University of California, Santa Barbara

Balancing Conservation and Commercial Fishing:

Methods of Incorporating Socioeconomic Impacts in the Design of MPAs in California

A Group Project submitted in partial satisfaction of the
requirements for the degree of Master's in Environmental
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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by the above MESM students and has been reviewed and approved by:

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Abstract

How can planners incorporate and address the socioeconomic concerns of commercial fishermen when designing marine protected areas (MPAs)? We investigated this question for the California Marine Life Protection Act (MLPA) which mandates the establishment of a statewide network of MPAs within state waters. Our project focused on the North Central Coast region to assist and inform stakeholder decision-making when designing proposal MPA networks. Using the spatial optimization tool MARXAN, we identified areas within the study region that possess high conservation value, yet low socioeconomic value to commercial fisheries. These maps were used by the MLPA Initiative and regional stakeholders to identify and investigate areas for potential inclusion in proposed MPA networks. Additionally, in order to estimate the impacts of proposed MPA networks upon commercial fishermen, we determined the change in fishermen density within the study region’s top five fisheries. We also formulated a model which estimates the socioeconomic impacts of a proposed MPA network assuming displaced fishing effort can be relocated into other areas. These tools and analyses fill critical gaps in knowledge, helping stakeholders design MPA networks that minimize socioeconomic impacts to commercial fishermen.

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BLM	Boundary Length Modifier
BRTF	Blue Ribbon Task Force
CDFG	California Department of Fish and Game
CFGC	California Fish and Game Commission
CFPF	Conservation Feature Penalty Factor
MLPA	Marine Life Protection Act
MPA	Marine Protected Area
NCC	North Central Coast
NCCSR	North Central Coast Study Region
RSG	Regional Stakeholder Group
SAT	Science Advisory Team
SMCA	State Marine Conservation Area
SMP	State Marine Park
SMR	State Marine Reserve
SMRMA	State Marine Recreational Management Area
SPF	Species Penalty Factor

Chapter 1: Executive Summary

Introduction

As a result of the widespread decline of economically important fish stocks and corresponding changes in overall ecosystem structure, the state of California enacted the Marine Life Protection Act (MLPA) in 1999. The Act directed the state of California to design and manage a network of marine protected areas (MPAs) with the stated objectives of "protecting marine life and habitats, ecosystems, and natural heritage, as well as [improving] recreational, educational, and study opportunities provided by marine ecosystems" (California Department of Fish and Game, Marine Region 2007). In 2004, an Initiative supported by private and public funding was formed to implement the Act through a series of regional processes. The pilot process was conducted in the central coast region, stretching from Point Conception to Point Arena. This first effort was completed in April of 2007, and the focus has now shifted to the north central coast region (NCC), extending from Point Arena to Pigeon Point.

Objectives

Upon completion of the central coast process, several reports summarized the lessons learned, strengths and deficiencies, and knowledge gaps of the MPA network planning process. The objective of this Group Project was to fill some of these knowledge gaps and provide the MLPA Initiative with information and analyses to improve the MPA network recommendations, especially with regard to socioeconomic impacts. Specifically, how can planners evaluate and address the socioeconomic concerns of commercial fishermen during the MPA design process?

To answer our research question, we addressed the following issues:

- Which areas within the study region have high conservation value, yet low socioeconomic importance to commercial fisheries?
- How will displacement of fisherman from a MPA network affect the density of fishermen in remaining open areas?
- How do the estimated socioeconomic impacts of a proposed MPA network change when fishermen are displaced into other fishable areas?

In response to lessons learned in the central coast region, we developed several methods to better integrate the actual impacts of MPAs on fishermen into the design process. This was achieved through the use of the reserve-design tool Marxan, as well as through the development of methodologies to estimate the cost to fishermen and the displacement of fishing effort resulting from the implementation of MPAs.

Methods

Several of the retrospective reports about the Central Coast MLPA process identified the problem of a lack of timely consideration of socioeconomic factors in the MPA network design process. We addressed this gap through a multi-criteria analysis of the importance to potential MPA networks of half-minute planning units in the north central coast study region using the decision support tool Marxan. We created maps displaying the conservation value of the planning units, first striving to meet an array of conservation targets using the smallest possible area, and second, endeavoring to meet the conservation targets at a minimum estimated cost to commercial fisheries. Conservation priorities were defined by the regional goals and objectives of the MLPA process developed by the North Central Coast Regional Stakeholder Group (NCCRSG). Data estimating the cost of MPAs to commercial fisheries was collected by our client, Ecotrust, through interviews with fishermen. In our analysis, we prioritized the conservation of representative habitats in the region, while minimizing socioeconomic impacts on fishermen.

Additionally, we estimated the current average density of fishermen per planning unit for five different fisheries (Dungeness crab, salmon, halibut, red urchin, and rockfish) by dividing the number of fishermen in the fishery by the total number of planning units that are utilized by the industry (only planning units containing greater than 0.01% of the total value of the fishery were considered utilized). To evaluate the potential changes in average density of fishermen due to displacement from MPAs, we used four actual MPA network proposals developed by the North Central Coast Regional Stakeholder Group (NCCRSG). We assumed that all fished planning units within the MPAs were used at an average density, and that the displaced fishermen would distribute themselves evenly across the remaining fishable planning units.

This analysis gives an indication of how fishermen density per fishable planning unit for each of five important north central coast fisheries will change with the implementation of stakeholder MPA network proposals. Additionally, this technique provides a systematic methodology for comparing potential socioeconomic impacts across a portfolio of proposed MPA networks.

Our Marxan analysis conforms to previous modeling approaches by assuming that fishermen displaced by an MPA are essentially removed from the fishery (Leeworthy and Wiley 2002). In reality, however, most fishermen do not simply disappear; some may transfer their effort into nearby open areas, resulting in a redistribution of the value associated with each planning unit. We generated a model to estimate the cost of an MPA network when fishermen displacement behavior is incorporated; to our knowledge, this has never been done as part of an MPA planning process.

We made several simplifying assumptions, common to economic models: fishing is performed optimally and efficiently, so that “at the margin” all fished planning units are equally valuable to fishermen; there are diminishing returns with increased effort in a planning unit; and a large number of planning units remain outside the MPA network into which effort may be displaced. With these assumptions the model can be used to estimate the fishery value that can be recovered from displaced effort from the closed areas, resulting in a more realistic estimate of the cost associated with closing an area to fishing.

We estimated the cost to the Dungeness crab fishery resulting from two of the actual MPA network proposals developed by the NCCRSG. We used Proposals 2 and 4, as they represent the largest and smallest proposals. The results of the model are dependent on estimates of total effort in the fishery and the marginal value of a fished planning unit, both of which are uncertain given the available data for the region. Our report provides detailed recommendations regarding the types of data that would be necessary for this analysis to be more accurate.

Results

Our first research objective was addressed primarily through the products of our Marxan analyses - maps displaying the sum of 100 high-scoring conservation options for the north central coast region. These maps identify planning units that were selected repeatedly by the planning tool, Marxan, to satisfy conservation targets. Marxan's selections were driven largely by areas of habitat rarity and diversity, as well as by areas of lesser importance to commercial fishermen. The areas selected repeatedly by the planning tool represent locations of high conservation value and therefore warrant consideration for inclusion in a network of MPAs.

As expected, we found average fisherman density per planning unit increased for each of five fisheries, if we assumed that MPAs were implemented using each of the four stakeholder proposals. The average density increase ranged from 5% for the Dungeness crab fishery in Proposal 2, to 58% for the red urchin fishery for Proposal 3. However these estimates of increased fisherman congestion do not reveal how an individual fishermen's catch might change. In future work, these estimates of how MPAs may affect fisherman density per planning unit can be improved with more specific spatial information on where fishermen fish.

Lastly, we provided a detailed methodology to estimate the socioeconomic impacts of a proposed MPA network when fishermen are displaced into other fishable areas. We applied this model to the crab fishery assuming implementation of Regional Stakeholder Proposals 2 and 4. The total value of the Dungeness crab fishery is $9,993,386 (MLPA Initiative 2007). We found that the inclusion of all planning units in Proposal 4 removes approximately $1,305,000. With the application of our model, and the incorporation of fisherman displacement, Proposal 4 only removes $724,000 from the total value of the crab fishery. Therefore, approximately 45% of the of the value within the MPAs can be recovered as a result of fishermen displacement. We also provided recommendations for collecting this type of data in future regions.

Conclusions

The design and implementation of MPAs in California state waters under the MLPA is a groundbreaking process, with contributions from stakeholders and scientists, considering the many impacts that MPAs can have on marine resources and related industries. Our project used and developed several different methods of including potential benefits and impacts of MPAs in their design.

The results from our Marxan analyses show that there are many possible ways of using this tool to aid in the process of planning MPAs. Many good solutions to problem of where to locate MPAs can be generated in Marxan and summarized in a map that identifies areas that are included in many of the solutions. The benefit of using summary maps is that summaries do not show specific MPA boundaries, allowing users to develop their own MPA designs with the Marxan output, other available information and their own knowledge of the region. Our suite of summary maps were presented and delivered to the North Central Coast Stakeholder Group during their December 2007 meeting. Several stakeholders requested our materials for review and we received useful feedback.

To evaluate the potential costs of proposed MPAs to fishermen, we developed a model that quantifies the fishing effort that is redistributed after MPAs are established. This model will be useful in future applications as an additional method to evaluate the socioeconomic impacts of proposed MPA networks. There are several limitations to the application of the model. Notably, the data required for an accurate estimation are not frequently available. However, Ecotrust has agreed to collect the necessary data within the next region of the MLPA Initiative process. With these data, the model we developed will provide a better estimate of potential costs of closing particular areas and it could also be incorporated directly into future Marxan analyses as the method of calculating the cost index.

Further, our methodology for comparing area available for the fishery before and after the implementation of an MPA proposal provides a systematic methodology for comparing potential socioeconomic impacts of a portfolio of proposed MPA networks. Future applications of this methodology could be improved upon by incorporating more data on the actual number of fishermen and the effort expended within each planning unit. If these data were available, a better estimate of displacement would be possible through the density analysis and the redistributed costs analysis.. Our estimates of increased average fisherman density could also be advanced if the realities of displacement were included. We could also include assumptions incorporating the natural limitations on the ability of fishermen to move, such as the fuel capacity of fishing boats, distance of fishing grounds from the fishermen’s home port, and various patterns from each port.

Our project used and developed a variety of methods for better incorporating socioeconomic information into a MPA planning process. Our work shows that the goals of conservationists and fishermen are not irreconcilable, and that the interests of both can be satisfied in the design of an MPA network. Our work also provides quantitative methods of comparison between MPA proposals allowing final selection committees, like the MLPA’s Blue Ribbon Task Force, to justify decisions. With these new methods of integrating socioeconomic concerns, fishermen, conservationists, planners and other stakeholders can improve the decision making process through increased knowledge of the possible impacts of network placement. Our work advocates socially responsible conservation planning that recognizes human activity as an integral component of our coastal ecosystem.

Chapter 2: Introduction

Background

Over twenty-five percent of the world's fisheries are known to be overexploited (FAO 2006). In the U.S. about twenty percent of fisheries are overexploited and the status of thirty percent of fisheries is unknown (FAO 2006). Declines are evident in entire communities across many ecosystem types (Myers and Worm 2003). This failure to maintain sustainable fisheries can be attributed to many factors, including increasing harvest rates, pressure from fishing communities on management councils, and mismanagement (Botsford, Castilla and Peterson 1997; Pauly et al. 2002). Most policy attempts to correct these problems have been in the form of single-species management tools, created on a case-by-case basis by multiple agencies, with often conflicting and overlapping jurisdictions (Cicin-Sain and Knecht 2000).

The widespread decline of economically important fish stocks also have led to changes in overall ecosystem structure. Loss in genetic variability in target species, incidental kill of non-target species (by-catch), habitat destruction from fishing gear (trawl nets), and changes in species interactions and trophic cascades can lead to drastic alterations in the overall ecosystem (Dayton et al. 1995). As a result, various ongoing efforts, including the Pew Oceans Commission (2003) and the United States Commission on Ocean Policy (2004) are calling for a policy shift towards broad ecosystem-based management.

According to a Scientific Consensus Statement on Marine Ecosystem-Based Management:

> "Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors.
>
> Specifically, ecosystem-based management:
>
> - Emphasizes the protection of ecosystem structure, functioning and key processes;
> - Is place-based in focusing on a specific ecosystem and the range of activities affecting it;
> - Explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species;

- Acknowledges interconnectedness among systems, such as between air, land and sea; and
- Integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences."
  (McLeod et al. 2005)

Marine Protected Areas

Marine protected areas (MPAs) are key tools for implementing ecosystem-based management. The National Research Council (2001) defines MPAs as areas of the ocean designated for special protection designed to enhance the resources within them. However, MPAs often have varying degrees of protection and multiple classification schemes that permit or prohibit different activities. The benefits and shortcomings depend on the specific restrictions of the MPA. Much of the literature on MPAs focuses on "no-take" MPAs, also called marine reserves, which prohibit all extractive activities.

There has been extensive academic discourse about the ecological and socioeconomic benefits and limitations of marine reserves. Generally, potential benefits of marine reserves include enhanced population and individual sizes, higher reproductive potential, maintenance of species diversity, preservation of habitat and of ecosystem function, and the potential support of fisheries through larval export, spillover, and precautionary management (Bergen and Carr 2003). A consensus statement on the science of marine reserves was signed by 160 scientists in 2001. The statement asserts the following ecological effects of marine reserves:

> "Ecological effects *within* reserve boundaries:
> 1. Reserves result in long-lasting and often rapid increases in the abundance, diversity and productivity of marine organisms.
> 2. These changes are due to decreased mortality, decreased habitat destruction and to indirect ecosystem effects.
> 3. Reserves reduce the probability of extinction for marine species resident within them.
> 4. Increased reserve size results in increased benefits, but even small reserves have positive effects.
> 5. Full protection (which usually requires adequate enforcement and public involvement) is critical to achieve this full range of benefits. Marine protected areas do not provide the same benefits as marine reserves.
>
> Ecological effects *outside* reserve boundaries:
> 1. In the few studies that have examined spillover effects, the size and abundance of exploited species increase in areas adjacent to reserves.
> 2. There is increasing evidence that reserves replenish populations regionally via larval export.
>
> Ecological effects of reserve *networks*:

1. There is interesting evidence that a network of reserves buffers against the vagaries of environmental variability and provides significantly greater protection for marine communities than a single reserve.
2. An effective network needs to span large geographic distances and encompass a substantial area to protect against catastrophes and provide a stable platform for the long-term persistence of marine communities."

   (National Center for Ecological Analysis and Synthesis 2001)

Marine reserves maintain large individuals in a population allowing for the continuance of the basic age/size structure that creates the stability and the ability to respond to varying disturbances. Fishing pressure generally removes the larger, and hence older[1], individuals of a population and frequently results in a decline in the average size of individuals (Pauly et al. 1998). Because larger females produce a disproportionately greater number of larvae, removing these larger females indirectly inhibits the overall population size by reducing larval production (Gunderson, Callahan and Goiney 1980; Hislop 1988).

While the benefits to species, communities, and ecosystems within reserves can be demonstrated with surveys, the effects of reserves on surrounding areas are not easily measured. Modeling studies indicate likely contributions of reserves to surrounding areas through spillover of adult fish and invertebrates and export of larvae. Spillover is the concept that adult species within the reserve will move out of the reserve, where they may be caught by fishermen (McClanahan and Mangi 2000; Rowley 1994). Export is the movement of larvae born in the reserve into surrounding waters where they may settle and grow, contributing to populations outside of reserves. Theoretically, fisheries could be maintained in the long run from replenishment of adult, juvenile and larval fish and invertebrates moving from reserves to surrounding regions. Movement tends to occur along continuous preferred habitat types leading to the hypothesis that animals would move in and out of reserves if continuous preferred habitat crosses the reserve boundaries (Carr and Reed 1993). Anecdotal evidence for spillover includes concentrated fishing efforts along the boundaries of existing reserves, also known as "fishing the line" (Roberts 2001).

Commercial and recreational fishermen may be apprehensive of the establishment of MPAs, which close areas to fishing, and therefore may concentrate fishing effort into smaller areas. Fishermen have argued that the concentration of fishing into smaller regions will lead to more rapid depletion of fishing stocks in open areas. In addition, fishermen have been concerned that reserves may be economically detrimental if the process of establishing reserves does not consider current fishery knowledge and economics. MPAs can result in decreased landings for local recreational and

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[1] Age is difficult to determine in many fish species so size is used as a proxy (Hislop 1988).

commercial fishermen (Sanchirico and Wilen 2001; Scholz et al. 2003). Most of these effects are felt initially by local fishermen and fishery-related businesses and these effects may diminish over time as fishermen adjust to the new regulations (Scholz et al. 2003) and ecological changes occur.

Management, enforcement, and monitoring of MPAs are expensive, yet necessary for effectiveness. Enforcement may become more efficient over time, as fishermen learn the locations of MPAs and if benefits become apparent to the community (NRC 2001). Yet, the costs for enforcement are in addition to the cost of enforcing fishing regulations and the initial economic loss to fisheries (NRC 2001). The costs of enforcing MPAs grow with distance from the mainland, a port or a monitoring station, and with increasing numbers of reserves (NRC 2001).

MPAs can have positive influences on the economy of a region. Positive influences include the potential for increased tourism, an increase in the area's existence value, and the economic increase of non-consumptive users coming to the area as visitors (Sanchirico and Wilen 2001; Scholz et al. 2003). If MPAs lead to increases in marine biodiversity and abundance, tourism and recreation also may increase in the forms of boating, scuba-diving, bird and whale watching and other ocean recreation (NRC 2001). The visual aesthetics that attract users to the ocean may increase in MPAs, along with the value that some people place on the knowledge that a thriving, sustainable and protected area exists in the region (NRC 2001).

Using science to increase the efficiency of MPA design requires consideration of varying habitat types and quality, target species' life histories and dispersal characteristics, and the intensity of exploitation around MPAs, as well as considerations for design such as the size and spacing of MPAs, and boundary porosity, among other variables (Roberts 2000). Further, networks of interacting reserves help to protect a broad range of key habitats and species, and a network reduces the uncertainty in the ecological processes (such as El Niño) and management policies (such as fishery regulations) that affect the ecological and socioeconomic impacts of reserves (Roberts 2000).

Previous Attempts to Quantify Socioeconomic Impacts

The extent to which socioeconomic impacts of MPAs have been observed or quantified has varied with different processes to design MPAs, but there is a strong consensus that socioeconomic impacts of MPAs have not been properly dealt with at an early enough time (Agardy et al. 2003; Scholz et al. 2003). When the social, cultural and economic impacts of MPAs are not addressed, the process to establish MPAs can be met with hostility and a lack of consensus (Badalamenti et al. 2000). This can divide people supporting MPAs for their conservation benefits and people who are skeptical of their usefulness to either the community or ecosystem. Fishermen, who usually dominate this second category (Agardy et al. 2003), are extremely keen to learn if any increase in fish abundance from MPAs will be enough to offset the lost revenues (Sanchirico and Wilen 2001).

A well-designed MPA maximizes ecological and fishery benefits while minimizing negative socioeconomic and cultural impacts (Guerry 2005). Several methods of economic analysis have been used in attempts to include data on the socioeconomic effects of MPAs. Some of these methods were utilized during the Marine Life Protection Act (MLPA) process of MPA implementation in the central coast of California. The MLPA, a piece of California legislation requiring the implementation of a statewide network of marine protected areas, included the goal of using knowledge from local fishermen to help guide the process of planning MPA locations. Complimentary studies used modeling software to identify the most economically efficient MPA locations (Scholz et al. 2003; Stewart and Possingham 2005; Chan et al.2006). It was recognized that in order to implement the MLPA in the timeliest and least controversial manner, local socioeconomic impacts must be considered during the implementation process to determine where conservation goals can be met with the minimum economic impact.

Some key recommendations from a number of “lessons learned” reports from central California MLPA process of implementing marine protected areas included the need to explore and clarify the interactions between MPAs and existing fisheries management policies, and to consider the broader suite of potential socioeconomic impacts from the MPAs earlier in the design process (BRTF 2006).

Although MLPA administrators commissioned a study of commercial fishing in the central coast region (Scholz, Steinbeck and Mertens 2006), the socioeconomic data were unavailable to the stakeholders guiding the MPA placement decisions until late in the process of designing MPA alternatives. Because of confidentiality concerns, only aggregated analyses of the data were made available to stakeholders (Harty and Dewitt 2006). Stakeholders could not easily incorporate this coarse-grained socioeconomic information when making decisions on MPA network design. Feedback on socioeconomic impacts of proposed MPA network packages and possible improvements to meet scientific guidelines were given only after stakeholder proposals had been created, forcing stakeholders into an inefficient design process through trial and error (Raab 2006).

Although it is widely recognized that at least a portion of fishing effort displaced by MPAs will relocate into the remaining fishing grounds, displacement of fishing effort has not been incorporated into evaluations of proposed MPAs. One reason for this is that the extent to which displacement occurs and its economic implications are difficult to measure. Most past efforts to understand the economic impact of MPAs on fishermen assumed that all fishing activity within closed areas disappears entirely, and that fishermen do not adjust or adapt to MPAs. For instance, a 2006 analysis of the potential economic impacts of MPAs in the central coast region of California assumed that establishment of a MPA completely eliminated fishing opportunities. The analysis did not account for displaced fishing effort and thus represented a worst case economic scenario (Scholz 2006).

Additionally, an analysis of the socioeconomic impacts of MPA alternatives for the Channel Islands National Marine Sanctuary by Leeworthy and Wiley (2002) did not consider any factor that might mitigate the level of impact of a MPA network. All fishing revenue associated with closed areas is assumed to be lost. The authors recognize that this maximum potential loss is not likely in reality, as humans are "adaptive, resilient, and quite ingenious in responding to changes" (Leeworthy and Wiley 2002). If fishermen adapt to MPAs, they may be able to prevent or minimize decreases in fishery landings and catch per unit effort. However, displacement of fishing effort may result in increased congestion and reductions in harvest, damaging the remaining fishing grounds. In this case, the estimate of maximum potential loss may be an underestimation of the true costs (Leeworthy and Wiley 2002).

Finally, a study by the Australian Bureau of Rural Sciences estimating the potential social impacts of increasing the percentage of Australia's Great Barrier Reef Marine Park zoned "no take" from 5% to 30% assumed that fishing effort would be completely removed from proposed no-take MPAs and that fisherman would not adapt to the changes by shifting their fishing effort to other locations. The authors state a clear preference for displaced fishermen to remain in the industry, and comprehensively described factors predicting the ability of fishermen to adapt to displacement by MPAs. However the extent to which these factors influenced fishermen's economic realities was deemed too complex for the scope of the study. Factors affecting the economic impacts on displaced fishermen included the adaptability of their fishing gear to be used in other fisheries, the degree of localization of their fishing effort, and family resilience, encompassing factors such as income, education, and family structure (Australian Government BRS 2003).

Some studies predict displaced fishermen may experience the same catch per unit effort in new fishing grounds (Milon 2000). Meanwhile, others estimate the worst case scenario of maximum potential impact and assume the complete exclusion of displaced fishermen (Australian Government BRS 2003; Chan et al. 2006; Leeworthy and Wiley 2002). Despite these hypothetical extremes, our literature review found no attempts to quantitatively estimate the extent of displacement and relocation of fishermen after MPAs were established.

Use of Marxan in Marine Protection Area Planning Processes

Optimization software utilizing algorithms for reserve siting has a short history of use for designing MPA networks in California. The software SITES v.1 was used to explore complex data and design MPAs for the California Channel Islands National Marine Sanctuary, by identifying suites of potential reserves meeting minimum criteria for size, habitat representation, and connectivity, while minimizing total reserve network area (Airamé et al. 2003). SITES v.1 was able to identify multiple satisfactory solutions, permitting the planning team some flexibility when incorporating socioeconomic considerations (Airamé et al. 2003).

Chan et al. (2006) used the decision support tool Marxan to generate planning scenarios for MPAs in the central coast of California that minimized cost while meeting conservation goals. Marxan was chosen because of its unique ability to provide multiple solutions meeting the objectives and its capacity to handle large data matrices (Chan et al. 2006). A suite of different solutions met biodiversity conservation requirements while minimizing recreational and/or commercial consumptive loses as measured by fishing effort (Chan et al. 2006). Chan et al. (2006) also incorporated data on selected non-consumptive activities to evaluate potential benefits and impacts of MPAs on those activities or interests. Chan et al. (2006) demonstrated that Marxan was capable of designing MPA networks that met all biodiversity goals of the stakeholder and scientific advisory groups and therefore could be considered as part of the MPA design process. The Marxan analysis was introduced *post hoc* to the design process for the central coast, but optimization decision-support tools will likely be directly influential in future MPA planning in other regions of California.

Marine Life Protection Act History

Motivated by the widespread decline of economically important fish stocks and corresponding changes in overall ecosystem structure, in 1999 the California state legislature enacted the Marine Life Protection Act (MLPA). The Act directed the state of California to design and manage a network of MPAs with the stated objectives of “protecting marine life and habitats, ecosystems, and natural heritage, as well as [improving] recreational, educational, and study opportunities provided by marine ecosystems” (California Department of Fish and Game, Marine Region 2007). The Marine Life Protection Act Initiative (Initiative) was formed in 2004 and is a public/private partnership comprised of the California Resources Agency, the California Department of Fish and Game, the Resources Legacy Fund Foundation, and others, guided by the advice of scientists, resource managers, experts, stakeholders, and members of the public.

California was divided into five regions in which the Act would be separately implemented, in order to make the task more tractable. The pilot process took place in the central coast of California, stretching from Pigeon Point to Point Conception. Several administrative, scientific, and decision-making bodies were formed to enact this legislation, including the Blue Ribbon Task Force, the Science Advisory Team, and a Regional Stakeholder Group.

The Blue Ribbon Task Force (BRTF) included five appointed members whose role was to oversee the regional project to develop alternative MPA packages in the region, to make policy and process judgments to resolve conflicts, to provide direction for expenditure of Initiative funds, and to direct staff efforts.

The Science Advisory Team (SAT), composed of biological and social scientists and economists, interpreted the goals and objectives of the MLPA and developed quantitative guidelines for MPA design. They also evaluated alternative MPA networks designed by stakeholders. Where the available science presented uncertainty, the SAT deferred to the BRTF's policy decisions.

A Regional Stakeholder Group (RSG) was formed for the region through a nomination process. The RSG consisted of representatives from the fishing community and businesses, as well as recreational and other users who brought significant local knowledge to the process. Initially, the RSG developed regional goals for MPAs and designed alternative proposal networks of MPAs for their region, using the scientific guidelines and data provided through decision support tools.

This complex process of deciding on a network of MPAs for the central coast lasted for two years. In April 2006, the BRTF presented three alternative MPA network proposals, including a preferred alternative, to the Department of Fish and Game (Department). In June of the same year, the Department added a fourth alternative, consisting of a modified version of the BRTF's preferred alternative. The changes by the Department were made to (1) ensure MPA boundaries were simple, clear, and easily enforceable, (2) consider key user groups such as existing kelp harvest leases and shoreline fishing, and (3) improve recreational opportunities in areas of minimal human disturbance (California Department of Fish and Game 2006).

Eventually, the Science Advisory Team provided a report of the estimated maximum potential economic impacts of proposed MPA network packages to the BRTF to aid in the selection process (Wilen and Abbott 2006). Finally, on April 13, 2007, the Fish and Game Commission unanimously voted to adopt regulations to create a new suite of MPAs, based on the BRTF's preferred alternative, launching the state's Marine Life Protection Act Program.

Goals and Objectives of Project

On April 13, 2007, the California Fish and Game Commission adopted a suite of marine protected areas (MPAs) for the central coast of California. On September 21, 2007, the MPAs went into effect, completing the first phase of the implementation of the Marine Life Protection Act (MLPA) in California. The central coast MPA network was the result of an intensive two-year collaborative, science-based stakeholder process. Reports prepared by facilitators, observers, and outside consultants detailed the lessons learned during this pilot effort and provided recommendations for MPA planning in future regions. These documents and the recommendations of the Central Coast Blue Ribbon Task Force (BRTF) identified gaps in knowledge that, if filled, could enhance the MLPA planning process.

The MLPA Initiative, a public-private partnership to implement the MLPA, incorporates an adaptive planning process; each of five study regions benefits from the experiences of previous regions. The second phase of the MLPA Initiative began in March 2007 for California's north central coast (NCC), an area bounded in the south by Pigeon Point in San Mateo County and in the north by Alder Creek in Mendocino County. Several retrospective reports resulting from the central coast process were concerned with the lack of adequate consideration of socioeconomic factors in the MPA network design process. This project is designed to address this gap. Specifically, we answer the following research question: How can the socioeconomic concerns of commercial fishermen be considered during the MPA design process? We focused on the impacts to commercial fishermen because we were limited by available data; ideally, other types of activities would be considered as well.

This project uses multi-criteria analysis and the reserve design tool Marxan to estimate the relative importance to potential MPA networks of different areas in the north central coast study region. Conservation priorities are defined by the regional goals and objectives of the MLPA process developed by the North Central Coast Regional Stakeholder Group (NCCRSG). Habitat data combined with socioeconomic values of commercial fisheries were utilized in Marxan analyses, resulting in reserve system scenarios that conserve marine/coastal habitats while minimizing socioeconomic impacts to commercial fisheries. Maps generated from the Marxan analyses display the relative conservation value of half-minute[2] square planning units.

Additionally, we present a novel method to estimate the redistribution of commercial fishing effort displaced by MPAs, as well as descriptions of the data necessary to complete this analysis. Previous modeling attempts that considered economic costs of MPAs to commercial fisheries assumed that fishermen displaced by MPAs were essentially removed from the fishery. In reality, most fishermen do not simply disappear, but may transfer their effort into nearby open areas or other fisheries. The extent to which effort can be displaced has not been calculated for a MPA network planning process.

Finally, we evaluated the potential displacement of fishermen from four MPA network packages proposed by the North Central Coast RSG to determine the effects on fishermen density per half-minute squared planning unit for five fisheries.

To answer our research question, we addressed the following issues. The results of these analyses will provide useful decision-support tools to the MLPA Initiative and fill knowledge gaps identified during the Central Coast pilot process.

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[2] At the equator a half-minute is equivalent to a half-nautical mile (0.57 miles or 924.5 meters). However, due to the curvature of the earth, the length of a half-minute varies across the surface and is actually less than a half-nautical mile in the study region. The average size of planning units in the study region is 548,000 square meters.

- Which areas within the study region have high conservation value and low socioeconomic importance to commercial fisheries?
- How do the estimated socioeconomic impacts of a proposed MPA network change when taking into account displacement of fishery effort into other fishable areas?
- How will displacement of commercial fisherman, resulting from a proposed MPA network, affect density of fishermen in the remaining open areas?

Significance

California's identity, vitality, heritage, and economy are interwoven with its coastal and marine resources. The creation of the MLPA Initiative is a clear acknowledgement of the value of these assets and the need to ensure their future biological, economic, and social viability. The MLPA offers an exceptional opportunity to develop effective MPAs based on sound science that will have profound effects on both California's coastal resources and on the future application of MPAs for ecosystem-based management.

This project contributes to the field of MPA design, specifically the incorporation of economic considerations in MPA planning processes. Maps and analyses generated by this project inform a critical planning and policy process in California that will impact the future condition of our coastal ocean. A well-designed MPA network that effectively balances conservation and socioeconomic needs will set an example for the future management of ocean and coastal resources.

The anticipated timeline for the North Central Coast Initiative process is March 2007 through March 2008, perfectly coinciding with the Bren Group Project cycle. We were able to take advantage of the nascent status of implementing the MLPA Initiative in the north central coast region, providing a unique opportunity to identify and fill gaps in knowledge in support of an ongoing management and policy process while applying lessons learned from the central coast region.

By addressing gaps in knowledge, this project filled the need for additional analysis of probable economic impacts of potential MPAs, as requested by state officials. In this work, we present a model for estimating how fishing effort displaced by MPAs might be redistributed among the remaining open fishing grounds, resulting in a more accurate estimate of the economic impacts of a MPA network. This project provides an alternative rubric to challenge the current assumption of maximum potential loss, in which all fishing effort displaced by a MPA is assumed to disappear. Our timely work provides unprecedented information for the north central coast MLPA process and other processes to establish MPAs in the future.

This project involved the use of the decision-support software and conservation planning tool, Marxan (Ball, Possingham and Andelman 2000). Marxan uses an optimization algorithm that minimizes cost while meeting user-defined conservation targets. This decision-support tool was used in the Channel Islands National Marine Sanctuary planning process (Airame et al. 2003), as well as retrospectively in the central coast region (Chan et al. 2006). Marxan has become a well-accepted tool for informing the design of MPAs. At the request of the NCCRSG, the Initiative staff conducted Marxan analyses to refine stakeholder MPA package proposals. Our Marxan work paralleled and complimented these official reports. We used the tool to identify areas of high conservation value and low economic impact on commercial fisheries, following the regional goals and objectives developed by the NCCRSG.

Chapter 3: Marxan Methodology

Background

Marxan is a decision support tool developed by Ian Ball and Hugh Possingham to assist in marine reserve system design (Ball and Possingham 2001). Marxan can contribute to a planning process by evaluating biodiversity conservation objectives and social, economic, and management interests and constraints. Our group used Marxan to explore options for marine reserve network designs in California’s north central coast as a parallel analysis to Marine Life Protection Act (MLPA) Initiative’s work. We used Marxan to identify areas that may contribute to the North Central Coast Regional Stakeholder Group’s (NCCRSG) goals for conservation of marine habitats and species while simultaneously minimizing economic impacts to commercial fishermen.

At the crux of this balance lies the need to minimize the area of the reserve system to reduce impacts to existing users while still meeting conservation goals. Marxan responds to this challenge by finding the most efficient reserve system meeting the user-chosen conservation goals (in this case, a percentage of representative habitats captured in reserves), while minimizing cost (in this case, potential impacts to commercial fisheries and area or boundary length of a reserve system).

The Objective Function

At the core of Marxan is the objective function (See Equation 3.1), an optimizing algorithm that controls the program’s functions. Various parameters within the objective function can be changed to achieve different conservation objectives. Each reserve system generated by the tool is assigned a value or score, allowing the user to compare reserve systems to determine the relative efficiency of differing network designs. In its simplest form, the objective function is a sum of the economic cost of the reserve and a penalty for any unmet conservation objectives.

$$\boxed{\sum \text{Cost} + BLM \sum \text{Boundary} + \sum CFPF \text{ X Penalty} + \text{Cost Threshold Penalty}}$$

Equation 3.1: Marxan’s Objective Function. ‘$\sum$Cost’ is the total cost of the reserve network. ‘$\sum$ *CFPF* X Penalty’ is the penalty for not adequately representing conservation features. ‘*BLM* $\sum$ Boundary’ is the total reserve boundary length multiplied by a modifier. The ‘cost threshold penalty’ is an optional penalty applied for exceeding a preset cost threshold. The lower the numerical value of the objective function, the more “efficient” the solution is. Please refer to text for a more comprehensive definition of the components of this function.

In broad terms, Marxan calculates, for each hypothetical reserve network, (a) the extent to which the network fails to achieve the conservation goals; (b) the fragmentation of the network; and (c) the “cost” of the planning units included in the network (these are each defined more precisely below). The network is scored based on a weighted sum of these three quantities, with the overall objective being to find a network with as low a score as possible.

The objective function (Equation 3.1) consists of four components.
The first component of the function, the Conservation Feature Penalty Factor (CFPF), is a weighting factor that determines the relative importance of meeting conservation targets. The conservation goals of the reserve network are defined as a set of "conservation features" to include in the network, each with a target amount. In the present analysis, we specified target amounts (a specified percentage) for each habitat type to be captured in the network (see below). For each conservation feature, a penalty is assessed to the algorithm if the target is not achieved, proportional to the shortfall from the target. The penalty for the entire reserve network j equals the weighted sum:

Equation 3.2 $$\text{penalty}_j = \sum_k \text{CFPF}_k \max\left(0, \text{target}_k - \sum_i I_{ij} t_{ik}\right)$$

where t_{ik} is the amount of conservation target k in planning unit i and I_{ij} is one if planning unit i is included in network j and zero otherwise. CFPF is the "Conservation Feature Penalty Factor" and specifies the relative importance of each conservation feature.

In essence, the CFPFs function as weightings, telling Marxan how important it is to meet a certain conservation target when evaluating tradeoffs between cost, boundary length, and capturing conservation targets. To ensure all conservation targets were being met, the CFPF values were set just high enough to allow Marxan to meet the conservation target, while avoiding an excessively large penalty factor that would have overpowered other cost considerations when Marxan was making tradeoffs. When Marxan encountered a conservation feature with a high CFPF, the feature was included in the reserve network even if the planning unit had a high cost associated with it. To keep our analysis robust we calibrated Marxan to determine the minimal CFPF values that would instruct Marxan to meet all conservation targets.

The second term in the function is the boundary length modifier (BLM), which is a parameter controlling the importance of minimizing a reserve system's boundary length. There are many ways to quantify fragmentation of a reserve network, however, Marxan uses (for computational reasons) the boundary length of the entire network as a measure of fragmentation. If two networks have the same total area, the one with the longer boundary is more fragmented as it has more individual reserves. "Boundary" is the sum of the length of the perimeters surrounding each individual reserve in the reserve system.

The boundary length modifier (BLM) coefficient directs Marxan to cluster groups of selected planning units together rather than selecting disconnected planning units. A low BLM will result in the selection of more numerous, smaller groupings, whereas a larger BLM will force fewer, larger areas to be selected. Essentially, the BLM controls the size of the individual reserves within a reserve system. As with the CFPF the BLM coefficient must also be calibrated because it adjusts the importance of compacting the reserve system (into fewer larger reserves) over other considerations such as 'cost' and meeting conservation targets.

The third component, called "cost", is some measure of the cost associated with the establishment of a reserve system. This could be in terms of reserve area, economic costs, or opportunity cost. Marxan works to minimize these when creating reserve systems. For the purpose of our analyses, we used the number of planning units included in the reserve (a measure of area), and the "cost" that would be incurred by commercial fishermen (in terms of relative importance) should the area be declared a no-take marine reserve. Data used to estimate "cost" was collected by Ecotrust in the form of "importance" (see The Cost Layer below for a more detailed explanation). The overall cost of reserve network j is simply the sum of the costs of all the planning units it includes:

Equation 3.3

$$\text{cost}_j = \sum_i I_{ij} c_i$$

where c_i is the cost of planning unit i and I_{ij} is one if planning unit i is included in network j and zero otherwise.

The fourth component of the objective function is the cost threshold penalty, which is an optional penalty applied to the objective function for failing to meet various criteria. These criteria may include a cap on the "cost" of the reserve system, and conservation goals such as capturing a particular percentage of representative habitats within the study region.

Using this penalty may be useful in exploring reserve network options under a strict cost threshold (e.g. 10% "cost" to commercial fishing). If the cost threshold function is not used, Marxan will simply minimize costs, rather than capping costs at the specified value. Another use of this aspect of the objective function is to explore how much habitat of different types can be captured for a specified cost. By setting conservation targets to 100% and applying a cost threshold, Marxan is able to explore the maximum amount of habitat that could be captured for that price. Adittionally, Marxan may select habitats that are difficult to capture under a cost-minimization scenario. This cost threshold penalty places a relative importance on meeting that cost threshold. The magnitude of the penalty may be determined by the Marxan user and can be any number, usually a fraction or the whole of the sum of the 'costs' within the study region.

These four aspects of the objective function combine to yield a numerical score for each Marxan solution. The *lower* the objective function's numerical value, the more efficient the reserve system is.

Simulated Annealing

A challenge associated with spatial planning is that there are far too many possible reserve network options (2^N, where N is the number of planning units, and our region has 3,610) to evaluate them all. Any optimization routine is an attempt to find a "good" solution from an initial guess for a reserve network. Simulated annealing, one type of optimization algorithm used by Marxan, provides an effective approach to addressing this type of problem.

Simulated annealing examines individual planning units for their conservation benefits and costs, and then collects a number of planning units into an initial "solution", or in our case a MPA network, that meets our conservation targets of capturing a particular percentage of representative habitats. The algorithm then proceeds to randomly discard and retain planning units in an effort to decrease the reserve network's score. The ability of the algorithm to make bad choices that temporarily increase the network's score ultimately results in better solutions and prevents the algorithm from being locked into "local minimums[3]". This random swapping of planning units allows Marxan more flexibility during the subsequent iterative improvement process, ultimately resulting in a more efficient reserve and an improved objective function value.

Methodology

Our project scenario was intended to parallel the design process developed by the California MLPA Initiative. To this aim, our Marxan analysis used geospatial data from the MLPA Geodatabase (http://www.marinemap.org) and was designed in accordance with the NCCRSG goals and objectives. Below is a description of the methodology used to prepare the data layers, determine the objectives of our Marxan analysis, and produce useful and informative products for the MLPA Initiative process.

Choosing Conservation Targets/Goals

California's MLPA specifies that "marine life reserves in each bioregion should encompass a representative variety of marine habitats and communities across a range of depths" (MLPA 1999). By recommendation of the Science Advisory Team (SAT), the MLPA Initiative adopted three bioregions in the north central coast to distinguish geographically distinct similar habitat types: North Region (north of Point Reyes to

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[3] Local minimum solutions result from another Marxan algorithm option known as the greedy heuristic.

Point Arena), South Region (south of Point Reyes to Pigeon Point), and the Farallon Islands.

The MLPA Master Plan Framework identifies several conservation targets (*i.e.* habitats, areas of biodiversity significance, and species of special status) that should be included in a network of marine protected areas (MPAs), including reserves. The MLPA Master Plan Framework specifically mentions the following habitats in reference to their inclusion in a system of MPAs: rocky reefs, intertidal zones, sandy or soft ocean bottoms, underwater pinnacles, seamounts, kelp forests, submarine canyons, and seagrass beds (MLPA 1999). With the exception of seamounts, submarine canyons, and underwater pinnacles, all of these habitats are found within state waters in the north central coast. Furthermore, the SAT recommended that the list of habitats referenced in the Master Plan Framework should include specific depth zones; such as intertidal, near shore (intertidal-30 m), and shelf I (30-100 m). These recommendations by the SAT stratify representative habitats into bioregions and by depth. Collectively, the habitats, stratified by bioregion and depth, are referred to as "biophysical conservation targets" throughout this document.

The table in Appendix A lists each of the biophysical conservation targets included in our Marxan analysis and indicates how each addresses the NCCRSG goals and objectives. Our analysis used 31 conservation targets derived from the most up-to-date data layers available at time of analysis from the MLPA Geodatabase. To prepare these conservation targets for use in Marxan, a half-minute planning unit grid of the study region was overlaid with habitat data from the MLPA Geodatabase. It should be noted that habitats at Shelf II depths (100-200 m) are very rare and were excluded from our list of conservation targets to prevent them from unduly influencing our results. Furthermore, to encompass the annual variability in kelp coverage, we created an average kelp canopy coverage layer using data on kelp coverage from the MLPA Geodatabase for years of 1998, 1999, 2002, 2003, 2004, and 2005.

The Cost Layer: Values to Commercial Fishing

Data on commercial fishing effort was collected for the study region using peer-reviewed socioeconomic interview techniques. Data collection was the responsibility of the non-profit research group Ecotrust, under contract to the MLPA Initiative. A commercial fishing value dataset was developed with the direct input of fishermen. Because fishermen and fishing communities are extremely knowledgeable about the marine ecosystems in which they work, their local insight simultaneously improved the quality of the data and allowed the concerns and perspectives of fishermen to be represented in the policy process (Scholz et al. 2003).

The most prolific fishermen in each of 34 commercial fisheries were identified through California Department of Fish and Game landing receipts. Specific fishermen were targeted for interviews in order to capture at least 50% of ex-vessel revenue dollars from 2000 - 2006 landings by fishery, gear type, and port complex. Additionally, interviews targeted at least 5 fishermen in each industry, except in cases where there were less than five. Interviews were performed from late May to August 2007, and were conducted in small groups or individually, either on the fisherman's boat or in a convenient restaurant or public space. The 175 fishermen interviewed identified a total of 308 individual fishing grounds, which were captured as GIS data layers using the GIS-based computer interface Oceanmap. Oceanmap is a socioeconomic data collection tool developed by Environmental Defense and Ecotrust. Questions concerning fishermen demographics and fishing operations were also asked.

The goal of interviewing fishermen representing at least 50% of ex-vessel revenue dollars of each fishery, gear type and port complex was not achieved in every case. Interviewing logistics were complicated because the interviewing season coincided with the salmon and Dungeness crab fishing seasons, and some fishermen were unavailable to participate.

Fishermen were asked to identify their most economically important fishing grounds from their cumulative fishing experience. Using Oceanmap, each respondent ranked their fishing grounds by distributing an imaginary "bag of 100 pennies" for each fishery they participate in. The pennies could be distributed between as many or as few shapes of any size as the fisherman wished The "pennies" or "points" assigned to each fishing ground were then weighted by the individual fisherman's ex-vessel revenue dollars for the relevant fishery and overlaid onto the half-minute squared planning unit grid comprising the study region. The points in each fishing ground were divided by the number of planning units in the fishing ground, giving a "points per planning unit" figure. For instance, assume fisherman X assigns 25 of his 100 pennies to a patch encompassing 10 planning units. These 25 points are weighted by the fisherman's ex-vessel dollar revenue, and then divided evenly between the 10 planning units making up the shape. Summing these weighted values for all fishermen results in a weighted importance surface of the north central coast study region. The weighted importance surface was then transformed into an index value ranging from 0 – 1, with the highest value planning unit given a value of 1

The decision to select the fishermen with the highest landings for interviews gives weight to more prolific or successful fishermen. These individuals represent a large economic share of the industry, but may be a relatively small number of total fishermen. Weighting the importance of fishing locations by the fishermen's ex-vessel dollars skewed the resulting index of importance towards income, rather than the number of fishermen affected. This method imparts a certain bias in the data, but remains a sensible approach given the difficulty of determining the number of fishermen in a fishery. Most fishermen exploit more than one species and can vary the fisheries they participate in year to year. The deliberate identification of the highest earning fishermen in each fishery from DFG landing receipts was the most efficient method of capturing data from a representative portion of the industry.

This socioeconomic data gathered from commercial fishermen by Ecotrust are in units of neither money nor effort, and can best be described as "importance". These numbers cannot be given any true unit, as they result from a combination of an "economic importance" ranking and ex-vessel revenue. The data was available to our team in two forms. In our Marxan analysis we used the previously mentioned index value data, ranging from 0-1 and indicating the relative importance of each planning unit to north central coast commercial fishermen, for all 34 fisheries and 5 port complexes. We utilized this same data in a second format for our fishermen density analysis. Here the importance data was differentiated per fishery and port complex and was not reduced to an index. These values range from 0 to slightly over 1,000.

Although this data is properly described as "importance", our report frequently refers to it as "cost", especially in the Marxan chapter. We used Ecotrust's "importance" data as a proxy for the cost of including any particular planning unit in a Marxan-generated solution in order to minimize the socioeconomic impact on commercial fishermen. Ecotrust collected both commercial and recreational importance data for fishermen in the north central coast in two separate interview processes. However, we did not use the recreational importance data in our analysis because it was not avaliable to us until too late a point in our project.

Conservation Scenarios: Determining Percentages of Habitat Conservation

Our Marxan analyses explored a variety of different conservation scenarios. We instructed Marxan to capture a different percentage or target (specifically 10%, 17% or 34%) of all biophysical conservation features in the study region in order to produce reserve systems that addressed a range of conservation goals and objectives. For instance, at the 10% conservation target, each potential reserve network included 10% of all intertidal surfgrass habitat in the North region, 10% of all intertidal surfgrass in the South region, 10% of shelf I sandy bottoms in the North region, and so on for all 31 conservation features.

Our range of conservation targets (10%, 17% and 34%) were determined based on the SAT's guidelines for MPA size and spacing:

> To best protect adult populations, based on adult neighborhood sizes and movement patterns, MPAs should have an alongshore extent of at least 3-6 mi of coastline, and preferably 6-12.5 mi. To facilitate dispersal among MPAs for important bottom-dwelling fish and invertebrate groups, based on currently known scales of larval dispersal, MPAs should be placed within 31-62 mi of each other.

From these recommendations we calculated how many MPAs could fit into the 146 miles of straight coastline in the study region, with the assumption that MPAs stretched 3 miles from the coastline out to the boundary of state and federal waters. If the minimum size and spacing recommendations were used to design a network of MPAs, the total area set aside would be approximately 10% of the study area. If the maximum size and spacing were used, the total area set aside would be approximately 17% and if the maximum size and minimum spacing were used, then the total area set aside would be approximately 34%.

The calculations for determining conservation targets in keeping with the SAT's size and spacing guidelines are presented below:

Determining Percentages of Habitat Conservation

- Higher Range of Preferred Size (12.5 miles) and Lower Range of the Maximum Spacing (31 miles) = 4 MPAs fit into the region
  - 4 MPAs x 12.5 mile size = 50 miles of MPAs
  - 50 miles of MPAs / 146 miles of coastline = **34.2% of coastline captured**

- Lower Range of Preferred Size Size (3 miles) and Lower Range of the Maximum Spacing (31 miles) = 5 MPAs fit into the region
  - 5 MPAs x 3 mile size = 15 miles
  - 15 miles of MPAs / 146 miles of coastline = **10.3% of coastline captured**

- Higher Range of Preferred Size (12.5 miles) and Higher Range of the Maximum Spacing (62 miles) = 2 MPAs fit into the region
  - 2 MPAs x 12.5 mile size = 50 miles
  - 25 miles of MPAs / 146 miles of coastline = **17.1% of coastline captured**

Figure 3.2: Calculations Determining Habitat Conservation Target Percentages..

It is important to note that many more MPAs could be established in the region than the percentages calculated above indicate. This calculation simply gives us a method by which to determine potential conservation scenarios that are consistent with the SAT's recommendations for reserve size and spacing. This approach linked our methods to the SAT's guidelines for the MLPA Initiative process.

Calibration

Marxan's powerful simulated annealing algorithm allows for flexibility through customizable user settings. However, changing these settings can have a large impact on solution efficiency. Careful calibration is necessary in order to ensure a robust analysis; in other words, to ensure that Marxan is producing optimal lowest cost reserve system solutions while meeting its conservation targets. (Fischer & Church 2005).

As previously described, the BLM and the CFPF are essential user settings. Additionally, the user also sets the number of iterations and runs, which are respectively the number of planning unit switches the program performs to create each solution, and the number of solutions the algorithm generates each time it is turned on. The calibration of Marxan user settings is a complex process with a lack of published material to provide guidance. In an effort to contribute to the body of knowledge concerning the effective use of Marxan, we have developed a calibration manual that describes the process of calibrating the user settings based on our project scenario. Calibration is specific to a particular project, which may account for the dearth of published guidelines about how to calibrate Marxan. Our calibration manual (Appendix A) serves as a framework, which can be applied and modified by future Marxan users to develop their own calibration methods.

Determining the Boundary Length Modifier

The BLM is a critical user setting that significantly influences the design of a reserve system and should be chosen with care. Fragmentation tends not to be a desirable trait for a reserve system and thus the BLM controls the relative importance of minimizing the sum of the boundary lengths within a system. The BLM can be any decimal between 0 and 1. A high BLM will result in fewer, larger reserves, while a lower BLM will produce more numerous, smaller reserves.

To determine the most efficient BLM for our project scenario, Marxan was run several times with a range of BLMs from 0 to 1. For each BLM used, we selected the "best" solution[4] from the run and plotted the total boundary length versus the cost (See Figure 3.2).

Although the 'correct' level of reserve system compactness is subjective, for the purpose of consistency within our project we defined the most efficient BLM as one that minimizes both 'cost' and boundary length. We determined an 'efficient' BLM as one that has the smallest area under the curve – that is, the smallest product of cost and boundary length. Using this technique, 0.003 was determined to be the most efficient BLM for our analysis of biophysical conservation targets alone, while 0.0001 was most efficient for the analysis of biophysical conservation targets and commercial fishing costs. Although we used different BLM values for each analysis the results are comparable. Because the most efficient BLM was used in each case, the same constraint of minimizing cost and boundary length applied in each scenario. It should be noted that the Marxan user is not required to use the most efficient BLM in every analysis. One may wish to choose a BLM simply based on the size or spacing of reserves that result. To maintain consistency we chose to use the most "efficient" BLM in our analyses.

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[4] The "best" solution is characterized by the solution with the lowest objective function score.

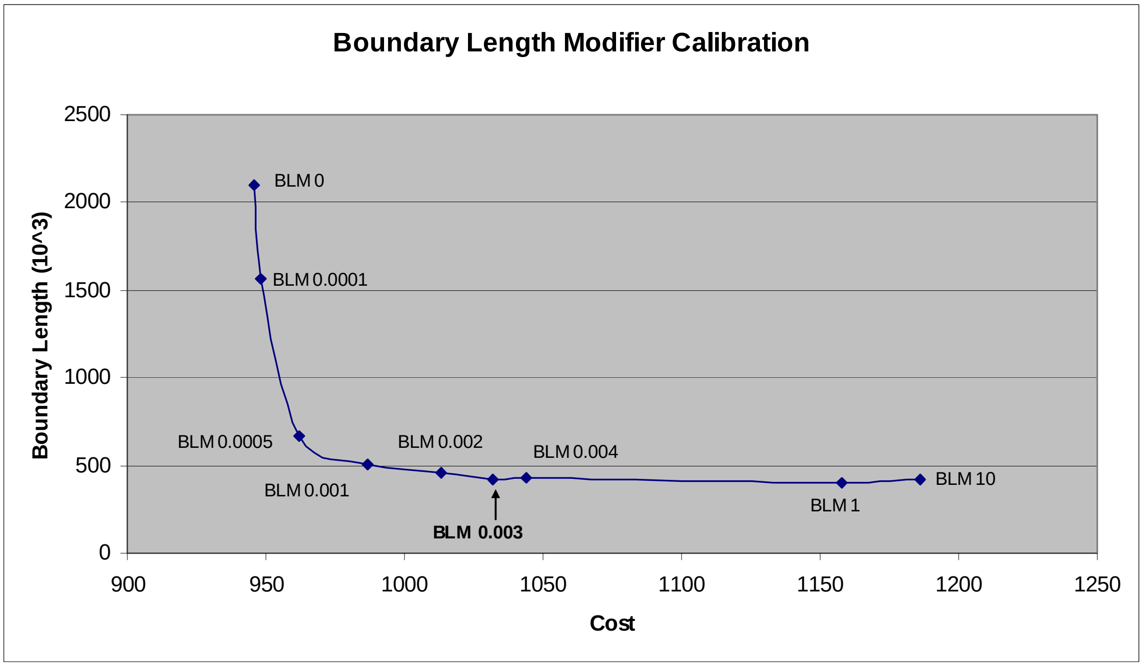


Figure 3.3: BLM calibration for analysis of habitat conservation targets. This graph plots total cost against total boundary length for the most efficient Marxan solution. This BLM calibration for the 34% biophysical analysis shows the most efficient BLM to be 0.003.

The Summed Solution: Top 100 runs

The objective of our project is to inform the MLPA planning process and support MPA-placement decision-making. Our purpose was not to recommend specific MPA network designs, but to provide a rigorous analysis of available data that would generate a starting point for discussion. Therefore, we created ‘summed solution’ maps to highlight areas that Marxan repeatedly chose to include in reserve system designs or ‘solutions’.

Marxan generates many solutions for each problem it is presented with. The iterative nature of the algorithm allows the tool more opportunities to solve the scenario in different ways and to produce ‘top scoring’ solutions. In our analyses Marxan was run 1,000 times, yielding 1,000 solutions for each percentage conservation scenario (10%, 17%, and 34%). From the 1,000 runs we selected the 100 ‘top scoring’ solutions – solutions that met the targets with the lowest cost (defined as smallest number of planning units or least cost to commercial fisheries, depending on the analysis) and shortest boundary length. We chose to select the top 100 solutions in order to improve the clarity and utility of our Marxan maps. Displaying a composite of the top 100 solutions gives a more efficient and informative result than displaying all 1,000 solutions.

These summed solution maps are useful for visualizing locations in the study region that most efficiently meet the habitat conservation goals and objectives of the north central coast region while minimizing costs. The resulting array of three conservation scenarios provides valuable insight into how the conservation value of planning units changes with increasing protection. In fact, the maps depicting the conservation targets based on maximum size and minimum spacing (34% conservation scenario) provide the greatest amount of information because the scenario forces Marxan to repeatedly choose to conserve particular planning units based on their high conservation value.

The methodology presented above details the inputs and parameters we used to incorporate the guidelines of the MLPA planning process into our Marxan analyses. In the subsequent chapter we describe our Marxan analyses and products, which provide decision support tools contributing to MPA network planning.

Chapter 4: Marxan Results

Maps displaying summed-solutions are the primary products of the Marxan analyses for this project and are the focus of this section. The principle value of the maps is to identify planning units that have been repeatedly selected and therefore represent locations of high conservation value, which can be considered for inclusion in a marine reserve network. Marxan also creates clumped solutions because it minimizes the boundary length of the network. Using the summed-solution maps, planning units and concentrations of planning units of high conservation value can be identified and then more closely evaluated using a Geographic Information System (GIS) by considering the type and quantity of associated habitats. In order to interpret these maps, it is helpful to understand why Marxan favors particular planning units or collections of planning units over others.

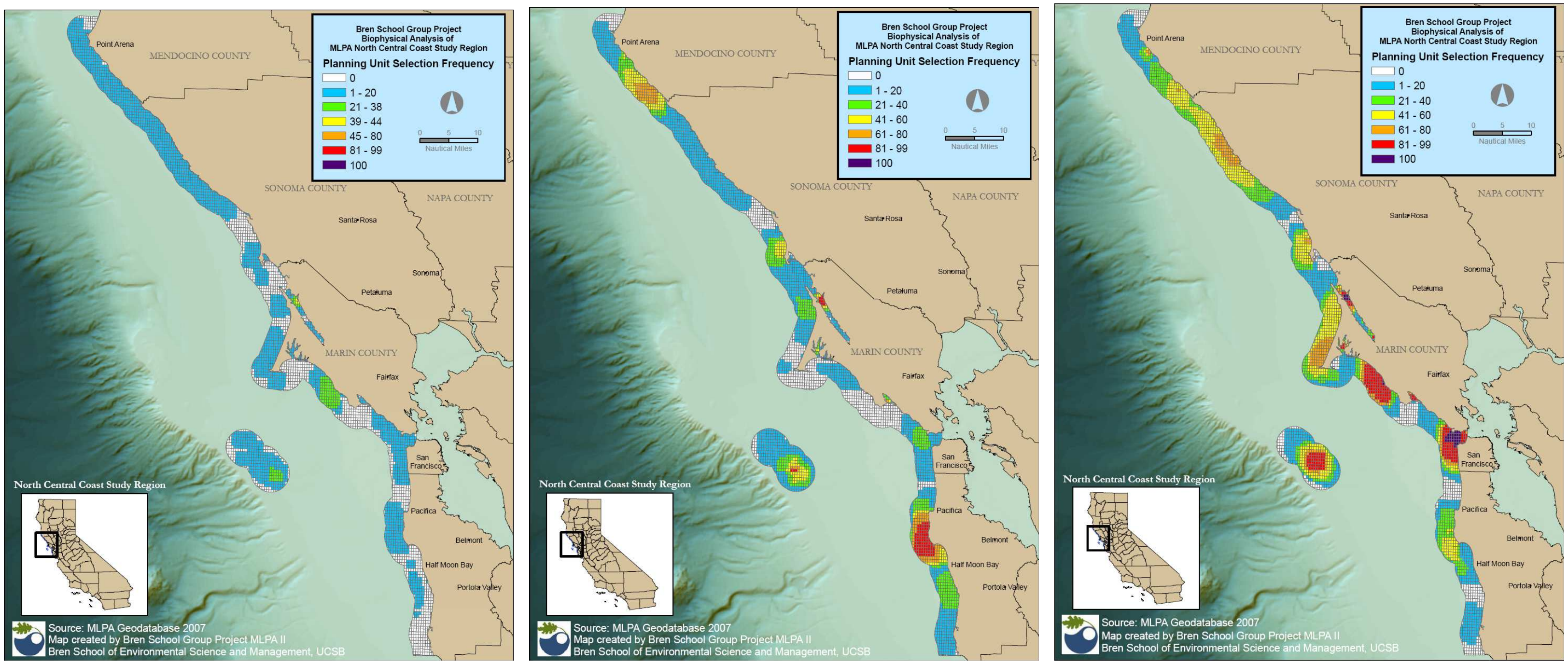
Results of Habitat Analyses

The following habitat analyses were designed to facilitate compliance with the North Central Coast Regional Stakeholder Group's (NCCRSG) goal to "protect marine natural heritage, including protection of representative and unique marine life habitats in north central California waters, for their intrinsic value." The decision support tool Marxan was utilized to address this goal by exploring conservation scenarios that maximized the amount of representative habitats placed into marine reserves while minimizing the area of a marine reserve.

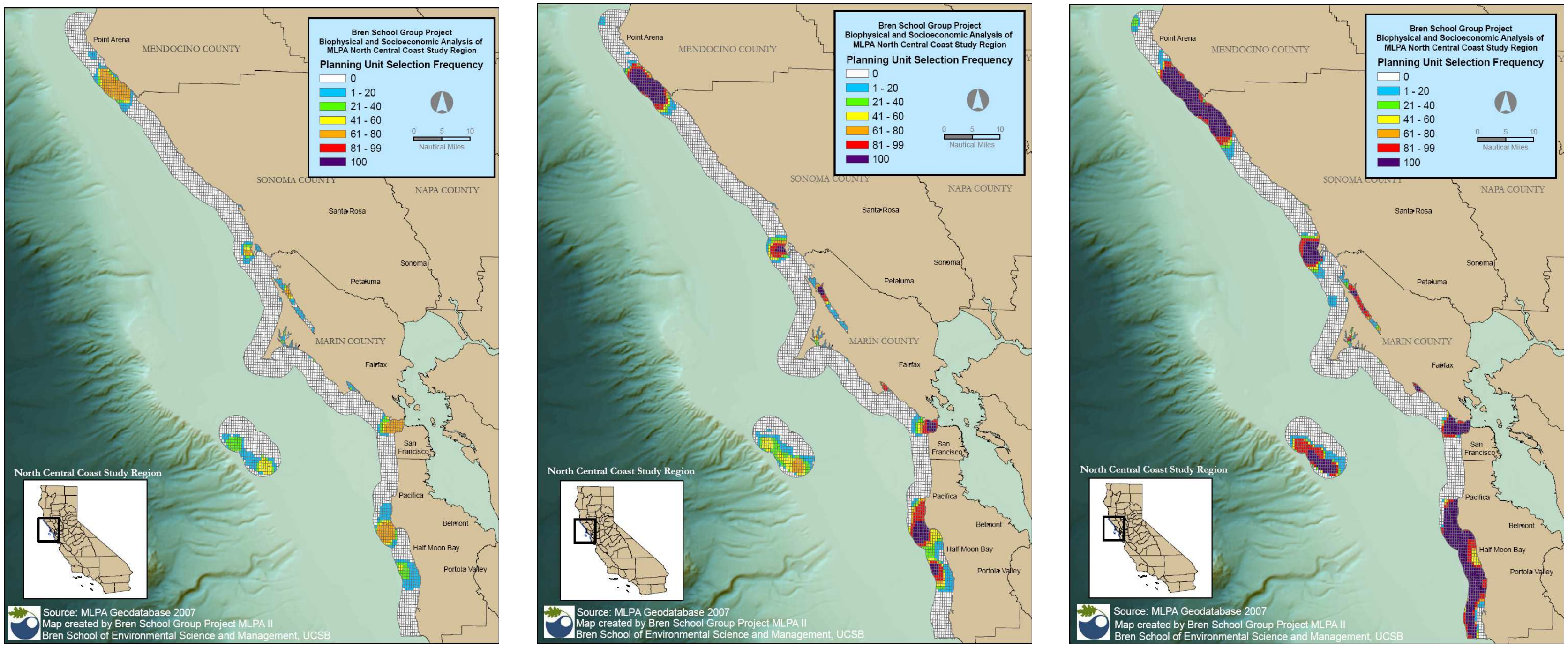
We explored three conservation scenarios in which we instructed Marxan to capture 10%, 17%, and 34% of representative habitats within marine reserves (Figures 4.1, 4.2 and 4.3). For this analysis, we assumed that the cost of including each planning unit was equal, without considering other economic costs. For our habitat analyses, Marxan found potential locations of marine reserves based on meeting conservation goals at a minimum cost, in this case, minimum number of planning units.

Results of Habitat Analyses with Cost Considerations

Goal 5.2 of the NCCRSG goals and objectives states the importance of minimizing "negative socio-economic impacts and optimiz[ing] positive socio-economic impacts for all users." To address this goal we performed an analysis in which we incorporated data on habitat conservation targets and the relative value of planning units to the commercial fishing industry. The socioeconomic data were collected through personal interviews of commercial fishermen by the non-profit research group, Ecotrust, and the data represent the relative importance of commercial fishing grounds in each planning unit across 34 separate fisheries and for 5 ports (See Chapter 3). As with the habitat analyses, Marxan identified areas of high conservation importance and potential locations for marine reserves while conserving 10%, 17%, and 34% of all marine habitat types (Figures 4.4, 4.5, 4.6). In this analysis, Marxan



Figures 4.1, 4.2 and 4.3: These maps depict the results of habitat analyses using the planning tool Marxan and the best available marine habitat data. Half-minute planning units, the most efficient boundary length modifier (BLM) of 0.003, and respective targets of 10% (4.1), 17% (4.2), and 34% (4.3) representative habitat conservation were used. The algorithm was run 1000 times and the 100 “best” runs were overlaid to identify planning units with potentially high biophysical conservation value



Figures 4.4, 4.5, and 4.6: These maps depict the results of a habitat analysis with cost considerations (specifically costs to commercial fisheries) using the conservation planning tool Marxan and the best available data. Half-minute planning units, the most efficient boundary length modifier (BLM) of 0.0001, and respective targets of 10% (4.4), 17% (4.5), and 34% (4.6) representative habitat conservation were used. The algorithm was run 1000 times and then the 100 “best” runs were overlaid to identify planning units with potentially high biophysical conservation value that considers costs to commercial fisheries.

found efficient networks of planning units that met conservation goals while minimizing the cost to commercial fisheries and the number of planning units. Table 4.1 shows the cost of each scenario for the habitat analysis with cost considerations.

Table 4.1: Cost Statistics for Habitat Analysis with Cost Considerations Scenarios. Average cost and percentage cost do not have any units. They were weighted by ex-vessel dollars, and because of the method in which the value was collected through fishermen interviews the resulting data was not based on a unit, but personal feelings of economic value from the fishermen.

	Average Cost	Percentage Cost	Standard Deviation	Range
10% Habitat with Cost Consideration	11.5	2.5%	0.33	10.9 to 12.3
17% Habitat with Cost Consideration	21.9	4.8%	0.33	21.1 to 22.6
34% Habitat with Cost Consideration	54.1	11.8%	0.41	53.2 to 55.1

Results of Cost Threshold Analysis

We conducted a third “cost threshold analysis” that limited the potential impacts to commercial fishermen to no more than 10% for each fishery. Marxan was asked to identify planning units for potential marine reserve systems that would conserve as much of all marine habitat types as possible (up to 100%), while ensuring that the cost to the commercial fishery would never be more than 10% of the total cost. The targets were set to 100% to maximize the capture of habitat, but none of the solutions satisfied all of the constraints. This map (Figure 4.7) and its adjoining table (Table 4.2) were useful in determining what habitats were difficult to place into reserve while minimizing costs to commercial fisheries. Table 4.2 displays the average percentage and standard deviation of each conservation feature that was captured in the 100 best runs. The only habitat that was conserved at less than 30% was the “Soft bottom shelf” (in all three bioregions).

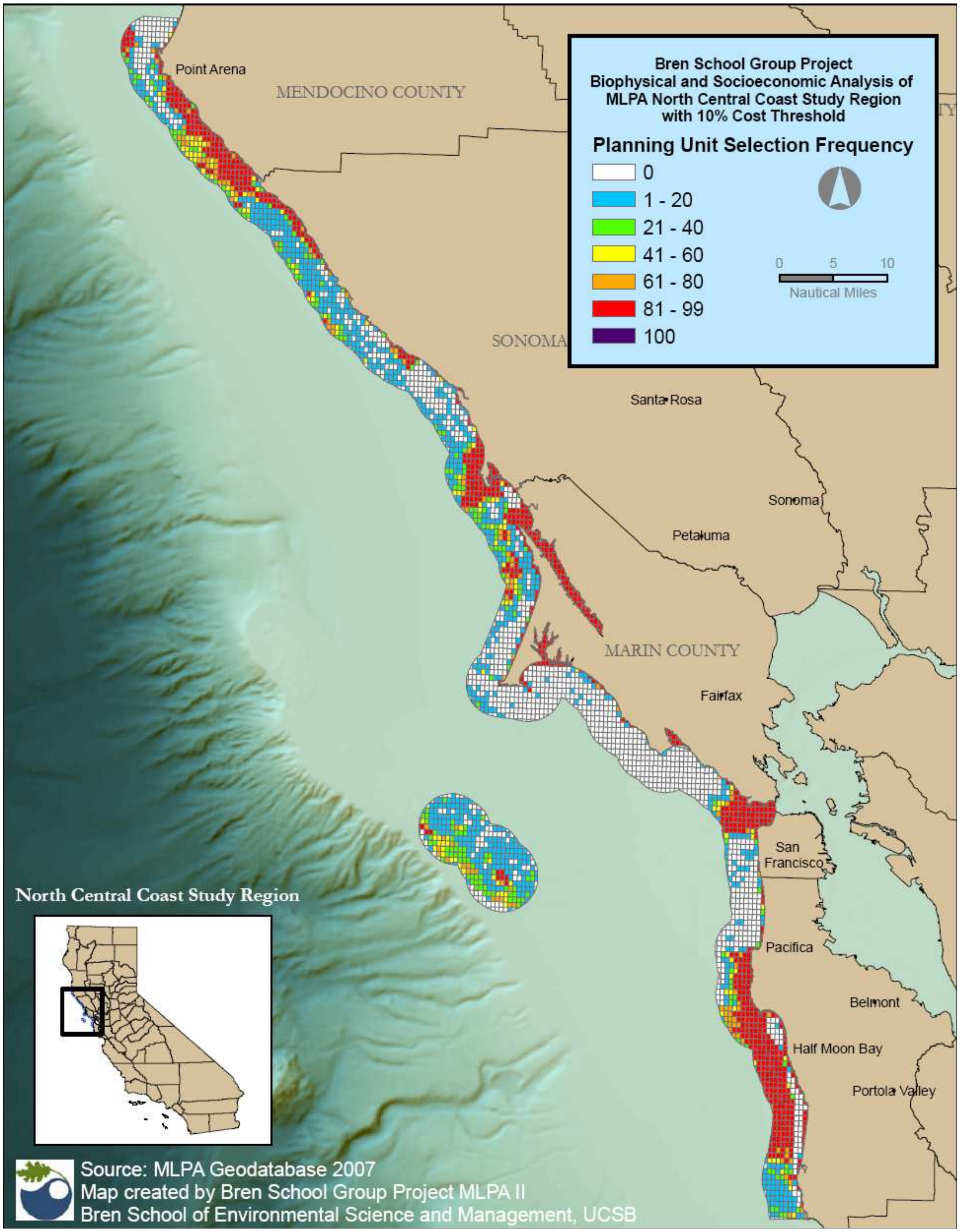


Figure 4.7: Results from the cost threshold analysis. The purpose of this analysis was to find the best solutions based on limiting the cost to the commercial fisheries in the north central coast study region to 10% of the total cost with the conservation targets set at 100%. Half-minute planning units, the most efficient boundary length modifier (BLM) of 0.0001, and a target of 100% representative habitat conservation were used. The algorithm was run 1000 times and then the 100 "best" runs were overlaid to identify planning units with a maximum cost of 10% to commercial fisheries.

Table 4.2: Mean percentage of habitat conservation features captured in the cost threshold analysis, with a maximum cost of 10% to commercial fisheries and a habitat conservation target of 100% of each of the marine habitats. Bioregions area north, south, and Farallons. Depth zones are intertidal and Shelf I.

Target Conservation Feature	**Percent Captured (Mean +/- standard deviation)**
Kelp Average South	74.7 ± 5.2
Kelp Average North	86.3 ± 1.4
Hard Bottom Shelf I Farallon	33.1 ± 5.5
Hard Bottom Shelf I South	68.5 ± 1.2
Hard Bottom Shelf I North	53.0 ± 1.9
Hard Bottom Nearshore Farallon	84.7 ± 9.3
Hard Bottom Nearshore South	55.7 ± 0.6
Hard Bottom Nearshore North	71.7 ± 1.5
Soft Bottom Shelf I Farallon	14.9 ± 1.8
Soft Bottom Shelf I South	20.2 ± 0.9
Soft Bottom Shelf I North	24.0 ± 0.8
Soft Bottom Nearshore Farallon	93.4 ± 6.7
Soft Bottom Nearshore South	37.6 ± 0.7
Soft Bottom Nearshore North	58.6 ± 1.1
Estuaries South	99.4 ± 0.01
Estuaries North	99.7 ± 0.07
Eelgrass South	100.0 ± 0.01
Eelgrass North	100 .0 ± 0.00
Surfgrass Farallon	98.8 ± 7.0
Surf grass South	79.3 ± 1.9
Surf grass North	94.7 ± 2.2
Intertidal Tidal Flat South	94.4 ± 0.4
Intertidal Tidal Flat North	100.0 ± 0.00
Intertidal Coastal Marsh South	98.2 ± 0.09
Intertidal Coastal Marsh North	99.9 ± 0.2

Target Conservation Feature	**Percent Captured (Mean +/- standard deviation)**
Intertidal Rock Shores Farallon	88.8 ± 5.6
Intertidal Rock Shores South	83.4 ± 1.5
Intertidal Rock Shores North	85.8 ± 1.2
Intertidal Sandy Beach Farallon	98.1 ± 5.4
Intertidal Sandy Beach South	82.1 ± 1.5
Intertidal Sandy Beach North	92.1 ± 1.1

Table 4.3 shows the minimum and maximum number of planning units for the 100 best solutions selected by the Marxan for (a) the habitat analysis and (b) the habitat analysis with cost considerations for each conservation scenario (10%, 17%, and 34%) and (c) the 10% cost threshold scenario, along with the average number and standard deviation for each scenario

Table 4.3: Average Number of Planning Units Captured in 100 Best Runs of Each Scenario

	Average	Standard Deviation	Range
10% Cost Threshold	1309.1	6.2	1295 to 1324
10% Habitat	304.4	4.1	295 to 315
10% Habitat with Cost Consideration	323.6	4.1	314 to 336
17% Habitat	595.5	18.9	552 to 638
17% Habitat with Cost Consideration	558.3	11.8	539 to 584
34% Habitat	1033.1	8.6	1012 to 1055
34% Habitat with Cost Consideration	1130.2	8.4	1110 to 1147

Methods for Interpreting Results

We compared summed-solution maps to the spatial habitat datasets that were used as conservation targets in each analysis. We investigated potential causes of concentrations of selected planning units by evaluating the locations of particular habitats and also planning units with high selection frequencies and by considering this information at different scales and in various combinations. Some of the general drivers of Marxan solutions are described below. For those analyses that involved the commercial cost index, summed-solutions also were compared with a map of the cost index (Figure 4.8). Additionally, a few possibilities were tested using linear regression to examine relationships between the hypothesized solution driver and the selection frequency of a planning unit.

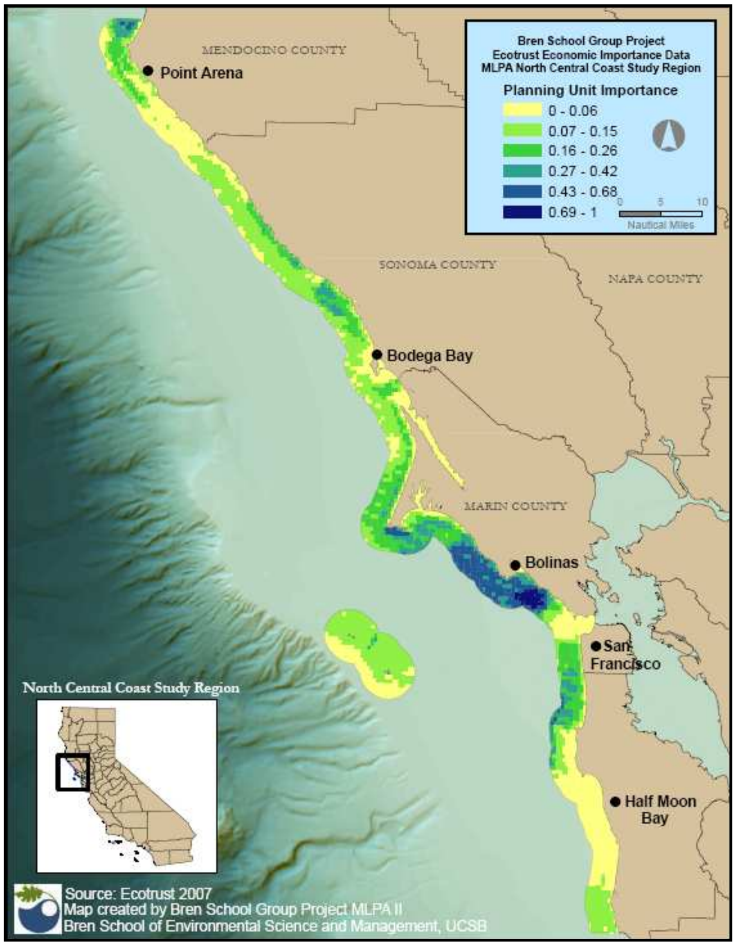


Figure 4.8: Map of cost index for north central coast region which shows the relative importance of each planning unit based on the commercial cost index.

Solution drivers

These factors below offer explanations as to why particular planning units were repeatedly selected in Marxan solutions:

Rare or localized habitat: Rare habitat can drive the location of a concentration of selected planning units. Recall that Marxan creates clumped solutions when the BLM is set with this objective. Marxan has limited options for incorporating rare habitats and will therefore build solutions around them. By the same reasoning, habitat that is not necessarily rare, but is concentrated and localized rather than located in different places, will have the same effect.

Habitat richness: Marxan frequently generates concentrations of planning units in areas with a high density of different types of habitat. Capturing many conservation features in close proximity is more efficient when one objective is minimum area or cost. Uniform habitats and areas with low habitat richness covering a relatively large extent were selected infrequently. This is partly because these habitats are abundant and thus easily included in locations with higher habitat diversity.

Habitat richness by cell: Marxan may be more likely to select a planning unit when there are a high number of habitats present within the planning unit. On the other hand, these planning units with high within-cell habitat diversity may be more likely to contain relatively low quantities of each habitat and this may cause them to be selected less frequently. To determine if within-cell habitat diversity was a factor in selection, we used linear regression with the independent variable of within-cell habitat diversity and the dependent variable of the number of times the planning unit was selected in the best 100 solutions. This did not result in a significant relationship between within-cell habitat diversity and selection frequency.

Planning units with no habitat data: Some habitat datasets were incomplete due to limitations in technology or data availability and consequently some planning units were missing or only partially contained habitat data. The use of these datasets was justified by the MLPA requirement of using the best available data. Marxan appeared to occasionally include planning units with no habitat data in a solution when the width of these planning units was narrow. This usually occurred when the no-data planning units separated two areas of habitat that were both included in a clump.

Analysis and Discussion of Results

The Marxan maps presented above are not intended to suggest specific locations for MPA networks. Rather, the maps prioritized areas for further consideration for inclusion in a MPA network. The Marxan algorithm selected planning units that most efficiently achieved conservation goals while minimizing costs, with costs defined as minimizing the number of selected planning units or the cost to commercial fisheries (See Chapter 3). These maps are valuable decision support tools, but do not show specific MPA boundaries; the maps show the number of times each planning unit was included in the top 100 separate MPA network designs.

Habitat Analyses with 10%, 17%, and 34% targets

The objective of the habitat analyses was to meet conservation targets while giving each planning unit equal weight and constraining costs only by minimizing boundary length and the number of planning units selected. Three habitat scenarios were run with targets of 10%, 17%, and 34%.

Comparison of the habitat summed-solution maps for conservation targets of 10%, 17%, and 34% showed that as the percentage increased, concentrations of planning units become more numerous, of wider spatial extent, and had higher selection frequencies. Additionally, fewer planning units were never included in one of the network solutions. This result is intuitive as increasing the amount of required habitat will increase the number of planning units selected. Also, as the target percentage increased, concentrations of selected planning units usually persisted and remained in the same basic location and less often shifted or diminished. As the target amount of habitat became higher, Marxan ran out of higher diversity areas around which to build solutions and add areas of lower habitat diversity and uniform habitat to meet the targets.

The summed-solution requiring 10% of each conservation feature resulted in three concentrations of higher selection frequency: (1) the southern Farallon Islands, (2) south of Drake's Bay and north of Duxbury Point, and (3) part of Tomales Bay. These concentrations had selection frequencies of 21-40 (of the top 100 solutions) although the Tomales Bay concentration was selected 40-60 times. In addition to the concentrations, a high percentage of each bioregion was selected 1-20 times. The relatively low selection frequencies and the wide spatial range of selected planning units show there are a range of options for meeting conservation objectives.

The summed solution that included 17% of each conservation feature resulted in several concentrations. The highest concentrations reached selection frequencies of 81-99 (of the top 100 solutions) at Tomales Bay, north of Half Moon Bay, and at the southern Farallon Islands. An additional concentration that reached selection frequencies of 60-80 was found off the Mendocino coast

The summed solution that included 34% of each conservation feature contained concentrations of planning units that reached the highest selection frequencies of 81-99 and 100. These concentrations included the San Francisco Bay and vicinity, south of Drake's Bay, the southern Farallon Islands, Tomales Bay, and a few of the estuaries that contain multiple rare habitats such as Limantour Estuary in the southern bioregion. Several additional concentrations reached the 61-80 selection frequency level.

The following examples demonstrate how concentrations of high frequency planning units can be attributed to specific solution drivers. The southern Farallon Islands concentration persisted across all habitat analyses for each target percentage. This location was repeatedly captured because of high habitat diversity in a relatively small area, including locally rare surfgrass and sandy shore habitats that do not occur elsewhere in the Farallon Islands (Figure 4.9). Marxan captured common habitats as well around this hotspot. The concentration south of Drake's Bay was probably driven by the largest amount of kelp habitat in the south bioregion. Other habitats including nearshore and Shelf I hard bottom, as well as surfgrass, which are only found in a few areas in the south bioregion also can be captured south of Drake's Bay. Despite the uncommon habitats, such as tidal flats and coastal marshes, found in the estuaries very close to this concentration, Marxan did not cluster these planning units together. This was possibly because the selected concentration of planning units and the estuaries were separated by planning units with no habitat data.

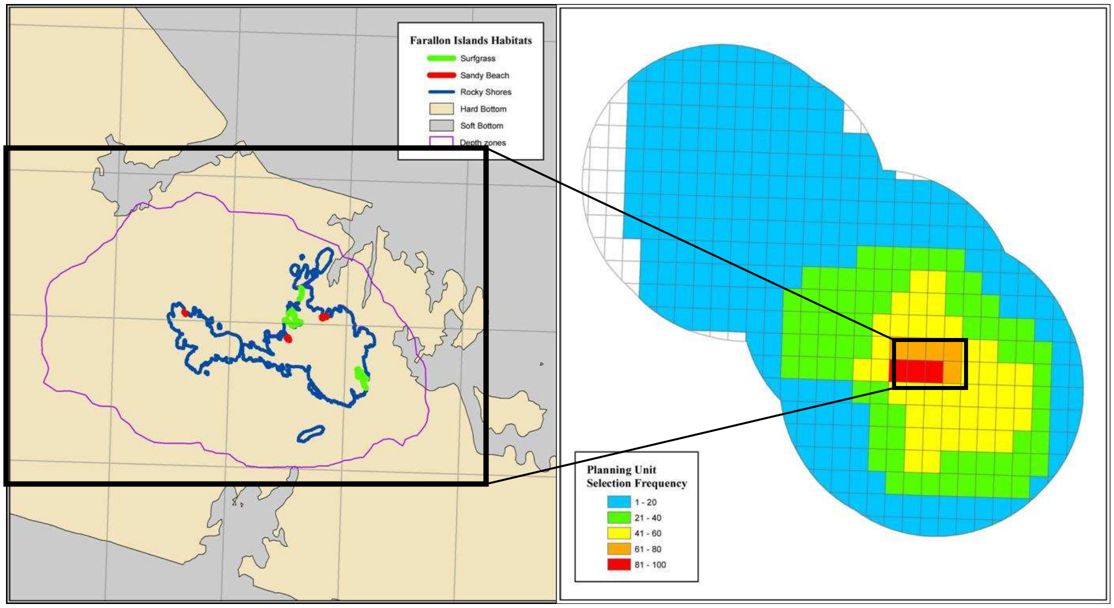


Figure 4.9: Southern Farallones Habitat Diversity. The figure on the right depicts the results from a habitat analysis. The eight planning units highlighted on the right are shown in an increased scale on the left. The left picture shows that several habitats, including habitats not found elsewhere, are found within this small area. This results in a high capture rate of these planning units in Marxan solutions.

In the north bioregion, surfgrass distribution was limited at the southern end and this appears to have driven some concentrations. Parts of Tomales Bay had high selection frequency over all habitat analyses because the bay contains a high diversity of uncommon habitats, including eelgrass, tidal flats, coastal marshes, and estuaries. In the northern half of the northern bioregion is a relatively even distribution of abundant kelp, hard bottom, and soft bottom. This uniformity appears to have resulted in a wider spatial range of selected planning units and therefore a wider range of potential solutions. The estuaries with their diverse and rare habitats, including eelgrass, were always selected frequently.

Habitat analysis with cost considerations using 10%, 17, 34% targets

The objective of the analyses of the habitat conservation targets with cost considerations was to meet conservation targets while minimizing the cost to the commercial fishing industry. An index that represented the importance of each planning unit to the commercial fishing industry was used to represent cost (See Chapter 3 and Figure 4.8 above). Three analyses of habitat conservation targets with cost considerations were run with targets of 10%, 17%, and 34%.

The habitat analyses with cost considerations were distinctly different from the habitat analyses because costs associated with each planning unit were not equivalent, but varied based on an index representing the value of each planning unit to the commercial fishing industry. The habitat analyses generated solutions that met conservation targets while minimizing area and boundary length. The analyses of habitat conservation targets with cost considerations also minimized boundary length and still tended to build concentrations in areas of rare and diverse habitat, but they also built solutions using planning units that were of lowest cost to the commercial fishing industry.

A comparison of summed-solutions map of the value to commercial fishing showed that solutions corresponded closely to areas of lowest cost. Summed-solutions also were densely concentrated in a few areas; each individual solution was similar, showing there were not a large number of possible network configurations when costs to commercial fisheries were considered. As the percentage of habitat required for the solution increased, summed solutions remained densely compacted and increased significantly in selection frequency rather than spreading into areas of higher cost. Increases in spatial extent generally went into remaining areas of lowest cost around the concentration.

The habitat analyses with cost considerations created distinctly different summed-solutions maps compared to the habitat analyses. The habitat analyses with cost considerations and the habitat analyses both generated solutions that met conservation targets. However, the habitat analyses had more flexibility to find areas of high habitat diversity than did the habitat analyses with cost considerations, which had stronger constraints on location due to variation in importance of each area to commercial fishermen. Therefore, the habitat maps were useful in highlighting areas that would significantly contribute to meeting habitat conservation goals.

The largest concentrations of selected planning units that occurred across all habitat analyses with cost considerations were off the Mendocino coast, near Bodega Bay, in Tomales Bay, in all estuaries, the San Francisco Bay and vicinity, the western side of the Farallon Islands, and north and south of Half Moon Bay. As previously mentioned, these concentrations all corresponded closely with the cost index and areas of lowest cost to fishermen.

The Farallon Island bioregion is a good example to demonstrate what is driving the spatial patterns in the solutions to the habitat analyses with cost considerations. Comparing the commercial cost index to the summed-solution maps showed planning units of greater value to fishermen tended to be in the eastern part of the bioregion and consequently Marxan solutions tended to be in the low-cost western side of the bioregion. Some of the planning units with rare habitat around the islands were also of high value to fishermen and therefore were selected less frequently compared to the habitat analyses.

Cost Threshold Analysis

The primary objective of the 10% cost threshold analysis was to determine the percentage of each habitat that could be captured when limiting the cost to the commercial fishing industry to no more than 10% of its total value The planning units with higher selection frequency correspond very closely with lower cost indexes.

Summed-solutions maps from the cost threshold analysis do show concentrations of planning units with high selection frequency. Those in the 81-99 or 100 ranges occur primarily in locations very similar to the areas selected by the habitat analyses with cost considerations: off the southern Mendocino coast, west of Bodega Bay, within Tomales Bay, the San Francisco Bay and vicinity, and north of Half Moon Bay extending south. The obvious differences in spatial pattern between the two types of cost analyses were wider distribution and less compact solutions for the cost-threshold analysis. Planning units with low selection frequency particularly in the 1-20 range were throughout the northern and Farallon Islands bioregions and occurred as scattered and isolated planning units as well.

Chapter 5: Estimating Changes in Fishermen Density

A particular concern about marine protected areas shared by many commercial fishermen is to what extent MPAs may result in increased congestion within the remaining open fishing grounds. Fishermen displaced from their old fishing grounds by MPAs often relocate their effort to other areas, resulting in increased density of fishermen per fishable area. In this section we explore a method for estimating this change in fisherman density for different MPA network proposals. This technique may be used to assess a MPA proposal's impact on fishermen density, and also provides a useful method for comparing the potential socioeconomic impacts stemming from an array of proposed MPA networks.

During Ecotrust's interviews of commercial fishermen in the north central coast, respondents were asked to identify their most economically important fishing grounds. Each fisherman was asked to distribute 100 imaginary pennies, or points, among their fishing grounds according to each area's relative importance. As explained in Chapter 3, these importance values were first overlaid with the 3,610 planning units in the study region, and ultimately weighted according to each fisherman's landing value from 2000-2006, resulting in more influence being given to more prolific and successful fishermen. Two different planning units could be assigned the same importance value by two different fishermen, yet after the landing value weighting has been applied, the planning unit fished by the higher earning fisherman will have a higher importance value.

This methodology is a departure from the type of analysis performed by Ecotrust in the central coast Marine Life Protection Act (MLPA) Initiative process. In the central coast, each fisherman's stated preferences were weighted through a "footprint" method based on the size of the fisherman's fishing grounds. However this technique made the implicit assumption that fishermen with smaller fishing grounds have smaller profits or effort. Ecotrust changed this weighting protocol in response to several external reviews of its central coast methodology (Wilen and Abbott 2006). Ecotrust's north central coast method of weighing by landing value results in a cost index that is inherently biased towards the interests of the more successful fishermen. Our Marxan analysis thus reflects the same bias.

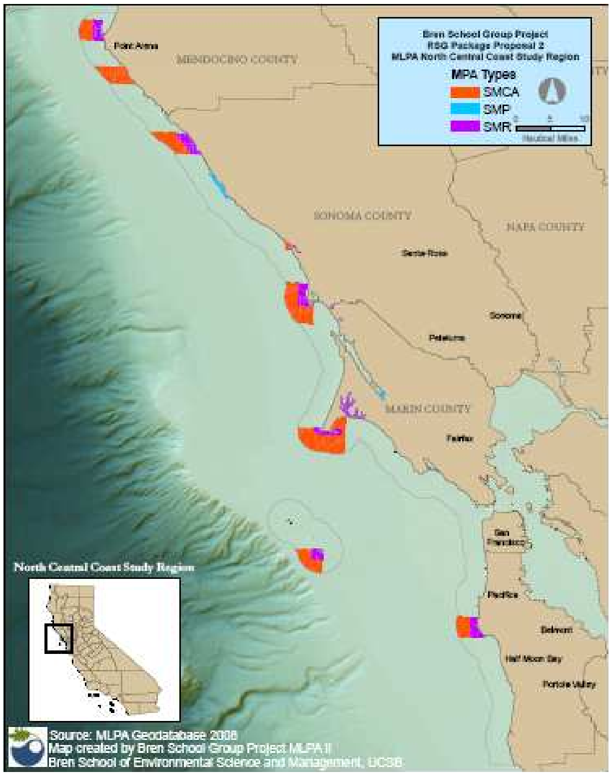
As a counterpoint to this bias imbedded in our Marxan work, we developed another analytical approach to evaluating the potential impacts of marine reserves in which no weighting was applied and all fishermen were treated as equal. We estimated the potential impact of MPAs on commercial fishermen by investigating how average fishermen density will change after MPAs are established. As additional MPAs are established in state waters in compliance with the MLPA, fishing effort will either be lost, as previous analyses have assumed, or fishing effort will be displaced from newly closed areas into the remaining open fishing grounds. This analysis calculates how the average density of fishermen per planning unit may change with the establishment of marine reserves and other protected areas, assuming fishing effort is completely displaced into the remaining open grounds. We selected the four proposals for MPA networks developed by the NCCRSG from the MLPA Initiative process for this work. This analysis provides a different perspective on the impacts of MPAs on commercial fishermen by considering numbers of fishermen, rather than weighted importance of planning units.

Methods

In December of 2007, the NCCRSG submitted four MPA network package proposals to the MLPA Initiative. We used all four proposals for this analysis. The stakeholder proposals range in size from Proposal 2, the smallest, (in other words, it bans fishing from the fewest planning units) to Proposal 4, the largest. Proposal 2 includes 11 state marine reserves, 2 state marine parks, and 9 state marine conservation areas, encompassing a total of 17.74% of the study region, while Proposal 4 includes 14 state marine reserves, 1 state marine park, and 9 state marine conservation areas, encompassing a total of 28.20% of the study region (California MLPA Initiative 2008). These different categories of MPA are zoned for different types of extractive activity. State marine reserves prohibit all types of fishing and other extractive activities. State marine parks allow recreational harvest, but forbid commercial harvest. State conservation areas allow varying degrees of recreational and commercial harvest according to the area’s specific zoning (California MLPA Initiative 2008). Figure 5.1 below displays Proposal 2 as an example of the four stakeholder-created MPA proposals.

Our analysis compares the current average density of fishermen per planning unit (N/PU1) to the estimated average density given the implementation of each proposal (N/PU2), where N is the total number of fishermen, PU1 is the number of planning units available to the fishery before MPAs are established, and PU2 is the number of planning units available to the fishery after MPAs are established. We assume that all fishermen displaced from their fishing grounds by the new spatial restrictions remain in the fishery and move to other fishing grounds. Additionally, fishermen are assumed to displace equally to any other planning unit containing pre-existing fishing effort. We do not take planning unit characteristics such as distance from port or current importance to the fishery into account. We used this analysis to compare the average density of fishermen for five important commercial fisheries before and after the adoption of each of the four MPA proposals.

The planning units currently used by five important commercial fisheries were determined through the planning unit importance data gathered by Ecotrust (See Chapter 3). The importance of planning units varied enormously, spanning 5 degrees of magnitude. For each fishery, the importance of many planning units was less than



Source: MLPA Geodatabase 2008
Map created by Bren School Group Project MLPA II
Bren School of Environmental Science and Management, UCSB

Figure 5.1: NCCRSG Proposal 2. This proposal includes three types of marine protected areas; state marine conservation areas in red, state marine parks in blue, and state marine reserves in purple.

0.01% of the value of the fishery, while the importance of a few planning units exceeded 1.70%. In order to refine the analysis and obtain more meaningful results, planning units supporting less than 0.01% of the total value of the fishery, as determined through interviews with commercial fishermen, were removed from the analysis and were assumed to not support any fishermen. Thus, these planning units with extremely low importance were not considered among those used to estimate fisherman density.

To determine fisherman density per planning unit, the total number of fishermen participating in a fishery was divided by the number of half-minute squared planning units in the study region that are utilized by fishermen in a particular fishery (N/PU1). For each proposal, we recalculated average fishermen density as the number of fishermen divided by the number of remaining planning units that are open to fishing (not included in a MPA) and are utilized by fishermen in a particular fishery (N/PU2). Table 5.1 compares average fisherman density per planning unit before and after the hypothetical implementation of each of the four stakeholder proposals.

As explained above, the three categories of MPAs - state marine reserves, state marine parks, and state conservation areas - allow and forbid different combinations of extractive activities. This analysis took these differing levels of restriction into consideration. We calculated the number of planning units remaining open to fishing after the implementation of each MPA proposal according to the specific fishing restrictions associated with each MPA. For instance, of the 22 MPAs constituting Proposal 2, only 13 prohibit crab fishing while 20 prohibit urchin collection.

Table 5.1: Comparison of average fisherman density per planning unit before and after hypothetical implementation of MPA proposals.

Fishery	Dungeness Crab	California Halibut	Red Urchin	Rockfish	Salmon
Number of Fishermen	227	80	13	76	339
Current Average Fisherman Density	0.12	0.16	0.05	0.04	0.17
With Proposal 1.	0.15	0.19	0.07	0.06	0.20
Percentage Increase	19.1%	17.4%	38.0%	38.8%	20.8%
With Proposal 2.	0.13	0.17	0.07	0.05	0.18
Percentage Increase	5.0%	10.0%	44.0%	22.3%	6.1%
With Proposal 3.	0.14	0.19	0.08	0.06	0.20
Percentage Increase	14.9%	22.5%	57.7%	38.9%	21.9%
With Proposal 4.	0.15	0.20	0.07	0.06	0.21
Percentage Increase	21.9%	24.6%	47.2%	46.9%	23.1%

As expected, average fisherman density per planning unit increased for each of the five fisheries and for every stakeholder proposal used in this analysis. Proposal 4 yielded the largest increases in fisherman density per planning unit, while Proposal 2 gave the smallest, in keeping with the size of the proposals. These percentages estimate how average fisherman congestion might increase. The possibility of increased congestion due to MPAs is a subject of major concern for commercial fishermen. In addition to the psychological effect of encountering other fishermen in areas individuals previously may have had to themselves, congestion could result in increased fuel and crew employment costs, as well as increased space and allocation disputes between users (Sanchirico 2002). The increased concentration of fishermen in the remaining open fishing grounds may result in the degradation of habitat (Leeworthy and Wiley 2002).

The percentage increase does not reflect potential changes in fishermen's catch. It is reasonable to assume that, at least initially, catch per unit effort would decrease due to increased competition. However, over time, the biological benefits of marine reserves, including spillover and export, may cause catch per unit effort to rebound, despite the increase in fisherman density. We also assume that all displaced fishermen remain in the fishery.

In reality, it is unlikely that displaced fishermen would disperse equally to all planning units important to the fishery and open to fishing after the establishment of marine reserves. Planning units likely differ in quality and convenience. Thus, the average values of fishermen density change we calculate are generalizations. Additionally, this analysis makes the assumption that the planning units that will be closed to fishing with MPA placement currently support an average number of fishermen. This is unlikely, as MPAs are often deliberately located in less-used areas in order to minimize impacts on users. Despite these approximations, this analysis provides some insight into the potential impacts of different proposed MPA networks.

This analysis projects that, for the twenty categories provided by four MPA proposals and five fisheries, only the salmon, Dungeness crab, and California halibut fisheries for Proposal 2 would see a 10% or less increase in average fishermen density. The smallest increase in average fisherman density was 5% and occurred in the Dungeness crab fishery with the implementation of Proposal 2. The largest average fisherman density increase impacted in the red urchin fishery with Proposal 3, in which average fisherman density increased by 58%.

This approach provides a systematic methodology for comparing potential socioeconomic impacts of a portfolio of proposed MPA networks. In the future, this work could be further refined by including more spatially-explicit data regarding the actual number of fishermen present in the planning units, rather than an average number. This type of data would allow a better estimate of displacement. Our estimates of increased fisherman density outside of MPAs could also be advanced if the logistical realities of displacement were included. Natural limitations on the ability of fishermen to move include the fuel capacity of fishing boats and the distance of fishing grounds from the fishermen's home port.

Chapter 6: Estimating the Redistributed Costs of a Marine Protected Area Network

Previous attempts to quantify the potential cost of marine reserves prior to implementation have assumed that fishermen effort displaced by a MPA is essentially removed from a fishery, despite the fact this is not likely in reality (Leeworthy and Wiley 2002). This approach assumes that the value of the catch from areas rezoned as MPAs is completely lost. As such, the predicted costs that are associated with a proposed MPA network can be high. In reality, however, most fishermen do not simply disappear, but may transfer their effort to other areas, resulting in redistribution of effort and a lower actual cost of MPAs. Several studies have modeled the redistribution of fish stocks after MPA placement (Apostolaki 2002; Roberts 2001), but the extent and spatial scale at which this redistribution would likely occur for fishermen has not been calculated. We have developed a model to (1) quantify the fishing effort that is redistributed after MPAs are established and (2) obtain an estimated cost of a MPA network that takes redistribution and displacement into account.

Development of Model

The development and use of a model involves various assumptions and depends on the definitions of the variables used within the model. This section will list each of our assumptions and explain why we believe that each assumption is reasonable. Next, we will describe the model and the parameters of each equation. Finally, we will examine the sensitivity of the model to specific parameters.

Assumptions

In order to quantify the potential socioeconomic cost of a proposed MPA network in the NCC study region, we made several assumptions. These assumptions are listed below and explained further in the following paragraphs.

- Fishermen are fishing optimally and efficiently;
- Fishermen are equally willing to move to any planning units where fish are caught;
- The slopes of the marginal value curve for each planning unit are negative; and
- There are a sufficiently large number of planning units into which effort can be redistributed.

First, we assume that all fishermen are fishing optimally and efficiently in the region. The marginal value at which effort occurs in a planning unit is equivalent across all planning units despite varying levels of effort. A fisherman will expend effort where he will maximize his value. As a result, we assume a fisherman is equally willing to move to any place where fish are caught to maximize profit. This assumption equalizes the marginal value across all planning units when fishermen are fishing optimally and efficiently. This is essentially an application of the marginal value theorem[5] (Charnov 1976).

We also assume that fishermen will only move to another patch that is of value to the fishery (based on the importance data gathered by Ecotrust). This assumption removes from consideration all planning units that do not have an associated current value to the fishery. In reality, fishermen can potentially move to any planning units open to fishing, thereby redistributing value from the closed planning units in marine reserves. However, we do not know the circumstances (i.e., no fish, unfavorable oceanographic conditions, too far, etc.) which caused fishermen to identify those planning units as having no value. A conservative estimate of redistribution assumes displacement of fishermen only occurs to planning units where fish are known to be caught[6].

We also assume the slopes of the marginal value curves are negative. A downward (i.e., negative) slope means that each additional unit of effort that is added to a planning unit will decrease the marginal value of the planning unit. With natural resources, such as fish, this is a reasonable assumption. Effort removes a portion of the resource. Additional effort removes an increasing portion of the resource, until either the resource is completely exhausted within the planning unit or the resource is reduced to a point beyond which the effort to remove the resource exceeds the profit gained from selling the resource. In the case of a wild fishery resource, generally, but with some exceptions, fishermen do not replace the resource through cultivation. For these reasons, we assume that additional fishing effort will continue to decrease the marginal value of the planning unit.

As previously mentioned, California state waters (0-3 nautical miles from shore) in the NCC region were divided into 3,610 half-minute by half-minute planning units. For the crab fishery, fishermen identified 1,864[7] of the 3,610 planning units as having some value to the fishery. The largest MPA proposal from the regional stakeholders would remove 335 of the 1,864 fishable planning units. Therefore, 82% of the fishery would still be available to the fishery. For the purposes of this study, this is a large enough number to redistribute the effort from the MPAs.

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[5] The theorem predicts that individuals exploiting a resource will stay longer in a patch that is more profitable when the environment as a whole is less profitable or the distance between patches increases (Charnov 1976).

[6] Planning units where fish are "known" to be caught are based solely on the data collected by Ecotrust (See Chapter 3).

[7] Ecotrust interviews actually indicated the fishery occurs in 3,316 planning units. However, we removed the planning units supporting less than 0.01% of the total value of the fishery.

With the above assumptions, we developed a working model to determine (1) the value of a MPA that can be redistributed to other areas and therefore (2) a more accurate estimate of the costs of MPAs.

Models

Given these assumptions, the value of a fishery in a particular planning unit can be presented as the shaded area in Figure 6.1. Previous analyses concluded that the cost of a MPA (or the value to the fishery that is lost) is this entire region under the curve (representing a loss of the value of the entire planning unit). However, in reality, some of this value can be recovered as fishermen move to other open areas and continue fishing. This model attempts to calculate the redistributed area (or value).

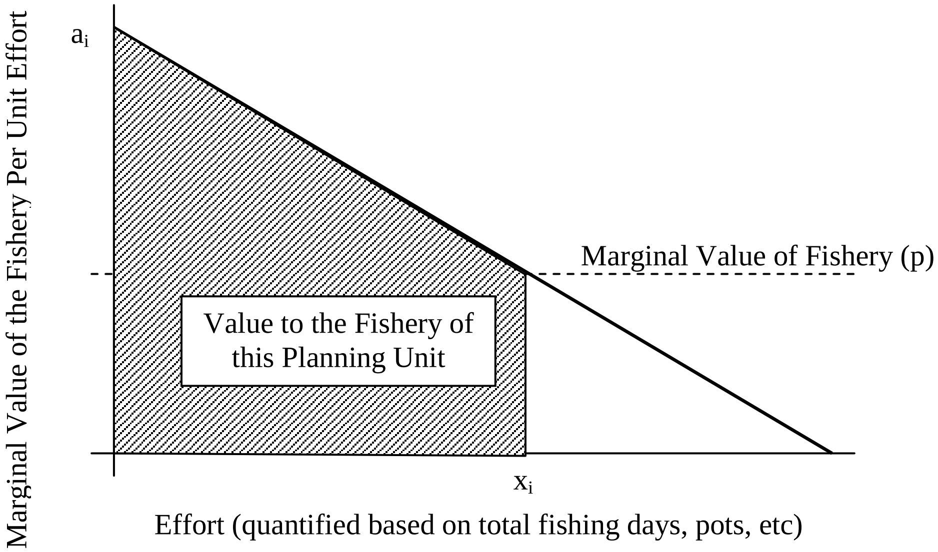

Figure 6.1: Marginal Value for a Single Planning Unit in the Region

The model was developed from one basic equation: the equation for the area of a trapezoid shown in Figure 6.1. The area of the trapezoid is the value of the planning unit, which is as follows:

Equation 6.1:

$$v_i = px_i + \frac{1}{2}x_i(a_i - p)$$

Where:

v_i: the value of planning unit 1
p: the marginal value of fishing across all planning units
x_i: the effort occurring in planning unit 1 at the marginal value (p)
a_i: the y-intercept of the marginal value curve for planning unit 1

In order to utilize this model, we would need planning unit specific value and effort data and an estimate of *p*, the marginal value across the fishery. It is important to understand that the effort level (x_i in Figure 6.1) is the effort that must be displaced to other planning units if the planning unit were removed from the fishery. Because we assumed that fishermen make optimal and efficient choices, this effort would be displaced equally into all other available planning units (See Figure 6.2).

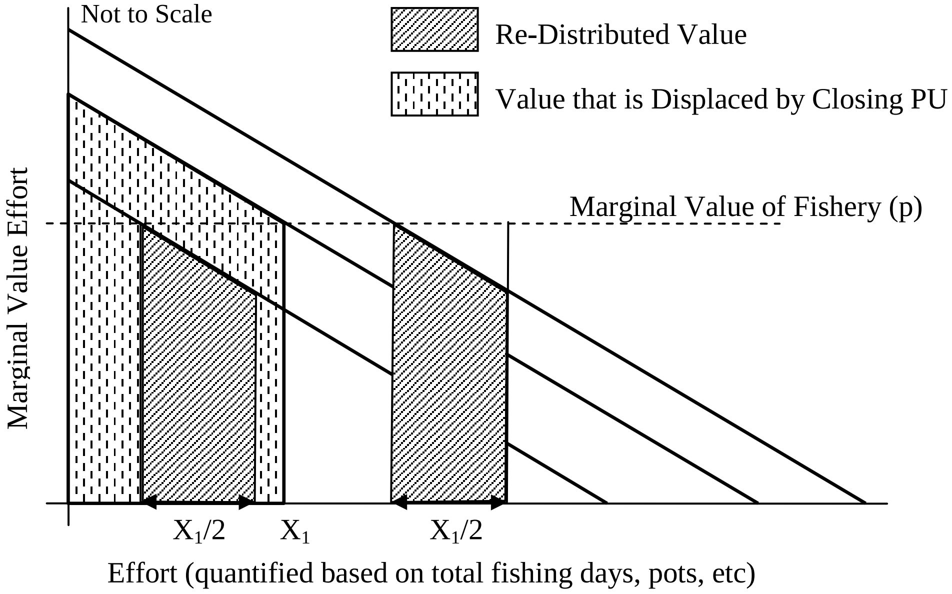

Figure 6.2: Redistribution of Value from Closed Planning Unit (PU). This figure graphically depicts the model explained above. Each curve represents an individual planning unit. The effort from the center curve, which is being removed from fishing, must be redistributed across all other available planning units. Not to scale.

As the number of planning units into which the value can be displaced increases towards infinity, the effort distributed into each additional planning unit becomes increasingly small; therefore the shape of redistributed effort essentially becomes a rectangle with a height equal to the marginal value of the fishery (See Figure 6.3). As such, only the value above the marginal value of the fishery (the triangle with a width of x_1 and a height of $a_1 - p$) is the value that cannot be redistributed [in other words, the cost of a reserve at this planning unit].

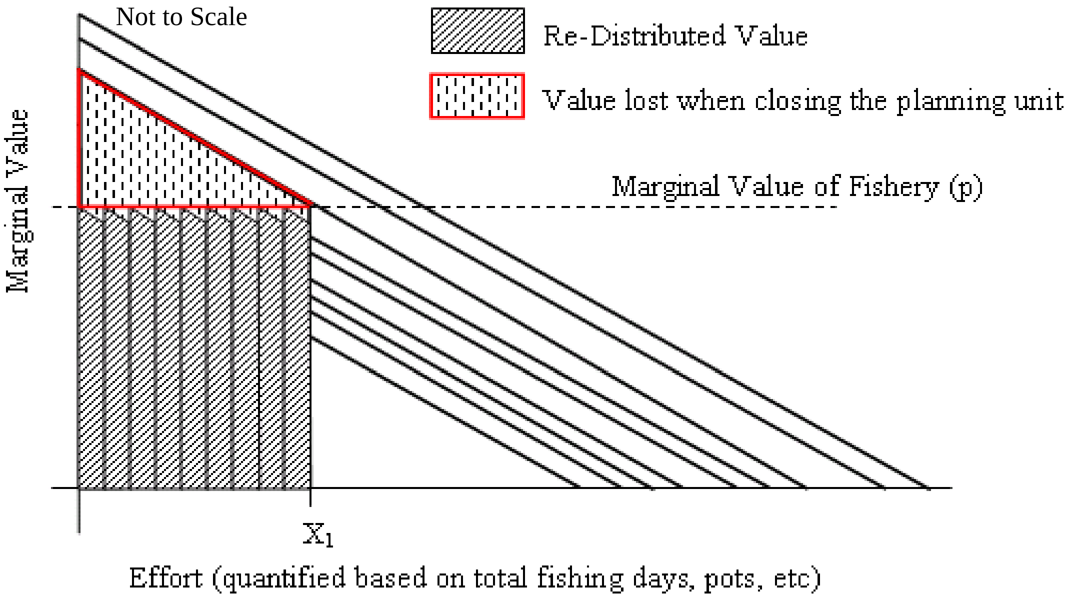

Figure 6.3: Redistribution of Value from Closed PU into Many Planning Units. This figure graphically depicts the assumption of a sufficiently large number of planning units into which effort can be redistributed. Each curve represents an individual planning unit. Not to scale

This area can be calculated by subtracting the area of the rectangle (px_1) from the total value of the planning unit (v_1). Therefore, the cost of a reserve at one planning unit is described by Equation 6.2.

Equation 6.2:

$$C_i = v_i - px_i$$

Where:
C_i: the cost of a reserve at planning unit i
p: the marginal value of fishing across all planning units
x_i: the effort occurring in planning unit i at the marginal value (p)

To calculate the cost of an entire reserve network (C_n), the area of the triangle (determined by Equation 6.2) must be calculated for each of the planning units that will be placed into reserves and then summed. This assumes a sufficiently large number of planning units into which effort can be redistributed. Therefore, the cost of a reserve network can be determined by the following equation:

Equation 6.3:

$$C_n = \left(\sum_{i=1}^{n} v_i\right) - p\left(\sum_{i=1}^{n} x_i\right)$$

This model requires data on the effort and value of each planning unit of the fishery. With this information, we can estimate the marginal value of the fishery and calculate the cost of a reserve network when some of the value in the reserve areas is recovered by displacement. The value data relies on the revenue each planning unit generates to the value of the fishery as a whole. The effort data would be a measure of the total effort expended by all fishermen within a particular planning unit. For example, effort can be measured for the crab fishery by the total number of traps that are laid by all the fishermen within a particular planning unit over the season. The marginal value is essentially the value for one unit of effort and can be estimated from the planning unit specific value and effort data.

The importance data gathered by Ecotrust and used to develop the cost layer (Chapter 3) was collected by asking fishermen about their economically important fishing grounds. Because some fishermen may have included factors other than revenue when considering their answers, this data is not truly a value but some combination of value and effort. Because Ecotrust interviews did ask about *economic* importance, for the purposes of this study we translated the importance data into planning unit specific value. Therefore, we did not have planning unit-specific effort data. However, if we assume that the slopes of the marginal value curves for all planning units are equal, then the following equation becomes important:

Equation 6.4: $a_1 - bx_1 = p$

Where:

b: the slope of the marginal value curve for all planning units; the slope is downward because each additional unit of effort will decrease the yield (marginal value) of the planning unit[8]

The assumption that the marginal curves for all planning units have the same slope essentially means that distributing an additional unit of effort across all planning units will result in an equal decrease in value in each unit. This may not be an accurate assumption because some regions are likely to be more productive than others. As a result, up to a certain point, increasing the effort may not result in a decrease in the value of some patches due to the area's natural biological productivity. Therefore, this assumption of a constant decrease in value with increased effort results in a conservative estimate of cost (a larger cost than actually expected) to a fishery.

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[8] It should be noted that the negative sign results from the assumed downward slope. It has been removed from parameter *b* and inserted into the equation for simplification.

The slope represents the rate of decreasing value with increased effort in the planning units. This is much harder to estimate without further information about the extraction of the resource or the effort within the planning units. By rearranging the model, the interdependency between slope and effort becomes clear. Using Equations 6.1 and 6.4, we removed parameter *a* through substitution and solved for *b*.

6.5:
$$b = \frac{2(v_1 - px_1)}{x_1^2}$$

Equation 6.5 illustrates that some type of effort data is required for at least one planning unit to estimate slope, in order to obtain an accurate estimate of the slope. It is clear from this equation that the slope could vary across all planning units. As such, with planning unit specific effort data, the assumption of constant slopes across all planning units can be relaxed. The above equations show that the slope and effort are linked and dependent. In other words, slope cannot be estimated without effort data.

However, with the assumption that the slopes of all planning units are equivalent, it is possible to calculate the slope if the total effort for the fishery is known. We solved Equation 6.4 for *x* as follows:

6.6:
$$x_1 = \frac{(a_1 - p)}{b}$$

Then we substituted the above into Equation 6.1 for the following result:

6.7:
$$v_1 = p\left(\frac{a-p}{b}\right) + \frac{1}{2}\left(\frac{a-p}{b}\right)(a-p)$$

We solved the above equation for parameter *a*, resulting in the following equation:

6.8:
$$a_1 = \sqrt{2bv_1 + p^2}$$

We know that the sum of the effort within all the planning units is equal to the total effort. Therefore, with Equations 6.6 and 6.8, we can substitute for *x* and *a* and obtain an equation that does not require planning unit specific effort data, but data on the effort for the fishery as a whole (Equation 6.9).

6.9
$$X = \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \frac{a_i - p}{b} = \sum_{i=1}^{n} \frac{\left(\sqrt{2bv_i + p^2}\right) - p}{b}$$

Where:
X: the total effort in the fishery

With values for all planning units in the fishery (v_i), an estimate of the marginal value (p), and the total effort of the fishery, an optimization program can find an estimate of parameter b. With a value for parameter b, we can substitute Equation 6.6 into Equation 6.3 and calculate the value that can be redistributed and thus the cost of a reserve network using Equation 6.10.

Equation 6.10: $$C_n = \left(\sum_{i=1}^{n} v_i\right) - p\left(\sum_{i=1}^{n} \frac{a_i - p}{b}\right)$$

Where: $$a_i = \sqrt{2bv_1 + p^2}$$

Methodology for Establishing Predicted Costs

After establishing the model, we applied the model to the North Central Coast region. In the Marxan analyses described in Chapter 3, the cost index was developed by combining the importance values from 34 commercial fisheries. While this model could be applied to the total value of the area based on all fisheries, it may be more useful to characterize the lost value to each fishery individually. We applied the model to the Dungeness crab fishery to illustrate its use. The Dungeness crab fishery was chosen because it is currently the most valuable fishery in the NCC region.

The individual fisheries cost data were developed per port. Therefore, we combined the cost values for the crab fishery for each planning unit from the various ports. Because each planning unit has a unique identity, this is a straightforward task. The data from Ecotrust is an “importance value” (See Chapter 3). We translated the importance value into an actual dollar value using the recent total value of the fishery described by the Regional Profile (a document produced by the MLPA Initiative providing an overview of the biological, social and economic context of the study region); for the Dungeness crab fishery the total value is \$9,993,386 (MLPA Initiative 2007). We then had a value associated with each planning unit. Similar to the fishermen density analysis presented in Chapter 5, planning units supporting less than 0.01% of the total value of the fishery, as determined through interviews with commercial fishermen, were removed from the analysis and were assumed to not support any fishermen. Thus, these planning units with extremely low importance were not considered among those used to estimate the value of each individual planning unit.

Next, we estimated the marginal value parameter (p). The marginal value is the value per unit effort at the margin. Essentially, it is the lowest value for one unit of effort that a fisherman is willing to accept. Any value lower than this, a fisherman will not expend any effort. This information is difficult to estimate from the information we have available to us. However, we can put some bounds on p. It is certainly no higher than the value of the planning unit with the lowest (non-zero) value. The value associated with this planning unit was \$1064. Furthermore, it must be lower than the *average* value per unit effort (if all units of effort returned the average value, then there would be no diminishing returns). As described below, we estimated the total effort to be about 200,000 crabpot-days. The ex-vessel value of an individual crab is about $5 (Fisheries and Oceans Canada - Pacific Region 2007), so this represents an average catch of 10 crabs per trap-day. We arbitrarily chose 2-4 crabs per trap-day as a "reasonable guess" for the point at which a fisherman would stop fishing, leading to estimates of the marginal value *p* of 10-20 dollars/trap-day. It should be noted that the smaller the marginal value is, the smaller the value is that can be retained by redistribution (Refer to Figure 6.3 and imagine that the line representing marginal value moves down).

Our data do not contain direct information on total effort in the Dungeness crab fishery, so we inferred the effort levels from the regulations and fishing methods. In the NCC, the crab season is open from November 15th to June 30th, or 227 days, and is restricted in access with a vessel-based permit system. Most of the capture occurs in the first six weeks of a seven-month season (Dewees et al 2004). However, there is no limit to the number of traps per vessel (MLPA Initiative 2007). The majority of vessels in the fishery deploy between 400 and 200 traps (Dewees 2004). Based on this data, we estimated total effort to be approximately 200,000 trap-days. With this effort value, the marginal value of $10 (estimated above), and the value of all planning units within the crab fishery, the estimated slope of the marginal value curve (*b*) is approximately 0.6. With a marginal value of $20, *b* is approximately 0.43.

After establishing the values for each planning unit and the parameters, we tested the potential impacts of two Regional Stakeholder Group Proposals on the Dungeness crab fishery[9]. We applied the model to RSG Proposals 4 and 2 because they are the largest and smallest, respectively. The MPA proposals were translated into GIS layers that were each intersected with the planning units. Once each proposal was intersected, we identified every planning unit included in each proposal. Using the value data for each of these planning units and Equation 6.10, we calculated the predicted cost of Proposals 2 and 4. Table 1 depicts the results with a marginal value of $10 and Table 2 depicts the results with a marginal value of $20.

Table 6.1: Predicted Costs of RSG Proposals 2 and 4 With and Without the Redistribution of Value Based on Fisherman Displacement and a Marginal Value of $10

	Value Lost when Displacement **NOT** Incorporated	Value Lost when Displacement **IS** Incorporated
Proposal 2	$373,000	$291,000
Proposal 4	$1,305,000	$1,002,000

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[9] Some MPA Package Proposals included MPA types that allowed the continued commercial fishing of Dungeness crab. To reflect reality, our results were based only on the MPAs within each network that prohibited the commercial fishing of Dungeness crab and not on all the MPAs within the proposed networks.

Table 6.2: Predicted Costs of RSG Proposals 2 and 4 With and Without the Redistribution of Value Based on Fisherman Displacement and a Marginal Value of $20

	Value Lost when Displacement **NOT** Incorporated	Value Lost when Displacement **IS** Incorporated
Proposal 2	$373,000	$214,000
Proposal 4	$1,305,000	$724,000

As noted throughout this chapter, there are several limitations to the model and to our application of the model. As noted above, to accurately estimate the slope associated with the marginal value curves, it is important to gather effort for each planning unit. The data collected for the north central coast region did not include fishing effort levels per planning unit. Therefore, our estimate of slope was, in itself, based on an estimate of the total effort of fishery which is difficult to quantify. Further, the optimization of parameter *b* is dependent upon the estimate of parameter *p*. As such, a sensitivity analysis of the model is crucial to knowing how much confidence we have in the results.

Sensitivity Analysis of Model Parameters

As defined, the model is dependent upon the value (*v*), slope (*b*) and marginal value (*p*) parameters. For this study, we had data on the importance or value of the planning units, but not the slope and marginal value. To determine the potential loss of value after establishment of MPAs, we estimated these parameters. If the model is particularly sensitive around the region of one or both of the estimated parameters, the results will be less reliable. Therefore, it is important to understand how the model responds to the various parameters included within it.

To determine the sensitivity of the parameters, we needed to see how the cost varied across different values of *b* and *p*. Rather than looking at the cost associated with a particular MPA network proposal, we calculated the average the predicted cost per planning unit across all of 1,864 planning units. This average is dominated by the higher value planning units within the system, which is desirable because these are the very planning units which, if closed would have the largest potential socioeconomic impact on the fishery.

We calculated the cost of removing each of the 1,864 crab fishery planning units for combinations of *b* and *p* values ranging from 1 to 450 in increments of 10. Figure 6.4 depicts the results. The three-dimensional surface shown in the plot varies significantly over the large scale. This sensitivity analysis was performed over a wide range of values in order to get an idea of the scale of variation.

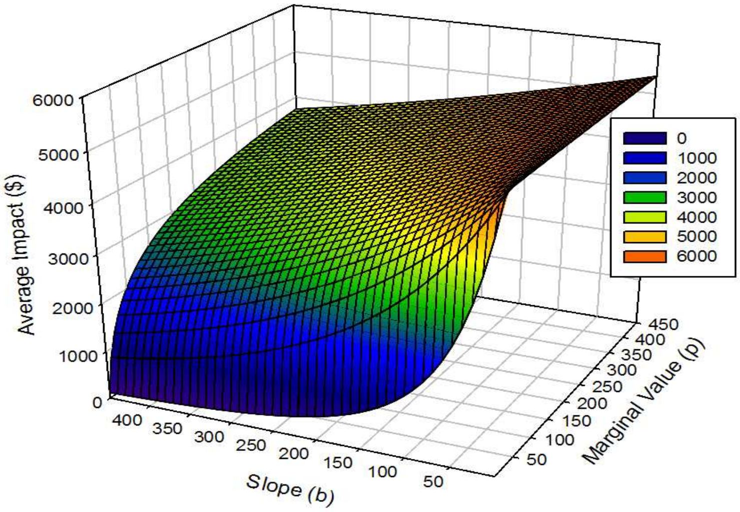

Figure 6.4: Surface plot depicting the average cost as slope and marginal value parameters vary. This figure depicts variation in the parameters in the range of 1 to 450 in increments of 10. Areas of the surface plot with a steeper slopes depict regions in which average cost is particularly sensitive to either or both parameters.

Figure 6.4 reveals that when *p* and *b* are relatively large, a one-unit change in either leads to a $2-3 change in predicted average cost. However, when *b* is small, the average cost is very sensitive to *p*, and vice versa. Thus we looked more closely at the region of small *p* and *b*, to reflect the values estimated for the crab fishery (Figure 6.5). This reveals that uncertainty in the parameters can have substantial impacts on the estimated costs. For example, as p is doubled from 10 (with b = 0.6) to 20 (with b = 0.43), the average cost declines about $1000, nearly a 20% change relative to the maximum possible cost. It should be noted that Figure 6.4 begins estimating the average impact at values of 1 for *p* and *b*. Figure 6.5 estimates the average impact for a range of *b* less than one. As such, there are different dynamics than one would expect, namely the average cost declines as p increases rather than increasing as shown in Figure 6.4. This likely results from the method of estimating *b*.

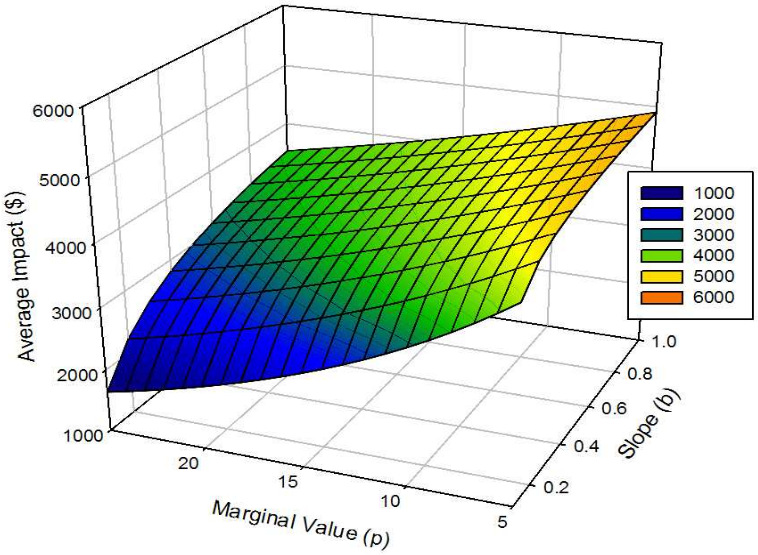

Figure 6.5: Surface plot depicting the average cost as slope and marginal cost parameters vary. This figure depicts variation in the parameters, ranging from 0.1 to 1.0 in increments of 0.1 for the b parameter and ranging from 5 to 25 in increments of 1 for the p parameter. Areas of the surface plot with a steeper slope depict regions in which average cost is particularly sensitive to either or both parameters..

These results focus on uncertainty in p and b. However, it should be noted that without planning unit specific data, the estimate of b is dependent upon the total effort of the fishery and the marginal value parameter, p, compounding the uncertainty in b. Figure 6.6 shows the estimated slope parameter as a function of the total effort when p = 20. As total effort increases, the slope decreases substantially. As total effort varies from 100,000 to 300,000 trap-days b is reduced from 2.5 to 0.12.

The sensitivity of the estimated costs to the parameters shows that it is crucial to have accurate estimates to have a useful result from the model. However, the uncertainty in our analysis was very high: +/- 35% for the marginal effort parameter p, and +/- 50% for total effort. With targeted data collection, it should be possible to reduce this uncertainty substantially.

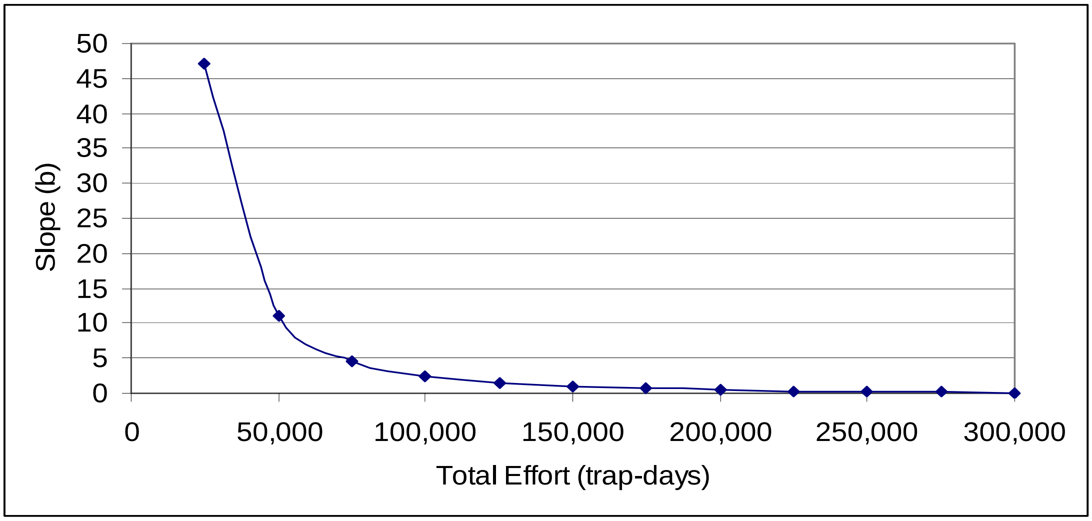

Figure 6.6: Slope Parameter as a Function of Total Effort when Marginal Value is $20

Conclusion

We have presented a novel method for estimating the costs of a MPA network. This cost estimate accounts for the fact that not all the value from an MPA area is lost because fishermen are highly adaptive and likely to displace their effort into the remaining open areas. We encountered several difficulties in applying the model due to a lack of data. Despite these limitations, we have established a baseline model to be improved upon to allow for a more realistic quantitative comparison of MPA networks.

In future regions of the MLPA Initiative process, data collection should include questions to elicit the value per planning unit, the effort per planning unit, and the perceived value per one unit of effort at which a fisherman will stop fishing an area. For the crab fishery, this can be done by asking the fishermen how much return they get from one crab trap, how many days during the season do they fish and how many traps are deployed on those days, and finally how much value is returned from each fishing area. With this information, the model can be applied much more accurately to obtain even more realistic estimates of the actual cost of MPA networks when fishermen displacement is incorporated.

Chapter 7: Conclusions and Recommendations

The design and implementation of marine protected areas (MPAs) in California state waters under the California Marine Life Protection Act (MLPA) is a groundbreaking process, as it is led by stakeholders and involves the consideration of the many potential impacts that MPAs can have on marine resources and their related industries. Our project used several different methods for informing MPA network design while considering some of their many potential impacts.

Marxan

We used a computer optimization tool, Marxan, to explore several possible ways of planning marine reserves. The Marxan algorithm selects specific locations from within a planning region that most efficiently achieve conservation goals while minimizing costs. For our project, efficient solutions minimized the number of planning units or minimized cost to commercial fisheries while achieving the conservation targets. Our group considered costs to commercial fisheries because the data were available; other costs (such as those accrued to recreational fisheries) could be considered, given appropriate data. Because of the flexibility of the Marxan program, we were able to choose and vary a suite of priorities for conservation, while simultaneously making an effort to reduce the cost to commercial fisheries. The Marxan program utilizes simulated annealing to explore solutions to the problem of MPA design and produces a large number of solutions that meet the conservation targets. For each set of conservation targets and costs, we generated a map that summarized the top 100 solutions. The maps presented in this report are not intended to be prescriptive. It is not the intent of these analyses to suggest specific locations for a MPA network. Rather, the maps highlight areas that warrant further investigation into their potential conservation value. These maps are valuable decision support tools, but do not show specific MPA boundaries. Our suite of Marxan maps were presented and delivered to the North Central Coast Stakeholder Group during their December 2007 meeting. Several stakeholders have requested our materials for review and we have received useful feedback for future recommendations.

Successes

Marxan’s ability to evaluate large datasets and its adoption for use by the MLPA Initiative offered an excellent opportunity to demonstrate the tool’s utility in a policy setting. Marxan is capable of spatially optimizing across multiple targets, making it a powerful tool for the multi-criteria analysis required for MPA network design. Marxan also offers flexible user settings that allow for fine-tuning of parameters that affect the final solutions. One such useful parameter is the boundary length modifier which allowed us to instruct Marxan to construct MPAs that were within the size and spacing guidelines of the MLPA Science Advisory Team. Furthermore, the fine-tuning of the Conservation Feature Penalty Factor, a type of weighting system, offered a way to control the tradeoff between individual targets and costs, and ensure that conservation targets were met.

At the core of Marxan is its simulated annealing program (described in Chapter 3), which allowed us to create thousands of suitable solutions with different MPA configurations. Moreover, Marxan's objective function, which evaluated the potential cost of each MPA network, allowed us to score and rank each solution, and to choose the best solutions for our analyses. The objective function was an invaluable component of Marxan that enabled us to construct composite maps of the top 100 solutions, offering a variety of potential locations to consider for MPAs with some flexibility for planning, rather than a single best MPA network option, which could be politically and socially intractable.

Marxan served as an effective tool in highlighting areas within the study region that warrant further investigation as to their conservation value and possible inclusion in a MPA network designed by stakeholders.

Limitations

Data availability and timing: Our analyses were limited to the available data at the time of analyses. The Science Advisory Team (SAT) identified many conservation targets, in addition to habitat representation, such as ocean circulation features (freshwater plumes, retention areas, and upwelling centers), that could have been included as conservation targets. However, at the time of our analysis these data sets were incomplete, and so we were unable to incorporate these features into our analyses. In addition, data regarding other activities, such as recreational fishing, were not available at the time but could be incorporated in the future using the same methods.

Data quality: The MLPA mandates the use of the "best readily available" data. Although all data in the MLPA Geodatabase were peer-reviewed by the MLPA Initiative staff, the data varied in quality and data collection methods. We restricted our analyses to datasets that were considered by the MLPA Initiative staff to be of good quality. The data we used were primarily biophysical data. In the future, this type of Marxan analysis may be expanded to include other conservation targets, such as species biodiversity hotspots and breeding grounds, if data of sufficient quality can be obtained.

Scale of data: Raw data were collected on various scales, causing some of the data to be less precise than other data. For example, some of the region's substrate data (i.e. sandy bottom and rocky reef at the Farallon Islands) have a lower spatial resolution than substrate data for other regions of the study area. This could be addressed in Marxan by creating different conservation targets for data at different scales. For example, fine-scale hard bottom data could be one target and coarse-scale hard bottom data could be another target.

Variability in data: The static nature of most data on habitat distributions does not account for environmental variation and climate change (Airamé et al. 2003). Certain habitats, such as giant kelp, vary seasonally and/or annually, making it difficult to assign such features to static planning units. We accommodated this variability by compiling six years of kelp data into one average kelp layer. We used this composite data layer to identify locations where kelp could exist, even if it is not there at present. Thus, in our analysis, certain areas that are selected to incorporate kelp habitat into the MPA network may not actually contain kelp in any given season or year.

Political Limitations: The guidelines developed by the Science Advisory Team were based on the MLPA goals, established in law, and regional stakeholder goals, developed during the Initiative process, for California state waters. However, the distributions of habitat types and species ranges are not restricted by human political boundaries, and often stretch beyond state waters into federal waters and adjacent states or countries. More efficient MPA networks, which minimize size while capturing the target percentages of different habitats, may be realized if conservation features within Federal waters or adjacent states or countries could be considered in the planning of a MPA network design for California.

Recommendations

Marxan is a powerful and sophisticated planning tool but the quality of its products depends on the quality of data used and aptitude of the user.

Fine-Scale Reliable Data

If Marxan will be further utilized by other regions within California, specific fine-scale datasets should be collected to address stakeholder concerns and goals. We chose to solely use habitat data because these were among the most reliable and comprehensive within the MLPA Geodatabase. Many other datasets were available, but had lower reliability and precision. We recommend that future Marxan analyses also take into account the other goals and objectives of regional stakeholders, such as placing MPAs near spawning grounds and marine mammal rookeries and haulouts, area of high fish and bird diversity and density, within existing monitoring and research sites, and near existing state parks. With appropriate data, the Marxan analyses could be designed to better reflect the myriad factors that stakeholders consider when designing a MPA network. Marxan results are also contingent on the quality of data available, which is critical for effective analyses.

Impacts to Individual Fisheries and Multiple MPA Zones

One drawback of Marxan is that the cost layer is an aggregate of all commercial fisheries within the study region. If the cost layer were disaggregated, then the user could conduct a more sophisticated evaluation of potential economic and social impacts. This disaggregation would enable the user to determine specific impacts based on a particular fishery or fishermen.

Furthermore, certain MPA types allow specific fishing activities to occur within their boundaries. Marxan assumes all MPAs are fully protected reserves that do not allow any sort of fishing. However, stakeholder proposals contain an array of MPAs at various levels of protection.

The program MarZone, based on Marxan, was developed to address these specific issues within the MLPA. At the time of our project, MarZone was not yet ready for use. Once it becomes fully functional, its ability to disaggregate MPA protection and commercial fishery costs will enable new levels of analyses that can better inform stakeholder design of MPA networks.

Fishermen Density

We developed a methodology for determining how the density of fishermen per planning unit would change in response to the implementation of proposed MPAs. During meetings to guide the establishment MPAs at the California Channel Islands, stakeholders aspired to design a network of MPAs that would displace no more than 10% of the value of each fishery from MPAs (S. Airame, personal communication, January 2008). For our project, we used the four stakeholder proposals for a MPA network developed for north central California to explore the potential fishermen displacement from each of the top five fisheries (Dungeness crab, salmon, California halibut, red urchin, and rockfish). We found average fisherman density per planning unit increased for each of five fisheries, if we assumed that MPAs were implemented using each of the four stakeholder proposals. The smallest increase in average fisherman density was 5% and occurred in the Dungeness crab fishery with the implementation of Proposal 2. The largest average fisherman density increase impacted in the red urchin fishery with Proposal 3, in which average fisherman density increased by 58%.

Limitations

The percentage increase in average fishermen density from proposed MPAs does not reflect potential changes in fishermen's catch. Catch per unit effort could decrease due to increased competition. Another possibility is that fishermen could expand to areas that were previously unfished. We also assume that all displaced fishermen remain in the fishery. In reality, some may diversify into other fisheries or leave the fishery altogether. Additionally, we assume that the planning units closed to fishing in a proposed MPA currently support an average number of fishermen, calculated as the number of fishermen found within an individual fishery per fished planning unit before implementation of MPAs. It is unlikely that the region-wide average number of fishermen utilize areas proposed as MPAs because the stakeholders take distribution of fishing effort into account when creating MPA proposals in an effort to minimize the potential impacts on users. Despite these approximations, this analysis provides some insight into the potential impacts of different proposed MPA networks.

Recommendations

Future applications of this methodology could be improved upon by incorporating more data regarding the actual number of fishermen present in the planning units, rather than an average number. If this type of data were available, then a better estimate of displacement would be possible. The estimates of increased fisherman density outside of MPAs could also be advanced if the realities of actual displacement were included. We could also include assumptions incorporating the natural limitations on the ability of fishermen to move, such as the fuel capacity of fishing boats and the distance of fishing grounds from the fishermen's home port.

Redistributed Costs

We developed a novel method to estimate the cost of a MPA network by quantifying the value of protected areas that can be redistributed across the entire planning region. Previous attempts to quantify the potential cost of MPAs prior to implementation have assumed that fishermen effort displaced by a MPA is essentially removed from a fishery, despite the fact that this is an unlikely assumption (Leeworthy and Wiley 2002). Our model accounts for the reality that not all value from protected areas is lost to the fishery.

The model utilizes four key assumptions. We assumed that: Fishermen are fishing optimally and efficiently; fishermen are equally willing to move to any planning units where fish were caught; the slopes of the marginal value curve for each planning unit are negative; and there are a sufficiently large number of planning units into which effort can be redistributed. With these assumptions, as well as data on the value of every planning unit to the fishery, the portion of total effort occurring within each planning unit, and an estimate of the marginal value across the fishery, we can quantify the fishing effort that is redistributed after MPAs are established and obtain an estimated cost of a MPA network that takes redistribution and displacement into account. This model will be useful in future applications as an additional method to evaluate the socioeconomic impacts of proposed MPA networks.

Limitations

There are several limitations to the model we developed. Notably, the data required for an accurate estimation may not be available. In order to apply our model, we used an estimate of total effort of the fishery because we did not have data on relative fishing effort within each planning unit. This simplification added an additional (probably unjustifiable) assumption to the model and limited the accuracy of our results. The remaining assumptions might not always be fully satisfied. For example, fishermen may not have the information required to fish optimally and efficiently. The assumption that the marginal value across planning units is equal may be violated if fishermen are not able to move freely to any planning unit in the study region to maximize their profits. Despite the limitations of the model, it advances our ability to predict the more realistic impacts associated with MPA proposals prior to implementation.

Recommendations

In the future, scientists who conduct interviews with fishermen could investigate both value and effort. Interviewers could ask fishermen to identify the areas where they spend their time in addition to the areas that are economically important. It would be necessary during the interview process to ensure that different interviewers ask the same questions in identical ways to ensure the responses will satisfy the need to distinguish value from effort. For the crab fishery, this can be done by asking the fishermen how much return they get from one crab trap, how many days during the season do they fish and how many traps are deployed on those days, and finally how much value is returned from each fishing area. Additionally, information about the wholesale price of crabs after landing would be helpful to estimate the marginal value across the region.

Ecotrust has agreed to collect information about the value of and fishing effort exerted in each planning unit within the next region of the MLPA Initiative process. With data on effort and value for each planning unit, the model we developed can help to predict the value of planning units that can be redistributed. Application of our model would provide a better estimate of potential costs of closing particular planning units. Therefore, our model can be used as one method to evaluate the differences in the potential socioeconomic impacts between various proposed MPA networks.

This analysis could be further refined by incorporating limitations to displacement, such as travel distance from ports and original fishing grounds.

Conclusion

Our project demonstrates that socioeconomic considerations can be incorporated effectively in the design of MPAs. It also shows that the goals of conservationists and fishermen are not irreconcilable, and that the interests of both can be satisfied in the design of an MPA network. Our work also provides quantitative methods of comparison between MPA proposals, allowing final selection committees, like the MLPA’s Blue Ribbon Task Force, to better justify their decisions. With these new methods of integrating socioeconomic concerns, fishermen, conservationists, planners and other stakeholders can improve the decision making process through increased knowledge of the possible impacts of network placement. These tools and analyses fill critical gaps in knowledge, helping stakeholders design MPA networks that minimize socioeconomic impacts to commercial fishermen and simultaneously aid in conserving California’s marine resources.

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Appendix A: Application of Science Advisory Team (SAT) Conservation Targets and Socioeconomic Considerations to the North Central Coast Regional Goals and Objectives of the California Marine Life Protection Act (MLPA)

Table B.1: Correspondence of Goals and Objectives to MARXAN Targets

SAT Identified Biophysical Targets	**North Central Coast Regional Goals and Objectives**																		
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2
Surfgrass North	Y[10]			Y	Y	Y	Y							Y		Y	Y		
Surfgrass South	Y			Y	Y	Y	Y							Y		Y	Y		
Surfgrass Farallon	Y			Y	Y	Y	Y							Y		Y	Y		
Intertidal Rock Shores North	Y			Y	Y	Y								Y		Y	Y		
Intertidal Rock Shores South	Y			Y	Y	Y								Y		Y	Y		
Intertidal Rock Shores Farallon	Y			Y	Y	Y								Y		Y	Y		
Intertidal Coastal Marsh North	Y			Y	Y	Y								Y		Y	Y		
Intertidal Coastal Marsh South	Y			Y	Y	Y								Y		Y	Y		
Intertidal Sandy Beach North	Y			Y	Y	Y								Y		Y	Y		
Intertidal Sandy Beach South	Y			Y	Y	Y								Y		Y	Y		
Intertidal Sandy Beach Farallon	Y			Y	Y	Y								Y		Y	Y		
Intertidal Tidal Flat North	Y			Y	Y	Y								Y		Y	Y		
Intertidal Tidal Flat South	Y			Y	Y	Y								Y		Y	Y		

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[10] A "Y" indicates that the target/data contributes to meeting the specific goal, objective, or design consideration.

Table B.1: Correspondence of Goals and Objectives to MARXAN Targets

SAT Identified Biophysical Targets	**North Central Coast Regional Goals and Objectives**																		
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2
Estuaries North	Y			Y	Y	Y	Y						Y	Y			Y		
Estuaries South	Y			Y	Y	Y	Y						Y	Y			Y		
Eelgrass North	Y			Y	Y	Y	Y							Y		Y	Y		
Eelgrass South	Y			Y	Y	Y	Y							Y		Y	Y		
Kelp Avg. Canopy Cover North	Y			Y	Y	Y								Y		Y	Y		
Kelp Avg. Canopy Cover South	Y			Y	Y	Y								Y		Y	Y		
Soft Bottom Nearshore North (Intertidal - 30 m)	Y			Y	Y	Y								Y		Y	Y		
Soft Bottom Nearshore South (Intertidal - 30 m)	Y			Y	Y	Y								Y		Y	Y		
Soft Bottom Nearshore Farallon (Intertidal - 30 m)	Y			Y	Y	Y								Y		Y	Y		
Soft Bottom Shelf I North (30-100 m)	Y			Y	Y	Y								Y		Y	Y		
Soft Bottom Shelf I South (30-100 m)	Y			Y	Y	Y								Y		Y	Y		
Soft Bottom Shelf I Farallon (30-100 m)	Y			Y	Y	Y								Y		Y	Y		
Hard Bottom Nearshore North (Intertidal - 30 m)	Y			Y	Y	Y								Y		Y	Y		

Table B.1: Correspondence of Goals and Objectives to MARXAN Targets

SAT Identified Biophysical Targets	**North Central Coast Regional Goals and Objectives**																		
	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2
Hard Bottom Nearshore South (Intertidal - 30 m)	Y			Y	Y	Y								Y		Y	Y		
Hard Bottom Nearshore Farallon (Intertidal - 30 m)	Y			Y	Y	Y								Y		Y	Y		
Hard Bottom Shelf I North (30-100 m)	Y			Y	Y	Y								Y		Y	Y		
Hard Bottom Shelf I South (30-100 m)	Y			Y	Y	Y								Y		Y	Y		
Hard Bottom Shelf I Farallon (30-100 m)	Y			Y	Y	Y								Y		Y	Y		
Socioeconomic Considerations	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	3.1	3.2	3.3	3.4	4.1	4.2	5.1	5.2	5.3	6.1	6.2
Fishing:																			
Commercial fishing areas of relative importance															Y		Y		

Appendix B: Marxan Calibration to Ensure Robust Analysis

Cheryl Chen
October 31, 2007

Project Description:
North Central Coast of California Marine Life Protection Act (MLPA) Initiative
Number of Planning Units: 3,610
Number of Conservation Targets: 31

This calibration manual is the methodology used to calibrate Marxan for a Donald Bren School of Environmental Science and Management thesis project. It may be used as a guideline to calibrate other Marxan scenarios, however, every scenario is different and thus requires adapting calibration methods that fit the particular project. This manual may serve as a starting point to begin formulation of a calibration method for various Marxan projects.

Step 1: Optimize the number of iterations

The purpose of optimizing the number of iterations is to ensure that Marxan is generating the best solutions possible within the available time constraints. The number of iterations is the number of times Marxan attempts to add or subtract planning units in search of a better solution. The more iterations that are set, the longer the program will run, and the more likely Marxan will generate a better solution (i.e., lower objective function score).

At an optimal number of iterations, Marxan runs efficiently and generates consistently “good” solutions. When an optimal number of iterations are achieved the user then can explore the various “good” solutions while keeping a consistent objective function or cost. If there is wide variability in objective function scores between runs the user probably needs more iterations to reach the point where the objective function stops significantly changing.

Ideally, through calibration the user finds a threshold point where increasing the number of iterations does not significantly produce a better score. To test whether a certain number of iterations produce significantly improved scores, we calculate the standard deviation between all the scores of the runs. We expected that, at a certain number of iterations, the standard deviations would remain the same, indicating the optimal number of iterations. However, in our calibration, we did not reach this threshold value. We increased our iterations from 1,000,000 to 13,000,000 and the standard deviations linearly declined to zero.

Alternatively, we examined our standard deviation values and selected a number of iterations that produced an acceptable standard deviation for a time efficient analysis. We chose our optimal number of iterations at 5,000,000 because, at this number of iterations, the standard deviation dropped to a level at which there was less than 5% variance between objective function scores. We decided that this was acceptable amount of variation considering the time needed to run the analysis.

Method:

1. Set all Conservation Feature Penalty Factor (CFPF) values to 1.
2. Set Boundary Length Modifier (BLM) to 0.
3. Set Marxan to 50 – 100 runs.
4. Set the initial number of iterations to 1,000,000.
5. Run Marxan.
6. Open the summary file that has details of each run.
7. Use the objective function values to conduct your analysis
    a. Conduct an analysis of standard deviations for all “scores” that are given for each run.
8. Continue calculating the standard deviation between runs for various numbers of iterations.
9. Choose a number of iterations per run that produce a variance between the “scores” of less than 5%.

Step 2: Calibrate the Boundary Length Modifier (BLM) and the Conservation Feature Penalty Factor (CFPF).

Before beginning a Marxan analysis, it is necessary to calibrate the model for the conservation feature penalty factor (CFPF) for each boundary length modifier (BLM) used to explore a range of solutions. Eventually, the user will select CFPF and BLM that produce solutions that include key species or habitats and are organized into clusters of suitable size (with an optimal BLM value), rather than highly fragmented (BLM=0). The CFPF and BLM are variables within Marxan’s objective function that must be set by the user. There are no universally good values for these parameters, as they are vary with the geometry of the study region, size of the planning units, values of the input data (e.g. costs and conservation features), and goals and objectives of the reserve design process.

Conservation Feature Penalty Factor (CFPF)

The CFPF controls how hard the algorithm tries to meet each conservation target. This value can be any positive number. However, setting the CFPF values should be done with care. It is undesirable to have a CFPF value that is too high or excessive. Values that are too high unnecessarily constrain the options Marxan has when switching out and comparing planning units in pursuit of a solution (Fischer & Church 2005). If a high CFPF value is placed on a particular target, Marxan will be limited in the choice of planning units because of the high penalty factor associated with removing the planning unit that contains a target with a large CFPF. Essentially, a CFPF value that is too high will produce solutions that are inefficient. Therefore, CFPF values should be set at the smallest number possible while still meeting the conservation targets.

For our project, an optimal CFPF produced solutions in the targets were met in 90% of solutions. For some projects, however, the user might want 100% of the solutions to meet their targets. For our project, the duration of the analysis increased substantially if we required 100% of the solutions to meet their targets. We did not want to constrain Marxan to get 100% of all targets so we did not set high CFPF values. Through repetition of the problem with a variety of CFPF values, we eventually found a suite of CFPF values for which targets were met 90% of the time. To avoid setting the CFPF at an arbitrary value, we refined our suite of solutions by selecting the top 100 scoring runs that met all their targets from 1,000 Marxan runs. Rather than setting high CFPF values and constraining Marxan to produce 100% of the runs that meet all their targets, we provided more flexibility for the program so that it could explore a wider range of solutions, including those that did not meet all of their targets.

Boundary Length Modifier (BLM)

The BLM controls the relative importance of boundary length to reserve cost (or area). The BLM value can be any positive number. A higher BLM value will result in a solution with more clumped planning units selected as potential reserves. In other words, a high BLM will result in fewer, larger reserves, while a lower BLM will result in more numerous, smaller reserves. If the BLM is set to 0, then the boundary length will have no impact on the solution. For each different BLM value, it is necessary to recalibrate the CFPFs for each conservation target. In our analysis, we used BLM values of 0, 0.0001, 0.001, 0.01, etc.

Narrative of Our Method in Calibrating CFPFs and BLMs

We began our calibration with a BLM of 0 and CFPFs for all 13 targets set initially at 1. Marxan was run 10 times with 5,000,000 iterations. The output files describing each run (displaying which targets were missed in the run) and the “sum” file (displaying the number of missed targets in every run) were evaluated to judge the suitability of the CFPF values.

When CFPFs were set at 0.1, no targets were met. When CFPF values were set at 0.25, 3 of 12 targets (or 3%) were met. When CFPFs were set at 0.5, 11 of 13 targets were met, and the CFPF values of 1.5 resulted in all our targets being met.

We used the suite of CFPF values of 0.25 as our baseline because they provided sufficient rigor and flexibility in our analysis. We chose a value of 0.25 as an interval between the next higher CFPF as we searched for the optimal values for each conservation target. We selected the lowest CFPF values that met conservation targets. If the CFPF value did not met a particular conservation target at 0.25, then we added 0.25 and evaluated the effect of a CFPF of 0.5, and so on, until all conservation targets were met. The final suite of optimal CFPFs for BLM = 0 at which all conservation targets were met ranged between 0.5 and 1.75.

Once the optimal CFPFs were determined for each BLM, Marxan was run 100 times with 5,000,000 iterations. This process was repeated for BLMs ranging from 0 to 1. Based on the results of this calibration analysis, we chose a BLM of 0.003 to use in our Marxan modeling runs. Two criteria were used to select this value. First, when we plotted cost versus reserve boundary length for a variety of trial BLMs between 0 and 1, a BLM of 0.003 resulted in the smallest area under the curve, implying the best trade-off between cost and boundary length. Additionally, Marxan runs using BLM=0.003 produced solutions that were consistent with the SAT's recommendations for MPA size and spacing.

Step by Step Method:

Set your parameters:

- Set the BLM value to zero or any other value used to determine an optimal BLM.
- Set the desired number of iterations. In this analysis, we used 5,000,000 iterations.
- Set a number of runs. The more runs set, the more information obtained on how well the solutions meet conservation targets.
    - 50-100 runs will provide a rough estimate of how well targets are met.
    - The optimal BLM value depends on the length of time for runs and the level of accuracy needed in the analysis.
    - We used 100 runs in an analysis that took a little over 4 minutes.

Calibrate CFPF values:

We used a calibration to find a suite of CFPF values for which all targets are met with the lowest CFPF values possible. We identified CFPF values when 90% of the solutions (runs) met their targets. The rationale is explained above in the conservation feature penalty factor (CFPF) section.

- Begin by setting all CFPF values to 1.

- First, if some targets are not met, increase all CFPF values uniformly until all targets are met.
    - The goal is to find a uniform CFPF value just high enough that all targets are met. This uniform CFPF value will provide a range for the upper bound of CFPF values needed to meet all targets. However, when adjustments are made to reduce some CFPF values, the value of others may increase and even may exceed the estimated upper bound CFPF value. The purpose of finding the upper bound is to determine the approximate range of CFPF values for a particular analysis.

- Second, set CFPF values collectively to a relatively low uniform CFPF value for which only a few targets are met. This is the lower bound of the range of suitable CFPF values for the analysis. Setting the lower bound is a judgment call based on the user's level of comfort with the results. For example with a uniform CFPF of 1 we met all our targets in this analysis. Then, we chose to use a value of 0.25 as a baseline at which only a few targets (3%) were met.

- Third, use the upper and lower bounds to determine the increment by which the CFPF values will be increased to explore the range. The increment used is a judgment call that reflects the level of desired precision and the amount of time available for calibration.
    - We recommend using an increment that allows evaluation of 5-20 different CFPF values between the upper and lower bound. The number of values selected depends on the desired level of precision and available time for calibration.
    - For example, with an upper bound of 100 and a lower bound of 10, a user could select increments of 5, 10, or 20 when calibrating the CFPF values.
    - For our project we had an upper bound of CFPF=1.50 and a lower bound of CFPF=0.25. We used a CFPF increment of 0.25.

- Calibration may begin once upper and lower bounds, and an increment have been chosen.

- Begin with the lower bound for the CFPF value. For all targets that were met, retain the lower bound CFPF. For targets that were not met, increase the CFPF by the chosen increment. For example, for all targets that were not met with our lower bound CFPF of 0.25, we increased the CFPF value for those unmet targets by an increment of 0.25 to yield a CFPF of 0.50 for all unmet targets.
    - Run Marxan with a suite of CFPF values.
    - Open the summary file.
    - Identify runs that have unmet targets.
    - Examine the details of the runs for which there were missing targets.
    - Assess which targets are not met for all runs with unmet targets and increase the CFPF values for unmet targets using the previously determined increment.

- Continue this process until the suite of CFPF values generate solutions that meet conservation targets in at least 90% (or other threshold) of the runs.

- This set will be the calibrated CFPF values

Example: CFPF Calibration for 34% Biophysical Analysis:

CFPFs for BLM = 0.003

Conservation Targets all set at 34% for Biophysical Analysis

Number	CFPF	Conservation Feature
1	1.5	Intertidal_Sandy_Beach_North
2	1.5	Intertidal_Sandy_Beach_South
3	0.5	Intertidal_Sandy_Beach_Farallon
4	0.75	Intertidal_Rock_Shores_North
5	1.0	Intertidal_Rock_Shores_South
6	1.75	Intertidal_Rock_Shores_Farallon
7	1.5	Intertidal_Coastal_Marsh_North
8	1.5	Intertidal_Coastal_Marsh_South
9	1.25	Intertidal_Tidal_Flat_North
10	1.5	Intertidal_Tidal_Flat_South
11	1.00	Surfgrass_North
12	0.5	Surfgrass_South
13	0.5	Surfgrass_Farallon
14	0.5	Eelgrass_North
15	1.5	Eelgrass_South
16	0.5	Estuaries_North
17	0.5	Estuaries_South
18	0.5	Soft_Bottom_Nearshore_North
19	0.75	Soft_Bottom_Nearshore_South
20	0.5	Soft_Bottom_Nearshore_Farallon
21	0.5	Soft_Bottom_Shelf_I_North
22	0.5	Soft_Bottom_Shelf_I_South
23	0.5	Soft_Bottom_Shelf_I_Farallon
24	0.5	Hard_Bottom_Nearshore_North
25	0.75	Hard_Bottom_Nearshore_South
26	0.75	Hard_Bottom_Nearshore_Farallon
27	0.5	Hard_Bottom_Shelf_I_North
28	1.5	Hard_Bottom_Shelf_I_South
29	1.5	Hard_Bottom_Shelf_I_Farallon
30	0.75	Kelp_Average_North
31	0.75	Kelp_Average_South

Finding the optimal BLM:

Once the suite of CFPF values is estimated for BLM = 0, run Marxan and record the cost and boundary length of the best solution. Continue calibrating the CFPF values for each BLM value and record the cost and boundary length of the best solution. The most efficient BLM will minimize cost and boundary length. This ensures that solutions are clumped as much as possible at the least cost.

Step by Step Method:

- First, run Marxan with a BLM = 0 with calibrated CFPFs.
  - Record the cost and boundary length of the best solution.
- Then, set the BLM = 1 and recalibrate a suite of CFPF values. Run Marxan with a BLM = 1.
  - Record the cost and boundary length of the best solution
- Add the values of the individual boundary lengths and costs to each other.
  - This is the called the "total cost".
- The optimal BLM will have the smallest "total cost," meaning it will have minimal cost and minimal boundary length.
- Begin to run Marxan with several different BLMs and record their costs and boundary lengths associated with the best solution.
  - A few good ones to try are: BLM = 0.0001, 0.001, 0.01, 0.10
- Attempt to isolate the most efficient BLM based on "total cost."
- The most efficient BLM will be reached at the smallest "total cost."

Step 3: Optimize the number of runs

By increasing the number of runs, we increase the number of chances Marxan has in generating a better solution.

Runs are attempts by Marxan to create a solution. Increasing the number of runs increases your chances that Marxan will find a better "best" solution. There is no prescribed threshold to indicate when increasing the number of runs becomes ineffective or inefficient.

The limiting factor is available time for the analysis. Marxan could explore a single analysis for a few seconds or minutes, an hour or even 24 hours if the number of runs is set high enough. For a particularly complex analysis, Marxan could find the "near optimal" best solution in the first hour or the 24th hour. There are a huge number of possible combinations of planning units that could be combined to create a solution. The more runs conducted, the greater the chances of generating a "better" best solution.

The number of runs should be determined by how much time is available for running Marxan. The number of runs should be large enough to obtain a good set of "best" solutions. One option is to select the best 100 of 1000 or more solutions.

For example, in our analyses we used 1,000 runs and used the top 100 best runs to analyze, ensuring that we only used the best solutions.

Appendix C: North Central Coast Regional Stakeholder Goals and Objectives

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

1. Protect/Include areas of high species diversity and maintain species diversity and abundance, consistent with natural fluctuations, of populations in representative habitats. [Question for SAT: does the SAT have comments on the respective measurability of these alternate terms (objectives 1 and 2)?]

2. Protect/Include areas with diverse habitat types in close proximity to each other.

3. Protect natural size and age structure and genetic diversity of populations in representative habitats.

4. Protect natural trophic structure and food webs in representative habitats.

5. Protect ecosystem structure, function, integrity and ecological processes to facilitate recovery of natural communities from disturbances both natural and human induced.

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

1. Help protect and/or rebuild populations of rare, threatened, endangered, depleted, or overfished species, where identified, and the habitats and ecosystem functions upon which they rely.

2. Sustain or increase reproductive capacity of species most likely to benefit from MPAs through retention of large, mature individuals, protection of larval source areas, and/or protection of breeding, foraging and rearing areas.

3. Protect selected species and the habitats on which they depend while allowing the commercial and/or recreational harvest of migratory, highly mobile, or other species where appropriate through the use of state marine conservation areas and state marine parks.

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

1. Ensure some MPAs are close to population centers, coastal access points, and/or research and education institutions and include areas of educational and nonconsumptive recreational and cultural use.

2. Protect or enhance cultural and recreational experiences, including collecting and recreational fishing, by … [science team, craft something measurable – including minimal human disturbances].

3. To enhance the likelihood of scientifically valid studies, replicate appropriate MPA designations, habitats or control areas (including areas open to fishing) to the extent possible.

4. Develop collaborative scientific monitoring and research projects evaluating MPAs that link with fisheries management information needs, classroom science curricula, volunteer dive programs, and fishermen, and identify participants.

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

1. Include within MPAs the following habitat types: estuaries and other habitats identified by the MLPA science advisory team as unique to the north central coast study region. [Comment: the SAT will discuss this at its next meeting.]

2. Include, and replicate to the extent possible, representatives of all marine habitats identified in the MLPA or the *California MLPA Master Plan for Marine Protected Areas* across a range of depths.

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

1. Minimize negative socio-economic impacts and optimize positive socio-economic impacts for all users, to the extent possible, and if consistent with the Marine Life Protection Act and its goals and guidelines.

2. For all MPAs in the region involve interested parties to; develop objectives, a long-term monitoring plan that includes standardized biological and socioeconomic

monitoring protocols, and a strategy for MPA evaluation, and ensure that each MPA objective is linked to one or more regional objectives.

3. To the extent possible, effectively use scientific guidelines in the *California MLPA Master Plan for Marine Protected Areas*.

Goal 6. To ensure that the north central coast's MPAs are designed and managed, to the extent possible, as a component of a statewide network.

1. Develop a process to inform adaptive management that includes stakeholder involvement for regional review and evaluation of management effectiveness to determine if regional MPAs are an effective component of a statewide network.

2. Develop a mechanism to coordinate with future MLPA regional stakeholder groups in other regions to ensure that the statewide MPA network meets the goals of the MLPA.