Ecosystem consequences of MPAs for the Monterey Bay National Marine Sanctuary

Ray Hilborn

Carl Walters

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Introduction and objectives

The purpose of this paper is to evaluate the ecosystem benefits of closing portions of the Monterey Bay National Marine Sanctuary (MBNMS) to fishing by declaring further areas as Marine Protected Areas (MPAs). The MBNMS was established under the National Marine Sanctuaries Act and in order to determine if closing areas to fishing will produce benefits we must examine the objectives of the MBNMS.

The following quote is taken from the "findings of the Act."

> 4) a Federal program which establishes areas of the marine environment which have special conservation, recreational, ecological, historical, cultural, archeological, scientific, educational, or esthetic qualities as national marine sanctuaries managed as the National Marine Sanctuary System will -
> (A) improve the conservation, understanding, management, and wise and sustainable use of marine resources;
> (B) enhance public awareness, understanding, and appreciation of the marine environment; and
> (C) maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas.

It should be noted that "management and sustainable use of marine resources" appear prominently. Further, the purposes of the Act are specified as:

> b) Purposes and policies
> The purposes and policies of this chapter are
> (1) to identify and designate as national marine sanctuaries areas of the marine environment which are of special national significance and to manage these areas as the National Marine Sanctuary System;
> (2) to provide authority for comprehensive and coordinated conservation and management of these marine areas, and activities affecting them, in a manner which complements existing regulatory authorities;
> (3) to maintain the natural biological communities in the national marine sanctuaries, and to protect, and, where appropriate, restore and enhance natural habitats, populations, and ecological processes;
> (4) to enhance public awareness, understanding, appreciation, and wise and sustainable use of the marine environment, and the natural, historical, cultural, and archeological resources of the National Marine Sanctuary System;
> (5) to support, promote, and coordinate scientific research on, and long-term monitoring of, the resources of these marine areas;
> (6) to facilitate to the extent compatible with the primary objective of resource protection, all public and private uses of the resources of these marine areas not prohibited pursuant to other authorities;
> (7) to develop and implement coordinated plans for the protection and management of these areas with appropriate Federal agencies, State and local

governments, Native American tribes and organizations, international organizations, and other public and private interests concerned with the continuing health and resilience of these marine areas;
(8) to create models of, and incentives for, ways to conserve and manage these areas, including the application of innovative management techniques; and
(9) to cooperate with global programs encouraging conservation of marine resources.

Of particular interest are item (2) which suggests the actions of the MBNMS should "complement existing regulatory authorities", in this case the Pacific Fisheries Management Council, and item (6) suggesting that the MBNMS should facilitate public and private use of the resources. There are potential conflicts with item (3) where one interpretation would be that "natural biological communities" would imply communities unaffected by human action including harvesting. Our interpretation is that the term "natural" can best be interpreted as "naturally functioning" and "protect" would imply to protect from non-sustainable human use. Given that establishment of sanctuaries did not include elimination of harvesting, this appears to us to be strong evidence that the act has not been interpreted as requiring ecosystems be maintained in their unexploited state.

Rather we would interpret the current suggestions for the need for no-take areas to arise from the concern that the existing regulatory system has failed to maintain the resources in a sustainable condition, and what is needed is no-take areas to complement existing regulations to achieve sustainable exploitation. We will see in the section below that there is a wide-spread perception that exploitation as currently practiced has not been sustainable, but we will present data later to show that this perception is misguided, and that achieving sustainable use to meet objectives (2) and (6) does not require additional no-take areas.

The history, structure and status of the ecosystem

History

The Monterey Bay National Marine Sanctuary (MBNMS) consists of 5,322 square miles along the central California coast that is imbedded in the California Current Ecosystem. This ecosystem has historically been severely impacted by human exploitation. The first documented impact of Europeans was intensive harvesting of sea otters and fur seals for their pelts and elephant seals for oil in the early 19th century. In the mid 19th century, coastal whaling began, seal lion exploitation continued and seabirds were harvested for eggs. At the end of the 19th century elephant seals were commercially extinct, sea lions depleted, and salmon fisheries were developing as canning technology provided distant markets. In the early 20th century finfish markets opened with the advent of refrigerated rail transport. In the mid 20th century a very large canning industry for sardines was developed, producing for a time one of the largest fisheries in the world. Small-scale fisheries primarily for salmon, crab and shrimp have been prominent features of the ecosystem through the 20th century. In the 2nd half of the 20th century, foreign factory trawlers began to intensively exploit groundfish, and local fisheries exploited shellfish.

In many ways the history of the California Current Ecosystem is typical of 19th and 20th century fisheries, the fisheries were largely unregulated, and market forces allowed most stocks to depleted to a point where they were not economically viable. As new markets or technologies developed there were profits to be made in new fisheries, and these fisheries developed, overexploited the stocks and commercially collapsed. Figure 1 shows the history of removals from this ecosystem (Field and Francis 2006).

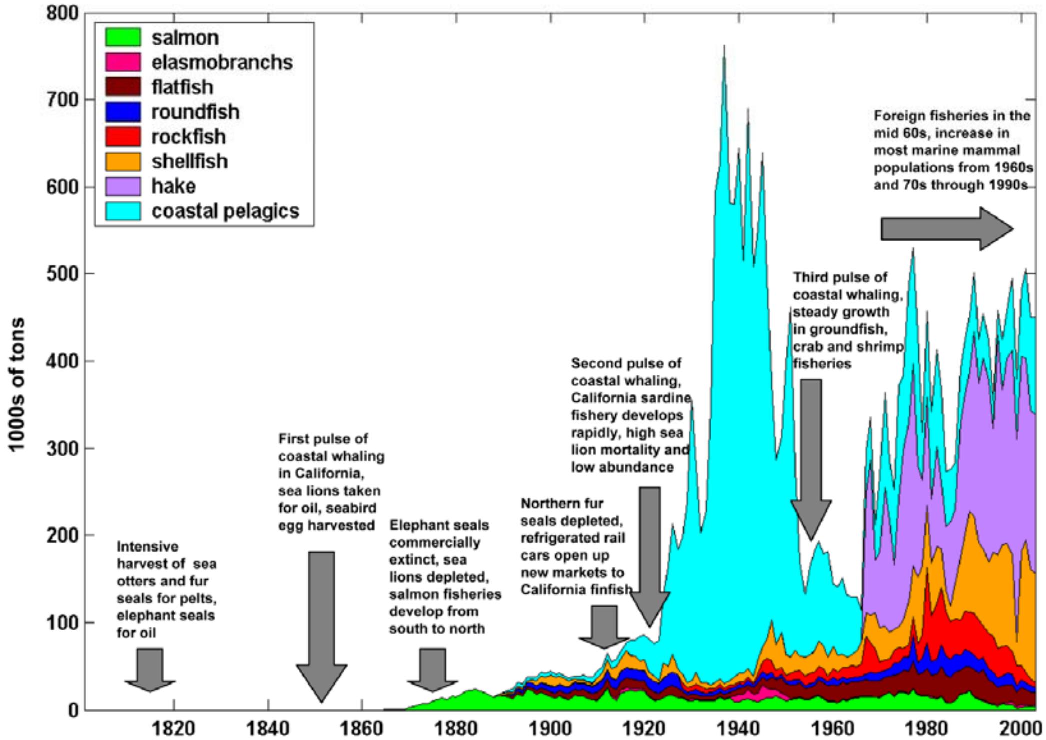

Figure 1. History of removals from the California current ecosystem (Field and Francis 2006).

This history has led to a generally pessimistic view of the state of this ecosystem. The following quote reflects the most common perception of the California Current.

> In the California Current, many fish populations and the communities that depend upon them are in a state of crisis. Many long-lived, slow-growing groundfish have become severely depleted due to overharvesting, and obligatory rebuilding plans suggest that some stocks could take many decades to recover. The condition of several stocks is so poor that the Pacific Fisheries Management Council (PFMC) found it necessary in 2003 to close the majority of the continental shelf to most fishing, an action that has resulted in dramatic

> impacts to fishermen and fishing-dependent communities. Salmon crises, driven by a complex combination of natural and anthropogenic factors, have been ongoing in the Pacific Northwest for decades, although recent changes in ocean conditions have boosted production in some regions to record levels. Fisheries for highly variable coastal pelagic populations could be entering a new phase as well, as some stocks may have recently entered into a period of low productivity. (Field et al. 2006)

As we will see in the sections below, there is general consensus that the salmon crisis and concern about the pelagics are largely unrelated to fisheries harvesting. For salmon the primary concerns are freshwater habitat and survival. For the pelagics the driving forces are natural changes. No one suggests that any no-take areas in the MBNMS could have any impact on the salmon or pelagics. The primary concern about fishing has focused on a range of groundfish stocks, primarily rockfish. We will see in the section below, and in an earlier section of this report, that the management actions have already been taken to rebuild these species, that the groundfish community as a whole has not been overfished, and that further no-take areas in the MBNMS would not make a significant contribution to rebuilding of overfished stocks.

Structure of the ecosystem

The structure of the California Current Ecosystem is shown in Figure 2 below (from Field and Francis 2006). The size of the boxes and the width of the bars connecting various boxes are scaled to the log of the standing biomass and biomass flow, respectively. Colors represent alternative pathways, with those derived from euphausiid shown in blue. Data on abundance trends are available for the major species that are of commercial value. The notable exceptions where there are no estimates of abundance trends are the major mesopelagics and “benthic fish”, none of which are significantly exploited.

For the commercially important fish species Figure 3 shows the estimated average unfished biomass. The ecosystem is dominated by Pacific whiting (hake), sardine, jack mackerel, anchovy and pacific mackerel. The groundfish constitute only 12% of the unfished biomass, and yet that is where almost all the concern about fishing impacts on ecosystem function has been directed. The overfished stocks mentioned in the earlier quote include the species shown in Table 1. Since they were declared overfished most of these stocks have increased significantly, and now canary, lingcod and widow rockfish are well above the level at which stocks are declared overfished, but not yet rebuild to the target levels. For cowcod and yelloweye the stock assessment models predict rebuilding, but with the large scale fisheries closures there are now no ongoing time series to inform the assessments of trends in abundance.

These overfished stocks constitute only 3% of the unfished biomass of the system, and the three stocks that are well below target levels, bocaccio, cowcod, darkblotched and yelloweye only constitute 0.3% of the unfished biomass. So concern about overfishing must concentrate on the specific habitats where these species were particularly important instead of a general concern about the ecosystem as a whole.

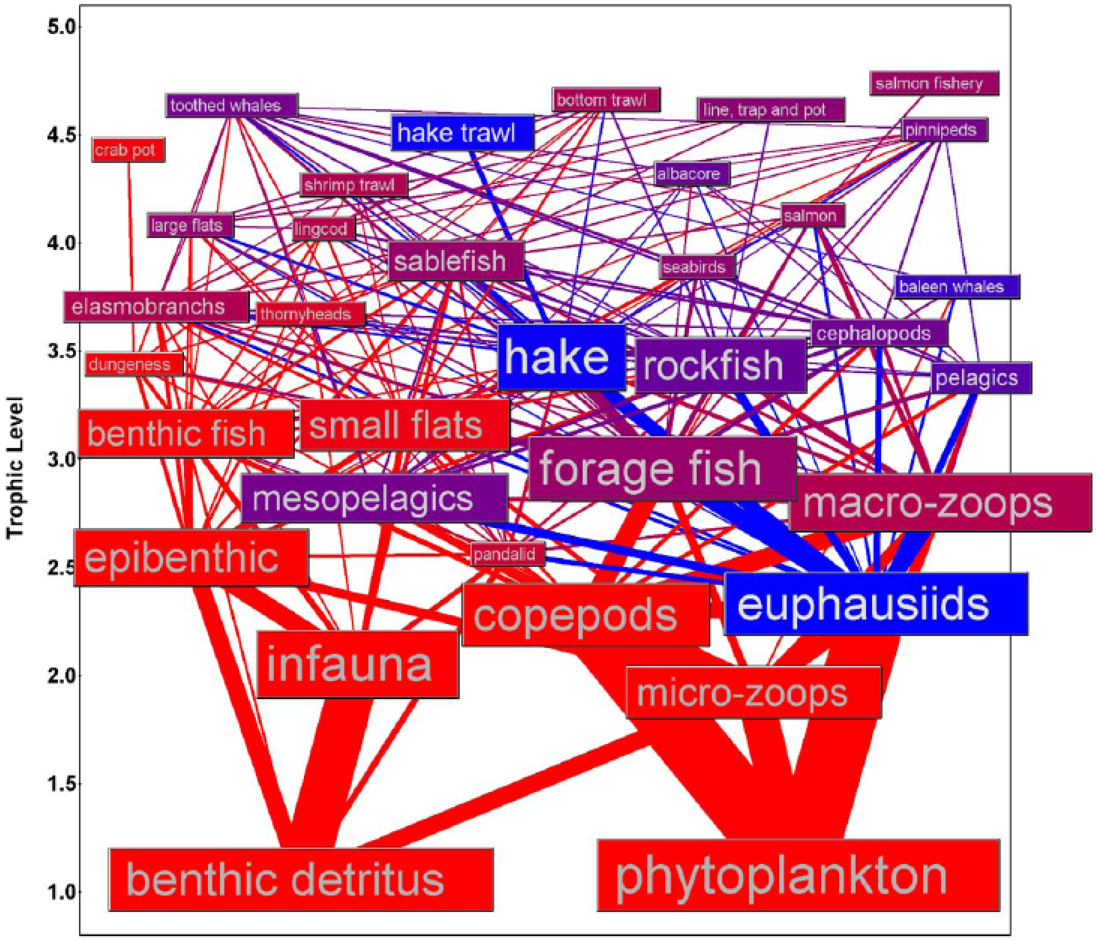

Figure 2. Trophic structure of the California Current ecosystem.

Table 1. Current status of stocks declared overfished.

Stock	Year declared overfished	Current status
Bocaccio	1999	11.0%
Canary	2000	38.0%
Cowcod	2000	17.0%
Darkblotched	2000	17.0%
Lingcod S.	1999	31.0%
POP	1999	23.4%
Widow	2001	31.0%
Yelloweye	2002	17.7%

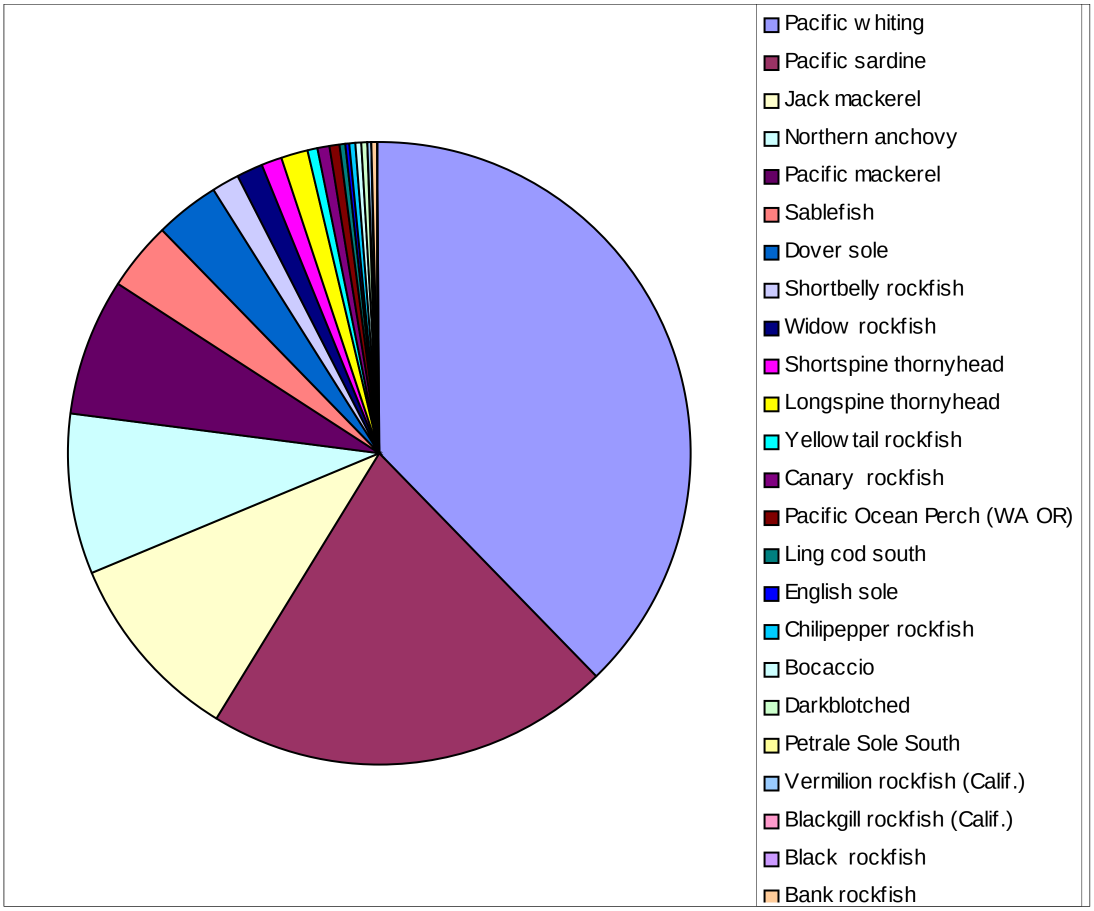

Figure 3. Distribution of unfished stock sizes for major pelagic and groundfish species in the California Current ecosystem

Our understanding of long term trends and status of elements of the ecosystem is highly variable. The history of several of the most abundant stocks, sardines, anchovy and hake have been reconstructed from scale records in anoxic sediments and some of these data are shown below.

When these data were first published they caused a minor revolution in the world of fisheries, which had largely accepted a theoretical framework in which it is assumed that in the absence of fishing the marine communities were in a general equilibrium, and one would expect, at any time, to find all stocks at their “carrying capacity.” The fact that the California sardine has apparently regularly had periods of very low abundance, prior to any industrial fishing, was a great surprise to most fishery scientists. While some of this variability is due to changes in the spatial distribution of these stocks (Parrish et al. 1989), there is a broader range of evidence that pelagics show high natural variability in several major current systems (Cushing 1982, Jacobson et al. 2001) The key pelagics in the California Current Ecosystem are the sardine, anchovy, mackerel and jack mackerel. These species have been shown to fluctuate dramatically in a number of ecosystems (Lluch-Belda et al. 1989, Lehodey et al. 2006.)

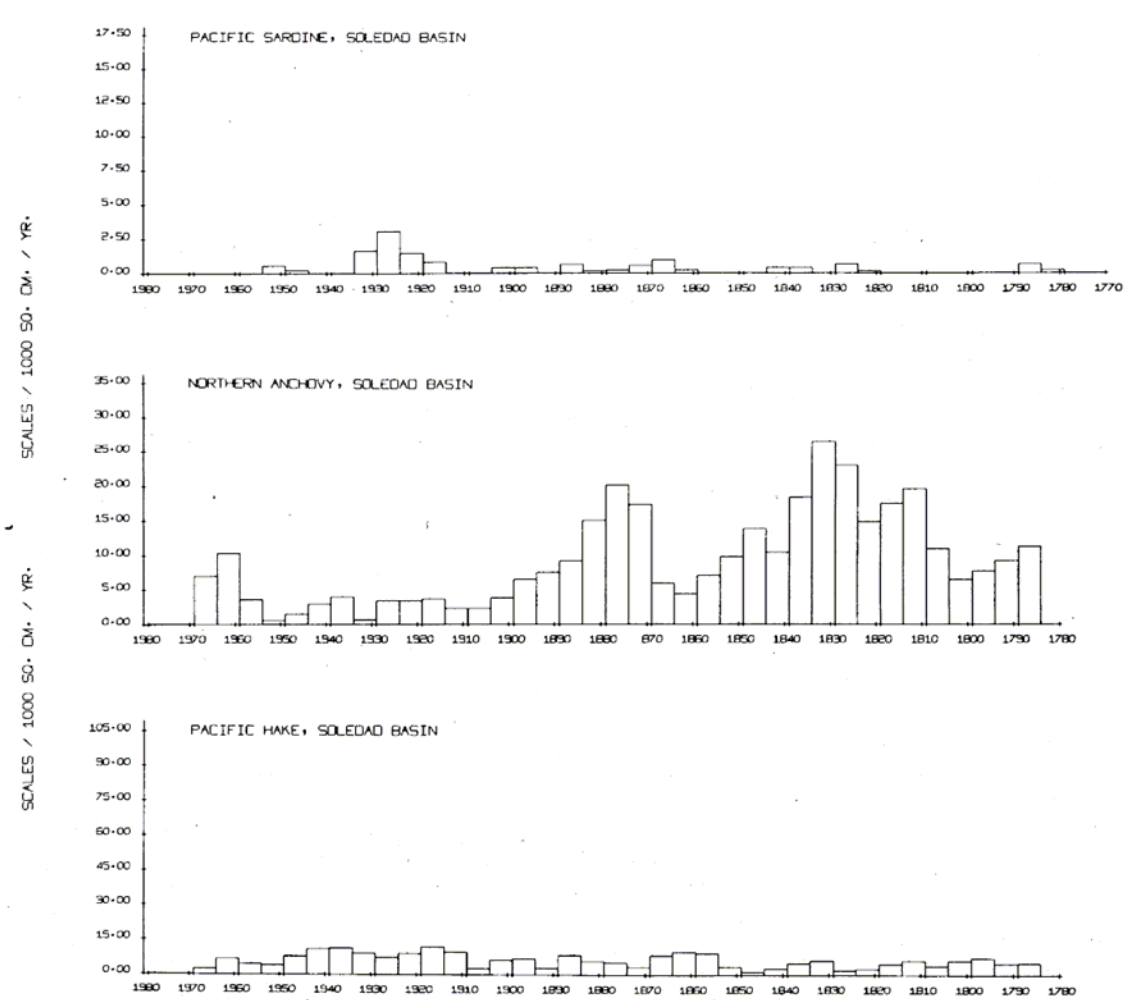

FIGURE 5b.—Histogram plot of the scale deposition rate of the Pacific sardine, the northern anchovy, and the Pacific hake in sediment of the Soledad Basin from about 1780 to 1969.

Figure 4. History of abundance of sardine, anchovy and hake reconstructed from scales deposited in anoxic sediments (by Soutar and Isaacs 1974). Note that the x axis is time and runs backwards, with recent years to the left and the past to the right.

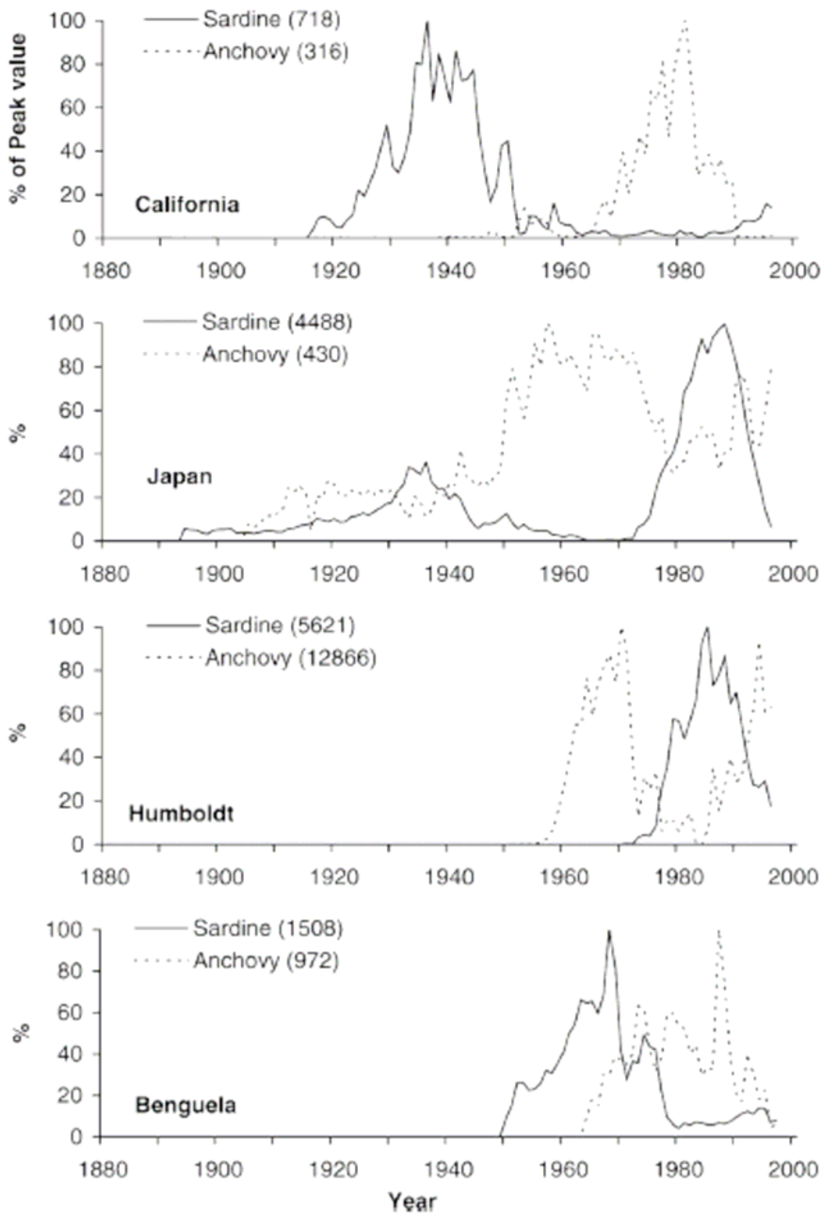

Figure 5. History of pelagic catches in some different ecosystems from Lehodey et al. 2006. Note that catch is likely not a good index of abundance changes for these stocks; peak catches reflect economic development of the fisheries rather than pulses of abundance, but there likely were anchovy increases following each of the sardine collapses.

Other than the scale records, our other primary data source are catches, and abundance reconstructions from stock assessments, based on catch, size and age distribution, and indices of abundance. Figure 6 shows the estimated total biomass of the most significant groundfish species since 1950, scaled to an estimated 2.4 million tons in 1950. We can see that the period 1950 to the late 1990s was one of declining biomass. In the last few years, primarily due to federal limitations on fishing, the biomass has been trending upwards. At the low point the groundfish biomass reached slightly less than 50% of hypothetical unfished value.

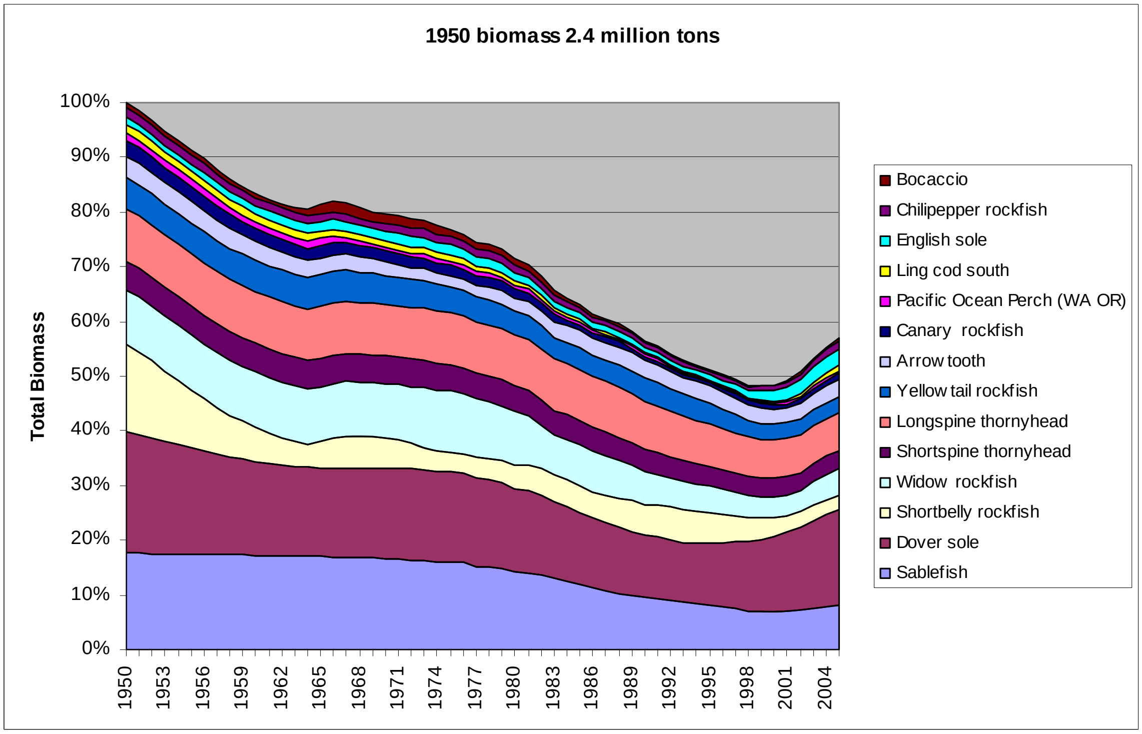

Figure 6. Trends in abundance of groundfish stocks off the west coast of the U.S.

The marine mammal populations in the ecosystem are generally rebuilding, often at near the maximum potential rate of increase. This is shown in Figure 7.

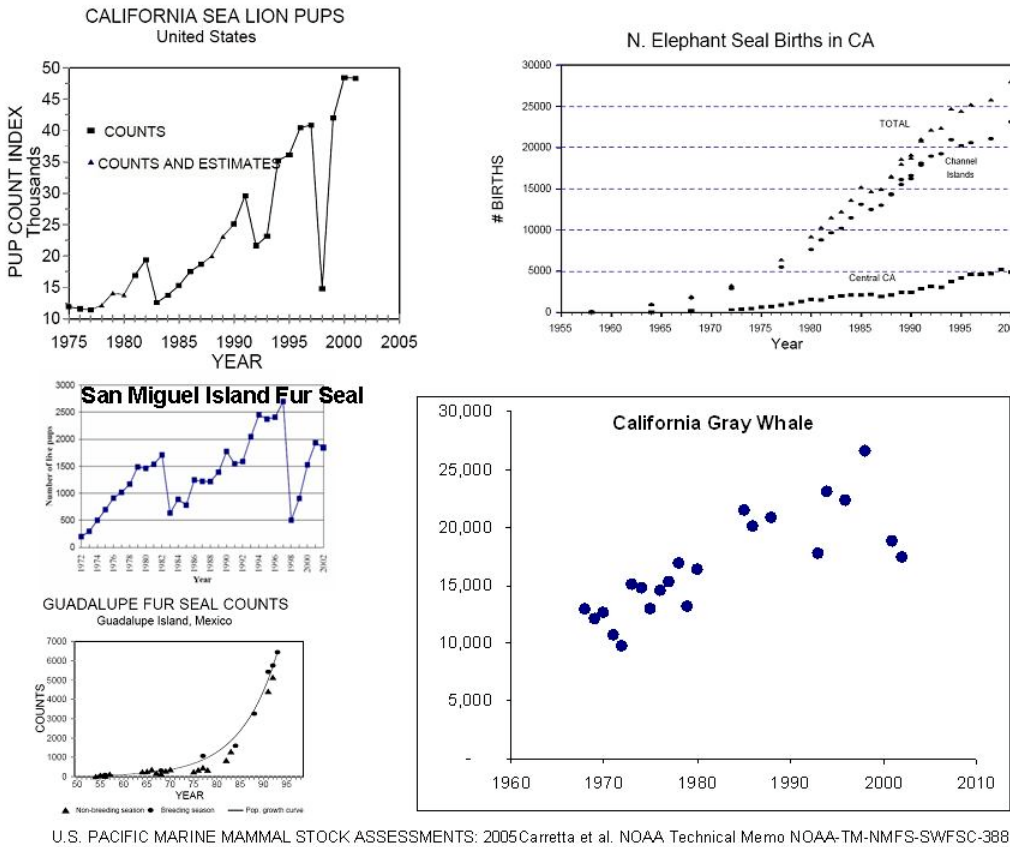

Figure 7. Trends in abundance of some marine mammals in the California current ecosystem

Thus we see that the key elements of the ecosystem that have historically impacted by fishing are recovering under sustainable, conservative management.

Elements of concern in the ecosystem: are protected areas part of the solution?

There are several elements of the ecosystem that have been the focus of concern. Several stocks of salmon are listed under the ESA, and have been the focus of considerable public attention. Because most of the concern of these stocks is about their freshwater life history, and in the marine ecosystem salmon are quite mobile, there is no impact of any proposed MPAs on salmon population dynamics.

Marine mammal populations are generally on the rebound within the ecosystem as a whole and often increasing at rates near their maximum rate of increase. It is difficult to understand how MPAs within the MBNMS would provide significant benefits to marine mammals. Indeed, fisheries have provided enhanced foraging opportunities for species like California sea lions, providing easily caught prey in the form of hooked fish with restricted movement and discards

As discussed in the quote from Field et al (2006) earlier there is concern that the pelagic ecosystem may be entering a new phase of low productivity. This is thought to be driven by physical changes in the ecosystem, and because the pelagic fish are also quite mobile, there are no arguments that additional MPAs within MBNMS would affect pelagics.

The one element of the ecosystem that would be affected by MPAs including those created under the MLPA, is the inshore sedentary fishes, particularly rockfish, and several of the overfished rockfish are in this category.. The status of these species was discussed in the Parrish section of this report, and ecosystem impacts are considered in the next section. Because further no-take areas within the MBNMS would encompass only the federal waters, little shallow rocky habitat would be included because of the closeness of the continental shelf to the coast.

It may be that there are special habitats within MBNMS that deserve special protection. Such areas would be characterized by unique ecological communities that are not represented in protected areas elsewhere. Our understanding is that the Davidson Seamount may be such an area that will be included in the MBNMS, and if brought into the MBNMS it would be protected as both a no-bottom contact gear and no extractive use under the PFMC EFH classification. Other areas may exist and would need to be identified and considered on a case by case basis. None of the proposals we have seen have identified such areas, but rather have generally repeated the mantra that fisheries management has failed and new closed areas are needed. If such areas are identified, it would be appropriate to carefully define what types of exploitation would impact the unique features. For instance, it is likely that it would be characteristics of the benthic ecosystem that were judged unique, and pelagic fishing might be compatible with protection of the benthic communities.

Impacts of MPAs within MBNMS

Model evaluation of effect of MPAs

The key scientific question regarding potential implementation of further fisheries closures within MBNMS is what will be the consequences to the ecosystem and the fisheries. How will the abundance of the various elements of the ecosystem change, and how much of the catch would be lost? There are two possible approaches to this question, reliance on empirical data from closures elsewhere, and use of models to evaluate expected consequences using best current scientific information. The NOAA Strategic Plan discusses the role of models as mandated by NOAA.

There is reasonably limited empirical data that is taken from this region. There are a few small areas that have been closed to fishing for a long time; the Channel Islands MPAs have only been in effect for a few years, and the Central Coast MPAs, including those within the MBNMS have just been implemented. Drawing on experience around the world it would be expected that heavily exploited species that are sedentary would be expected to increase in abundance inside of the protected areas. We would not expect major changes in abundance in unfished species or those who have movement rates high relative to the size of the protected areas.

We have constructed a spatially explicit simulation model of the ecosystem using the software "EcoSpace" drawing on the non-spatially explicit version of "EcoSim" constructed by Field et al. (2006). Figure 8 shows the key elements in this model, which is essentially the Field et al. model with some groups omitted or aggregated and with age-structured (multstanza) population models added for key inshore species. The abalone, nearshore rockfish and lingcod represent the inshore stocks that could potentially benefit from protected areas. While many of these species have been addressed both in the section on single species management, and in the State's MLPA program, we explore the impact of closed areas through trophic connections. Thornyhead, shortbelly rockfish and widow rockfish are all too mobile and have habitat preferences for deeper water so that there is no realistic expectation of any impact of protected areas.

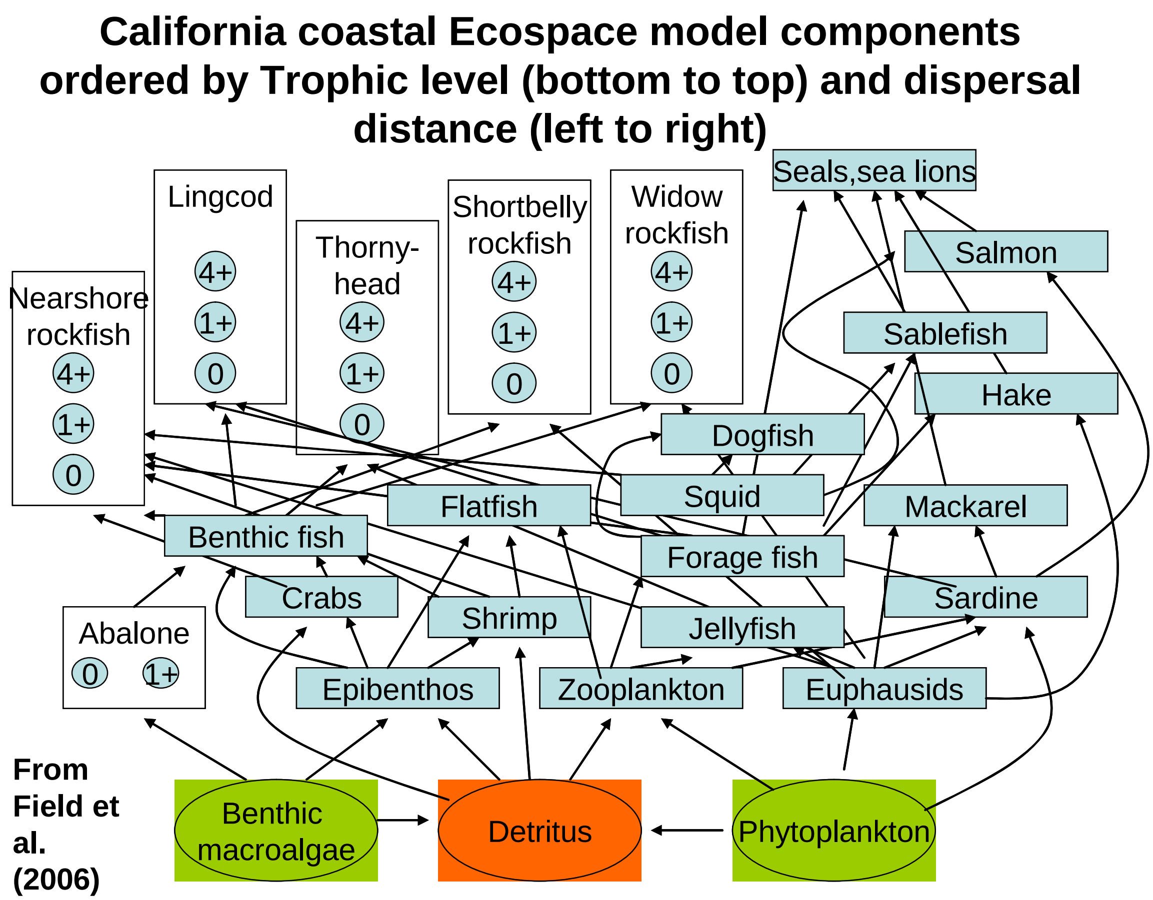

Figure 8. Key elements in the EcoSpace model. Boxes with circles inside represent populations where Ecospace biomass dynamics equations are replaced by monthly age-structured population dynamics accounting (growth, survival, recruitment).

The key elements of the Ecospace model are:

- Ecospace replicates the food web structure in each model grid cell. 2 x 2 mi. cells, out to 500m depth (shelf edge), although the trophic structure considers the entire ecosystem including thornyheads which are predominantly found on the slope.

- Each cell has a habitat "type" (shallow rocky, deep rocky, shallow mud/sand, deep mud/sand, estuary), species use one or more types

- Dispersal and ontogenetic habitat shifts among cells

- Spatial variation in productivity

- Spatial movement of fishing efforts dependent on total profitability

- Cells designated as MPAs can be selectively open to some fisheries

For the species represented by multi-stanza age structured population models, each stanza (range of ages) can be assigned distinctive:

- Total mortality rate Z, varying with stanza-specific predation rates

- Prey and habitat preferences (diet composition, distribution)

- Behavioral tactics: respond to changes in food availability by changing growth rate and/or activity and associated predation risk Total mortality rate Z, varying with stanza-specific predation rates

- Prey and habitat preferences (diet composition, distribution)

- Behavioral tactics: respond to changes in food availability by changing growth rate and/or activity and associated predation risk

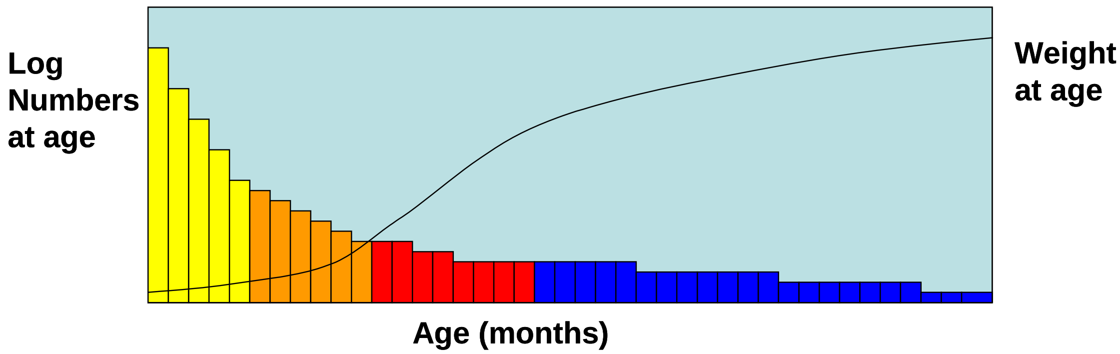

Figure 9. Representative age structured abundance and growth pattern of a Ecospace component represented by multi-stanza submodel. Colors represent different stanzas for a typical rockfish..

Total fishing effort is provided to Ecospace as a forcing time series or scenario. At each simulated time step, this total effort is allocated over model grid cells using a "gravity" model (logit choice model with log utility for total profitability), where each cell's proportion of the total effort is its total profitability per unit effort (sum of biomass densities x catchabilities x prices) divided by the sum of such profitabilities over all cells. Cells that are designated as MPAs are set to have zero profitability. In the demonstration scenarios, we deliberately decreased total fishing effort after 2006 in order to account for regulations (e.g. trip limits, reduced TACs) intended to reduce impact of effort shifts inshore following implementation of RCAs. Without such reductions, the gravity effort allocation model predicts massive increases in inshore effort, which has not apparently occurred at least as evidenced by changes in catches of inshore species. Note that the model includes all major fisheries (hake, crab, etc. in addition to rockfish). Fishing efforts for these species were treated as constant over time, but were subject to spatial reallocation under RCA/MPA policies, the same as for targeted fishing for rockfish.

The complete Ecosim/Ecospace model used in this analysis, with all parameters, including spatial habitat maps and assumed MPA cells, is available on request from the authors as an Ecopath database (California.mdb). The Ecopath 5 or 6 software is required to access this database. Note that model users can easily test effects of alternative parameter values (e.g. spatial movement distances, trophic interactions) and policies (MPA locations) by running the model interactively using the Ecopath software.

Using the non-spatial Ecosim model, predictions are fit to historical assessment data (Figure 10) to insure trophic interaction, growth, and survival parameters imply realistic response to changes in fishing mortality.

For reconstruction of the historical pattern up to 2006, we used the estimated historical effort rates that led to the stock declines through the late 1990s and then the stabilization in the last decade. The Ecospace model considers effort and species specific vulnerabilities to effort. As areas are closed effort shifts and the species are differentially impacted. For instance, when the rockfish conservation areas are put in place in recent years, some effort moves inshore. In the model runs when MPA's are put in place, this causes some effort to move offshore.

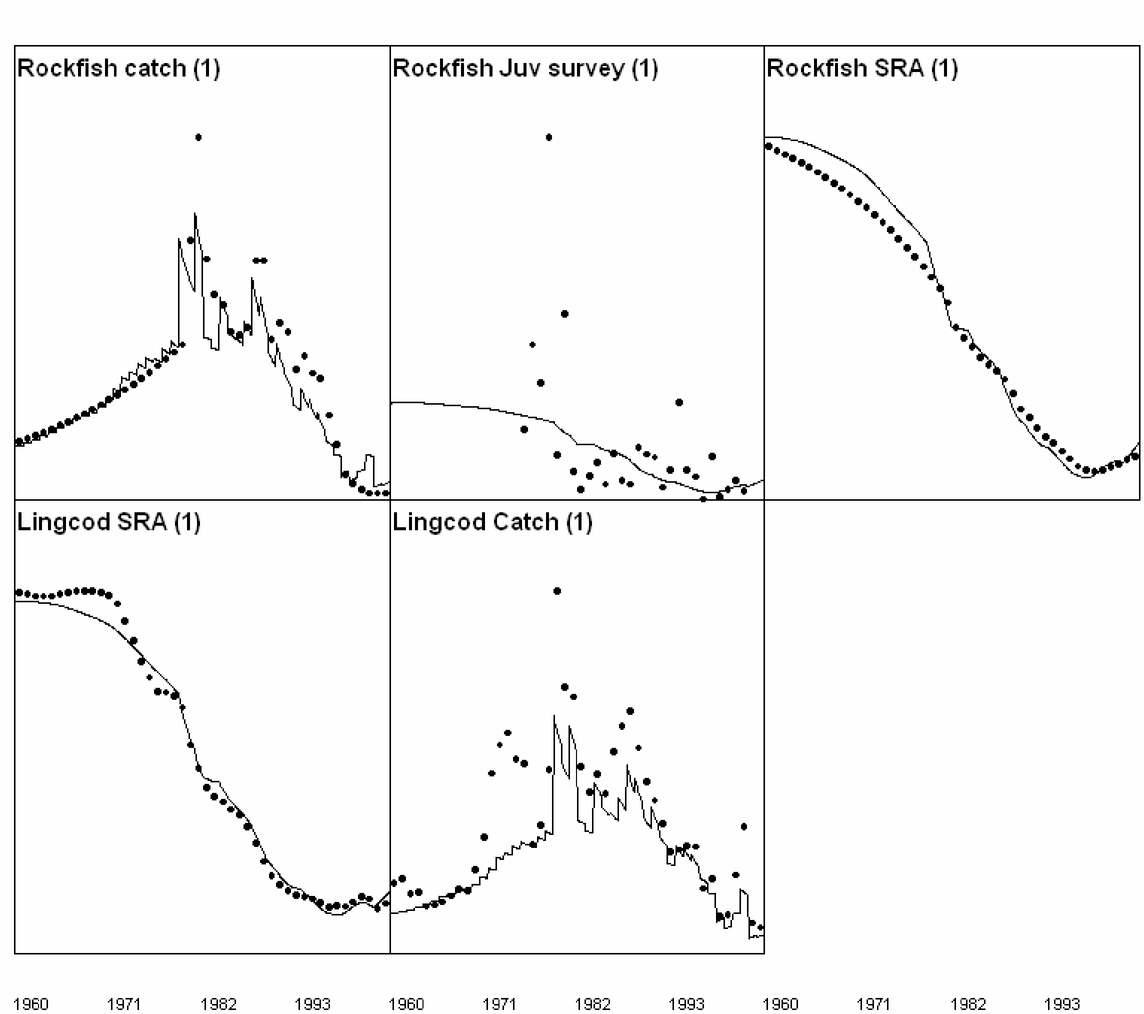

Figure 10. Model fits to historical catch and survey data with each dot representing data and each line representing the model fit. The five panels are rockfish catch (top left), rockfish juveniles (top middle), rockfish adult abundance (top right), lingcod abundance (bottom left), and lingcod catch (bottom middle).

To consider the trends in the future we then ran two scenarios/ First, that effort remains low as is currently the case, or that effort rebuilds to the high levels that led to the declines of the past. Within each of these effort scenarios we explored 4 cases, (1) no protected areas, (2) RCA's only as implemented by the PFMC, (3) RCAs plus 20% of habitat in MPA's and (4) RCAs plus 50% in MPA.s These overall results for specific indicator groups are shown in Table 2. As more protected areas are added, the sedentary and inshore lingcod and nearshore rockfish increase. The more mobile widow, shortbelly and thornyheads decrease because more effort moves to the deeper waters.

Shortbelly was treated as having low fishing mortality rate over the whole simulation, with some depletion coming from incidental fishing impacts (as measured by historical catches; the species has not been "unfished"). We assume catchabiltiy and value of the species will not change into the future. The modeled declines are due to incidental fishing, not to changes in trophic interactions

These runs are for the spatial arrangement of proposed North Central coast MPAs, but the trophic structure of the ecosystem is the same and we use this model to explore how the trophic connections would interact with protected areas.

Table 2. Biomass ratios (2026/2006) predicted by Ecospace for California North Central Coast model

	Efforts remain at 2005 (low) levels				Efforts rebuild to 1980 (high) levels			
Indicator Group	No protected areas	RCAs only	RCAs plus 20% MPA	RCAs plus 50% MPA	No protected areas	RCAs only	RCAs plus 20% MPA	RCAs plus 50% MPA
Lingcod	1.34	1.15	1.27	1.47	0.79	0.60	0.82	1.09
Thornyhead	1.87	2.37	2.47	2.46	1.11	2.00	2.12	2.18
Shortbelly rockfish	1.23	1.44	1.42	1.27	0.97	1.26	1.26	1.23
Nearshore rockfish	1.73	1.53	1.66	1.83	1.03	0.94	1.15	1.37
Widow rockfish	3.42	4.16	4.06	3.55	1.85	3.26	3.21	3.10

The key overall results are

- Slow recovery of long lived species under all policies
- Negative impact of RCAs on inshore species (lingcod, nearshore rockfish) as effort is shifted from deeper waters to inshore areas that remain open
- High inshore protection does not guarantee higher protection for offshore species (shortbelly, widow rockfish)
- Even low dispersal rates coupled with high fishing mortality outside MPAs will result in high enough cumulative mortality to prevent natural population age structure.

Hopes by some biologists that MPAs could lead to the restoration of near unfished age structure are unrealistic given the movement of these species. The age structure will be much more “natural” if the fisheries effort regulations of the PFMC succeed, than if MPAs are implemented and fisheries exploitation rates return to where they were in the 1980s.

MPAs will either not reseed adjacent areas (self-seeding), or else suffer impaired recruitment due to lack of larval sources from outside MPAs (unless fisheries outside are managed effectively). MPAs simply will not ensure against management failure.

Another way to look at these results is shown in Figure 11 in which the Y axis is total biomass cumulative across elements of the ecosystem, showing all of the commercially fished species. In this scenario the projections are for current low levels of fishing effort with no protection from new MPAs. We can see that with these fishing mortality rates (very low) the overfished components of the ecosystem are expected to rebuild over the next 40 years.

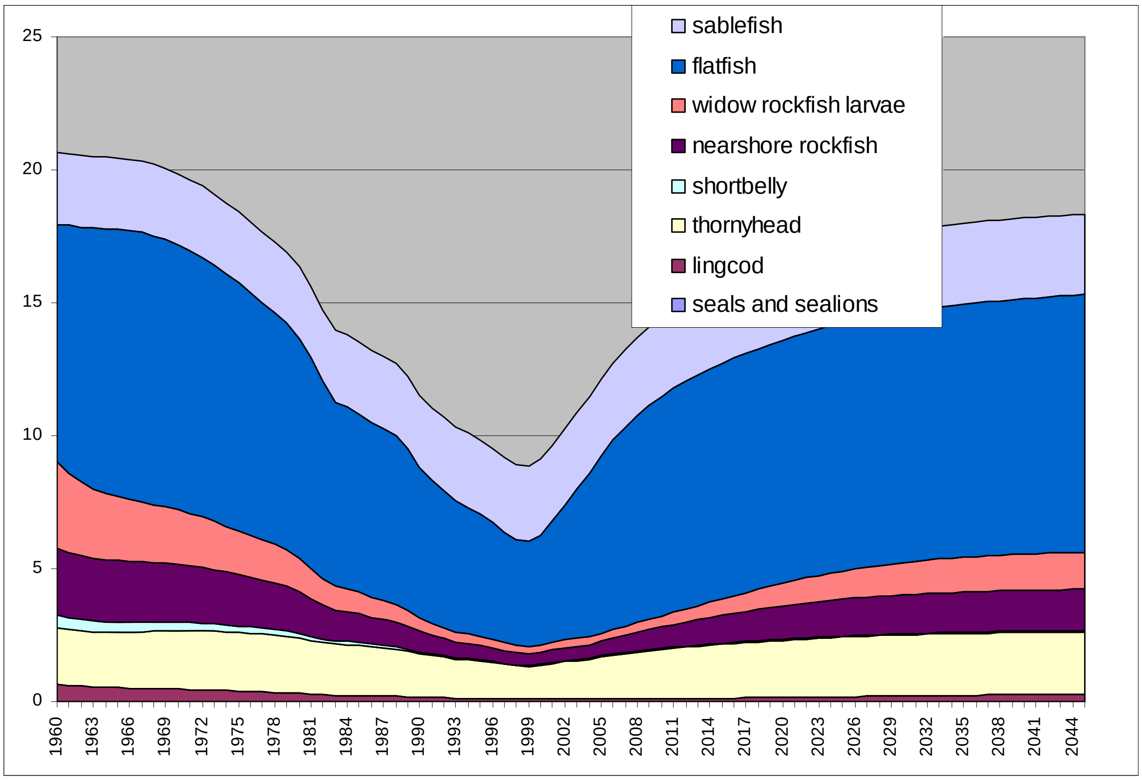

Figure 11. Projected biomass under the assumptions that fishing mortality remains low in the future and no MPAs are added.

In contrast, Figure 12 shows what happens if fishing mortality rates in the future increase again to the levels they were in the 1980s, and no MPA protection is implemented. We see the recovery that occurred between 2000 and 2008, but then some declines after that. We see continued decline of the move vulnerable rockfish stocks, and the situation staying generally similar to what it was like around 2000.

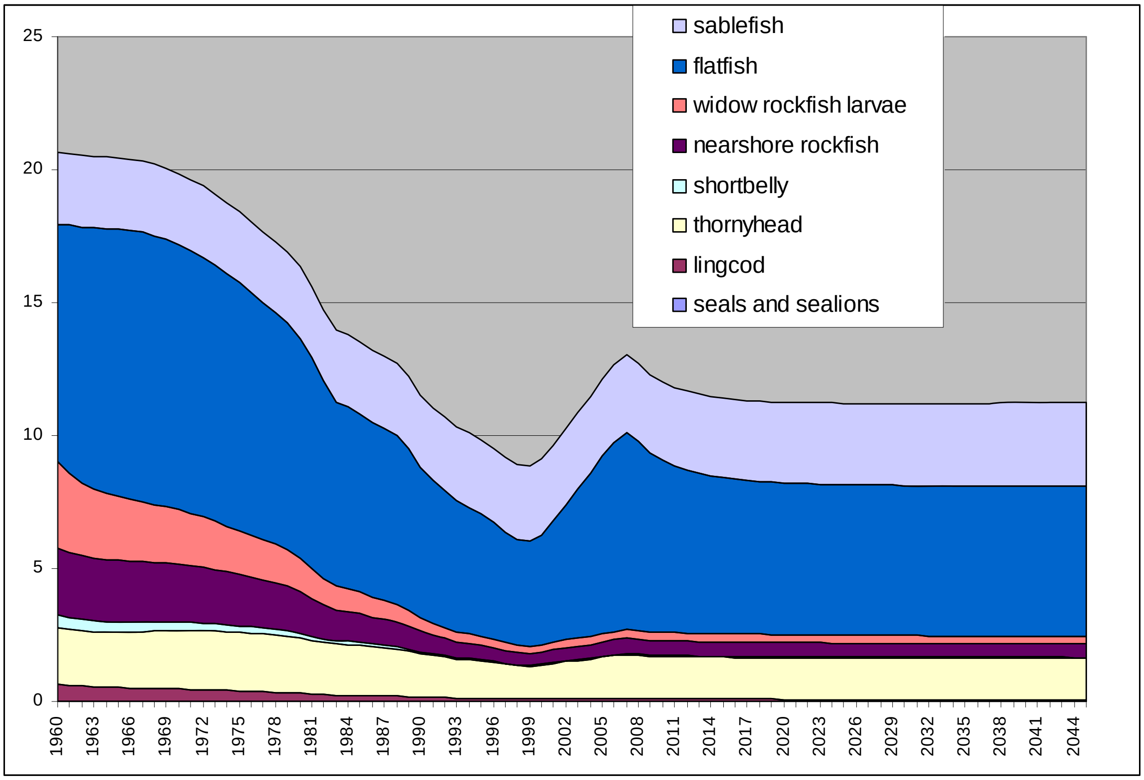

Figure 12. Projected future biomass under the assumption that fishing mortality returns to the high levels in the 1980s with no significant additional protection.

In Figure 13 we explored a scenario in which RCA's were in place over the entire period, MPAs put in after 2006, and fishing effort increases after 2006. We see that by 2006 the ecosystem would not have been as depleted by 2006 as in the previous two scenarios in which the RCA protection was not in place prior to the 2000's. Ecospace predicts that RCAs would have substantially prevented historical overfishing, hence will likely do so in the future if they are maintained However, in the future the results would be in between the two previous scenarios. The RCAs and MPAs are not as effective at rebuilding stock size as was maintaining low fishing effort as seen in Figure 11.

Returning to Table 2 we see that the dominant driver of the abundance of key species of the ecosystem is the fishing effort, and that conservation of the ecosystem depends primarily on regulation of catches and effort. The effects of additional MPAs are small differences in abundance compared to the impact of the effort level or the RCAs.

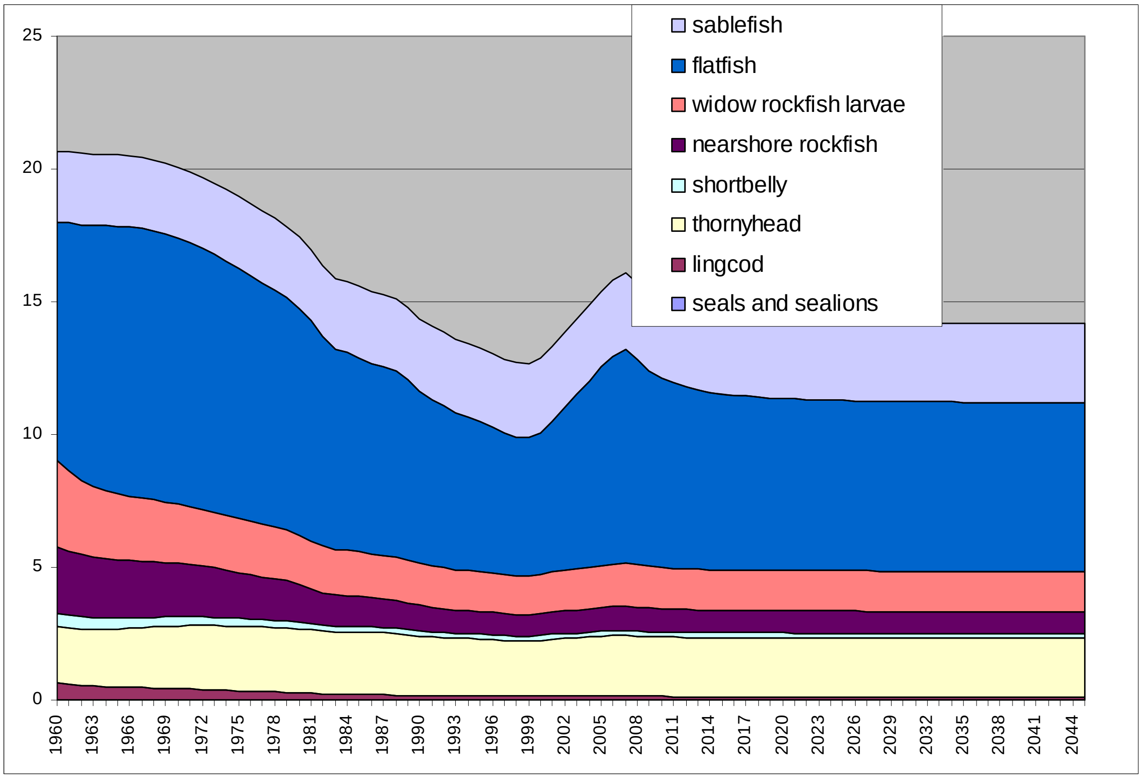

Figure 13. Projected future biomass under the assumption that fishing mortality after 2006 returns to the high levels in the 1980s but rockfish conservation areas and 20% MPAs are implemented. This scenario examines the consequences of RCAs having been in place beginning in 1960 and this accounts for the difference in the trajectory up to 2006. Additional MPAs were added at 2006 in inshore cells, to represent MPA configurations suggested in initial planning for MLPA implementation. These simulated inshore MPA cells were located so as to protect about 30% of the hard bottom habitat. It was not necessary to add offshore MPA cells (extend MLPA closures offshore, since such cells are assumed to already be in RCAs.

Conclusion from results of ecosystem modelling

The simulations show that the impacts of protected areas is confined to the benthic communities and specifically to the sedentary species within the benthic communities. Recognizing that the pelagic components of the community are highly mobile, neither any proposed MPAs or RCAs affect the pelagic community, nor the lower trophic levels in any significant way. Thus evaluation of the potential impact of MPAs within the MBNMFS is really an evaluation of the population dynamics of some individual, sedentary species because the species that are mobile, or dominantly deeper will be unaffected by MPA proposals.

The ecosystem model also shows that it is critical to coordinate state and federal management policies that may impact onshore-offshore distributions of fishing effort and differentially protect species that spend parts of their life cycles in State vs Federal waters (e.g. young fish in inshore nursery areas, older fish offshore in Federal waters). Lack of coordination could result in rapid depletion of inshore species/life stages if all the offshore effort were to shift inshore.

One of the main factors that could cause the Ecospace model predictions to fail is often called “vampires in the basement”, namely large changes in abundance of species not included in the model, due to fisheries and to interactions with modeled species. A particular concern is that smaller species of rockfish might increase substantially in areas where larger species have been depleted, which could lead to reduced survival and recruitment of juveniles of the larger species. Such apparent depensation is not common in historical data sets on stock and recruitment (Walters and Kitchell, 2001), but is a significant management risk.

One might argue that protected areas are needed to preserve the “structure and functioning” of the ecosystem. However, when we recognize that the stocks that have been overfished are now under very restrictive fishing regulations and that the groundfish community as a whole is now at nearly 60% of the unfished biomass, the only concern can be towards the habitats where the overfished species are important (shelf break and rocky reef) if the existing fisheries regulations and existing areas closed to fishing somehow fail to lead to recovery. We found no complex predator-prey interactions leading to highly non-linear dynamics over the range of exploitation rates that have occurred in the past.

Summary

The MBNMS ecosystem is a rich and diverse one that has been seriously impacted by fishing. Present fisheries management policies are extremely conservative, and should allow rebuilding of heavily impacted species over the next few decades. Potential fisheries production in the system is concentrated in mobile, pelagic species like sardine and hake. Sedentary species, mainly rockfishes, have high natural biomass but low production, so they were able to contribute substantially to overall fishery yields only by depleting stock sizes; on a sustainable basis, the sedentary species represent only a small proportion of total ecosystem production and potential yield.

MBNMS MPAs will not offer significant protection from potential future fishery management for any of the mobile species that represent most of the ecosystem biomass and production, since the area of protection is small compared to the dispersal-migration ranges of such species. However, protected areas could offer significant protection to a variety of inshore, sedentary species that have been historically impacted severely by fishing. If federal and state management policies are not coordinated, continued protection of offshore waters may lead to inshore shifts in fishing activity that could severely impact inshore species and threaten sources of larval seeding and recruitment within any inshore protected areas and sanctuaries. In such a scenario, fishing pressure increases dramatically inshore as offshore areas are closed. Since the RCAs and EFH closures have been in effect for several years, such an inshore shift in fishing effort should have already occurred. We have seen no data that suggests such a shift has occurred, but data on fishing effort has been limited.

Our primary conclusion is that the marine ecosystem in Central California is in intact and naturally functioning, and elements that have historically suffered from overexploitation, the marine mammals and some groundfish, are recovering under current management systems. Ongoing concern about salmon and possible changes in the pelagic ecosystem are not primarily the results of overexploitation, and there is no evidence that no-take areas, in the MBNMS or elsewhere would contribute to the recovery of salmon or increase in pelagic fish productivity.

In the last few decades the only "overfishing" issue has been in several species of rockfish, and in response to the decline of these species enormous changes in the management system have been implemented. These measures include the reductions in TAC for rockfish, the rockfish conservation areas, the areas closed to trawling under EFH, and the inclusion and protected of the Davidson Seamount.

We can then ask if additional no-take areas within MBNMS would contribute to the objectives of the National Marine Sanctuaries Act, especially: "(3) to maintain the natural biological communities in the national marine sanctuaries, and to protect, and, where appropriate, restore and enhance natural habitats, populations, and ecological processes; " The evidence from the trends in population abundance is that the overfished populations and the groundfish community is indeed recovering and the modeling shows no significant contribution to the rebuilding of these species from additional no-take areas.

One of the findings of the Act is the need to "(C) maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas." Again the data points to the existing management system achieving this objective.

There is a clear tradeoff between the harvest of fish and the total area allocated to no-take reserves and the total abundance of the species in the protected areas. As the total area allocated to no-take protected areas increases, catch will decline and abundance in the no-take areas, and total abundance, will generally increase. Since primary objectives of the Act include "wise use" and production of "goods and services," since there is a management system that is protecting these ecosystems from overexploitation, further protected areas within the MBNMS would decrease the "wise use" and "goods and services" without enhancing the objective of "maintain for future generations the habitat, and ecological services, of the natural assemblage of living resources that inhabit these areas."

One argument for no-take areas is they provide insurance against management failure (Sladek-Nowlis and Roberts 1999). There is now an extensive network of no-take areas implemented within State waters in the Central California coast. Any additional areas within the MBNMS would constitute a reasonably small contribution to these nearshore ecosystems. For the species in deeper water, the area of the MBNMS is insignificant in relation to the total area, and with large areas closed to trawling under the EFH provisions of the Magnuson-Stevens act, we cannot see how additional closures within the MBNMS would provide a significant buffer.

One of the basic principles of population dynamics is that there is a tradeoff between the biomass of the population being harvested and the sustainable yield so long as the stock is not overexploited. This principle is true for a population being harvested uniformly in space, or where protected areas are in place. If we want a larger standing stock of fish we have to accept lower sustainable harvest. Where managers choose to operate along this tradeoff is not a scientific question -- science can only provide the tradeoff between abundance and sustainable yield. Society could choose to protect the species (or ecosystem) almost completely, as has happened in the US for most marine mammals, or society could choose to attempt to produce near maximum sustainable yield as has happened in the US for most fish stocks under the Magnuson-Stevens act.

What science can provide is guidance on ecosystem consequences. Models such as we used earlier can be used to see what is different in ecosystems at different levels of exploitation. What ecosystem benefits would be obtained by putting in protected areas? The key difference is that some particularly sedentary species would be at higher abundance, the ecosystem would not function differently, it would not be "healthier." Science can also provide guidance on how to achieve higher abundance if that is a societal objective. One thing that is different with protected areas when catch is well regulated is that abundance is higher inside reserves, and lower outside. The same levels of abundance can be achieved with catch regulations which would provide a more uniform distribution of abundance.

Finally we must caution that there are potentially negative ecosystem impacts of no-take areas. The primary impact of closing areas to fishing is to redirect fishing effort to other sites. If more areas are closed to fishing, the pressure in remaining open sites will increase. This would be especially true in the MBNMS close to the major point of Monterey.   These areas would be under increasing fishing pressure and this could have negative ecological consequences on the remaining fishing areas.

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