habitat type.

Assessment of the levels of protection is greatly hampered due to the failure of the SAT to provide any context for their protection levels. There is no evidence that the SAT based their protection levels on any given fishery management regime; although so called 'scorched earth' fishery management was discussed in SAT meetings. Present Pacific Coast groundfish management is designed to maintain population biomass above 40% of the unfished biomass, and lifetime fecundities are to be maintained at 40 to 50% of unfished levels (depending on the species). In the context of present fishery management, MPAs that fall within the SAT's 'low protection classification' should produce biomass densities of sedentary species that are well above those presently deemed sustainable. However, the SAT analysis of MPA packages considered only SMR, SMCA-high (salmon fishing only) and SMCA-moderate (salmon and one other fishery, for example, salmon and spot prawn). The SAT graded the "no trawling" areas as SMCA-low and did not consider the benthic protections provided by the RCA and groundfish essential fish habitat areas, which now encompass hundreds of square miles in State waters and hundreds of thousands of square miles in Federal waters along the west coast.

4.4. Science Advice #4: evaluation of each of the proposed "MPA plans" against the criteria established in the preceding three steps

We see no evidence that any such evaluation was conducted, beyond simple and not very helpful calculations of percentages of area protected and degree of protection afforded by alternative MPA types (reserves, parks, conservation areas). Such calculations cannot be used as direct predictors of population and community responses over highly variable types of life histories.

To assess the effects of the several packages we developed two spatial models. The simpler model (described in Appendix A) was run with a constant habitat array and with a variable habitat array based on an assumed relationship with habitat quality based on the spatial distribution of fishing effort on rocky bottom.

The constant habitat simulations were run with fishing mortality rates based on current stock assessments and with rates approximating the rates that existed in the 1980s and early 1990s (Figure 4.4.1). The results from these simulations show that abalone has a moderate increase in total abundance in comparison to the situation with no MPAs; abundance increases and catch decreases with increasing area in MPAs (Table 4.4.2.).

The fishes show remarkably little increase in abundance with any of the MPA networks; however, cabezon (which has the least adult movement of the species used) has a small increase in abundance and a small decrease in catches. In the simulations with fishing mortalities based on a successful fishery management regime, the increases in local abundance inside the MPAs is largely offset by the reduction in local abundance outside of the MPAs. Abalone, due to its very limited dispersal both as larvae and adults, differs from the other species in that the total abundance is considerably higher and the catch considerably lower with MPAs. In all species the abundance levels are heavily determined by the fishery management outside of the MPAs (Figure 4.4.1).

Table 4.4.1 Model parameters used in simulations.

Simple model parameters	Abalone	Widow rockfish	Lingcod	Boccacio rockfish	Cabezon
Base recruitment (Ro)	1	1	1	1	1
Annual "adult" mortality (M)	0.1	0.125	0.25	0.15	0.3
Fishing mortality rate (F) successful management	0.08	0.07	0.25	0.056	0.2
Fishing mortality rate (F) unsuccessful management	0.2	0.3	0.4	0.3	0.4
Adult emigration rate (~mi/yr)	0.01	1	6	6	1.5
Larvae per adult (k)	100	100	100	100	100
Goodyear compensation ratio (K)	3	20	10	4	10
Larval transport distance parameter (S)	0.3	40	15	45	1.5

Figure 4.4.1. (on page 22)

Predicted equilibrium patterns of relative abundance for a selection of indicator species, calculated using the spatial model with constant habitat described in Appendix A.

X-axis of the graph is geographic position, from just below San Francisco Bay at the left to Point Conception at the right. Positions of some proposed MPAs are shown to indicate position.

Relative abundance is measured in relative (per recruit) units. Note predicted abundances drop off near the "range" limits due to not accounting for dispersal of larvae and older animals into the modeled area from outside regions, but while accounting for dispersal losses to those regions. Parameter values for simulations are as shown in Table 4.4.1. The left column shows scenarios with fishing mortality rates set to target equilibrium values under current management (note that present rates on species with rebuilding plans are less than those used here). The right column shows scenarios without successful management with fishing rates set to 0.2 to 0.4 to simulate high historical fishing impact.

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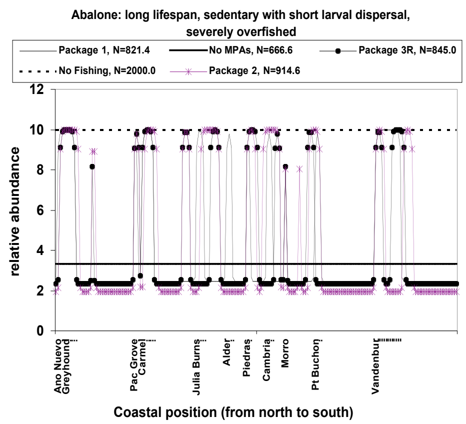
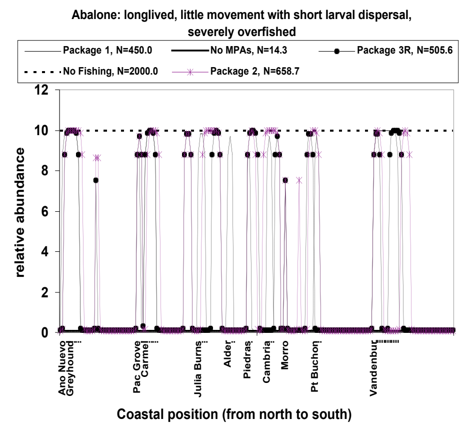
<tr><td>Abalone</td><td>
</td><td>
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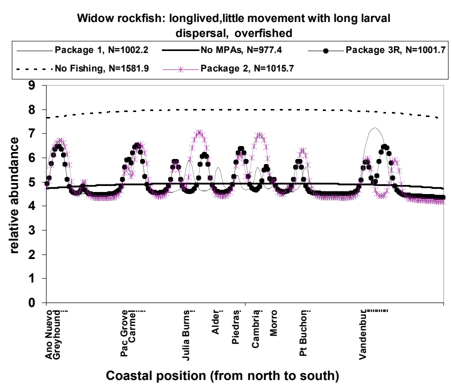
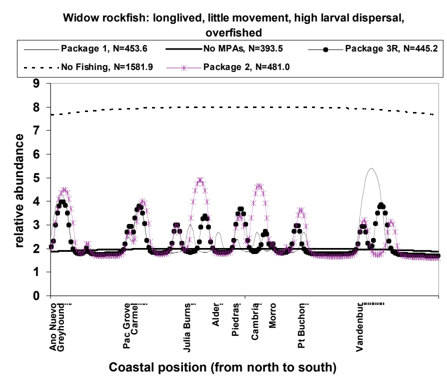
<tr><td>Widow rockfish</td><td>
</td><td>
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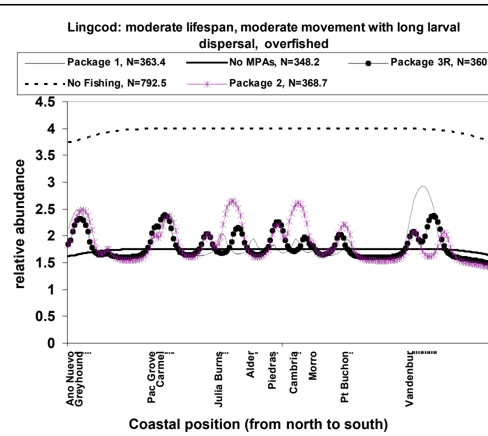
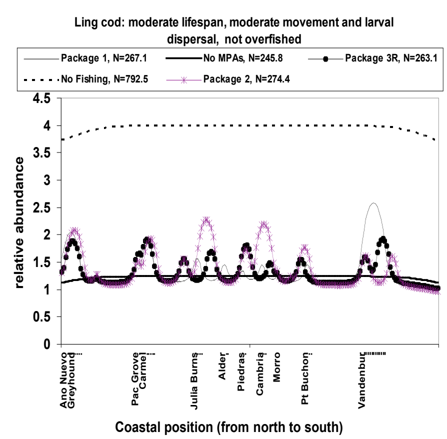
<tr><td>Lingcod</td><td>
</td><td>
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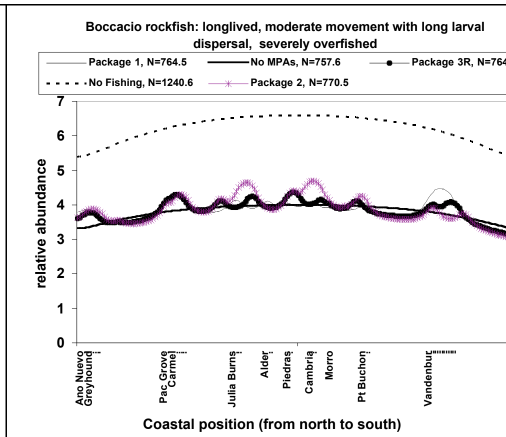
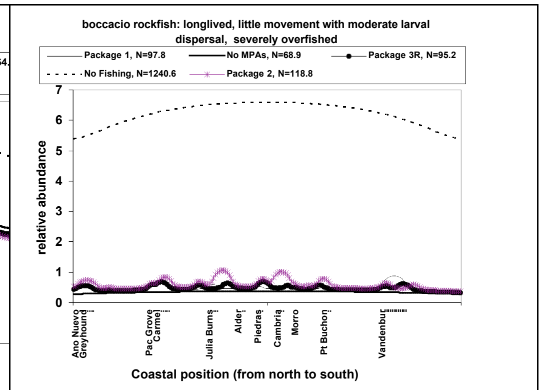
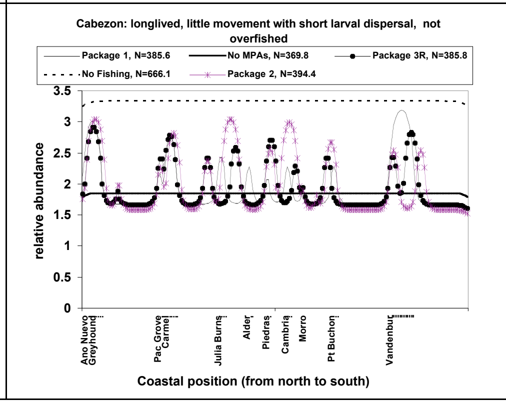
Bocaccio rockfish





Cabezon



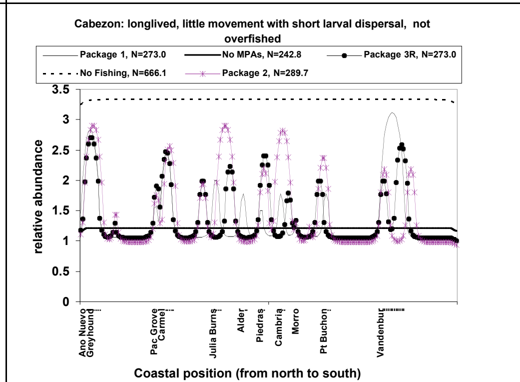


Table 4.4.2. Predictions of average abundance and response to fishing for the simple model, but without spatially variable habitat conditions; successful management (left column of Figure 4.4.1).

	Abalone	Widow rockfish	Lingcod	Boccacio	Cabezon
ABUNDANCE					
without fishing	2000.0	1581.9	792.5	1240.6	666.1
without MPAs	666.6	977.4	348.2	757.6	369.8
Package 1	821.4	1002.2	363.4	764.5	385.6
Package 3R	845.0	1001.7	360.8	764.5	385.8
Package 2R	914.6	1015.7	368.7	770.5	394.4
CATCH					
without fishing	0.0	0.0	0.0	0.0	0.0
without MPAs	53.3	68.4	87.1	42.7	74.0
Package 1	39.7	65.8	84.8	42.2	69.7
Package 3R	37.8	65.8	85.2	42.2	69.8
Package 2R	31.9	64.3	83.8	41.9	67.5
FISHING MORTALITY (F)					
without fishing	0.00	0.00	0.00	0.00	0.00
without MPAs	0.08	0.07	0.25	0.06	0.20
Package 1	0.05	0.07	0.23	0.06	0.18
Package 3R	0.04	0.07	0.24	0.06	0.18
Package 2R	0.03	0.06	0.23	0.05	0.17

The simulations with the simple model including variable habitat show more 'reserve' effect than those with constant habitat (Figure 4.4.2 and Table 4.4.3). This is primarily due to the fact that all of the MPA packages have a larger percentage of the rocky habitat, and an even larger percentage of the best rocky habitat (i.e. kelp), in MPAs. Abalone (in the absence of sea otter populations) show increases in abundance from 13% (Package 1) to 18% (Package 2R) of the equilibrium biomass without a fishery; catch declines from 31% (Package 1) to 51% (Package 2R) from the no MPA situation. All of the other species have smaller increases in total abundance and decreases in catch. Lingcod abundance increases from 7% (Package 2R) to 9% (Package 1). The smallest increases in abundance occur in widow rockfish, 4.2% (Package 2R) to 4.7% (Package 1).

Figure 4.4.2. Predicted spatial distributions for Bocaccio rockfish, model including spatial habitat variation assumed to be correlated with spatial distribution of fishing effort. No MPAs scenario assumes successful long term harvest management to low fishing mortality rate target of 0.06. Compare fourth row of Figure 4.4.1 above.

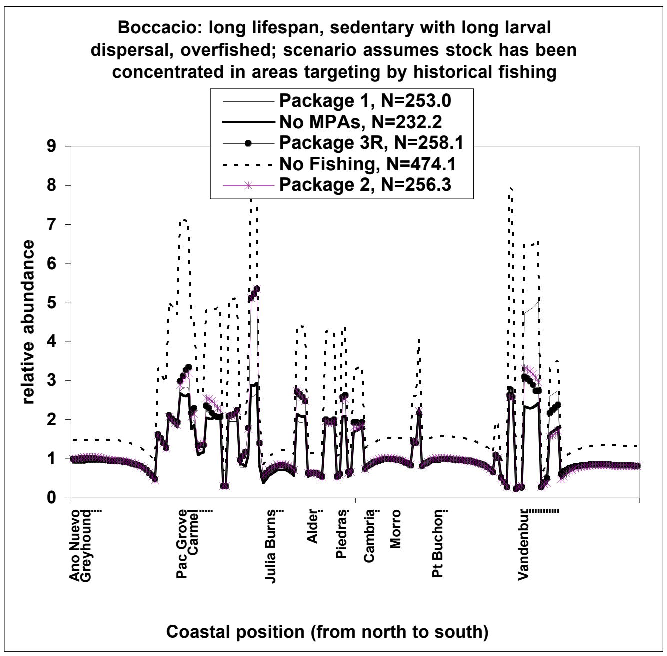


Table 4.4.3. Predictions of abundance and response to fishing for the simple model with spatially variable habitat conditions; successful management (as in Figure 4.4.2).

	Abalone	Widow rockfish	Lingcod	Bocaccio rockfish	Cabezon
ABUNDANCE					
without fishing	683.8	637.8	296.8	474.1	249.2
without MPAs	205.0	293.1	72.2	232.2	100.2
Package 1	293.4	323.2	99.4	253.0	119.7
Package 3R	317.2	322.6	95.0	258.1	122.5
Package 2R	329.6	319.9	92.9	256.3	122.8

CATCH					
without fishing	0.0	0.0	0.0	0.0	0.0
without MPAs	21.1	32.2	25.1	20.8	27.4
Package 1	13.1	30.0	25.2	19.5	23.1
Package 3R	11.2	30.2	26.3	19.5	23.7
Package 2R	10.3	30.4	26.2	19.6	23.5
FISHING MORTALITY (F)					
without fishing	0.00	0.00	0.00	0.00	0.00
without MPAs	0.10	0.11	0.35	0.09	0.27
Package 1	0.04	0.09	0.25	0.08	0.19
Package 3R	0.04	0.09	0.28	0.08	0.19
Package 2R	0.03	0.10	0.28	0.08	0.19

In summary: our comparison of the MPA proposals using population dynamics models that account for spatial organization in recruitment, dispersal, and harvest impacts; using population parameters for a range of representative species found that:

(1) proposals 1-3 give very similar results for most species;

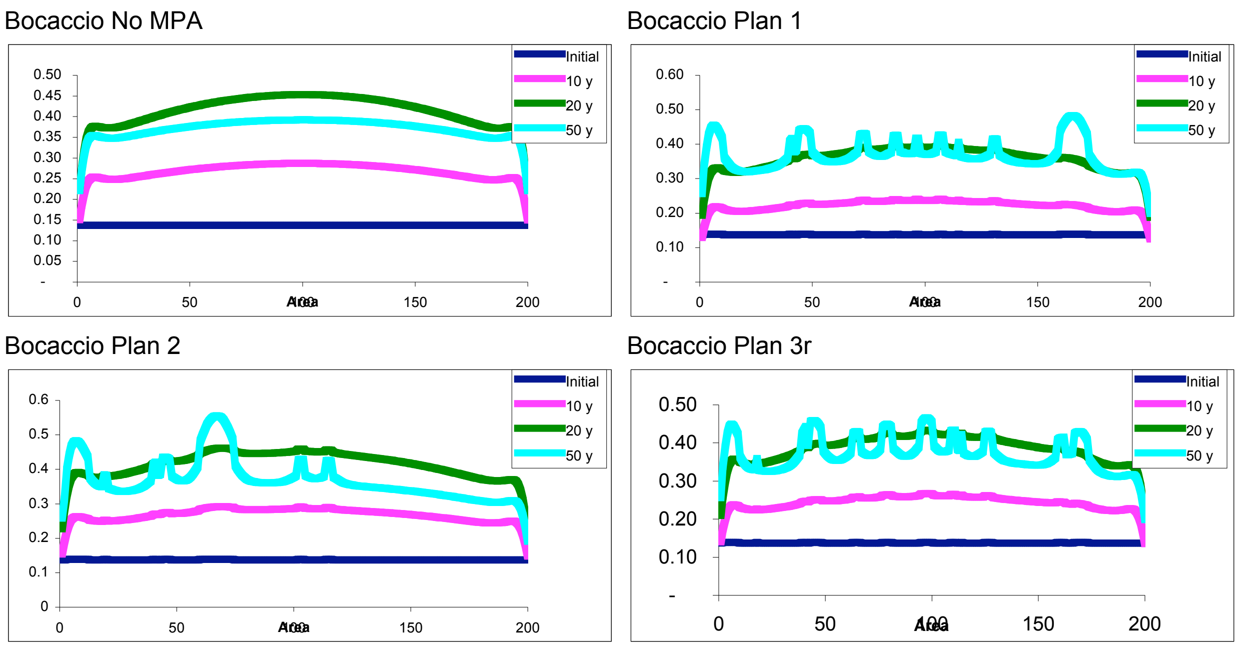
(2) anything close to natural abundances inside MPAs would only be achieved for highly sedentary species like abalone;

(3) for all but the most sedentary species, impacts of the MPAs will be trivial compared to impacts expected from current management measures aimed at meeting low target fishing mortality rates.

(4) the most critical parameters are *not* larval dispersal distances, but rather (1) adult movement rates, since these create dispersal imbalances that can extend well into MPAs even for low movement distances of order one mi/yr, and (2) compensatory changes in post-settlement juvenile survival rates, which determines the larval settlement necessary for adequate recruitment to both MPAs and areas still open to fishing.

Simulations using the full age structured model, described in Appendix B, shows the time trajectory of bocaccio (Figure 4.4.2). In this scenario there is a very low harvest rate (1%) for the first 20 years until the stock reaches the rebuilding threshold (40% B^0), then when harvest rates are increased to their sustainable levels, differences in abundance between reserve and non-reserve areas appear. However, because the reserves are small relative to the adult movement, the build up inside reserves is not particularly significant.

Figure 4.4.3. Results for bocaccio using the dynamic fully age structured model of Appendix B. The X axis in all cases is the coastline with the north on the left and the south on the right.



Not only do the models predict very modest gains in abundance from having MPAs over the gains likely to be realized through existing and future fishery management, they further predict that such additional gains in abundance will be at the expense of fishers, in the form of reduced yields (Tables 4.4.2 and 4.4.3). This effect occurs because of depressed catch per effort in areas open to fishing, due to concentration of effort in those areas.

Model scenarios like those shown in Figures 4.4.1, 4.4.2 and 4.4.3 are not intended to be precise, quantitative predictions of distribution patterns for particular species. Detailed spatial data are not available to calibrate or test any such predictions. Rather, the scenarios are intended to provide comparative results for policy screening and for detection of "hidden assumptions" that might cause even more severe failure of predictions, based purely on intuition or simpler calculations. A serious failing of the SAT was the fact they did not use any form of quantitative model in formulating their guidelines.

4.5. Science Advice #5: specification of the species to benefit list developed by the SAT.

As mandated in the MLPA, the SAT developed two lists of species that would benefit from the establishment of MPAs. The SAT engaged in considerable discussion of the merits of lists of important species of concern that would be expected to be the most benefited by MPAs vs. lists of species that occur in the area and might benefit by MPAs. The second approach was finally adopted, and the lists include both harvested and other species that may benefit from MPAs due to reduced bycatch, habitat disturbance or enhanced ecological function due to increased abundance of harvested species. There was no attempt to list species that may have detriments due to increased competition or increased predation caused by higher population levels of harvested species in MPAs. The only common fish species specifically excluded from the list were those that are known to have extensive adult dispersal, although some species with high adult movement were included in the list (i.e. lingcod and white seabass), and some were excluded (i.e. market squid). In addition, the vast majority of small fishes were not included in the fish list (i.e. poachers, cottids, blennies pricklebacks etc). The value of the two lists is minimal because there was no attempt to quantify the potential benefits to individual species.

5. Adaptive management, Enforcement and Evaluation

5.1. Adaptive management

The MLPA calls for an Adaptive Management (AM) planning process and implementation. However, the concept of Adaptive Management as described in California planning documents is largely an administrative or bureaucratic process advocated by recent practitioners with extremely limited case experience. As it was originally developed by Holling, Walters, and Hilborn during the 1970s and 1980s through very large numbers of case studies, the AM policy design process emphasized the critical importance of quantitative modeling, with strong scientific and stakeholder involvement in model formulation, as a critical early step in the planning process. The aim of such models is not to obtain the best policy prescription immediately, but rather to integrate available knowledge about key processes so as to identify critical gaps in information and to provide initial screening of policy options that appear unlikely to succeed due to blatant inadequacies in scale or type of impact.

Had developers of the science advice incorporated in the MLPA master plan framework followed the AM prescription, they would very likely have developed models like those described in Appendices A and B, and use of these models would have been a central feature of SAT discussions, and possibly stakeholder MPA designs as well. Discussions, particularly about scientific data needs and uncertainties, would have looked quite different. Most of the emphasis in the MLPA planning documents that we reviewed was on developing comparative information on larval transport distances and adult movements. But, in fact, the quantitative models are not all that sensitive to movement parameters; rather, the model predictions are much more sensitive to uncertainties about current and future fishing mortality rates in areas open to fishing (i.e. future fisheries management policies outside the MPAs), and to uncertainties about whether recruitment is currently limited by larval settlement or instead by juvenile rearing capacities (i.e. the "stock-recruitment" problem of whether juvenile nursery areas are currently underseeded).

For species that are currently recruitment overfished (e.g. abalone), the models predict (see Figure 4.4.1) short-term underseeding in both open and MPA areas. This implies both a much less positive impact of the MPAs than would be expected if recovery in them were dependent only on the buildup of older, more fecund animals, and a critical need to solve the recruitment overfishing problem through wide-spread fisheries management protection whether or not MPAs make some contribution to recovery. In the case of abalone, an additional factor to consider is the presence or absence of sea otters, which are known to limit abalone and other shellfish populations in areas that they inhabit. *(Fanshawe et al, 2003)*

The MLPA process could become an important case study in Adaptive Management, but not in the way that one might hope. If the process continues on its present course, without careful attention to past lessons from AM planning, what will very likely occur is one of the best classroom examples of how not to do AM.

An obvious uncertainty in MPA planning is how much increase will be seen in MPAs of different size. If adult movement is as high as current estimates, then few species will rebuild to densities much above the level determined by fishing pressure. A good adaptive experimental design would have an explicit design of reserves of different size, and a planned evaluation program to determine if our current understanding is correct.

5.2. Enforcement

Reserves that are not enforced can actually do more harm than good, by attracting illegal fishing effort. This has been suspected to occur, for example, on outer atolls of the Great Barrier Reef in Australia, despite clear evidence of reduced fishing impacts on experimentally closed reefs in the Effects of Line Fishing (ELF) experiment and earlier GBR closures (Mapstone et al. 2004; Williamson et al 2004).

For severely depleted stocks where remaining individuals are spatially concentrated, it may only take modest illegal fishing effort to cause high enough fishing mortality rates to prevent stock rebuilding (small total catch does not imply small impact; what matters is the ratio of catch to stock size). For long-lived species with population dynamics similar to abalone, a 10% annual illegal fishing mortality rate can mean the difference between recovery in a few abalone generations to recovery that takes centuries to occur. Thus for such species there is a special need to provide enforcement that is close to 100% effective at stopping illegal take. This is a very tall order indeed, given the size of the California coastline and the number of people potentially willing to violate fishing regulations for valuable creatures like abalone. There has been frank admission of the severity of the problem:

"Though seemingly impressive, when compared to the more than 5,000 square miles of California State waters and the federal waters beyond, as well as California's vast inland area, these numbers are quite small. " (California Department of Fish and Game Master Plan Framework August 22, 2005 Page 64).

The master plan framework calls for two really critical steps toward "effective and comprehensive operational ability," namely to hire additional enforcement officers and to explore and acquire "remote observation technology and techniques." Such technology could also make major contribution to monitoring, especially of fishing activity.

5.3. Evaluation and monitoring

The California MPA program will be implemented in an ecological and management setting where abundances of many species will be changing anyway due to other management initiatives (e.g. rockfish and essential fish habitat closures, the nearshore fishery management plan; among others) and due to environmental factors. Thus the adaptive management program will be at risk of obtaining misleading "signals" about the efficacy of MPAs unless the program is carried out in the context of a careful experimental design that provides adequate control for effects other than those caused by the MPAs. The obvious experimental design to consider is the BACI (Before-After, Control-Impact), as has been used to study effects of fishing on the Great Barrier Reef (Campbell et al. 2001; Walters and Sainsbury 1990). In this design, monitoring of abundance trends would be carried out both within each MPA and in nearby outside areas (allowing for paired comparison of control and impacted sites), and over time beginning before the MPAs are established (so as to measure recovery trends over time both inside and adjacent to the MPAs). Further, the planned staggered implementation of MPAs over time, i.e. phasing, would lead to a "staircase design" (Walters et al. 1988) of treatments, permitting estimation of time-treatment interaction effects (whether impact of MPAs changes over time with changes in ecological conditions such as recovery of larval sources for juvenile settlement in protected areas, due to protection from offshore fishing effects).

The biggest danger in not having a careful BACI design is that ongoing changes due to other fisheries management initiatives will be incorrectly attributed to MPAs. It would then not be the first time that proponents of MPAs have claimed gains from MPAs that in fact may have been due to other factors entirely (Hilborn 2002).

One of the most important impediments to implementation of adaptive management has been the formidable cost of monitoring programs needed to track changes in time and space within the context of planned experimental designs (Walters 1997), as recommended in the previous section. So far, it appears that most of the planning for monitoring MLPA impacts has focused on assuring that a broad suite of ecological and socioeconomic response indicators is measured, and that is a laudable and necessary step in the monitoring design process.

It is common in adaptive management monitoring design to develop long wish lists of performance indicators that could be monitored. But when it comes time to multiply out the number of observations over the number of sites and times for which these are needed, and to assess monitoring costs, or when mock decision analysis exercises assign values to the many indicators and seek to evaluate preferences among outcomes, there is likely to be a dramatic shrinkage in the indicator set to a relatively small number of well-defined, critical indicator variables for each major area of concern (ecological status, productivity, economic performance).

In typical scientific monitoring programs, attention is focused on precise measurement of selected indicators for relatively few spatial sites, over relatively short periods of time. However, development of an effective adaptive management program calls for just the opposite, i.e. measurement of a broad indicator set, perhaps not very precisely, over a broad range of sites for long periods of time. To accomplish this, it will be necessary to look far beyond existing monitoring programs, and in particular, there will be a critical need to develop new approaches to large-scale monitoring that substantially reduce the unit costs of key measurements like changes in relative abundances.

As noted in the first section above on Adaptive Management, we generally find that participants in policy comparison exercises end up focusing on relatively few quantitative indicators in actually comparing policy options, even after claiming that they need a wide suite of indicators in order to make such comparisons. In MPA comparisons, the really critical indicators for evaluating performance are also likely to be relatively few, including time series of:

1. Density and overall stock size for a few key indicator species inside and outside of reserves

2. Biological community structure surveys that monitor simple indices (diversity, percent occurrence, etc.) for large numbers of species in particular habitats where technology is available to examine many species at once (e.g. ROV video surveys, trawl surveys).

3. Catch per effort of a few key indicator species in the major fisheries

4. Numbers of active fishing licenses, total fishing effort, and spatial distribution of effort

Two basic approaches can be used in the design of spatial sampling programs for densities, diversity, etc. The first (and most popular) is stratified random sampling, which requires detailed habitat mapping to establish the sampling strata. Results from this approach are readily interpretable from a statistical perspective (error in estimates, power to detect differences among areas and over time can be easily calculated), but the approach is logistically complex and expensive to implement. The second is transect sampling, with transects deliberately oriented across the strongest spatial gradients (i.e. from onshore to offshore, so as to deliberately cut across depths). This approach is logistically much easier to implement, but does not permit the use of traditional statistical calculations of precision and power (the observations along each transect are treated not as independent but rather as components of a single multivariate observation of spatial pattern; statistical calculations are made only on comparisons among transect totals or means). For the same amount of field effort/time, transect sampling can result in radically more precise estimates than stratified sampling, but at the risk of possible bias. For very large monitoring programs as will be required for MLPA adaptive management, the risk of bias is probably a less important consideration than getting at least transect observations at the largest number of possible sites.

There are two possible ways to reduce unit costs of monitoring so as to make it economical to monitor a large number of study sites. One is to make relatively large up-front investments in innovative monitoring technologies, such as large-scale fixed acoustic arrays and listening arrays for acoustic tags and time-lapse digital photography for measurement of fishing effort, which then have relatively low maintenance costs over time. The second is to greatly increase the number of people involved in labor-intensive methods (like visual surveys), through collaborative arrangements with people besides scientists who are knowledgeable about ocean creatures and assessment methods (e.g. fishers). In the second (and likely more practical) approach, there is a key need to develop economic incentive systems for fishermen and others to help in information gathering (survey fishing incidental to regular fishing activity, per-dive payment for inshore visual surveys, etc.).

Two very large field programs are currently underway for evaluation of MPA impacts, one by NMFS in the Florida Keys (Bohnsack, Ault, and colleagues) and one on the Great Barrier Reef in Australia. Both of these programs are making very heavy use of visual survey transects to provide information on relative abundances and habitat patterns. Both use a small number of experienced dive teams, organized to visit large numbers of sites each year. In the NMFS case these teams are formed each year mainly of NMFS and RSMAS staff; in the GBRMP case, the teams are outside (university and private) contractors. A few such teams could be organized and trained to work along the California coast at relatively low annual cost, gathering comparable data along hundreds of dive transects each year with particular emphasis on the various sedentary species most likely to benefit from the MLPA MPA network.

For deeper waters, a key method for data collection is likely to be trawling. This can involve a mixture of scientific survey trawling and commercial fishing with onboard observers/recorders of catch composition information (like the NMFS Cooperative Groundfish Trawl Program that is beginning to provide a wealth of information about relative abundances and distributions of bottom species along the Pacific coast). Key to making such information useful is to have precise logbook information on spatial location of each shot. Given precise georeference information, data from commercial fishing and more widespread, spatially representative survey trawls (preferably by cooperating fishers) can be combined using geostatistical methods into maps of changing distribution patterns over time.

For all relatively inexpensive observation methods (e.g. visual surveys, trawling), expansion of the survey counts to estimates of overall abundance requires calibration experiments to establish the relationship between counts and total numbers of organisms actually present at sample sites. Such experiments typically involve methods such as local depletion experiments to estimate numbers of animals actually present, and typically must be replicated at a large number of sites due to high variation in the ratios of counts to actual abundances.

The California Department of Fish and Game pioneered the development of visual scuba transects for assessment of fishes in MPAs. Extensive baseline studies were established at two of the three marine reserves established in 1994. The most extensive studies were conducted at the Big Creek Reserve, where scuba transects were carried out for several years after the reserve was created. The studies included transects inside and outside of the reserve. Unfortunately the baseline surveys at the Big Creek Reserve and the Punta Gorda Reserve, in northern California, were not continued.

The fact that the State was unable to monitor even one group of fishes in three MPAs established more than a decade ago, and that the baselines at two of the MPAs have not been reassessed after they had been in place for 12 years, should stand out as a caution for anyone attempting to establish a monitoring program for the 29-31 MPAs proposed in the MLPA Initiative stakeholder packages. At a minimum, the Big Creek and Punta Gorda baselines should be resurveyed before any permanent monitoring program is designed. In addition, Packages 2R and 3R alter the present boundaries of the Big Creek Reserve. Alteration of this reserve would be a very poor way to carry out research on MPAs, as the Big Creek baseline is the best long-term reference site on the entire California coast.

6. Evaluation of other forms of protection

6.1. Historical fishery management regulations

The SAT and stakeholder processes demonstrated that there is a perception that the region's hard rocky bottom areas are more at risk than soft bottom areas. This may be due to the fact that the majority of resident soft-bottom fishes and invertebrates are most efficiently harvested with gillnets, trammel nets, Danish seines, dredges, beam trawls and otter trawls and the productive sandy beach surf zone can only be efficiently harvested with large beach seines. With the exception of gill and trammel nets, which have been more recently declared illegal in State waters, all the above gear types have been illegal in most or all of State waters for more than 50 years.

The only one of these fishing gear types that can be used in central California State waters is the otter trawl, and this gear cannot be used within 3 miles of shore along most of the central coast. In addition, trawls will soon be banned from the State waters portion of the Monterey Submarine Canyon that lies within the Federal Monterey Bay essential fish habitat (EFH) closure. With the exception of the trap fisheries for crab and spot prawn, neither of which are considered to be overfished, the commercial fishery does not have the capability to economically harvest resident soft bottom fishes and invertebrates at levels that would cause these populations to fall very far below their unfished levels. Recreational fisheries on resident soft bottom fishes have never been very large in the central California area, and the recently enacted seven-month seasonal closure, reduced bag limits and the complete exclusion from waters deeper than 20 fathoms have resulted in reducing the previous small, recreational take of these species. Due to the very low historical fisheries on resident soft bottom species in the central California region, these species are presently not much reduced from unfished abundance levels; in fact, with present regulations, nearly the entire soft bottom area within State waters could be classified as a moderate protection conservation area.

The perception with hard or rocky bottom areas is quite different. Resident bottom fishes are readily taken with hook and line, and sizeable commercial and recreational fisheries have exploited these species for more than a century. In addition, the continental shelf and nearshore species were extensively fished with gill and trammel nets for several decades, and the development of the nearshore trap and hook fisheries placed additional fishing effort on the relatively small populations of nearshore species. However, the nearshore species, for which there is enough information to develop stock assessments, have not been shown to be overfished by current standards (i.e biomass less than 40% of their expected unfished biomass). The deep-water species, that have primarily been taken with trawls, were fished at higher rates than the shallow water species, and the populations of several species were reduced to very low percentages of their unfished level.

6.2. State and federal response to overexploitation of bottomfishes in the 1990s and early 2000s.

In the late 1990s and early 2000s, joint action by the California Fish and Game Commission and the Pacific Fisheries Management Council resulted in the development of very strict rebuilding regulations for the six overfished groundfish species, along with sharp increases in protection for the other species. These regulations include limited entry and reduction of the number of fishing vessels (Table 6.2.1), annual harvest quotas (Table 6.2.2) prohibition on the use of gill nets in State waters and enactment of the Rockfish Conservation Area (RCA). Recreational fishing for resident bottomfishes also was severely limited in the central California region; a seven-month closed season was enacted, overall bag limits were reduced from 15 to 10 fish, overfished species have either no take or take of a single fish, anglers can only use one hook and the Rockfish Conservation Area prohibits fishing in waters deeper than 20 fathoms.

Table 6.2.1. California limited-entry fisheries.

Bottomfish trawl	Coastal Pelagic Species
Deeper Nearshore Species	Nearshore Fishery (four regions)
Drift Gill Net (shark and swordfish)	Nearshore Fishery Bycatch
Dungeness Crab	Northern Pink Shrimp
General Gill/Trammel Net	Salmon
Herring Gill Net	Sea Cumber Diving
Market Squid	Sea Cumber Trawl
Market Squid Brail	Southern Rock Crab Trap
Market Squid Light Boat	California Halibut (April 1,2006)
Spot Prawn (3 tiers)	Sea Urchin Diving

Table 6.2.2. Species and species groups managed with annual quotas.

Pacific sardine	Pacific mackerel
Market Squid	Herring
Lingcod	Pacific cod
Pacific whiting	Sablefish
Pacific Ocean perch	Shortbelly rockfish
Widow rockfish	Canary rockfish
Chilipepper rockfish	Bocaccio
Splitnose rockfish	Yellowtail rockfish
Shortspine thrornhead	Longspine thornyhead
Cowcod	Darklbotched rockfish
Yelloweye rockfish	Black rockfish
Bank rockfish	Blackgill rockfish
Sharpchin rockfish	Yellowtail rockfish
Cabezon	Dover sole
English sole	Petrale sole
Arrowtooth flounder	Other flatfish

Minor rockfish (nearshore group)	Minor rockfish (slope group)
Blue	Aurora
Brown	Bank
Calico	Redbanded
Copper	Rougheye
Olive	Shortraker
Quillback	Yellowmouth
Treefish	

Minor rockfish (shelf group)

Bronzespotted	Chameleon
Dwarf-red	Flag
Freckled	Greenblotched
Green spotted	Greenstriped
Halfbanded	Honeycomb
Mexican	Pink
Pinkrose	Pygmy
Redstripe	Rosethorn
Rosy	Silvergrey
Speckled	Squarespot
Starry	Stripetail
Swordspine	Tiger
Vermilion	

Comparisons of the harvest rates of common central California bottomfishes with high to low population levels (Figure 6.2.1) clearly shows that recent (2004) harvest rates of overfished species (bocaccio and lingcod) are far below those of the 1980s and early 1990s and species with healthy populations also have large decreases in harvest rates (Table 6.2.3).

Figure 6.2.1. Biomass of common central California fishes relative to their biomass in 1950; or the starting point of the stock assessment.

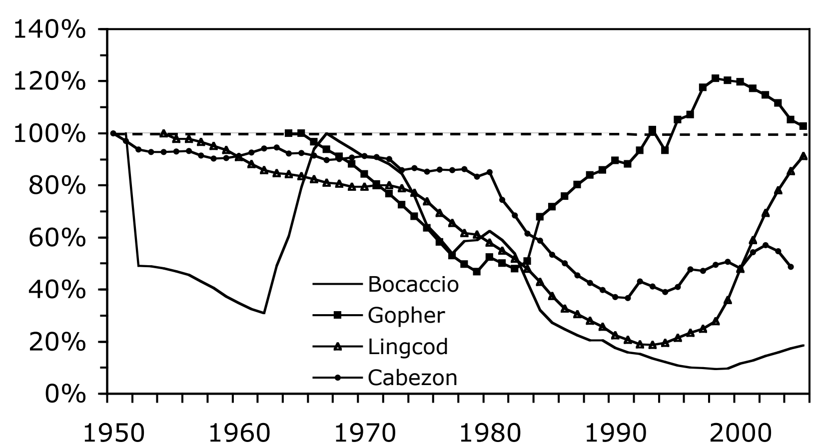


Table 6.2.3 Historical and current exploitation rates for selected species

	Exploitation Rates 1980-95	2004
1. Bocaccio	24.5%	1.0%
2. Gopher rockfish	4.9%	1.9%
3. Lingcod	11.9%	0.8%
4. Cabezon	12.1%	8.2%

The perception that rocky bottom fishes are presently being over fished is incorrect, and the small number of species that were over fished in the 1980s early 1990s are now under very strict rebuilding fishery management regulations; in fact one species, lingcod, was declared by the Pacific Fishery Management Council in November 2005 to be rebuilt.

6.3. Inefficient management using biomass based annual quotas in combination with permanent MPAs

The transformation in how west coast and California fisheries are managed has been primarily the result of (1) increases in knowledge of marine resources due to extensive monitoring, data analyses and modeling activities and (2) political transformation of the scientific results into effective management strategies. The principal strategy adopted was the use of annual catch quotas based on the size of populations as determined by timely stock assessments. Most bottomfishes are managed by annual quotas, and many of the species with smaller populations have been managed by habitat-based group quotas. Species that were considered to be overfished have been assigned very small quotas, and in addition, species at very low levels had large portions of their habitat placed in conservation areas where directed fishing for all bottomfishes was prohibited. In the case of bocaccio, probably more than 90% of the adult habitat in central California was closed to fishing for all bottomfishes.

When fishery management includes quotas, the use of MPAs will not reduce the volume of fish taken; it will only change the geographical distribution of the take. It does not require a complicated population model to know that the increase in biomass inside of MPAs will be roughly balanced by the decrease in biomass outside. The models used in this review are based on fishing mortality rates and do not include the increased mathematical complexity necessary to assess fisheries based on annual quotas; however, the results from these models show that the increased abundance with the MPA packages (Table 6.3.1) is associated with decreased catch (Table 4.4.2 and Table 4.4.3). Therefore, even though the abundance increases are much less than the effective areas of the habitat in MPAs, the models overestimate the reserve affect.

In the bocaccio situation, where most of the adult habitat that would be placed in the MLPA network is already inside of the Rockfish Conservation Area, fishing has already been prohibited. The results of the bocaccio model (Figure 4.4.2) clearly show that there is no additional buildup of bocaccio biomass inside or outside of the MPAs in the several Packages until the bocaccio population is rebuilt, the Rockfish Conservation Area is opened and the fishery resumes; this is not expected to happen for several decades.

Table 6.3.1 Percentage of unfished abundance without MPAs and with Packages 1-3. Simple model with constant habitat quality (See Appendix A and Figure 4.4.1: left column)

	Area	Abalone	Widow	Lingcod	Bocaccio	Cabezon
Without fishing		100.00%	100.00%	100.00%	100.00%	100.00%
Without MPAs	0.00%	33.33%	61.79%	43.94%	61.07%	55.52%
Package 1	14.90%	41.05%	63.35%	45.85%	61.62%	57.89%
Package 3R	17.25%	42.25%	63.32%	45.53%	61.62%	57.92%
Package 2R	19.25%	45.73%	64.21%	46.52%	62.11%	59.21%

As shown earlier, the effects of the MPA networks on bottomfishes in the several Packages will primarily be dependent upon the fishery management outside of the networks (Section 4 and Appendix A). However, density-dependent factors in species life history rates will potentially cause secondary effects due the fact that population densities will eventually be considerably higher inside MPAs than outside. Unfortunately, the knowledge needed to tell if the net effect of density-dependent factors will cause increased or decreased population growth is presently not available. The alteration in the densities inside and outside of MPAs could result in overall increases in biomass if the MPAs sites are located in areas where the habitat quality produces above average population growth. The reverse is also true, and it has already been noted that Packages 2R and 3R have the majority of their MPAs located at headland locations that will have maximum offshore loss of larvae. If larval retention is a critical factor in recruitment, these packages could result in a net loss of biomass in comparison to the status quo.

We note that the SAT realized that fishery management would be the primary determinant of the abundance of species outside of the MPA network; however, as they did no modeling of their guidelines and did not consider present fishery management, they failed to realize that for the great majority of species, fishery regulations will have more effect on the populations of species inside of the MPAs than the protection provided by the MPAs.

7. Other comments

7.1. General comments on process

The MLPA Initiative has obviously triggered an elaborate planning process, and the participants in that process are to be commended for a thorough job of identifying ecological factors that need to be considered in design of a comprehensive network of MPAs, including SMR, SMP, and SMCA designations. As reviewers of these plans, we take our primary role, objective, and potential benefit to the process to provide advice on best available science, integrating (largely theoretical) MPA science into existing fishery management, and in that context to be troubleshooters of possible pitfalls and gaps in the planning and implementation process, and how adaptive management plans could be improved to deal with those pitfalls.

We are in general agreement that the MLPA process should proceed to implementation of an MPA network plan for the Central Coast test region; in fact, implementation is mandated by statute. Below we offer a wide variety of comments and suggestions about how the planning and implementation process might be improved, so as to insure adequate protection for species and communities prized by non-consumptive users while minimizing social and economic impacts on consumptive users (fishers).

7.2. Protecting the interests of ocean-dependent coastal communities as a high planning priority

The MLPA planning process pretends to aim for balanced representation of all stakeholder interests. Presumably this means picking and choosing among specific site proposals from the main interest groups, through a multi-step process that begins with regional proposals from stakeholder teams, proceeds through scientific review by the Science Advisory Team (SAT), screening by a Blue Ribbon Task Force and Fish and Game staff, and finally selection of a plan by the Fish and Game Commission.

MLPA staff and the BRTF nominally considered minimizing impacts, but in the final analysis the BRTF significantly increased impacts of package 3R – all predicated on the SAT "recommended" size/spacing advice and the perceived but undocumented need to protect headlands for birds and mammals.

While this screening process is admirable in bringing a wide variety of expertise to bear on the MPA design process, we wonder whether it is not in fact based on an inappropriate assumption that all stakeholder interests should be given equal weight or credibility in arriving at alternatives to be presented to the Commission. In particular, only one of three plans will come from fishers and harbor communities, the people whose livelihoods and community culture will be most affected by the decision. Why in the world should equal weight be given to the interests of non-consumptive users (like scientists who value in-situ biodiversity for its own sake), who have little at stake and who will bear almost none of the costs of the decision? Nothing constrains non-consumptive users from recommending unreasonable and unnecessary closures, and there is likely to be considerable sympathy for their views among the SAT members; this means that absent some explicit priority for the recommendations of consumptive users, who have first-hand knowledge of resources and habitats, the views of those users may be undervalued.

Further, recent evaluation of MPA performance, such as the work that Mike Mascia of World Wildlife Fund has done on Caribbean islands (Mascia 2003, 2004), highlights the importance of fisher participation in self-governance (design, implementation) of MPAs. Where there has not been strong support by fishers and others who derive significant livelihood from marine resources (i.e. where MPA selection has been viewed as unfair, unlikely to produce at least some value to fishers and other ocean harvesters, and/or not legitimately needed), it has been virtually impossible to enforce closures. This warning extends as well to situations where the MPA process leads to deliberate or inadvertent reallocation among user groups, e.g. from commercial to recreational users, or in the case of the MLPA Initiative, from consumptive to nonconsumptive users.

The planning process missed a great opportunity to use simple models, such as the models we present here, as a forum for different interest groups to discuss alternatives. A quantitative model has the potential to find "win-win" solutions when used in an interactive way, and to identify elements of any plan that have particularly adverse consequences to different stakeholders.

7.3. The pretense that MPAs will offer substantial protection for "ecosystem function" or will insure development of "intact communities"

The master plan framework recognized that 'Ecologically dominant species play the largest roles in the function of coastal ecosystems', however, it is apparently not recognized that the dominant species in the California Current System are almost entirely mobile and/or migratory species that would achieve almost no protection from MPAs of the size proposed in the several stakeholder packages. The smaller stocks of inshore, mainly demersal species that will benefit from MPAs certainly do depend on the more mobile species (e.g. small pelagics are important food for some benthic piscivores), but it is by no means clear that the reverse is true.

The exploited species that have biomass levels that have exceeded 1 million metric tons, MMT, (whiting, sardine, jack mackerel, anchovy and Pacific mackerel) are all highly mobile as adults and, in addition, their spawning habits and early life histories make them subject to extensive larval transport (Table 7.3.1). Species whose biomass has observed peaks between 0.1 and 1.0 MMT are mostly deepwater, continental slope species (sablefish, Dover sole, shortspine thornyhead and longspine thornyhead) or shelf-break rockfish species with schooling behavior (shortbelly, widow and yellowtail rockfishes). All except the thornyheads, whose mobility is unknown, are quite mobile and they have very extended larval and pelagic juvenile stages (18-20 months for longspine thornyhead). Species whose virgin biomass was between 0.01 and 0.1 MMT are principally shelf break and continental shelf species. All the rockfishes in this group are primarily schooling species that have considerable movement. Many of the species in this group move from inshore nursery grounds to deeper water as they mature. There are six assessments for species whose virgin biomass was below 0.01 MMT; three of these are nearshore species.

Table 7.3.1. Virgin or peak observed biomass (mt) of species with stock assessments.

	Virgin or Maximum Observed Biomass		Virgin or Maximum Observed Biomass
Pacific whiting	7,272,000	Northern anchovy	1,598,000
Pacific sardine	4,015,000	Pacific mackerel	1,394.000
Jack mackerel	1,905,000		
Sablefish	723,000	Shortspine thornyhead	230,000
Dover sole	596,000	Longspine thornyhead	228,000
Shortbelly rockfish	295,000	Yellowtail rockfish	138,000
Widow rockfish	265,000		

	Virgin or Maximum Observed Biomass		Virgin or Maximum Observed Biomass
Canary rockfish	93,000	Darkblotched	28,000
Pacific Ocean Perch	83,000	Petrale sole	26,000
Lingcod	76,000	Vermilion rockfish (Calif.)	21,000
English sole	63,000	Blackgill rockfish (Calif.)	21,000
Chilipepper rockfish	58,000	Black rockfish	20,000
Bocaccio	46,000	Bank rockfish	14,000
Yelloweye rockfish	8,700	Cowcod (Southern Calif)	3,200
Starry flounder (Calif. only)	5,800	Cabezon	2,400
Gopher rockfish	2,400	Scorpionfish	2,000

It appears to have not been appreciated that the species that dominate the California Current Region are very unlikely to benefit from an MPA network designed along the guidelines suggested by the SAT. The species that would be expected to benefit are mostly nearshore, sedentary species that have quite small populations. This contrast does not appear to have been included in the "how much is enough and how much is too much" MPA discussions.

Further, the fact that the "communities" consist of species with widely varying movement patterns implies that it is impossible to reconstruct, or even sensibly define, completely "intact" communities without shutting down all fisheries, including some that are not even within US jurisdictions (like the Mexican sardine fishery, that may very likely impact future abundance of small pelagic species along the California coast). The prevalence of mobile species in the ecosystem biomass spectrum emphasizes the point that fisheries management plans, especially for the more mobile species, must be carefully coordinated with MPA planning, as noted above.

"Biodiversity" has become a catchword for protection of relatively rare, specialized, and charismatic species, particularly birds and mammals. If we were really interested in maximizing biological diversity, as ecologists typically define and measure it, we would likely want to promote "intermediate disturbance" regimes involving fisheries as an ongoing, even healthy agent of disturbance. There is certainly a legitimate case for protection of the species typically used as biodiversity indicators, without use of ambiguous terminology.

A wide variety of ecosystem models has been developed to evaluate impacts of fisheries on ecosystem function, particularly food web structure and productivity. While differing widely in details, these models generally agree on one key prediction about the predators (birds, mammals) that represent biodiversity interests: these species at the top of the food web should be the most sensitive indicators of loss of ecosystem function. That is, declines in natural productivity and food web components due to fishing should have the largest negative impact at the top of the food web. The existence of healthy, growing marine mammal populations along the California coast is certainly not indicative of gross loss of ecosystem function due to historical fisheries. Moreover, recent research has found that *Toxoplasma gondii* and other parasites, rather than fishing, is largely responsible for limiting the central coast sea otter population, although that population, too, is growing slowly.

Proponents of ecosystem restoration often assume that simultaneous protection of all species will somehow lead to harmonious increases in abundances of all of them. This assumption is dangerously wrong, particularly in cases where top predators (marine mammals, birds) are increasing while feeding on fish and invertebrates that are initially at low abundances due to historical fishing impacts. In such cases, the top predators can cause severe, depensatory mortality impacts on their prey, so as to prevent the prey populations from recovering. An obvious example in California is the impact of growing sea otter populations on recovery of abalone on the central coast (Fanshawe et al. 2003). There is correlative evidence that growing seal, sea lion, and bird populations along the Pacific coast are causing increasing mortality rates of juvenile salmon. Some believe that recovery of cod populations off eastern Canada is being prevented by large, growing seal populations.

In reviewing the major functional groups in the California coastal marine ecosystem ranked by biomass (Field, Francis and Aydin 2006) as a key indicator of functional significance (at least in trophic aspects of ecosystem structure), it is obvious that all of the big contributors are species that are either not fished (i.e. krill and midwater fishes), are relatively mobile and have complex seasonal migration patterns, or are mainly found in deeper waters, and so will be offered little, if any, real protection under any of the MPA proposals. Thus none of the MPA plans contributes very much to the ecosystem function of the region.

It is well know that the California Current System is impacted by environmental and climatic variation at a wide range of time and space scales, ranging from extreme storm events, variations in seasonality, El Niños and regime (decadal) scale processes (Parrish and Tegner 2001). These variations result in both species specific (El Niño and squid; regime changes and sardine) and trophic level (El Niño and regime changes in plankton) alterations in the abundance of dominant organisms. Sorting out the relative impact of ongoing climatic variations and recent changes in fishery management from the relatively smaller impact expected from the establishment of MPAs is going to be a very difficult science problem.

7.4. Integration of marine reserves with fishery management measures

Although the MLPA simply calls for "more than one" marine life reserve of eight key habitat types in each bioregion, the science advice incorporated in the MLPA master plan framework calls for a very extensive network of marine reserves, and all of the plans proposed consist of a substantial number of reserves and a significant proportion of the total area closed to fishing. However, it is quite clear that the impact of MPAs is minor relative to the fisheries management actions taken by the PFMC and State. For commercially important species, we find there would be absolutely no benefit to the sustainable harvesting of these species from any proposed MPA network.

For example in our simulations of bocaccio management, there would be essentially no impact of MPA's until the stock is rebuilt, because the exploitation rate in the rebuilding period is so low. Further, once the bocaccio stock is rebuilt to 40% of virgin abundance, MPAs would have no benefit in larval production because of the very substantial larval production coming from outside the MPAs. The same conclusion is true for any species being managed for commercial fishing: if the stock is overfished, the PFMC and State put it on a rebuilding schedule that involves very low fishing mortality rates.

There are a variety of reasons proposed for creating reserve networks, ranging from providing a backstop or hedge against ineffective fishery management, to providing reference areas for evaluating effects of fisheries with highly uncertain ecological impacts (e.g. for urchins and sea cucumbers), to protecting habitats and non-target species from gear and bycatch impacts. Generally, protection of large percentages (20-30%) of fishable areas has been recommended mainly for the first of those purposes, fishery management failure, or for situations involving severe bycatch impacts on non-target species.

All of the stakeholder packages have area in MPAs that exceeds the midpoints of the size and spacing guidelines recommended by the SAT. The mid-points for size (12.5 km) and spacing (75 km) result in a percentage of 14.3% of the area in MPAs if all MPAs extend out to 3 miles from shore. The California Nearshore Fishery Management Plan calls for at least 10% of nearshore area in MPAs and it suggests that 20% would be called for if fishery management were ineffective.

Although fishery management in California has resulted in a number of species being listed as overfished, changes in fisheries management policy for important species have been dramatic, and the regulations to reduce fisheries pressure, for example implementing extensive no-trawl MPAs to protect benthic habitat and demersal species and quotas to limit bycatch, are both draconian and effective. Further, our spatial modeling results indicate that protection levels of the range of Packages 1-3 would act as an effective hedge against failures of management policy **only for highly sedentary species**, as indicated in the left versus right panels of figure 4.4.1.

7.5. Spatial redistribution of fishing effort and consumptive impacts

Spatial site selection by commercial and recreational fishers is a complex process. When particular fishing opportunities are lost, fishing effort does not simply go away; fishers go elsewhere and may target different species if they have the flexibility to do so. This means that if total efforts are not reduced in proportion to the loss of fishing area into SMR, and if commercial effort shifts are not considered in relation to areas lost to SMCAs and SMPs, fishing effort and mortality rates caused by it will likely increase in remaining open areas. Such effort response dynamics can end up doing more harm than the benefits gained in protected areas, if fishers move into areas where species more needful of protection are concentrated. An example of this effect was reported by Walters and Bonfil (1999), where detailed spatial data from the British Columbia trawl fishery were used to map distributions of 16 demersal species, and impacts of shifting effort distributions over these fish distributions were predicted for a series of local closure options.

One option for long-term management of sensitive species, particularly deep-water rockfish, would be to permanently close large areas now protected as essential fish habitat (EFH closures) and rockfish conservation areas (RCAs). Our models indicate that if such closures were the only available management measures, it would be necessary to keep at least 70% of the deep water area closed to fishing in order to limit fishing mortality rates to MSY target levels of less than 10%/yr. But if such large areas were closed to fishing, so that the majority of the fish stock was in protected areas, several negative consequences occur for the fishing fleets. The abundance outside the reserves is low, and as a consequence catch rates are low and fishing even less profitable than it is now. Any future in which the average density outside of the reserves is low would lead to declines in catch rates and probably economic failure of the commercial and recreational fisheries. For this reason, other methods for regulation of total catch and fishing mortality rate are essential to maintain economically viable fisheries, and stock abundance outside of reserves must be maintained or increased.

Negative effects of effort redistribution on target populations are highly nonlinear with exponentially increasing fishing mortality necessary to catch the same amount of fish as the percentage of the population within MPAs increases (Parrish, 1999). Negative effects would occur at lower MPA percentages if closures were placed in areas where effort is now particularly concentrated, such as in areas near headlands. In that event, there would be no safe alternative but to seek reductions in total fishing effort, through commercial license/quota reduction programs and/or imposition of direct limits on recreational fishing effort.

As mentioned above, the stakeholder process was influenced by a perception that nearshore hard bottom habitats 'merited' special protection. The three stakeholder packages do not have a wide range (i.e. roughly 15-19%) in the total percentage of area in MPAs (Table 7.5.1). However, all of the packages have 21-47% of all the classes of nearshore hard bottom habitats and 40-47% percent of the persistent kelp habitat in MPAs. Packages 2R and 3R have more than 30% of these habitats (37% to 47%) in MPAs. Clearly all of the packages developed by the stakeholders have a moderate to huge bias in the percentage of these habitats that were included in MPA.

Table 7.5.1. Percentage of near-shore hard bottom habitat types included in MPA Packages 1, 2R and 3R.

	Total MPA	Hard Bottom 0-30 m	Average Kelp	Persistent Kelp	Rocky Shore
Package 1	14.90	20.54	24.59	39.96	29.56
Package 2R	19.26	31.26	40.36	46.88	38.05
Package 3R	17.25	31.43	38.73	43.10	37.45

If such extensive MPAs are approved, this issue will need to be addressed by the fishery managers responsible for the Nearshore Fishery Management Plan, because the present precautionary quotas and regulations could not be expected to produce sustainable fisheries if 21-31% percent of the habitat (i.e. 0-30 m hard bottom) and 25-47% of the prime habitat (i.e. average kelp, persistent kelp and rocky shore) were placed in MPAs. The NFMP suggests 10% set aside in MPAs with precautionary fishery management.

7.6. Failure to account for dispersal imbalance effects in assessing needed MPA sizes: need to confront the SLOSS tradeoff more carefully

Computer simulation studies (e.g. Fig. 11.10 in Walters and Martell, 2004; see also Meester, et al. 2001 and Figures in this report) warn that impacts of heavy fishing pressure near MPA boundaries can have impacts on abundance that extend well into the MPA, beyond typical dispersal distances for the impacted species. Two mechanisms cause this effect: (1) individuals with home ranges near the boundaries are still subject to risk of harvest, and more importantly, (2) "dispersal imbalance" effects, which have not been widely recognized by proponents of MPAs. Dispersal imbalance effects occur when there is movement out of sites near the boundary, but this movement is not balanced by movements into the site due to lack of "source" animals to move into the site from sites toward and outside the MPA boundary. Models with density-dependent movement (more movement of individuals from high-density sites near the core of the MPA, (see e.g. Abesamis and Russ 2005) predict even larger imbalance effects on overall MPA abundance. Such effects are difficult to measure in patchy environments and may take years to develop after an MPA is created, but can considerably reduce the long-term abundance benefits of localized protection from fishing.

For MPAs located against shorelines, where dispersal movements are mainly alongshore, models of 10km alongshore MPAs indicate that dispersal imbalance effects will cause about half the reduction in overall population increase in the MPA as the annual dispersal rate out of each 1km reach within the MPA. That is, if 20% of the animals disperse from each 1km reach within the MPA to settle in adjacent 1 km reaches, overall long-term abundance across the 10 km will end up about 10% lower than would be predicted in the absence of movement. The predicted reduction is roughly halved for a 20km wide MPA.

Concerns about dispersal loss from MPAs, along with concerns about costs of enforcement to prevent illegal fishing near MPA boundaries, have been at the heart of the so-called "SLOSS debate" (Single Large or Several Small) about design of regional MPA networks. The MLPA SAT appears to favor the SS (Several Small) side of this debate, in calling for multiple (3-5) "replicates" of relatively small MPAs within each major regional habitat type.

7.7. Inappropriate use of simple percentage guidelines in comparing plan alternatives

We caution against the use of simple percentage standards for evaluation and screening of MPA plans, e.g. setting targets like protection of 20% of each habitat type. No sound ecological basis for particular percentages has been demonstrated using ecological models or historical data, nor is there a sound economic or social justification for them. The numbers typically mentioned, 20%-30%, appear to have been derived from stock assessment models that commonly predict recruitment overfishing when spawning abundance falls to less than about this level, but such estimates are typically highly unreliable due to scarcity of recruitment observations at lower stock sizes. Further, using the same percentages for protection targets as for minimum spawning abundance assumes that the only substantial spawning will be in the protected areas, i.e. all other spatial components of the spawning stock will be destroyed by fishing. Such catastrophic depletion is extremely rare, and mainly involves migratory stocks that have exhibited severe range collapse (e.g. cod, herring) and for which small MPAs would be inappropriate in the first place.

Further, reasonable and acceptable levels of protection may vary widely among basic habitat types. For example, we doubt that there would be few people, excluding those who harvest clams, who would object to SMR protection of essentially 100% of the very unique estuarine habitats along this section of the California coast. But at the other extreme, it may be unnecessary to have SMR-level protection for more than a few percent of shallow, rocky inshore areas where exploitation is mainly by recreational fishing/diving and for which there is already protection for species being selectively depleted (abalone).

7.8. Inappropriate goals for rebuilding stocks of long-lived species

There seems to be an assumption by the Scientific Advisory Team that long-lived species need to have higher spawning stocks relative to unfished levels, i.e. targets for stock rebuilding for species like rockfish need to be on order 50% of unfished levels. However, meta-analyses like the paper by Goodwin et al (2006) indicate just the opposite, with longer-lived fishes showing much steeper stock-recruit relationships (higher Goodyear compensation ratios), i.e. lower spawning numbers needed to insure adequate recruitment. If this is true, historical recruitment overfishing may not have been all that severe for many species, and rebuilding of age structure in such species will lead to increased larval settlement, but not increased recruitment out of nursery areas. Failure to anticipate this strong possibility could lead to systematic misinterpretation of the results of monitoring programs.

7.9. Naïve assumptions about importance of connectivity among reserves in setting standards for reserve number and spacing

For species that have been severely reduced by historical fishing, particularly those that have life history ontogeny involving inshore nursery areas and later movement into deeper waters, there is the possibility that nursery areas are now widely “underseeded” with larvae, i.e. are not producing nearly as many offshore recruits as they could. If this is the case, then even onshore-offshore protection (MPAs that extend well offshore) will not insure rapid population recovery, since abundance even in the MPAs may be limited by inadequate recruitment rather than depressed survival. For such species, the main “connectivity” among MPAs will be due mainly to relatively large-scale larval dispersal rather than alongshore movement of older fishes. But if even larval settlement into MPAs is depressed due to large-scale historical overfishing, then recovery in MPAs will be slow enough that (unless a very high proportion of the offshore population is protected) most larval settlement will have to come from spawning outside the MPAs. That is, it may be wrong to suppose that MPA spawning abundances will recover rapidly so as to provide widespread larval seeding including connection through larval transport with other MPAs.

In short, considering ontogenetic patterns of movement in fishes, except for species with very short dispersal distances (like abalone), the main connections between MPAs will be due to larval dispersal, and it is only if there are no fish left outside of the reserves that such connections are significant.

7.10. Coordination of state and federal MPA development to insure onshore-offshore continuity of protection and effective monitoring programs

The design of effective onshore-offshore protected areas to cover the full life cycle of the many species with ontogenetic habitat shifts will obviously require close State-Federal cooperation. So far that does not seem to be a major problem in California, with if anything even stronger fishery restrictions being imposed offshore (rockfish closed areas, groundfish EFH) than inside the three-mile State jurisdiction. It is probably a safe assumption that Federal management programs will continue to be strongly conservation oriented with emphasis on rebuilding depleted stocks to productive levels as mandated under the Magnuson-Stevens Act.

But it is not just in relation to coordination of closed area designations that close State-Federal cooperation will be required. Much of the key monitoring data, especially for deepwater fishes and habitats impacted by activities like trawling, will have to come from ongoing Federal science programs. There will likely continue to be dramatic changes in Federal policies for fishery access, toward limited entry and quota management programs aimed at creating property right incentives for fishers to cooperate in sustainable management, which could strongly enhance (or prevent if not implemented) opportunities to develop collaborative fisher-scientist research programs.

8. Recommendations

We offer the following recommendations to the Department of Fish and Game and Commission, based on our findings and adaptive management experience, both to improve this decision-making process and those to follow in the future.

Recommendations (General)

1. Implement a phased MPA network designed with a variety of MPA sizes and with an adequate long-term monitoring plan and sufficient resources to test MPA theories.

2. Recognize that there is little chance that MPAs will contribute significantly to maintenance of marine ecosystem function; the function of these ecosystems is largely determined by highly mobile species that will be totally unaffected by MPAs. Only widespread, effective fisheries management will insure maintenance and restoration of ecosystem function.

3. Enforceability (proximity to populated areas, more eyes and ears) should be the number one criterion for specifying locations of SMRs and SMPs, until it is clear whether increases in enforcement staff combined with use of new monitoring technologies will make this criterion unnecessary.

4. Closely examine existing bycatch data and apparent fishing mortality rates suffered by non-target species to quantify the extent and severity of the problem, including identification of spatial areas where bycatch problems are most severe as possible candidate areas for SMR designation.

5. Work with State and Federal management agencies to develop by-catch reduction plans as part of the overall MLPA planning and implementation process.

6. There is a critical need to develop spatial maps of fishing efforts and impacts for the major California fisheries, using commercial logbook and creel census information along with assistance from knowledgeable fishers (using workshop data synthesis and mapping processes) where quantitative distribution data are not available.

7. Using such maps, fishing effort displacement should be calculated for each MPA plan proposed, and estimates made of the increase in fishing effort and impact in remaining areas open to fishing.

8. Long-range proposals and plans should be developed for reduction in overall fishing efforts for those fisheries where substantial (20 % or larger) displacement is likely to occur.

9. Avoid using concepts from terrestrial protected area planning in MPA design, and instead use appropriate models

Recommendations (to improve scientific guidance and analysis)

10. The Scientific Advisory Team, in collaboration with experts on enforcement, should look more carefully at guidelines for MPA number and size, and in particular should consider recommending fewer (2 is the minimum needed for statistical comparisons, not 3) but larger protected areas per key habitat type for more efficient and economical implementation and enforcement.

11. We recommend that the Scientific Advisory Team be required to provide specific guidelines for desired levels of protection by habitat type, with precise justification for each of these guidelines and with quantitative predictions (using population dynamics models for a range of representative species) of the consequences of failing to meet them.

12. We recommend that the Scientific Advisory Team develop quantitative classification guidelines to be used to evaluate the levels of protection assigned to MPAs.

13. The Scientific Advisory Team should develop a list of species to be benefited by MPAs that provides a quantitative assessment of the degree of benefit that each species is expected to receive.

Recommendations (Modeling)

14. Consider investing in a California coast-scale hydrodynamic modeling and larval drifter/vertical movement model that can realistically examine alternative hypotheses about likely connection patterns among spawning and larval settlement areas for a variety of indicator species (Note: this is a risky approach and could fail completely due to inadequate knowledge about spawn timings and vertical movement patterns of larvae).

15. Use the models we have provided as a starting point for more careful quantitative analysis and comparison of alternative MPA proposals.

16. Involve stakeholders in game-playing with the models, and in trouble-shooting possible missing model components and functional relationships needed for prediction, as a central part of the adaptive management planning process and as a means to stimulate development of cooperative monitoring programs.

17. Use the models as an aid to development of monitoring designs, both in terms of helping to identify key monitoring variables (i.e. what model predictions do people really look at in comparing policy alternatives) and in design of spatial sampling programs and inside-outside comparisons of open areas versus MPAs.

Recommendations (Monitoring)

18. Adopt the institutional design framework recommended in the "Final Draft Adaptive Management and Monitoring and Evaluation Framework", but modify it immediately to address the hard-nosed issues of exactly what to monitor, where, and when, and

how. Focus on the recommendations in Appendix 3B of that report and incorporate the monitoring recommendations provided in this review. Discard the recommendation in that draft of designing monitoring programs around broad biogeographical regions; there is no need to do that for effective adaptive management based on paired comparison data between nearby protected and fished areas.

19. A joint State-Federal task group should be formed to develop a detailed, cooperative monitoring program with costs and cost sharing proposals, taking full account of possible cooperative monitoring efforts that will become feasible given planned changes in fishing property rights and recent support for collaboration between industry and fishery management agencies.

20. Begin monitoring basic ecological response indicators (relative abundances, sizes of representative species, i.e. essential fishery information) ideally at least two years before implementation of each new MPA.

21. Plan to continue these paired monitoring programs for at least a decade after establishment of each MPA, so as to assess cumulative effects of both the MPA and other management influences and to allow staircase comparisons to MPAs initiated later in time.

22. There should be a careful enumeration of the total number and kind of field measurements that will need to be taken annually for the foreseeable future as the core of the core adaptive management monitoring program, with particular attention to the need for paired measurements in and near each protected area.

23. A consensus statement should be developed on a basic, key indicator set that must be measured on all experimental (and reference) areas.

24. There should be increased funding for and very careful evaluation and encouragement of the cooperative programs between fishers and scientists that are now underway in some locations (e.g. tagging in Channel Islands area), with a view to extending such programs much more widely along the coast.

25. Carry out the same monitoring (same methods, etc.) on at least one “control” or reference area in close proximity to each protected area (treatment-control pairing).

26. Monitoring programs should attempt to measure both settlement rates of very small juveniles, especially rockfishes, and also net production (recruitment) of larger juveniles out of nursery areas.

27. Monitoring programs for longer-lived species should regularly collect size-age distribution samples to assess rebuilding of population age structures, and the component of overall abundance increase due to this rebuilding as opposed to increases in recruitment rates.

28. Monitoring plans for adaptive management should include transect sampling of abundance for a set of indicator species with different movement rates, along transects from well outside MPA boundaries into the middle of the areas.

29. A study team should be formed to evaluate options for large-scale investment in new, automated technologies for ecological monitoring, in particular the deployment of large-scale listening arrays for acoustic tags that would provide an opportunity to measure movement and exploitation patterns directly for a variety of larger species.

9. Conclusions Regarding Goals of the MLPA

Based on the work we have done and our reading of the documents, we can make specific conclusions regarding the impact of the alternative proposals on the goals of the MLPA. First, however, it is important to acknowledge the significant contributions of environmental and climatic variation, as well as the impacts of coastal development, pollution and other non-fishing human activities, on the diversity and abundance of marine life and the structure, function and integrity of marine ecosystems. Such effects were not considered in the science advice or analysis of MPA proposals, although these climatic effects and non-fishing impacts play a significant role in achieving (or not achieving) Goals 1, 2 and 4.

9.1. Goal 1: To protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems.

Our primary finding with respect to this goal is that the high mobility of most key species in the central California marine ecosystem precludes any of the MPA designs from having a significant impact on the structure, function and integrity of the marine ecosystems. The primary determinants of the structure and functioning of the marine ecosystem will be the management of catches of the mobile species through the State and Federal harvest regulations. Only for the species with highly sedentary adults will the abundance inside of the MPAs be dramatically higher than outside of the MPAs; **however, outside of the MPAs their abundance will be less than the case with no MPAs.** The solitary, rocky bottom nearshore species managed under the California Nearshore Fishery Management Plan are good examples of species with this type of behavior (for example: gopher, black and yellow, china, and kelp rockfishes and cabezon). This group is also the most readily monitored with non-extractive methods.

9.2. Goal 2: To help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted.

Because of the mobility of most species, especially those of commercial importance, none of the proposed patterns of MPAs will have a significant role in protecting species of economic value or in rebuilding those that are depleted. The main positive impact will be on the abundance and diversity of sedentary, demersal species that are now impacted by various coastal fishing and poaching activities, as well as by coastal development and non-point source pollution.

9.3. Goal 3: To improve recreational, educational, and study opportunities provided by marine ecosystems that are subject to minimal human disturbance, and to manage these uses in a manner consistent with protecting biodiversity.

Each of the alternative MPA plans provides for a large number of areas across a range of habitats that meet the objectives above. There is no scientific data in any of the material we reviewed to suggest criteria for how these objectives will be affected by the absolute number or size of protected areas.

9.4. Goal 4: To protect marine natural heritage, including protection of representative and unique marine life habitats in California waters for their intrinsic value.

Again all plans considered appear to meet this objective.

9.5. Goal 5: To ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines.

We found that all plans presented have a number of failings with respect to this objective. Implicit in the science advice is the objective of building large protected populations inside of reserves, with reserves "linked" by larval dispersal. As we have discussed throughout our report, there does not appear to be any basis for this – for few species will abundance be much higher inside of reserves than outside, especially compared to protected areas that are not MPAs. Thus we don't find the MLPA planning process to have realistic expectations regarding what can be achieved. We found almost no realistic evaluation of the management measures and enforcement.

9.6. Goal 6: To ensure that the state's MPAs are designed and managed, to the extent possible, as a network.

In the science advice we reviewed, the primary interpretation of the "network" concept was the linking of protected areas by larval dispersal. We found no evidence that this is a realistic expectation; our analyses suggest that most larvae arriving in MPAs will come from outside of MPAs. The primary networking of MPAs will be administrative, in their role as educational and recreational showcases.

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APPENDICES

Appendix A: A simple model for examining impact of MPAs on distributions and abundances of aquatic organisms with different dispersal and recruitment biology

At some point in the development of an MPA plan, it is necessary to make quantitative prescriptions about how large individual MPAs need to be and how they should be arranged in space. When MPAs are to be placed along a coastline like California's, where each MPA is intended to protect an inshore-offshore band that includes both juvenile nursery and older fish residence areas, the most important long-shore population impacts of protection can be quantified by using a simple, one dimensional spatial model with a large number of long-shore spatial cells or local sites that are linked through dispersal of both larvae and older animals, and that includes reasonable assumptions about two critical issues: (1) the local (per cell or site) relationship between local larval settlement and subsequent recruitment, and (2) impact of increased fishing effort in open areas when effort is displaced from MPAs.

We used the model described in this appendix to do a large number of simulations of long-term changes in distribution along the Central Coast shore line for five management scenarios (no fishing, no MPA protection, proposals 1, 2R, and 3R) for five species (see Fig. 1) for two alternative assumptions about the success of current coastwide management measures at reducing fishing mortality rates. The resulting 50 scenarios were also repeated with and without spatial fishing effort responses, and with and without spatial variation in habitat quality.

Suppose we divide a coastline up into i=1…n spatial cells, each extending a longshore distance of say 1 mi. and extending offshore for an unspecified distance large enough to protect all life stages of a species. Suppose initially that all of these cells are equally suitable for the species in terms of habitat conditions. If N_i is the number of older individuals in cell (summed over all ages from an arbitrary age of recruitment or maturity), the dynamics of N_i can be approximated by the continuous recruitment-movement-mortality rate relationship

$$dN_i/dt=r(L_i)-MN_i-F_iN_i-2mN_i+m(N_{i-1}+N_{i+1}) \qquad \text{(A1)}$$

where the rate components are:

$r(L_i)$ is local recruitment rate as a function of local larval settlement rate L_i

MN_i is natural mortality rate

FN_i is fishing and/or bycatch mortality rate

$2mN_i$ is movement rate of older animals out of cell i to the two adjacent cells

mN_{i-1}, mN_{i+1} are movement rates of animals in to cell i from surrounding cells.

For evaluation of the long-term impacts of protection, we need not solve eq. (1) over time, and can instead try to find the long term mean or equilibrium N_i implied by $dN_i/dt=0$. This equilibrium abundance field must satisfy the relationship

$$N_i=[r(L_i)+m(N_{i-1}+N_{i+1}]/[M+F+2m] \qquad (A.2)$$

(this is obtained just by setting dN/dt to zero and solving eq. (1) for N). Due to the nonlinear dependence of L_i and $r(L_i)$ on larval transport and survival patterns, eq. (2) cannot be solved analytically for the long term N_i; however, it can be easily solved by numerical "relaxation" methods, which basically just involve substituting successive estimates of the L_i and N_{i-1}, N_{i+1} into the right-hand side of (2) and using the resulting estimates of N_i as the inputs for the next iterative substitution.

The really critical term in eq. (1)-(2) is the recruitment function $r(L_i)$, which involves issues of both how far larvae are dispersed (how L_i is formed as a sum of larval contributions from other cells), and whether there is strong density-dependence in post-settlement survival rates (whether or not juvenile nursery habitats are "fully seeded" so that recruitment is independent of larval settlement). Absent strong long-shore advection of larvae in particular direction(s), we would expect dispersive mixing processes to result in a normally distributed pattern of larval settlement from spawning in each cell, with a spread or standard deviation parameter proportional to larval duration and mixing velocities per unit time. The normal distribution assumption for larval settlement implies that if there are no larval sources outside the study region, average larval settlement L_i on each cell i should consist of a sum of larval contributions from potentially all other cells, with the functional form

$$L_i = k\sum_{j=1}^{n} N_j e^{-0.5(j-i)^2/S^2} \qquad (A.3)$$

Here, *k* is a scaling constant for total larval settlement from each source cell, and S is the standard deviation of the spatial distribution of larval settlement (e.g., S=10 implies that settlement of larvae produced in a cell drops off rapidly beyond 10 mi. from that cell). Note that summing over all cells j implies that larval settlement on cell i may include contributions from any or all of the other cells j.

Using eq. (3) to predict average larval settlement to each cell i, the key issue then becomes prediction of how recruitment rate $r(L_i)$ varies with L_i. Absent evidence of recruitment suppression at high N_i due to cannibalism or spacing behaviors by the animals already present in cell i, we would expect the recruitment function to be of a saturating or Beverton-Holt form, i.e.

$$r(L_i)=\alpha L_i/(1+\beta L_i) \qquad (A.4)$$

where α is the maximum survival rate of larvae from settlement to recruitment, and α/β is the maximum recruitment rate (carrying capacity of the cell to produce recruits). Suppose we hypothesize a base or reference natural natural settlement rate L_o for each cell, calculated by setting k=1, i=n/2 and all N_j in eq. (3) to a base unfished abundance $N_j=R_o/M$ where R_o is an average natural recruitment rate per cell. Then we can parameterize the recruitment relationship in terms of R_o, L_o, and the "Goodyear compensation ratio" K, by setting

$$\alpha=KR_o/L_o$$

$\beta=(K-1)/L_o$ (A.5)

Note that in this parameterization of the Beverton-Holt function, absolute larval production per spawner (*k*) does not matter, since only the product of it times maximum larval survival rate (that product is α) actually appears in the recruitment prediction. Metaanalyses of stock-recruitment data indicate that we should expect the compensation ratio K (ratio of maximum larval survival at low densities to survival at unfished natural abundance) to be in the range K=5 to K=100, with most likely values for long-lived benthic species in the range K=10-50. The critical parameter in this representation is K, which determines how much larval settlement can be reduced before net recruitment r(L) is impaired; R_o is simply a scaling parameter that is determined by (or implies, or represents) the units of measurement of N_i.

Note that in assuming that local recruitment is a function only of local larval settlement (Eq. A4), we join other modelers (e.g. Gaylord et al. 2005, Botsford et al. 2004; Kaplan and Botsford, 2005; see also review by Gerber et al. 2003) in ignoring post-settlement longshore movement by juveniles prior to recruitment to the older population N. This is not a serious issue for species where juvenile nursery habitat is widely distributed along the coast, since for such species juvenile movement just acts like wider spreading of larvae in the first place (we could account for it by increasing the S parameter in eq. A3). But for species that depend on very restrictive nursery habitats (e.g. estuaries) from which juveniles fan out to occupy other habitats as part of their ontogeny, we really should include calculations of pre-recruit juvenile movement using the same approach as eq. A3 but applied to the survivors from density-dependent mortality effects in the restricted nursery areas. The age-structured model in Appendix B allows for fully age-dependent movement rates.

The above formulation allows for variation among species in the following basic life history parameters:

M-natural longevity (annual natural mortality rate)

m-adult diffusive movement rate between cells (per year)

F-base (and policy) fishing mortality rate (per year)

S-larval dispersal distance (standard deviation of normal settlement curve, mi.)

K-compensatory improvement in juvenile survival at low stock sizes.

Equations (2)-(5) can be easily solved for equilibrium N_i patterns given these life history (and exploitation) parameters, in a spreadsheet format that calculates successive estimates from previous trial estimates: use last trial estimates of all N_i to calculate L_i using eq. (3), then calculate $r(L_i)$ using eq. (4), then substitute this estimate of $r(L_i)$ into equation (2) to obtain updated estimates of the N_i; repeat these steps until the N_i stop changing. Note that this iteration produces numerical "chatter" in the predicted spatial distribution for high m values (>5/yr); this can be corrected by setting the N_i for each iteration to w times the updated estimate from the equations, plus (1-w) times the estimate from the previous iteration, where the "relaxation weight" w is less than 1.0 (values like 0.8 usually work well, but result slower convergence of the estimates).

The only major population dynamics factors that are not represented in the above equation system are (1) changes in mean larval production per adult with changes in age-size composition, i.e. increases in mean fecundity per N_i in spatial cells that have lower total mortality rates $M+F_i$; and (2) spatial variations in juvenile and adult habitat capacity, as might be reflected in spatial variation in the juvenile carrying capacity parameter β and in adult dispersal rate m (higher dispersal rates out of areas with relatively poor habitat). It is not difficult to model spatial variation in mean fecundity with variation in $M+F_i$ for species that are not highly dispersive (low movement rates m), and omitting this variation results in somewhat conservative predictions about the benefits to larval production of reducing local mortality rates (when dispersal rates are high, mean fecundity cannot increase in protected areas since loss of older animals into fished areas prevents the development of a "natural" age structure; only relatively small, e.g. 5%, annual emigration rates are enough to substantially lower mean fecundity for long-lived species). We have tested variable fecundity versions of the model for the species shown in Fig. 1, assuming fecundity proportional to the ratio of numbers per recruit to unfished numbers per recruit (mean fecundity declines with decreasing survival rate in rough proportion to this ratio), and found no substantial change in the basic predictions. It is likewise simple to model variation in nursery capacities (β) among cells, and movement rates m.

When using the model to evaluate MPA proposals that involve closing a large proportion of the cells to fishing (by setting F_i for those cells to zero or to some lower predicted poaching rate), a key consideration is what to assume about fishing effort displaced from the cells after closure. One simple option is to assume historical F_i, which amounts to assuming that total fishing effort will be reduced so that the F_i in each remaining cell does not increase. A more realistic option is to assume that displaced effort is spread across the remaining open cells, so that F_i for each cell changes from a base value F_o to a higher value

$$F_i=F_o/(1-c) \qquad \text{(A.6)}$$

where c is the proportion of the cells closed to fishing under the proposal. A still more realistic option would be to use a gravity or multinomial logit model to predict spatial redistribution of fishing effort, so as to recognize likely concentration of fishing effort near MPA boundaries where abundances are enhanced by "spillover" effects of movement rates m.

For simple policy screening exercises involving general comparisons of how well alternative MPA proposals are likely to perform at enhancing abundances of animals with a range of different life histories (M, m, S, F, K values), it is probably best not to complicate the comparisons by including variations in spatial habitat and effects of increased longevity/fecundity. In simple game-playing exercises where we have varied the life history parameters widely, we have found that predictions are typically not particularly sensitive to the longevity (M), adult movement (m), and larval spreading (S) parameters except in evaluations of very small MPAs (<3 mi wide). Instead, the most critical parameters for predicted performance are the historical fishing rate and recruitment compensation parameters F and K. These are exactly the same parameters that are most critical in comparisons of fisheries harvesting policies in general, using standard stock assessment models.

Two extensions of the basic model can be used to generate considerably more realistic scenarios for particular species. First, spatial variation in fishing effort can be predicted with a multinomial logit (gravity model) based on the assumption that average "utility" of each area to fishers is proportional to the logarithm of abundance in that area. This leads to the spatial effort or fishing mortality allocation model

$$F_i=F_{total}N_i^{1/v}C_i/\Sigma_j N_j^{1/v}C_j \qquad (A.7)$$

Here v is a "standard deviation" among fishers in perception of the utility of fishing in cell i compared to other areas (higher v spreads effort more evenly along the coast), Ftotal is the total number of spatial cells times the base assumed fishing rate F_o per cell, and C_i is set to 1.0 for cells that are open to fishing and to 0 for closed cells. Second, spatial variations in habitat "quality" or carrying capacity among cells can be represented by variation in dispersal rates and recruitment carrying capacities. For each cell, assume that relative habitat quality can be represented by a 0-1 index value h_i, where $h_i=1$ represents the best quality habitat and $h_i=0$ represents completely unsuitable habitat. A simple way to estimate the h_i is to examine distributions of fishing effort, since effort is likely to be concentrated in cells with higher habitat quality and fish abundance. Then we simply multiply the recruitment α for each cell by h_i in predicting recruitment, and further assume that emigration rates (m's out of the cell) increase to m/h_i for cells with low h_i while immigration rates (m's into the cell) decrease to him for cells with low h_i.

An improved numerical procedure is necessary to solve for the equilibrium N_i for the "full" model with spatially varying effort and habitat quality, since for such cases the simple iterative procedure described above is likely to either converge very slowly (hundreds of iterations required) or to "chatter" so as not to converge at all. The following procedure converges very rapidly (10-20 iterations) for most parameter combinations. First, set the N_i to initial, trial values $N^{(1)}_i$, e.g. $N^{(1)}_i=Ro/(M+Fo+2m)$. Then (2) use these estimates to solve eq. (3)-(6) for larval production, recruitment rates, and spatial F_i (setting F_i for closed areas to zero). Next, (3) treating the resulting recruitment and F estimates as fixed constants, solve a tridiagonal equation system for equilibrium N_i, where each equation in the system is given by $r(L_i)=MN_i+F_iN_i+2mN_i-m(N_{i-1}+N_{i+1})$. This results in a vector $N^{(eq)}_i$ of new N estimates. Then (4) combine these with the previous estimates using a relaxation weight W of around 0.9, to give a next iterative estimate $N^{(2)}_i=WN^{(eq)}_i+(1-W)N^{(1)}_i$. Then use these estimates in step (2) to begin another iteration, repeating steps (2)-(4) until the N_i estimates stop changing.

Appendix B. A fully age structured model for evaluation of MPA proposals

This model is a simulation of a completely age structured stock using a spatially structured coastline identical to that used in the model described in Appendix A.

We use the normal age structured model calculating the dynamics before movement

$$N'_{i,a+1,t+1} = N_{i,a,t}(1-u_{i,t}v_a)s_a \quad \text{for } a>1,\ a<n$$
$$N'_{i,n,t+1} = \left(N_{i,n,t} + N_{i,n-1,t}\right)(1-u_{i,t}v_n)s_n \quad \text{for } a = n$$

(B.1) $$E'_{i,t} = \sum_a N_{i,a,t} f_a$$
$$V_{i,t} = \sum_a v_a N_{i,a,t} w_a$$
$$C_{i,t} = \sum_a u_{i,t} v_a N_{i,a,t} w_a$$

Initial conditions are calculated at equilibrium with an initial exploitation rate assumed the same at all areas

$$N_{i,1} = R_\infty$$
(B.2) $$N_{i.a+1} = N_{i,a}(1-u_\infty v_a)s_a \quad \text{for } a>1,\ a<n$$
$$N_{i,n} = N_{i,n-1}\frac{(1-u_\infty v_n)s_n}{\left[1-(1-u_\infty v_n)s_n\right]} \quad \text{for } a = n$$

(B.3) $$R_{i,t} = \frac{E_{i,t}}{a + bE_{i,t}}$$

(B.4) $$S_\infty = \frac{SBPR - a}{b \times SBPR}$$

$N'_{i,a,t}$ number of individuals area i, age a time t before movement
$N_{i,a,t}$ number of individuals area i, age a time t after movement
$u_{i.t}$ fraction harvested area i time t
u_{∞} fraction harvested at initial equilibrium
v_a vulnerability to fishing age a
n oldest age considered
s_a survival from natural mortality
$E'_{i,t}$ eggs producted area i time t before movement
$E_{i,t}$ eggs producted area i time t after movement
f_a egg production age a
g recruitment function (B/H, Ricker etc)
$C_{i,t}$ biomass of catch
$V_{i,t}$ vulnerable biomass
w_a mass at age a
R_{∞} recruitment at equilibrium

the fish are then moved according to a movement probability matrix

(B.5) $$N_{i,a,t+1} = \sum_{j=1}^{n} N'_{j,a,t+1} p_{j,i}$$

(B.6) $$E_{i,t+1} = \sum_{j=1}^{n} E'_{j,t+1} p_{j,i}^{egg}$$

The movement matrix is calculated by assuming that the movement probability has a normal shape centered on the area of origin, the same functional form is used for both the eggs and individuals age 1 and older, they just have a different value of m.

(B.7) $$p'_{j,i} = \exp\left(-\frac{(i-j)^2}{2m^2}\right)$$

which is normalized to sum to one for each donor area.

This same relationship is used for egg and larval dispersal.

(B.8) $$p_{j,i} = \frac{p'_{j,i}}{\sum_i p'_{j,i}}$$

The number of boats in an area is calculated as follows

$$\begin{cases} B_i^{'} = \exp\left[-c\left(1-\frac{V_i}{\tilde{V}}\right)\right] & \text{if area } i \text{ is not in a reserve} \\ B_i^{'} = 0 & \text{if area } i \text{ is in a reserve} \end{cases}$$

(B.9)

$$B_i = B\frac{B_i^{'}}{\sum_i B_i^{'}}$$

These equations cause boats to concentrate in places of highest fish abundance. The larger the value of *c*, the stronger the concentration.

The fraction harvested in each area is determined by the number of boats, the efficiency of boats (*q*) and a scaling factor when regulations reduce the allowable catch (*z*).

(B.10) $u_{i,t} = B_{i,t} q\, z$

(B.11) $TAC_t = \left[s \sum_A V_{i,t} \right]$

where *I* is the intercept and *s* is the target harvest rate for the stock summed over all areas inside and outside the MPA.

If the catch that would occur without regulation is less than the TAC then the regulations have no effect. If the catch that would occur without regulation is greater than the TAC then the catch in each area is reduced proportionally so that the total catch is equal to the TAC by adjusting the scaling factor *z*.

(B.12) $z = \frac{TAC_t}{\sum_i q B_{it} V_{it}}$

In general there are three harvest rates specified, the initial equilibrium harvest rate used to set the population at its initial age structure and abundance, the "rebuilding" harvest rate to be used if the stock is below 40% of its virgin biomass, and finally a sustainable management harvest rate to be used if the stock has rebuilt to above 40% and is now in sustained management. Even if the sustainable management harvest rate drops the stock below 40% of virgin biomass, we do not change the harvest rate.

Appendix C. Documents reviewed in preparing this report

Besides scientific papers cited above and information on specific network proposals that we obtained from the MLPA website (http://www.dfg.ca.gov/mrd/mlpa/centralcoast.html#maps), we used the following documents in preparing this report:

1. California Marine Life Protection Act Initiative Master Plan Framework adopted by California Fish and Game Commission August 22, 2005.

2. Appendices to the Master Plan Framework, California Marine Life Protection Act Initiative Master Plan Framework adopted by California Fish and Game Commission August 22, 2005.

3. NFCC Concensus Statement, Integrating Reserve Science and Fishery Management, June 2004.

4. California MLPA Initiative, Central Coast Project, Adopted Regional Goals and Objectives Package Amended by the Blue Ribbon Task Force, Design and Implementation Considerations, November 2005.

5. California Marine Life Protection Act Suggested Text Revisions to Pages 37-47 of the MLPA Master Plan Framework for Consideration by the Master Plan Science Advisory Team February, 2006.

6. DRAFT Document Rationale for SAT categorization of MPAs by relative levels of protection by Mark Carr, Rick Starr, and Mary Yoklavich. January 2006.

7. California Marine Life Protection Act Initiative draft SAT Summary of Goals 1, 2, 3, 4, and 6. March 2006.

8. California MLPA Initiative Final Draft Adaptive Management and Monitoring and Evaluation Framework. March 2006.

9. Integrating MPA monitoring into Sustainable Fisheries Management. Outline of Presentation to Fish and Game Commission, Dec. 2005 by Donna Schroeder, Chris Hoeflinger, and Chris Miller.

Appendix D. Curricula Vitae for Peer Reviewers

NAME **RAY WILLIAM HILBORN**

EDUCATION

B.A. (Biology) Grinnell College, Grinnell, Iowa (1969)
Ph.D. Department of Zoology, University of British Columbia (1974)

EMPLOYMENT HISTORY

2001-present	Richard C. and Lois M. Worthington Professor of Fisheries Management
1987-present	Professor, School of Aquatic and Fishery Sciences, University of Washington.
1996-1998	Director, Fisheries Research Institute, University of Washington
1985-1987	Senior Fisheries Scientist, Tuna and Billfish Program, South Pacific Commission, Noumea, New Caledonia
1980-1985	Adjunct Associate Professor, Institute of Animal Resource Ecology, University of British Columbia.
1975-1980	Policy Analyst, Departments of Environment and Fisheries, Government of Canada. Concurrently Honorary Lecturer, Institute of Animal Resource Ecology, University of British Columbia.
1974-1975	Research Scholar. International Institute for Applied Systems Analysis, Laxenburg, Austria.

MAJOR PROFESSIONAL ACTIVITIES

2002 – present	Member Editorial Board, Canadian Journal of Fisheries and Aquatic Sciences
2003 - present	Member Editorial Board, New Zealand Journal of Marine and Freshwater Research
1999-present	Member Editorial Board, Fish and Fisheries.
1993-present	Member Editorial Board, Reviews in Fish Biology and Fisheries
1993-present	Member Editorial Board, Natural Resource Modeling.
1999-present	Independent Science Advisor, Commission for Conservation of Southern Bluefin Tuna
2002 – 2003	Chair, National Academy of Sciences/National Research Council Committee on Cooperative Research in the National Marine Fisheries Service
2002 - 2004	Member Scientific Advisory Board for Presidents Commission on Ocean Policy
1999-2001	Member Ocean Studies Board, National Research Council
1996-2000	Member International Committee for recovery of the vaquita (*Phocoena sinus*)
1997-1998	Member National Academy of Sciences Panel on status of New England groundfish stocks.
1997-1999	Member NMFS panel to review fisheries closures to protect Steller's Sea Lions
1996-1997	Member National Academy of Sciences Panel on Fisheries Stock Assessment Methods
1989-1994	American co-chairman: Pacific Salmon Commission working group on mark-recovery statistics.
1988-1990	Editor for Fisheries, Marine Policy Reports.

HONORS AND AWARDS

2005	Elected Fellow of Royal Society of Canada
2005	Recipient of American Fisheries Society 2005 National Award of Excellence
2005	Recipient of Western Division, American Fisheries Society, Award of Excellence
2001-2006	Richard C. and Lois M. Worthington Professor of Fisheries Management
1997	College of Ocean and Fisheries Sciences Distinguished Research Award

1988-1991	H. Mason Keeler Professor of Recreational Fisheries Management.
1985	Stevenson Memorial Lecture, Canadian Conference for Fisheries Research.
1976	Wildlife Society award for best paper in fisheries science. (Adaptive management of renewable resources with C. Walters).
1972-1974	National Research Council Canada. Graduate Fellowship.

BOOKS AND MONOGRAPHS

Punt, A. and R. Hilborn. 2002. Bayesian stock assessment methods in fisheries. FAO Computerized Information Series (Fisheries) No. 12. 56 p.

Hilborn, R. and M. Mangel. 1997. The Ecological Detective: confronting models with data. Princeton University Press, Princeton, N.J. 315 pps.

Punt, A.E. and R. Hilborn. 1996. Biomass dynamics models. FAO Computerized Information Series (Fisheries). No. 10. Rome, FAO. 62p.

Hilborn, R. and C. J. Walters. 1992. Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman and Hall, New York. 570 p. Also available in Russian.

Bazykin, A., P. Bunnell, W.C. Clark, G.C. Gallopin, J. Gross, R. Hilborn, C.S. Holling, D.D. Jones, R.M. Peterman, J.E. Rabinovich, J.H. Steele, and C.J. Walters. 1978. Adaptive Environmental Assessment and Management. John Wiley and Sons, New York. 375 pps.

145 PUBLICATIONS IN REFEREED JOURNALS

.

National Research Council Reports

National Research Council. 2003. Cooperative Research with the National Marine Fisheries Service. NRC Press. 131 pps. Chairman of committee.

National Research Council. 1998. Improving fish stock assessment. NRC Press. 188 pps. Member of Committee.

National Research Council. 1998. Review of Northeast fishery stock assessments. NRC press. 136 pps. Member of committee.

12 Book Chapters

11 Reviews

13 Papers in Peer Reviewed Conference Proceedings and Peer Reviewed Reports

12 Popular Articles

NAME **RICHARD HENRY PARRISH**

PRESENT POSITION: **Retired (**Fisheries Biologist GS-14 (Research))
National Oceanic & Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
Environmental Research Division
1352 Lighthouse Avenue
Pacific Grove, CA 93950-2097
(831)648-9033

DISCIPLINE Fisheries Oceanography

EDUCATION

BA., Zoology, University of California, Berkeley, 1962
MS., Fisheries & Wildlife, Oregon State University, 1966
PhD., Fisheries with minors in Oceanography & Statistics, Oregon State Univ., 1977

EXPERIENCE

Dec 1975 – Mar 2006	Fisheries Biologist (Research) GS-14 Pacific Fisheries Environmental Group National Marine Fisheries Service Pacific Grove, California
May 72 - Jan 74	Manager Scientific Research (Oman Project). Del Monte Corporation San Francisco, California
Apr 69 - May 72	Associate Marine Biologist. Bottomfish Program California Dept. of Fish and Game, Monterey, California
Jul 66 - Apr 69	Assistant Marine Biologist. Pelagic Fish Program California Dept. of Fish and Game,Monterey, California
Sep 68 - May 72	Lecturer San Jose State University Moss Landing Marine Laboratory Moss Landing, California
Dec 62 - Jun 64	Lakes Management Research Officer Victoria Fisheries and Wildlife Department Melbourne, Australia.

RESEARCH INTERESTS

Population Dynamics	Marine Climatology	Commercial Fisheries
Resource Assessment	Fisheries Management	Marine Protected Areas

HONORS AND AWARDS

U.S. Department of Commerce, Lifetime Achievement Award 2005

Ricketts Memorial Lecture Award: For Exemplary Research in Marine Science; 1994 Monterey Bay Research Symposium

U.S. Department of Commerce, Certificate of Recognition: Awarded for authoring a Publication on the Comparative Climatology of Eastern Boundary Currents.

SELECTED SERVICE ON SCIENTIFIC COMMITTEES

1979-81	INP/CalCOFI Modeling Subcommittee.
1981	IOC Committee on Climate Change and the Ocean (CCCO) Biology Panel.
1981-3	IOC/SCOR Ocean Science in Relation to Living Resources (IOC Working Group-67).
1982-9	Chairman: NMFS Task Force on Strategic Planing for North Pacific Albacore.
1983-6	AGU Committee on Climate Variability of the Eastern Pacific and Western North America.
1987	NMFS External Review Committee for the SWFC Groundfish Program.
1993-4	PICES Working Group 3 (Dynamics of Small Pelagics in Coastal Ecosystems).
1993-7	SCOR Working Group 98 Worldwide Fluctuations of Sardine and Anchovy Populations.
1997	STAR Review Team for Widow and Chilepepper Rockfishes: Pacific Fisheries Management Council
1997-00	Coastal Pelagic Species Plan Development Team: Pacific Fisheries Management Council
1999-01	Marine Reserves Drafting Committee, Pacific Fisheries Management Council
	2000-03.1 Master Team: California Marine Life Protection Act, Marine Protected Areas.
2005	Expert Reviewer: Portuguese Sardine Reseach Program, GLOBEC

66 PUBLICATIONS on Climate, Ocean and Fisheries

NAME **CARL J. WALTERS**

FACULTY Graduate Studies/Science

DEPARTMENT & SCHOOL Fisheries Centre/Zoology, University of British Columbia

Present Rank: Professor

EDUCATION

a) **Undergraduate (where, dates, degree(s) received):**
Bakersfield College, Bakersfield, California 9/61 - 9/63, AA
Humboldt State College, Arcata, California 9/63 - 9/65, BS

b) **Special Professional (e.g. Internships, Residencies, Specialty Boards):**
National Science Foundation, Graduate Fellow, 1966-1969

c) **Graduate (where, dates, degree(s) received):**
Colorado State University, Fort Collins, Colorado 9/65 - 8/67, MS
Colorado State University, Fort Collins, Colorado 9/67 - 6/69, Ph.D.

d) **Titles of theses written for graduate degrees (indicate the degree; name and title of main supervisor for each):**
Ms. - Distribution and production of midges in an alpine lake C.S.U., R.E. Vincent
Ph.D. - Effects of fish introduction on invertebrate fauna of an alpine lake C.S.U., R.E.Vincent

e) **Academic awards and distinctions (prior to final degree):**
National Science Foundation Graduate Fellow, 1966-1969
American Fisheries Society, Best Student Paper, 1968
Various Scholastic Honors at Bakersfield and Humboldt State Colleges
Student Body vice-president, Bakersfield College, 1962

PROFESSIONAL EMPLOYMENT RECORD

a) **Teaching, professional or research positions held prior to U.B.C. appointment (indicate rank or title, dates and name of institution for each position held):**
Seasonal Aide, June - Sept. 1963 and 1964, California Dept. of Fish & Game, Bishop, California.
Student Assistant, Sept. 1964 - June 1965, Humboldt State College, Arcata, California
4th yr. Fisheries Biology, Humboldt State, 1964-5 (labs, 1/2 lectures)
Temporary Aide, Jan. 1966 - Sept. 1967, Colorado Game, Fish & Parks Department, Fort Collins, Colorado
Graduate Fellow, Sept. 1967 - June 1969, Colorado State Univ., Fort Collins, Colorado
Consultant, Dec. 1968-1970, Colorado State Univ., Fort Collins, Colorado
Graduate Research Assistant, June 1966 - Sept. 1967, Colorado State Univ., Fort Collins, Colorado

b) **Date of first appointment at The University of British Columbia:**
July, 1969

c) **Rank at which first appointed:**
Assistant Professor

d) **Subsequent ranks including dates of promotion:**
Associate Professor, July 1977
Professor, June 1982

e) **Date of granting of Appointment without Term:**
July, 1974

f) **Principal University and Department teaching and service responsibilities over the last five years:**
Applied Ecology (Biol. 408), Population Dynamics (Zool. 527)
Fisheries population dynamics course (Fish. 505, Zool. 521)
(have bought out teaching for past two years using Pew Fellowship)

PROFESSIONAL ACTIVITIES

a) **Membership in professional and learned societies (including any offices held, committee memberships, etc.)**

American Fisheries Society, AAS (not active)
Associate Editor, Journal of Applied Mathematics and Computation, 1982 - present
Associate Editor, Northwest Environmental Journal, 1985 - 1993
Associate Editor, Environmental Software, 1986 - present
Editorial Board, Canadian Journal of Fisheries and Aquatic Sciences
Associate Editor, Environmental Management, 1995 - present
Editorial Board, Conservation Ecology
Editorial Board, Ecosystems

b) **Academic or professional awards and distinctions:**

Wildlife Society award for best paper in fish ecology and management:
Walters, C.J. and R. Hilborn. 1976. Adaptive control of fishing systems, J. Fish. Res. Bd. Canada 33(1): 145-159.
Fellow of the Royal Society of Canada, Jan. 1998
Pew Fellow in Marine Conservation, 2001-2004
Mote Eminent Scholar, Florida State University and Mote Marine Laboratory, 2001-2002
Murray A. Newman Award for Marine Conservation (Vancouver Aquarium), 2005

c) **Professional service and experience (consultancies, professional committees, commissions, visiting professorships, invited lectureships, etc.:**

Member, National Research Council Grant Selection Committee for Population Biology, 1973-1976
Research Scholar, International Institute for Applied Systems Analysis, Vienna, 1974-75 (Deputy project leader for ecology project involving six scientists)
Adjunct Professor, Department of Zoology, University of Florida, 1989-1991
Consultant to Environment Canada on Policy Planning & Research, 1972 to present
Consultant to Government of US Fish & Wildlife Service, 1977-80
Investigator for the Pearse Commission on Pacific Fisheries Policy, 1981
Advisor on the Board of Technical Experts for the Great Lakes Fishery Commission 1980-82
Director of Environmental & Social Systems Analysts Ltd. 1980-82
Research Scholar & Project Leader for Adaptive Resource Policy Project, International Institute for Applied Systems Analysis, Vienna, 1982-83
NSERC Strategic Grants Committee, Open Area (1984-87, Chairman 1985)
NSERC Interdisciplinary Operating Grant Committee, 1992-1994
Council Member, Pacific Fisheries Resource Conservation Council, 2001-2004
Research Project Leader, stock assessment, Mote Marine Laboratory, 2004 to present
Adjunct Professor, Fisheries and Aquatic Sciences, University of Florida, 2005-present

d) **Other public service:**

Extensive fisheries advisory work for public agencies and industry groups.

RESEARCH AND PROFESSIONALLY RELATED SCHOLARLY AND CREATIVE ACTIVITIES

a) **Areas of special interest and accomplishments in discipline:**

I have been heavily involved in the development of rapid techniques for teaching systems analysis and mathematical modelling to biologists and resource managers, using problem-oriented workshops and seminars. I have conducted over two dozen three to ten day workshops in the past ten years, first for the International Canadian Fisheries Service, US Fish and Wildlife Service, and the International Institute for Applied Systems Analysis.

My main research work now is on the theory of harvesting in natural resource management. I have published on applications of stochastic optimal control theory to the analysis of populations in variable environments, and my chief interest is in the basic problem of how to behave adaptively in the face of extreme uncertainty.

I also maintain an active field research program on the responses of aquatic communities to disturbances such as removal of selective species by introduced fish populations and enhancement of productivity through fertilization.

PUBLICATIONS RECORD

a) 179 Publications or original works

Books

*Adaptive Management of Renewable Resources. 1986. MacMillan Pub. Co., Inc. N.Y. 374 pp.
*Quantitative Fisheries Stock Assessment and Management. 1991.Chapman-Hall, Pub. Co., New York (Ray Hilborn, Carl Walters), 580 pp.
*Fisheries Ecology and Management. 2004. Walters, C. and S. Martell. Princeton University Press, Princeton, 399p.

b) 24 Completed and unpublished material including Commission Reports, Discussion Papers or similar material