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Final Year Narrative
California Sea Grant College Program Project No. R/F 179
Spatial Management of Fisheries
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The overall project objective was to develop, calibrate, and refine an integrated spatially explicit bioeconomic model of the California sea urchin fishery. The model was designed to gain some insights into how spatial management measures, primarily reserves, might impact both the biological and economic health of a fishery in general, as well as how spatial policies might impact the California sea urchin fishery, in particular. We were successful in meeting our primary objectives for this project, and we have a variety of new and interesting results that we are in the process of publishing and presenting in workshops. This project involved fieldwork, econometric and statistical estimation, and programming, calibration, and simulation with a newly developed integrated bioeconomic model.

A. Fieldwork

The fieldwork we conducted involved measuring larval settlement in several locations along the Northern California coast and correlating settlement with recent oceanographic events. One project involved deploying artificial substrate in order to measure settlement on a fine time scale basis. This work continues a long term Sea Grant funded effort that we began in 1992 and that is intended to understand how oceanographic mechanisms affect larval distribution and settlement (Lundquist et. al. 2000). During this project period we were able to gather new data on currents using a high frequency radar system at the Bodega Bay Marine Laboratory (BML). Since high frequency radar has not been deployed at this site before, we first did a statistical analysis of the local surface currents (Kaplan, et al. 2003). We found that the currents indicated by the radar system corresponded closely to observations from acoustic current profiler. Another point of interest is that the dominant mode of variability at this location was driven by the daily scale shifts between upwelling and relaxation that we had identified as being important to larval transport and settlement (cf., Botsford 2001).

We also began a new study on a smaller scale intended to look at larval settlement in the outer bay at Bodega Bay and correlate these data with radar data on currents. Sea Grant Trainee Amber Mace worked with Steve Morgan to develop this data collection effort. Analysis of larval settlement data collected at the BML is still being analyzed, and a paper describing the results will be prepared soon. One heartening result is that we do see an effect of the currents indicated by the radar, which goes beyond the effects of wind and temperature. Larval settlement data collected in outer Bodega Bay indicates that larval settlement follows a similar, but not identical, pattern to that observed on the open coast. Additional mechanisms appear to come in to play on smaller scales. Also, since this site is more accessible in foul weather, more frequent sampling is possible, which led to important results regarding the effects of sampling on weekly or longer intervals. The data are still being analyzed and manuscripts are in preparation.

Our overall findings confirm that settlement is correlated in important with wind relaxation events. These relaxation events break the fundamental patterns of wind and currents during active upwelling that predominantly push larvae southward along the coast. During relaxation events, larvae that are entrained in eddies or gyres off promontories such as Point Reyes and Point Arena are redistributed northward. These important empirical findings were used to formulate the model of the dispersal process that is a critical component of the spatial dynamic model of the urchin population developed under this grant.

B. Conceptual Models of Reserves

Part of the effort expended during this grant focused on developing deeper understanding of the impacts of marine reserves on population sustainability and yields using conceptual models of reserve designs. The starting points for these investigations were earlier work under Sea Grant R/F 169. With regard to the issue of sustainability of populations in reserves, our prior work focused on the effects of larval dispersal, assuming sedentary juveniles and adults (Botsford, et al. 2001). That work showed that for a model system of reserves with complete removal by fishing between them, single large reserves would sustain species with larval dispersal distances on the same order as the dimension of the reserves. Alternatively, a system of small reserves that covered a minimal fraction of the coast may produce a network effect, and sustain species dispersing any distance. The minimal fraction of coastline required for sustainability was found to be the minimal fraction of lifetime egg production required to sustain the species, which is frequently taken to be 35 percent.

On the current grant, we first showed the result in Botsford, et al. (2001) did not depend critically on the shape of the dispersal function used (Lockwood et al. 2002). While the shape of dispersal functions can matter in some problems, such as species invasion, the shape appears to make little difference to sustainability under reserves, and only mean dispersal distance appears important. We also extended this work to the case in which: (1) the fishing between reserves does not completely remove all fish and (2) the coastline includes species boundaries set by suitability of benthic habitat, beyond which dispersing larvae are lost to the population (Lockwood, et al. 2005). These conceptual investigations showed how to combine fishing mortality rates and marine reserve configurations to allow population sustainability. Results also showed specifically how the loss of larvae across species boundaries leads to increased requirements for space in reserves.

A second thrust of the conceptual work completed under this project focused on comparing conventional management measures with explicitly spatial measures, particularly marine reserves. The starting point of this analysis are the results indicating the dual nature of conventional fisheries management and management by marine reserves (Hastings and Botsford 1999). That study and studies by others shows that the effect on yield of implementing a marine reserve is roughly the same as reducing fishing effort. A corollary of this idea is that adding marine reserves to a fishery will increase yield only when the fishery without reserves is very heavily fished (Sanchirico and Wilen, 2001a, and 2002a). The duality of conventional management and management by reserves serves as an initial benchmark from which other factors might cause deviations in either direction. For example, pre-dispersal density-dependence would diminish the relative gain due to reserves, hence would make conventional fishery management relatively more favorable, compared with reserves. We are continuing our efforts to flesh out yield comparisons between reserves and conventional management methods using both conceptual and calibrated empirical work (Botsford, et al. 2003).

A third focus of conceptual work done under this project attempts to combine both yield and sustainability objectives into a single analysis. For example, some have suggested that our early results regarding sustainability and yield have been misleading because they often involve uniformly spaced reserves. To examine that issue we examined the effects of random placement of marine reserves on yield and sustainability (Kaplan and Botsford 2003). The results suggest that random placement of marine reserves makes little difference for both yield and sustainability. It is only under conditions in which the population is just about to collapse anyway, that the random placement can have an effect.

In addition to the above, we prepared five reviews and synthetic papers describing various aspects of these conceptual issues and their relevance to current policy debates. The first is a review of how marine reserves might apply to sustainable fisheries, and it was based on a talk at the Sustainable Fisheries Conference in Miami in 2001 (Botsford 2005). The second is a review of fishery management of sea urchin fisheries in North America based on a talk at a conference in Halifax, Nova Scotia at a conference on the use of biological reference points in invertebrate fisheries (Botsford, et al. 2004). This paper pointed out some of the spatial problems involved with rapidly developing sea urchin fisheries, and the various attempts to manage them. A third paper (Wilen 2003) describes future visions of fisheries management that incorporate new scientific discoveries about the spatial distribution of populations and their oceanographic determinants. Two other papers place current fisheries management within the global context and discuss both the reality of current management successes and the potential under future scenarios involving more rationalized management systems, particularly using spatial policy instruments and zoning schemes (Sanchirico and Wilen 2002, Smith and Wilen 2002).

C. Integrated Bioeconomic Model of the Sea Urchin Fishery

A major effort under the current grant was to develop and calibrate an integrated model of the California sea urchin fishery. This work builds on conceptual work developed to depict the interaction between a spatially explicit and dynamic population and a behaviorally responsive harvester fleet (Sanchirco and Wilen 2001b, and 2002a). We successfully developed and calibrated a new and complex integrated model, using data gathered from the field work, new data gathered to analyze urchin diver behavior, and ongoing data from our investigations of larval settlement. The integrated model links two major components, a spatially explicit dynamic model of the Northern California urchin population, and a spatially explicit model of diver harvester behavior. The population model of urchin dynamics that we constructed for this project is novel in several respects. First, it is fully dynamic and explicitly spatial, so that we are able to examine both transitionary and steady state impacts of any policies we wish to simulate. Much of the existing simulation modeling on reserves looks only at steady state results.

This is an important omission for policy analysis, since the costs incurred during adjustment to a new steady state after reserve formation may be very important to stakeholders. Second, the population integrates both biology and economics by making effort variable and dependent upon relative profits of different locations as well as other factors such as weather, market conditions, and port location. Third, our population model is capable of incorporating a range of assumptions about the key process of larval dispersal. The model allows any dispersal process to be depicted by formulating a dispersal matrix; we use a particular likely example that reflects our field work findings about gyres, eddies and relaxation events along the Northern California coast.

One of the unique features of our modeling effort is that it is truly integrated in the sense that economic behavior of divers determines the intensity and spatial distribution of effort. This effort intensity and spatial distribution, in turn, determines harvest pressure in different locations, and spawning biomass over the whole spatial expanse of the fishery. The dispersal process then determines larval settlement and subsequent recruitment to the fishery. To model the behavior of divers, we gathered logbooks and landing records of individual divers identified by code numbers to preserve anonymity. We then estimated a series of models aimed at predicting choices made by divers. We found that the daily decision to fish is determined importantly by weather conditions and expected profits from fishing overall, and from fishing in particular patches. Similarly, decisions by particular divers about where to fish depended mostly on anticipated profits, which we modeling using average actual profits over the previous month in each patch. In the final analysis, we depicted behavior and urchin population dynamics using an 11 patch model of the Northern California fishery.

Our attempts to model spatial behavior of actual divers led to several methodological challenges, some of which we outline and discuss in detail in journal articles (Smith, 2000, Wilen, 2000). Among the challenges are how to model divers' unobservable expectations about opportunities present in each area (Smith 2000), how to model heterogeneity of behavior (Smith and Wilen 2003c), and how various levels of temporal and spatial aggregation affect the ability to forecast behavior (Smith 2002). We are currently investigating how weather risks affect decisions to participate and whether risk aversion appears to differ in systematic ways across the population of divers.

Our predictive models of the determinants of diver behavior were linked up to the spatial dynamic population model in order to investigate various management options. While we are still preparing papers from this effort and delivering presentations in workshops and conferences, the results so far are important as basic understanding and for policy making. In one paper (Wilen et. al. 2002) we investigated conventional management measures such as minimum size limits, in models that ignored economically driven diver behavior and models that incorporated behavior. Our findings show that models that naively assume spatially uniform and constant behavior misestimate the implications of conventional measures in dramatic ways. In other papers (Smith and Wilen 2003a and 2003b) we investigate and simulate the formation of spatial measures such as reserves in a system in which divers respond to spatial economic incentives. Again, results from modeling that realistically incorporates the drivers of behavior differ dramatically from results that make more conventional (but naïve) assumptions about effort. Overall, these results suggest important and timely new results that should have bearing on issues such as marine reserve formation, reserve siting, and spatial management in realistic complex settings.

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