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Empirical evaluation of regional scale marine reserves and the groundfish trawl fishery

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Abstract

This Sea Grant project responded to a call from the California Sea Grant Strategic Plan 2001- 2005, which stated a need to model the performance of area closures from a resource management standpoint (including assessment of reserve size and the response of commercial and recreational fisherman to creation of reserves and the economic and conservation implications of reserves). Analyzing responses to spatial management, for example marine reserves, has been a topic recently in the literature on marine resource economics. This project made an important contribution to that literature (Dalton and Ralston, 2004), which extended previous work on dynamic models of fishing effort. Previous work treated abundance, ex-vessel prices, and climate as uncertain factors with a testable hypothesis, known as rational expectations, of how fishermen forecast future values of these variables.

Empirical evaluation of regional scale marine reserves and the groundfish trawl fishery with geographical information systems, analysis of covariance, and bioeconomic modeling

California Sea Grant Project R/MA-42

Final Report

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*I am submitting this final report for California Sea Grant project R/MA-42 as an employee of the Alaska Fisheries Science Center to comply with NOAA's ethics requirements.

Introduction

This Sea Grant project responded to a call from the California Sea Grant Strategic Plan 2001-2005, which stated *a need to model the performance of area closures from a resource management standpoint (including assessment of reserve size and the response of commercial and recreational fisherman to creation of reserves and the economic and conservation implications of reserves)*. Analyzing responses to spatial management, for example marine reserves, has been a topic recently in the literature on marine resource economics. This project made an important contribution to that literature (Dalton and Ralston, 2004), which extended previous work on dynamic models of fishing effort. Previous work treated abundance, ex-vessel prices, and climate as uncertain factors with a testable hypothesis, known as rational expectations, of how fishermen forecast future values of these variables.

An advantage of the methods developed in this project, which are based on models that are widely used in macroeconomics, is in their ability to scale-up from individual decisions to aggregate outcomes, at industry- or fleet-wide levels. An important assumption in the bioeconomic model used for this project is that behavior of different vessels is assumed to be identical from a statistical point of view, which imposes restrictions that may be tested with panel data. Failing these tests can imply biased results. We found several cases that did not satisfy these restrictions, which motivates new lines of research for fisheries economics in the areas of learning and game theory.

California's groundfish trawl fishery was used as a case study for this project. The empirical analysis considered a particular strategy of trawlers in California to catch a combination of species: Dover sole, Short and Longspine Thornyheads, and Sablefish (DTS). As data, we used spatial time series on fishing effort and catch that were derived from logbooks collected from vessels in California's Limited Entry Groundfish Trawl Fishery. These logbooks are a unique, and rich, source of spatial data on individual vessels over time. In addition, we compiled time series on ex-vessel revenues and landings by linking information on trips in the trawl logbooks to fish tickets for landings, and we used these time series to calculate price indices for the DTS complex for each port in the analysis.

Two hypotheses were proposed in this project:

1. Spatial management will cause major changes in the behavior of groundfish trawlers;
2. These changes will have significant ecological and economic effects.

To test these hypotheses, work in the project was done to complete the following objectives:

1. Conduct a three-stage empirical analysis (GIS, analysis of covariance, and bioeconomic modeling) to test hypothesis 1;
2. Analyze the ecological and economic effects of trawlers' responses to spatial management to test hypothesis 2.

A third objective was described in the proposal to "Evaluate benefits and costs of marine reserves over a range of scenarios that includes other approaches to groundfish management (i.e. catch and effort restrictions)." However due to time constraints, and the fact that work on this third objective was not needed to analyze either hypothesis, only a limited amount of attention was given to it.

Both hypotheses stated above were confirmed by actual events in the West Coast Limited Entry Groundfish Trawl Fishery. The DTS strategy is associated with rockfish bycatch that varies by depth of each tow. Bycatch is a critical issue in the groundfish fishery, and eight rockfish species are currently overfished. An overfished stock requires a rebuilding program that can severely constrain landings. In 2003, the Pacific Fishery Management Council (PFMC) closed a portion of the continental shelf to reduce bycatch. These closures, known collectively as Rockfish Conservation Areas (RCAs), took on a fundamental role in this project as a natural policy experiment for analyzing the dynamic effects of spatial management. The RCAs are not marine reserves, but are a type of spatial management. Due to the long rebuilding horizons for some species (e.g. bocaccio), the RCAs may be in place for decades. Therefore, these closures presented a unique opportunity for analysis, and the project's work plan was modified. In particular, objectives of the project were tailored to analyze the two hypotheses using changes in fishing effort outside the RCAs to measure effects.

Without the presence of direct spatial-dynamic interactions, a simplifying assumption that was used by Dalton and Ralston (2004), closing an area does not cause a direct displacement of fishing effort because the remaining open area is already in a long run economic equilibrium that limits further entry. In other cases, economic theory is not definitive about the direction of spatial-dynamic interactions, but stability of the bioeconomic model used in this project does imply bounds on these effects. In general, spatial-dynamic interactions may be positive, or negative, depending on how long run expected profitability in one area is related to the other. Our results show that long run expected profitability in the two areas is positively related for about half the ports in our analysis, which in terms of economics, implies a type of substitutability in production. For these ports, the model predicts an increase in fishing effort outside the RCAs. This type of displaced fishing effort is often raised in policy discussions about marine reserves, and the notion of substitutability in this case is related to a type of irreversibility in information, knowledge, or experience that is acquired through fishing in a particular area.

The remainder of this report describes work on the two objectives listed above. The three stages of empirical analysis under the first objective are described first, followed by a summary of the analysis that was performed under the second objective. The report concludes with a brief description of ongoing and future research.

Objective 1.1: Project Data and Geographical Information System

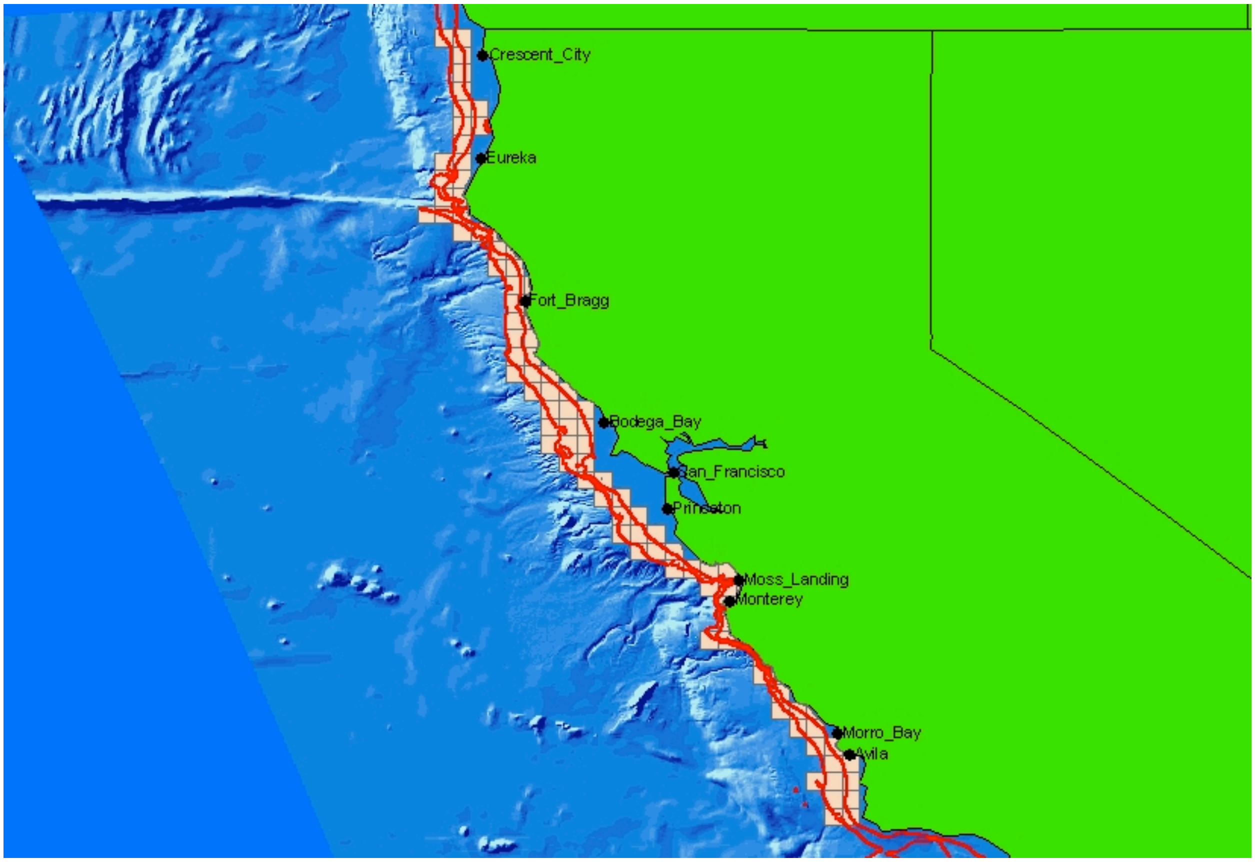
Dynamic GIS Animations:

- Full Set: http://science.csumb.edu/~mdalton/pacfin;
- Summary: http://science.csumb.edu/~mdalton/pacfin/results_hr_nosfb_sum.htm.

In the project's first year, data from several sources were obtained and compiled into a geographical information system (GIS). Fisheries data from trawl logbooks and fish tickets were acquired from the Pacific Coast Fisheries Information Network (PacFIN). Logbook records from 1981-2001 for tows in the area between Point Conception and the Oregon border were used for analysis. Logbook records were stratified by the 10 major ports in California where DTS landings occur: (from north to south) Crescent City, Eureka, Fort Bragg, Bodega Bay, San Francisco, Princeton, Moss Landing, Monterey, Morro Bay, and Avila.

California's Department of Fish and Game (DFG) assigns the location of each tow in the logbook records to a statistical fishing block. Logbook records identify the block where each tow started, and its duration (in hours). A GIS file was obtained from DFG with the fishing blocks, which was used to map the location of each tow. The total duration of tows, associated with each block and each port, was computed and mapped for each year of the analysis. These GIS maps were further stratified by species, including those in the DTS complex, and the overfished stocks of bocaccio, canary, darkblotched, and widow rockfish. A set of GIS files with bathymetric data for California was also obtained from DFG, and these files were queried to determine the boundaries of the RCAs based on their original specifications in terms of depth-contours. The ten ports, depth-contours of the RCAs, and fishing blocks included in the RCAs, are displayed in Fig. 1.

Fig. 1: Boundaries of the Rockfish Conservation Areas in California, North of Point Conception.



A Visual Basic Program was developed in ArcGIS for creating dynamic GIS animations. A student research assistant at California State University Monterey Bay (CSUMB), Don Jayakody, used this program to produce a set of GIS animations, and he developed a website to present these results. Don recently transferred to Cal Poly San Luis Obispo to study computer science. Some GIS animations are presented with the RCAs, while others display habitat information (hard, soft, and mixed bottom types) for areas where this information is available. The GIS habitat layers were obtained from the Sea Floor Mapping Lab at CSUMB.

Records in the trawl logbooks were linked to PacFIN fish tickets to determine total landings, and total ex-vessel revenues, of DTS species at each port for each year of the analysis. Ratios of total landings over total revenues were used to calculate an index of ex-vessel prices for each port and year, 1981-2001. The project's Co-Leader provided spatial time series for sea level pressure. Sea surface temperatures off the California Coast were obtained from the International Research Institute at Columbia University. These climate data were converted into a GIS format for mapping, used in the economic model, and in the analysis of covariance that is described next.

Objective 1.2: Analysis of Covariance

Working Papers:

- M. Dalton (September 2005). *Simulated Maximum Likelihood Estimation and Analysis of Covariance with a Panel Tobit Model*;
- M. Dalton (January 2006). *Simulated Maximum Likelihood Estimation and Analysis of Covariance in a Panel Tobit Model of California's Groundfish Trawl Fishery, 1981-2001*.

In the project's second year, an analysis of covariance was conducted using the fisheries data described above to test whether the use of pooled time series could be a problem. Time series for individual vessels, of which more than four hundred are represented in the logbooks, were used to form a panel at each of the ten ports in Fig. 1. Logbook records were ordered by, first, the number of years each vessel recorded non-zero hours for tows that yielded DTS species, and second, the total number of hours for these tows. The distinction in these criteria is important for statistical work because zero values for a vessel in multiple years could lead to biased results. For practical reasons, the first hundred vessels in this ordering were selected for the sample of vessels to analyze. Time series for vessels below this threshold are ridden with zero values, and even a few zero values can bias results, which required that a new econometric procedure be developed for hypothesis testing in this project. Development of this new procedure, which utilizes a simulated maximum likelihood technique that appeared recently in the econometrics literature, was not anticipated at the start of the project. The new procedure required additional time, but its development was accomplished without additional cost.

The two working papers listed above are complete. These contain a full description of methods, results, and an application to California's groundfish trawl fishery. The first paper describes the dynamic panel Tobit model with fixed effects, numerical code to implement the model, and results of Monte Carlo simulations for estimation and testing. Tests include an analysis of covariance to identify when individual restrictions are significant, and thus, when the use of pooled time series data could lead to biased results.

The second paper applies the new method to the panel of data formed with the logbook records on fishing effort, ex-vessel prices, climate variables, and regulations. Regulatory variables are bi-monthly caps on landings of various species, such as those for DTS, and rockfish, that were used as the primary instrument to regulate individual vessels in the groundfish trawl fishery before 2003. A CSUMB student research assistant, Savannah Armstrong, compiled the regulatory data from Stock Assessment and Fishery Evaluation (SAFE) documents published by the PFMC. Savannah graduated in spring 2006 with a B.S. degree from CSUMB.

To summarize results, Monte Carlo simulations show that maximum likelihood estimates are consistent (i.e. converge to true values), but the rate of convergence varies among parameters in the model. Results show the likelihood ratio tests used in the analysis of covariance are quite accurate, even for relatively short panels (e.g. 20 periods). The analysis of covariance for California's groundfish trawl fishery showed the dynamic panel Tobit model with fixed effects captures the main features of the data from logbooks and fish tickets. For example, maximum likelihood estimates are consistent with economic theory, such as an increase in ex-vessel prices implying an increase in fishing effort. In addition, some parameters must satisfy strict bounds to ensure stability of the model, and these conditions are met by the maximum likelihood estimates for all but a few cases.

Regulatory limits on widow rockfish are significant at the 5% level in the model at eight of the ten ports that were analyzed. At seven of these, a reduction in the limit on widow rockfish implies a decrease in fishing effort for DTS species, which is reasonable because rockfish bycatch is associated with trawling for DTS species.

Test results show that parameter restrictions associated with using pooled data are rejected for six of the ten ports in the analysis. The model corrected for individual effects on the response to ex-vessel prices is not rejected for three of these ports, and the model corrected for individual responses to ex-vessel prices and regulations is not rejected for one more. In other words, the analysis of covariance finds significant individual effects in the model's dynamic variables for two ports.

<u>Objective 1.3: Bioeconomic Model</u>

Published paper:

- M. Dalton and S. Ralston (2004). The California Rockfish Conservation Area and Groundfish Trawlers at Moss Landing Harbor, *Marine Resource Economics* **19**(1), 67-83.

Working paper:

- M. Dalton (March 2006). *Monte Carlo Simulations of a Linear Rational Expectations Model with Static and Stock Externalities and Dynamically Interrelated Variables*.

In the project's final year, a spatial version of the rational expectations fisheries model was fully developed. A default version of the bioeconomic model, without direct spatial-dynamic interactions, was developed in the project's first year, and presented to NOAA Fisheries at a meeting on spatial management in Silver Spring. The default model was applied only to the subset of groundfish trawlers that were associated with the port of Moss Landing over the sample period. This analysis was published in a special issue of *Marine Resource Economics* with other papers that were presented at the meeting in Silver Spring. The default model was extended in the final year of the project to include direct spatial-dynamic interactions. The working paper cited above describes results of Monte Carlo simulations with the extended model.

Results of Monte Carlo simulations for maximum likelihood estimates with the spatial version of the rational expectations fisheries model are not encouraging, and show that estimates are typically far from true values with time series of about twenty periods. The reason is that rational expectations implies a set of nonlinear cross-equation parameter restrictions, and obtaining constrained maximum likelihood estimates with the model that are consistent seems to require very long time series. Signs are correct for each estimate with time series of about 100 periods, but even longer time series are needed to achieve accuracy in the estimates on the order of 10%. An important insight of the Monte Carlo simulations was to reveal relationships in the model among related sets of parameters that create identification problems. For example, the magnitude of the effect of ex-vessel prices on behavior in the model was not identified in the Monte Carlo simulations, and this parameter was normalized for the analysis of data from California's groundfish trawl fishery.

In contrast to maximum likelihood estimates, Monte Carlo results for likelihood ratio tests of the rational expectations hypothesis are accurate with time series of about 20 periods. The null hypothesis for these tests is an unconstrained vector autoregression (VAR), and two types of errors are considered. A Type I error occurs if the null hypothesis is rejected when it is true, and a Type II error occurs if the null hypothesis is not rejected when it is false. Simulated data from an unconstrained VAR were used in the likelihood ratio tests to analyze Type I errors, and simulated data from the rational expectations model were used to analyze Type II errors. The likelihood ratio tests did not produce errors of either type in the Monte Carlo simulations, but required using a different numerical algorithm than the one used to compute maximum likelihood estimates. In particular, a maximum likelihood procedure based on a conjugate gradient method produced the most accurate parameter estimates, but performed poorly in the likelihood ratio tests. Alternatively, a genetic algorithm produced accurate results for the likelihood ratio tests.

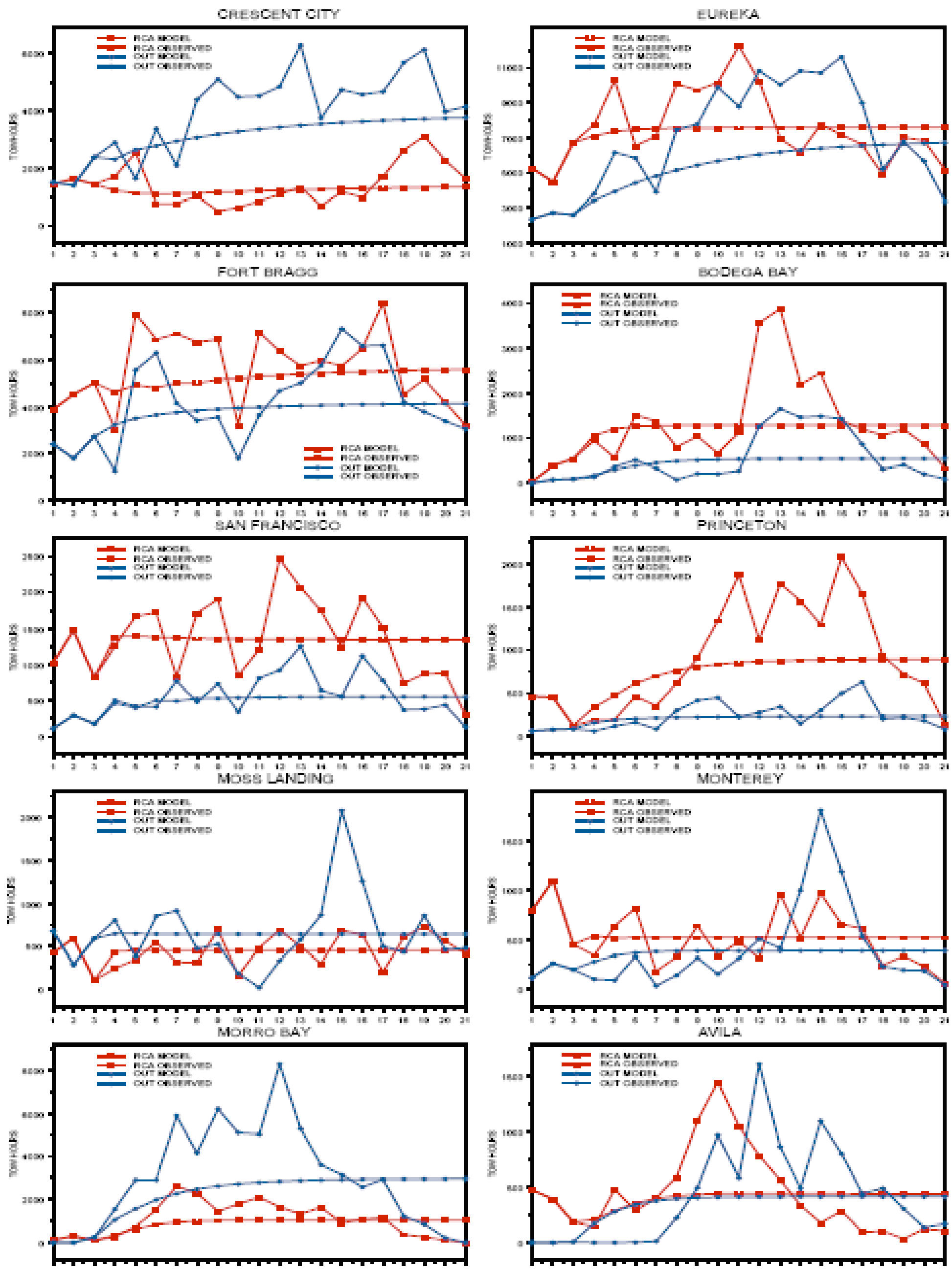
<u>Objective 2: Analysis of Responses to Spatial Management</u>

Working Paper:

- M. Dalton (May 2006). *Effects of Spatial Management on Fishing Effort in California's Groundfish Trawl Fishery: Results from a Rational Expectations Model with Dynamically Interrelated Variables*.

In addition to the Monte Carlo simulations described above, the spatial version of the bioeconomic model was applied to data from logbooks and fish tickets from California's groundfish trawl fishery. Despite results from the Monte Carlo simulations, maximum likelihood estimates from the fisheries data are generally consistent with stability conditions in the model and predictions of economic theory. In fact, the working paper cited above presents 150 estimates (15 for each port) that are subject to model assumptions on admissible parameter values, and these assumptions are violated in only 4 instances. One of these is due to an anomalous data point that was easily corrected.

Fig. 2: Model Simulation and Observed Trawl Effort in Tow Hours by Port (North to South), Inside (RCA) and Outside (OUT) the Rockfish Conservation Area, 1981-2001.

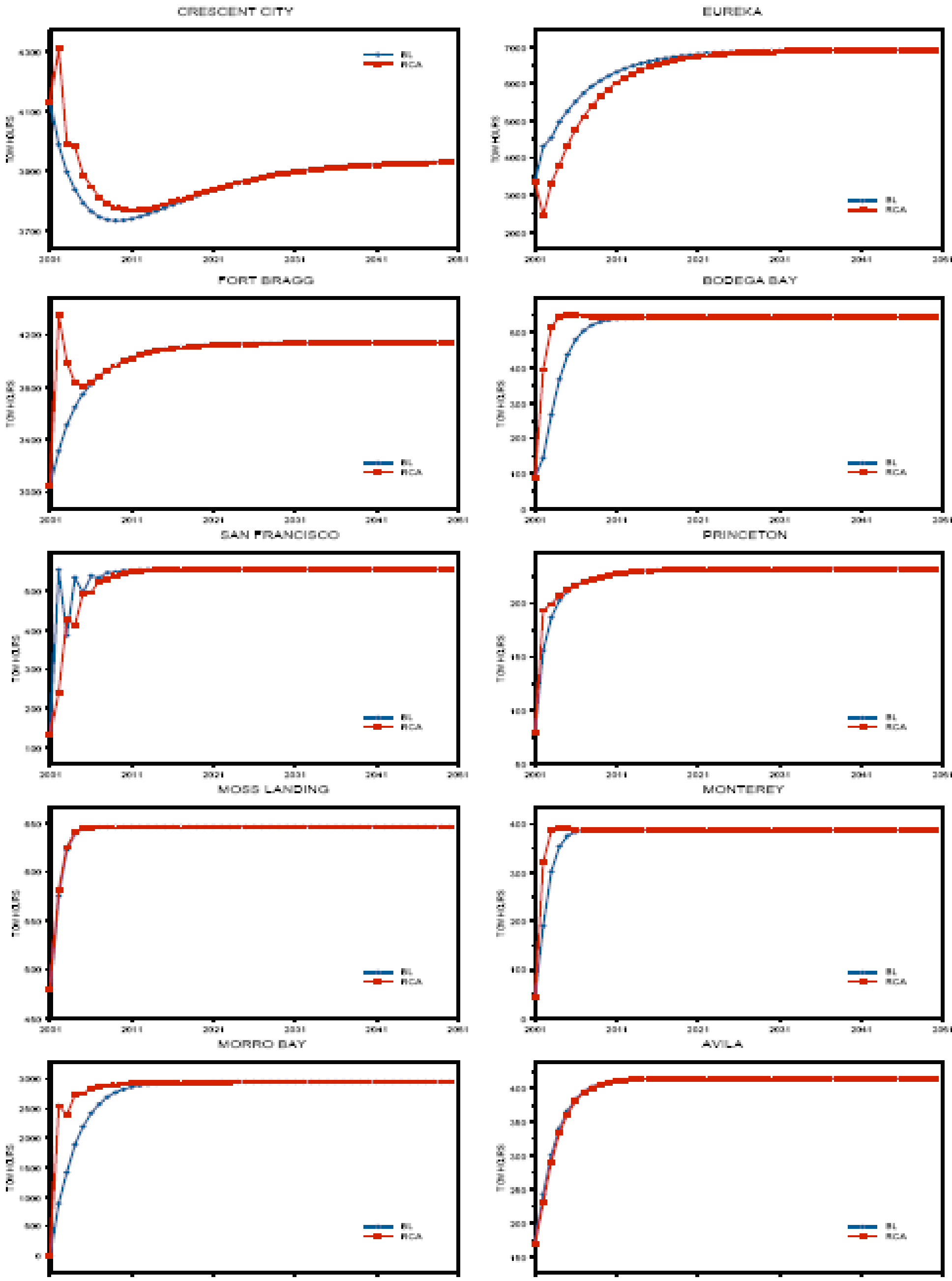


Following estimation and testing, the bioeconomic model was used to simulate optimal responses for each port to implementation of the RCAs after the 2001 fishery. The spatial bioeconomic model in this project has two areas: one area is in the depth zone that defines the RCAs, and the other is outside this depth zone. The policy experiment conducted with the model for each port is a permanent closure of the RCAs. Three types of responses are possible in the model. The null hypothesis is no response in the open area following a closure, which would be the case if the parameter in the model that represents spatial-dynamic interactions is zero, as in Dalton and Ralston (2004). An increase in fishing effort would occur if this parameter is positive, implying the two areas are substitutes in production, and a decrease would occur if this parameter is negative, implying the areas are complements.

An analysis of responses to the RCAs is complicated by the fact that closing an area is a discrete event that can fundamentally change the structure of the dynamic optimization problem faced by fishermen. Changing the level of fishing effort in the open area incurs two types of adjustment costs. One type is a sunk cost, because the adjustment to zero effort in the closed area is unavoidable, but the other type is variable, and depends on spatial-dynamic interactions. On the other hand, changing the level of effort in the open area generates benefits. The theory of stochastic dynamic programming defines a value function for these benefits that gives the maximized expected present value of each level of fishing effort in the open area, conditional on zero effort inside the RCAs after 2001. Information derived from the maximum likelihood estimates described above is sufficient to define a conditional value function for each port. In general, rational fishermen balance short run adjustment costs with long run benefits by using a dynamic equimarginal principle for spatial resource management that equates marginal adjustment costs with the marginal expected present value of the resource. The dynamic equimarginal principle that is presented in the paper listed above is a new contribution to the literature on spatial resource management.

Numerical simulations of equations implied by the dynamic equimarginal principle, using data from logbooks and fish tickets for the ports in Fig. 1, provide an economic basis for predicting optimal responses to closing the RCAs. Specifically, the bioeconomic model for each port was simulated out to 2050, conditional on the three years of data from 1999-2001, with and without closure of the RCAs. A comparison of fishing effort outside of the RCAs in the two cases for each port, in terms of total tow hours per year through 2050, is displayed in Fig. 3. An increase in fishing effort is predicted for Crescent City, while a decrease is predicted for Eureka. In other cases, except for San Francisco, effort increases (i.e. Fort Bragg, Bodega Bay, Princeton, Monterey, Morro Bay), or effects on effort are small. These results are a final objective of the project.

Fig. 3: Model Simulations 2001-2050 of Trawl Effort Outside the Rockfish Conservation Areas for a Baseline (BL) Without Area Closures Versus Effort With Area Closures (RCA).



<u>Ongoing and Future Work</u>

Project leaders will work with a graduate student at CSUMB, Donna Kline, to develop stock assessments of DTS species for each port in Fig. 1, and these assessments will be used in the type of analysis that is described under Objective 1.2. To evaluate forecasting skill, predictions in Fig. 3 will be compared to activity recorded in trawl logbooks for vessels that remained in the fishery after 2001. Methods developed in this project will also be applied to groundfish and halibut fisheries in Alaska.