ECONOMIC EFFECTS OF OIL AND GAS DEVELOPMENT ON MARINE AQUACULTURE LEASES

Principal Investigator:

Magriet F. Caswell

FINAL REPORT
Study 17
March 1991

Southern California Educational Initiative

ECONOMIC EFFECTS OF OIL AND GAS DEVELOPMENT ON MARINE AQUACULTURE LEASES

Principal Investigator:

MARGRIET F. CASWELL
ECONOMICS AND ENVIRONMENTAL STUDIES
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

The research leading to this report was supported by the Minerals Management Service as part of the Southern California Educational Initiative under Cooperative Agreement No. 14-35-0001-30471.

TECHNICAL COMPLETION REPORT

March 1991

TECHNICAL SUMMARY

STUDY TITLE: Southern California Educational Initiative

REPORT TITLE: Economic Effects of Oil and Gas Development on Marine Aquaculture Leases

CONTRACT NUMBER: Minerals Management Service Cooperative Agreement No. 14-35-0001-30471

SPONSORING OCS REGION: Pacific

OCS PLANNING AREA: Coastal California

FISCAL YEAR: August 1989 - July 1990

COMPLETION DATE OF FINAL REPORT: March 1991

COST: FY 1990: $22,000

PROJECT MANAGER: Russell J. Schmitt
Director, Coastal Research Center
Marine Science Institute
University of California
Santa Barbara, California 93106

PRINCIPAL INVESTIGATOR: Margriet F. Caswell

KEY WORDS: Mariculture; marine aquaculture; co-development; offshore leasing

BACKGROUND: Seafood is becoming an increasingly important part of the world's diet. The wild populations of many species have been over-harvested or diminished due to coastal pollution. Many nations are developing aquaculture industries so as to meet the growing demand. Currently, aquaculture provides one sixth of the seafood consumed directly worldwide, but production in the United States is low. The supply of seafood historically has been abundant, so the U.S. has begun to promote its domestic marine aquaculture industry only recently. California has offered strong support for the industry only for the last decade. Mariculture development has taken place primarily in the shallow waters of bays, estuaries, and lagoons. Industry expansion, however, is limited by the scarcity of shallow-water sites with good water quality. Deep-water leases are being granted by the State of California on an experimental basis to assess whether industry expansion in coastal waters is economically viable.

Most potential deep-water lease sites are within or near Outer Continental Shelf (OCS) oil and gas leasing areas. Therefore, the future of the California mariculture industry will depend on offshore oil and gas production. Offshore oil and gas development may have both short- and long-term effects on water quality with resulting changes in the productivity of marine aquaculture leases. Much of the focus of past research has been to analyze the effects of major catastrophic events such as blowouts or oil spills, but the possible chronic effects on aquaculture products of offshore oil and gas development could be more important to the health of the mariculture industry than the acute effects caused by an oil spill. Prolonged exposure to sublethal concentrations of toxicants associated with drilling muds and produced water may be serious due to effects on recruitment and marketability of commercial species. The physical effects of drilling effluents on commercial biological species must be assessed before future profitability can be estimated. When potential returns are known, leasing schemes for the joint development of oil and gas resources and mariculture products can be designed. By co-developing the coastal resources, the State and Federal agencies as stewards of the public's natural assets would be able to capture the returns to development.

PROJECT OBJECTIVES: (1) Assess the current economic conditions of the mariculture industry in California and to predict the likely potential for the industry in the future. (2) Suggest the scientific information necessary to assess the economic consequences to the California mariculture industry of chronic exposure to oil and gas development.

METHODS: A survey of all marine aquaculture leaseholders in California was conducted so as to assess the current economic conditions of the mariculture industry and to predict the likely potential for the industry in the future. For each of the 66 leases, information was obtained for the period July 1, 1987 to June 30, 1989 on the size and location of the lease, the identification of the lease holder and the lease grantor, the species grown, annual production, and future plans. We made site visits to representative lease areas to study the latest mariculture growing techniques. Growers in other geographic areas were contacted to compare growing methods. Market price data were obtained for the major mariculture products. We interviewed personnel from the California agencies directly responsible for mariculture regulation. A literature search was also conducted to assess past research and to survey the legal and regulatory framework that currently exists for the mariculture industry in California.

RESULTS: There are three primary mariculture products grown in California waters: oysters, mussels, and abalone. The annual production of 15 million oysters has a value of around $4 million. Mussels are a relatively low value product, so production was only about 190,000 pounds earning a revenue of $250,000. Abalone are a high-priced item, so although only 1.1 million cultivated abalone were sold, they had a value of $2.2 million. In total, the California mariculture industry earns revenues of about $6.5 million. If current expansion plans are realized, the value of the industry would double by the year 2000.

Water quality degradation was the primary concern of most growers. Coliform bacteria and pesticide residues are currently threatening several shallow-water sites. Lease holders (and potential lease holders) for deep-water sites state that coliform bacteria from municipal sewer outfalls and offshore oil and gas drilling effluents are the greatest dangers to their profitability. The Southern California Educational Initiative is an attempt to determine whether such concerns are warranted.

A simple model of economic externalities was described to highlight the scientific data one must gather so as to choose the optimal production levels for both energy and mariculture resources. That information is necessary to assess the economic consequences to the California mariculture industry of chronic exposure to oil and gas development. The co-development model shows that the marginal (incremental) effects of oil production effluents (e.g., hydrocarbons, drilling muds, and produced water) on mariculture costs needs to be assessed. The model also shows that if the effects are moderated by distance from the point of discharge, such changes must be estimated in order to determine optimal lease boundaries. The report concludes that interdisciplinary cooperation is essential for designing a co-development plan that maximizes the social welfare to be gained from developing multiple coastal resources.

STUDY PRODUCTS: Caswell, Margriet F. 1991. Economic Effects of Oil and Gas Development on Marine Aquaculture Leases. A final report for the U.S. Department of the Interior, Minerals Management Service Pacific OCS Office. Contract No. 14-35-0001-30471. 51 pp.

Caswell, Margriet F. 1991. Co-Development of Coastal Resources: Oil vs. Mariculture. Contemporary Policy Issues. Vol. IX, April, pp. 1-9.

ECONOMIC EFFECTS OF OIL AND GAS DEVELOPMENT ON MARINE AQUACULTURE LEASES

PRINCIPAL INVESTIGATOR: MARGRIET F. CASWELL

PROJECT OBJECTIVES

1. Assess the current economic conditions of the mariculture industry in California and predict the likely potential for the industry in the future.
2. Suggest the scientific information necessary to assess the economic consequences to the California mariculture industry of chronic exposure to oil and gas development.

I. INTRODUCTION

In the past, development of each ocean resource has occurred without comprehensive planning designed to maximize the returns from all the resources involved. For instance, the bases of agency decisions concerning the location and timing of oil and gas development apparently have been industry profits and government oil revenues. If other resource uses were considered, they were considered only as a constraint on siting or scale. Currently, however, pressure to develop all ocean resources is increasing and the "either/or" type of decision making exacerbates the conflicts between resource uses. The optimal co-development of society's marine biological and mineral assets will efficiently allocate scarce resources and increase welfare.

Objections to offshore oil and gas development have remained strong on the West Coast due to the belief that such development would negatively affect or preclude natural fisheries, the mariculture industry, and recreational benefits. Petroleum production may impose several external effects on the marine environment. Machine operation, support boats, and escaping hydrocarbons can cause air pollution. Major spills (blowouts) or oil leaks that are low-grade but chronic can degrade the quality of water, sediments, and coastal habitats. Because biological and aesthetic assets along the coast are becoming more scarce, the once "free" resources are now being fiercely protected (U. S. Committee on Merchant Marine and Fisheries, 1988). As natural fisheries become depleted, many coastal states look to marine aquaculture to provide a supply of some commercial marine species. Potential conflict may exist between two valuable industries--energy and mariculture--in many locations. In California, for example, the Santa Barbara Channel in California lies over large oil and gas reserves and also is a biologically productive coastline area.

Offshore oil and gas development may have both short- and long-term effects on water and sediment quality, and these may change the productivity of aquaculture leases. Much of past research focused on analyzing the effects of major catastrophic events, such as blowouts and oil spills (LaBelle, 1989; National Research Council, 1985; Teal and Howarth, 1984). These effects might be great, but they would not affect each segment of the commercial fishing industry in the same way. For instance, an oil spill might have a greater economic impact on harvesters of animals in the natural environment than it would have on growers with mariculture leases due to the "private property" nature of such leases. Any action taken on a lease will benefit the lease holder directly. For instance, an aquaculturist could reseed the crop as soon as the water clears and be back in production more quickly than could a harvester awaiting natural regeneration.

The possible chronic effects on aquaculture products of offshore oil and gas development could be more important to the health of the mariculture industry than could the acute effects of an oil spill. Prolonged exposure to sub-lethal concentrations of toxicants may be a serious problem due to its effects on recruitment and marketability -- and hence profits. Any change in the real or perceived quality of the commercial species may seriously harm the profitability of the industry. Because the lease is fixed regarding location, the lessee cannot avoid these long-term effects by harvesting in another area. A marine aquaculturist would have an advantage over a natural harvester if an oil spill occurred, but the former may be at a disadvantage if chronic conditions have a negative effect on the aquaculture product. The long-term effects of drilling muds and produced water on commercial marine species are not yet known, and research is continuing.

The constituents of drilling discharges and produced water are of particular concern. One uses drilling "muds" to remove cuttings from under the drill bit, to control well pressure, to cool and lubricate the drill string, and to seal the well. Produced water is the aqueous waste that has existed in interstitial spaces of fossil fuel-bearing formations for thousands of years. Drilling fluids may contain clay minerals, barite, trace metals, sodium hydroxide, biocides, diesel fuel, and other minor constituents, while produced water may contain elevated concentrations of metals, hydrocarbons and other organic substances. Oil and gas development is not the only source of these potential toxicants in the ocean environment. River inflows, municipal wastes, and dredged materials also contribute to the pollutant loading. A complete analysis of an aquaculture site should include <u>all</u> sources of contamination so as to assess the relative contribution and impact of each source on the biological resource. For simplicity only, the following discussion assumes that oil and gas development is the only contributor of potential toxicants.

The volume of oil and gas drilling wastes is enormous. On the outer continental shelf of the United States alone, discharges of drilling fluids total at least two million metric tons annually (National Research Council, 1983). Most effects of the drilling muds are assumed to be localized within 1 to 2 kilometers of the point of discharge. Many are concerned about the accumulation of these discharges, especially regarding multiple-well platforms -- one may drill 50 or more wells from a single production platform -- and concentrations of platforms on the same field. Produced water is the largest source of contaminants from offshore oil and gas development (Neff et al., 1987). Some estimate that, with offshore production wells, each barrel of crude oil recovered yields up to one barrel of produced water. An open ocean environment quickly dilutes the produced water. In shallow water, however, the hydrocarbons and metals may adsorb to sediments until they accumulate to toxic levels. The effects of drilling wastes on marine biological resources could take many pathways, and such effects may differ markedly among species and even among life cycles of a single species.

In the Santa Barbara Channel area of the California Coast that extends from Point Conception south to Point Hueneme, oil production has been an ongoing activity since the 1920's. Currently along the 60 miles of shore, there are 35 oil lease tracts in state waters (within 3 nautical miles of shore) containing 6 drilling platforms, 5 marine terminals, and 10 onshore treatment facilities. There are only 3 platforms and 3 onshore facilities proposed. In the federal waters, which are less likely to be potential mariculture lease sites, there are now 13 drilling platforms with 3 more planned. Although the federal leases lie beyond the three mile state limit, the effluents from federally leased production might affect mariculture production within the state leasing area.

Early oil and gas development was physically limited to shoreline drilling due to the lack of offshore technology. The area ten miles west of the City of Santa Barbara was one of the first coastal sites to be developed because of the natural oil seeps that had coated the shore with tar for centuries. Despite the high amount of hydrocarbons naturally occurring in the Santa Barbara coastal environment, wildlife flourished (e.g., see Straughan, 1980). Some marine species suffered negative effects, but these effects diminished rapidly with distance from the seep site (Spies and Davis, 1982). Biological studies show that chronic oil drilling external effects may be relatively small with respect to some shellfish (Kanter, 1974). Mussels apparently thrive attached to oil drilling rigs to the extent that they are a "pest" that must be removed. The chronic effects of oil and gas production on other species (or on mussels grown on or near bottom sediments) are not known yet.

The mariculture industry probably has no physical effect on the profitability of the offshore oil and gas industry, but mariculture may impact certain aspects of the natural environment (International Council for the Exploration of the Sea, 1988). Some have argued that the presence of aquaculture might reduce over-fishing natural stocks and thus enhance those populations. However, Berck and Perloff (1985) and Johnson (1990) have disputed this point. It is suspected, however, that there are external effects of oil production on commercial marine species. Oil drilling operations may affect both supply and demand in the mariculture industry. For instance, for shellfish, supply would be affected if the population is reduced or the health of the animals is diminished. Shellfish demand is affected by consumers' perceptions of product quality (associated with water quality). One group of state and federal agencies is promoting the expansion of offshore oil development (in the face of popular opposition) while other agencies are promoting the expansion of offshore mariculture leasing. To maximize the value of the coastal environment, the optimal size and mix of development needs to be assessed. Institutional barriers such as the existence of conflicting agency goals must be reduced to affect such an improvement.

Designing the optimal pattern of development can be complex in the best of circumstances, but dealing with natural resources compounds the problem. Interdisciplinary research is essential since a strong scientific component will drive economic analyses and theoretical economic models must contain enough physical reality to address the complex resource allocation issues. Economic theory can help to direct scientific research, the results of which will strengthen the economic analysis. What follows describes such an interdisciplinary and iterative process. This report shows how one can use an economic model based on the knowledge of biological and environmental conditions so as to identify the scientific information necessary for further economic research. The report describes California's mariculture industry and how producing offshore oil and gas may affect that industry. It then describes a simple model of economic externalities highlighting the scientific data one must gather so as to choose the optimal production levels for both energy and mariculture resources. The government might achieve optimal levels by instituting a policy such as imposing an effluent tax. Once the chronic external effects of oil development on commercial marine species are internalized within the decision process, one still needs further scientific information so as to determine the lease boundaries that would maximize the social value of both energy and mariculture resources.

II. MARICULTURE DEVELOPMENT

Seafood is becoming an increasingly important part of the world's diet. In many nations, the overharvesting of wild populations has led to the development of aquaculture industries. The term "aquaculture" refers to farming (or ranching) an aquatic crop in fresh, brackish, or salt water, while "mariculture" refers to farming an aquatic crop in salt water. Aquaculture development -- including seaweed harvesting -- has existed for at least 4,000 years, but the industry is still relatively small. Output totals just 9 million metric tons, or roughly one seventh of the oceanic wild catch. However, aquaculture provides one sixth of the seafood consumed directly (Brown, 1985). There is strong worldwide interest in expanding aquaculture activities, particularly in developing nations (OECD, 1989). The United States has an abundant food resource base, so has only begun to promote its domestic mariculture industry. However, plans are underway to expand the geographic extent and the number of products that will be produced -- especially on the Pacific coast. Unfortunately, there has not been a concerted effort made to study the breeding, nutrition, and health of aquatic organisms as was done for livestock. The institutional support network that is well developed for agriculture is in its infancy for aquaculture. Therefore, many aquaculture operations still are experimental despite the industry's long history.

Since 1979, when the California Aquaculture Development Act was passed, the number of growing areas in California have doubled. The California Department of Fish and Game leases certain of the state's marine waters for growing marine life for profit. Thus far, the state has granted 38 marine aquaculture leases totalling 2,702 acres. Included in this number are 8 new leases, all of them issued in 1989 and each of 25-year duration. In addition, municipal and private entities have granted 28 leases totalling 2,179 acres. Appendix I lists the registered leases within California marine waters, including acreage and mariculture species by lease. Most of the state leases specify the cultivation of bay mussels (Mytilus edulis), European oysters (Ostrea edulis) and Pacific oysters (Crassostrea gigas) in the designated areas. Although rock scallops (Hinnites giganticus) were listed on several lease applications, none are currently in commercial production. Red abalone (Haliotis rufescens) are primarily grown on private leases in land-based facilities fed with seawater. Although the term "shellfish" usually applies only to bivalve filter-feeding mollusks, for this discussion the term will be used to encompass abalone as well. Finfish are grown in coastal waters in many other parts of the world, but there are no marine leases for finfish cultivation in California at this time. Certain species and growing technologies might be successfully introduced to the California coastal area in the future, however, such as yellowtail, grouper, halibut and red snapper, grown in submergible net cages. Authorities plan to expand the number of aquaculture products so as to include red sea urchins (Strongylocentrotus franciscus), shrimp, finfish and a wider variety of oysters.

State mariculture leases are granted for a nominal annual fee and revenues for the state are generated by a privilege tax on all products harvested from the lease. Private leases have traditionally required the payment of a rental fee that may or may not be tied to production levels. Most mariculture leases are located in relatively sheltered and shallow waters -- bays, lagoons, and estuaries. The major growing areas are Tomales Bay (17 leases), Monterey Bay (eight leases), and Humboldt Bay (six leases). The Central coast segment extending from Bodega Bay south to Big Sur has 29 leases.

Recently, authorities have granted several deep-water leases in the Santa Barbara Channel and off the coast near San Diego so as to test the viability of expanding the areal extent of the industry farther out into state waters. The types of culture techniques used in deep water differ from the traditional methods used in shallow water. The ocean's physical characteristics, such as currents and wave action, have both positive and negative effects: Water movements provide a continual supply of food to the animals, but water movements also affect the ability to keep culture structures in place. The greater distance from the shore increases maintenance and transportation expenses and possibly creates problems enforcing property rights. There have also been resource use conflicts between mariculturists and commercial fishermen as the fishermen claim that mariculture equipment interferes with their ability to work traditional grounds without obstruction. There may be other future resource use conflicts if mariculture equipment is visible from the shore and is deemed aesthetically offensive. Because much of the California coastline is within potential state and federal oil and gas leasing areas, the future expansion of offshore mariculture leasing activities will depend on the extent of multi-use development -- i.e., co-development.

There are several government and private entities involved directly in the aquaculture industry in California. Offshore shellfish production and sales are regulated by the California Department of Fish and Game, the Department of Health, and the United States Coast Guard. The California Coastal Commission, various local government agencies and planning commissions, the California Mussel Watch program, Seagrant, the Shellfish Growers Association and the California Aquaculture Association have interests in the industry as well. California has no comprehensive and consistent body of laws and regulations for marine aquaculturists to follow. Many agencies are involved, and some have conflicting regulations for the mariculture industry (California Interagency Committee for Aquaculture Development, 1988). These agencies have little interaction with those regulating the use of other marine resources. To maximize the value of the coastal environment, one must assess the optimal size and mix of development. One must reduce institutional barriers -- e.g., conflicting agency goals -- so as to effect such improvement.

California waters potentially can be very productive for growing marine aquaculture products. Any grower's profitability will depend primarily on water quality within the lease area, and the lease owner's revenues ultimately will depend on the productivity of the lease. The biological component of water quality includes the quantity of phytoplankton or particulate organic matter that the animals can use for food. The pollution of coastal waters threatens both cultured and natural marine species world wide. Oysters and mussels are bivalve filter feeders. Consumers eat them whole and often eat them raw. These mollusks pick up pollutants from the water through their respiratory systems and bioconcentrate certain constituents. Oysters, in particular, are excellent indicators of water quality since they process five to six gallons of water per day.

Mariculturists in California have worked assiduously to improve water quality in their areas. Growers in the Santa Barbara area used lawsuits to force sewer districts to convert to secondary treatment for municipal wastes, and oyster farmers in Humboldt Bay worked with the City of Arcata to upgrade wastewater facilities in that area. These actions were both time consuming and costly. But growers invested in such efforts because improved water quality can benefit the mariculture industry directly (McConnell and Strand, 1989). This is not the case with open-access fisheries. Many natural populations of commercially valuable species are in "open-access" areas where anyone may harvest. Little incentive exists for an individual to expend resources to improve the area when others can capture the reward for free. Because the biological resource within the lease area is privately owned, the mariculturist can reap the benefits of any expenditures on site improvement. Therefore, and individual in the mariculture industry has a greater incentive to work toward improving the quality of coastal waters through direct action or cooperative agreements than does the individual commercial or recreational fisherman harvesting wild populations. Industry profits would increase and there would be an increase in net social returns from the coastal resource as well.

In California, wastewater discharges have posed a major concern with respect to water quality for mariculture, though non-point source pollution -- e.g., from agricultural runoff -- seriously threatens shallow-water mariculture enterprises (United Nations Food and Agriculture Organization, 1976). Municipal wastes may contain heavy metals and coliform bacteria which can pose a threat to consumers. The implementation of the Clean

Water Act has resulted in lower coliform bacteria counts in all the major growing areas, but limited state and local budgets have slowed the cleaning process (California Water Resources Control Board, 1988a and 1988b). Most pollution standards relate to immediate consumer safety rather than to the long term health of the shellfish. In addition, although each source of pollution may be within its respective tolerance level for the health of the shellfish, the combination of contaminants may be very detrimental.

"Natural" phenomena such as Paralytic Shellfish Poisoning (PSP), commonly known as "red tide", affect both the health and marketability of the animals. The State Department of Health regularly tests the coastal waters and declares quarantine conditions for harvesting shellfish from natural populations. Depuration in non-contaminated waters may be required for cultured mussels or oysters. Areas in which PSP occurs frequently, such as California's northern coast, are not likely candidates for mariculture leasing. Currently, this area covers the entire offshore coastal area north of Monterey Bay. The following discussion examines only the effects of contamination that energy development causes. A complete analysis would include the additive or synergistic effects of the total pollutant load.

III. METHODS AND RESULTS

The first objective of the study was to assess the current economic conditions of the mariculture industry in California. We began by estimating the current revenue of existing mariculture operations. We used production figures and implied sales as the primary measure of value. The methodology for obtaining the necessary data included a survey of individual firms, supplemented with aggregate production estimates from various other sources.

All mariculture operations, both experimental and production-oriented, are required by law to register with the State of California. We obtained a list of all registered marine aquaculturists from the California Department of Fish and Game (DF&G). The list provided us with the addresses and telephone numbers of all 66 mariculture operations registered by March 3, 1989. In addition, holders of state leases (38 in all) must report their annual production to the DF&G for fee assessment. We obtained copies of output records for the period from July 1, 1987 to June 30, 1989.

We directly contacted firms with non-state (private or local government) leases to ascertain which species were being raised, to obtain estimates of their production, and to discuss the current and future state of the mariculture industry. In general, lease holders gladly provided us with the required information, appreciating the opportunity to air their concerns about water quality, mariculture regulations, and the state of local shellfish markets, including current wholesale prices. We also found that a small number of leases are currently not in production, the apparent causes being (1) a concern about water quality, or (2) an inability to generate sufficient cash flow. For example, several leases granted by the Moss Landing Harbor District (Central Coastal Segment) are currently not in production due to water contamination associated with agricultural run-off in the Elkhorn Slough. One of the lease holders must depurate his crop of Pacific Oysters at another location in order to bring them up to Department of Health standards to ready them for sale (Moss Landing Harbor District and Monterey Bay Marine Farm, personal communication). Also, the operators of the two major deep water leases in the Santa Barbara Channel Coastal Segment have experienced financial problems associated with the high capital costs necessary to install and maintain the growing equipment. The lease-specific results of this survey are reported in Appendix I. In addition, aggregate production estimates and prices have been used to calculate total revenues by coastal segment and by species. These results are reported in the following species-specific discussion.

A. Oysters

Oysters are grown on most mariculture leases in California. Worldwide, oyster production has remained steady at about 1 million metric tons (UN-FAO, 1983). California, however, currently is producing only about 3,500 metric tons per year. The oyster industry is one of California's oldest aquaculture industries (since 1875) and one of the most heavily regulated. The Pacific oyster (Crassostrea gigas), a cupped oyster closely related to the Portuguese oyster (C. Angulata) common in Europe, is grown on the majority of leases. A detailed description of the nutritional requirements and other characteristics of the Pacific oyster can be found in Pauley, Van Der Rey, and Troutt (1988). It typically takes up to five years to raise oysters to a marketable size. Oysters are bivalve filter feeders which process five to six gallons of water per day. Since they bioconcentrate certain pollutants, they are excellent indicators of water quality and are often used as monitoring sentinels.

Cupped oysters are a subtropical species, so they will not reliably reproduce in the cool California waters. They fill with spawn in July and August, making them unmarketable, but the larvae will not survive unless water temperatures remain around 70 degrees Fahrenheit for at least three weeks. Therefore, most oyster beds are "seeded" using broodstock purchased from growers who can provide the service due to their favorable location. Much of the broodstock is obtained from the Pacific Northwest or Japan (Magoon, 1985), although there is one seed provider in the Humboldt area. Oyster larvae attach to a hard substance, or "cultch", such as concrete, rock, or, most frequently, clean oyster shells. Once the oyster becomes established (usually within six months), the cultch is transplanted to the growing area.

Oysters are a tidal shellfish that can tolerate periods of drying and the wide range of temperatures associated with tidal cycles. They can also withstand total, uninterrupted immersion throughout their lifecycle. Therefore, there are many locations and growing methods available for oysters. Most oysters beds in California are cultured in a shallow water body, either directly on the bottom or on a tray placed on the bottom. For bottom culture, the ground should be firm and the wave action slight. Otherwise, the oysters will become buried or tumble from their beds.

The traditional methods of bottom culture work well if the sediments are not contaminated and if predators and pests do not harm the crop. Starfish, the Japanese oyster drill (a snail), and some crabs and rays eat oysters and can be particularly destructive during the first two years of growth when the oyster shell is relatively thin. There are also several pests that affect the growth of an oyster crop by competing for scarce food resources and disrupting the habitat. The sediments also can be disturbed by pests. Ghost shrimp dig through the bottom, softening the ground, and have the potential of burying the oysters. Mussels and barnacles can also be pests by attaching in large numbers to the oyster shells and smothering the animals.

Growers recently have adopted off-bottom methods which are more expensive to build and maintain, but can reduce predator losses and contamination significantly. Although there are many variations of off-bottom culture (stake, umbrella, rack, raft, trays, nets, and long line), the basic principle is the same: oysters are supported by a structure and suspended above the bottom. In shallow water, the framework has been traditionally built of wood, but many leaseholders in Tomales Bay have begun using more durable plastic pipes. For a comparison of various growing techniques, see Iversen (1976), Korringa (1976b, 1976c), Milne (1979), Norgaard (1988), and Yonge (1960).

If intertidal grounds are not available, growing structures can be placed in deeper water. These oyster rigs can be significantly more expensive to construct, maintain, and harvest from than near-shore culture methods. The oysters are suspended on lines or in nets from rafts or buoys. The cultch is attached to a rope or wire and the young oysters grow around the substrate until mature. The animals grown in this way tend to develop faster than their shallow water counterparts due to greater access to nutrients. In deep water, long-line growing structures can cover up to an acre. A series of ropes are tied between large corner buoys and smaller buoys support interconnecting ropes. The growing lines are then suspended from this submerged framework. The non-rigid nature of the long-line structure allows the rig to withstand the roughness of open water conditions. The length of the growing lines are restricted by two factors: (1) oysters do not grow productively in deep waters; and (2) the weight of a line full of mature oysters may sink the structure and is enough to make harvest feasibility a serious consideration. This long-line technique has been used on the East Coast of the United States for years, but at present, only one leaseholder in California (Jeff Young, Pacific Seafood Industries) is experimenting with this technique for oysters.

Currently there are 38 mariculturists holding leases which specify the growing of Pacific oysters (<u>Crassostrea gigas</u>). Of these, 16 are producing oysters commercially, compared to 8 growers in 1973 (Ebert, 1973). The total harvest for 1988 was over 15 million oysters. [Note that the designation "1988" does not refer to the calendar year, but applies to the period starting July 1, 1988 and ending June 30, 1989. This designation was created by the California Department of Fish and Game, and will remain in use throughout the remainder of the report.] The number of state leases increased markedly in 1989 with the issuance of 8 new leases in the Central Coastal segment. Each of these leases will be in effect for 25 years, from 1989 to 2014, and it is expected that many will be used for the culture of Pacific oysters.

Most of the commercial oyster growing historically has taken place in two northern regions of the state: (1) in Humboldt Bay near the city of Arcata, and (2) in Tomales Bay about 40 miles north of San Francisco. Of the 16 leases in California used to raise oysters for sale to the wholesale market, 11 were leased by the State and the remainder by local harbor districts or private landowners. All of the leases in the Humboldt segment are included in the latter category. Of the six leaseholders in the Humboldt segment, three produced a total of 5,546,100 oysters in 1988 (over 37% of statewide production), while another specialized in the raising of seed only. Most of the remaining California oyster production comes from the Central Coastal Segment, including Tomales Bay and Drakes Estero. In all, 10 growers in this region harvested a total of 8,219,129 oysters (56% of the State's output) in 1988. Three remaining leases, in Morro Bay, Santa Barbara, and Mission Bay, accounted for the balance of statewide oyster production (about 7%), with output totalling slightly more than a million oysters annually.

Wholesale prices vary widely with season, size and perceived quality. The price per dozen for Pacific oysters ranges from $3.10 to $4.50, while the price per bushel averages about $38.00 (Estero Oyster Farms, Pacific Mariculture, personal communication). Both prices apply to shucked oysters for the half-shell trade. A conservative estimate of the value of the 1988 harvest is $4 million.

B. <u>Mussels</u>

Mussels are the second major shellfish crop in California. Some consider mussels a pest (e.g., operators of offshore installations and oyster growers), but the worldwide demand for the crop is growing. Traditional European mussel beds have been contaminated, and California growers hope to exploit that export market. Mussels are also filter feeders, but they tend to grow faster than oysters. Therefore, they may not bioconcentrate as much harmful matter as oysters do. Mussels are not as tolerant of temperature variations and drying as are oysters, so they are usually grown in deeper waters. Most mussels in California are grown off-bottom using long-line techniques similar to those used in Italy. In shallow waters such as lagoons, the lines are suspended horizontally near the surface and can reach for more than fifty yards. Birds (e.g., gulls and ducks), fish (e.g., perch), and crabs are the most serious predators for mussels in the shallow waters. In the open ocean the lines are suspended vertically from buoyed structures anchored to float up to 30 feet below the surface. Although many of the shallow water culture techniques mentioned with respect to oysters are applicable to the growing of mussels, there are few growers in California using these methods.

Unlike oysters, mussel seed are obtained from natural spatfalls. Spawning times are not predictable, but usually occur in late spring or early summer. In the warmer waters of Southern California, there are sometimes two spawning seasons. Although spawning does alter the condition of the animal, the crop is still marketable. During spawning, the mussels command less than premium price, but harvesting need not be interrupted as is the case with oysters. The mussel larvae tolerate colder water than oyster larvae, so they can survive up to a month riding the currents of California waters. The best area for reliably intercepting the spat would have slow and predictable currents. The spat will settle most readily to a fibrous substrate, such as a rope or bag suspended in the water, will crawl to a solid object for attachment, and once it has set will grow rapidly. The mussel attaches itself to objects by exuding byssal threads from its foot and can adhere to almost any object (Korringa, 1976a). Mussels reach harvest size (about two inches) in a year to eighteen months. Maintaining the "crop" in a marketable state (characterized by an even size distribution and clean shell) takes considerable effort and expense, especially at deep water sites.

The Santa Barbara Channel has many mussel-bearing oil drilling rigs that fortuitously provide the broodstock for the local mariculturists. However, the weight of a large population of mussels can affect the navigation and stability of a drilling rig. One company -- Ecomar, Inc. -- has a contract with the managers of operating rigs to periodically clean the mussels from the structure. Currently, the timing of harvest is determined by the oil operator and is not based on the size and condition of the mussels. The animals can grow to a large size -- up to six inches in length. There is a limited market at this time for such "giant" animals. Restaurants demand a uniform shell size of 2 to 3 inches. West Coast mussel growers have not entered the processed seafood market to the extent of several companies in the East (e.g., Blue and Gold, Inc.). Therefore, many of the mussels harvested from the oil platforms under current arrangements are discarded. In addition, the shells are often encrusted with barnacles and other fouling agents which consumers find unappealing. Preparing these mussels for market is more expensive than for cultivated mussels. The obvious benefit of the arrangement is that there are no cultivation costs for the mariculture company. The joint production of oil and mussels from the offshore structures is an excellent example of innovative co-development, but improvements in timing could be made to increase profitability for the mariculture firm. Institutional barriers to such mutually beneficial agreements -- e.g., joint management of the location -- need to be removed.

California mariculturists sold 190,193 pounds of mussels in 1988. Although mussels were grown for the wholesale market on ten lease sites, over 90 percent of the State's production (172,867 lbs.) was generated by two highly successful mariculturists: Seafarms West and Ecomar. Seafarms West of Carlsbad (in the San Diego Coastal Segment) leases a five acre site in the Agua Hedionda Lagoon from San Diego Gas and Electric (Smith, 1986). Although the owner-operator, Richard Glenn, has considerable experience with oyster cultivation, he has decided in recent years to focus his attention primarily on the growing of bay mussels (Glenn, 1987). He ships many of the mussels by air immediately after harvest for sale to East Coast buyers. Seafarms West was granted a state deep-water lease in 1990. It is hoped that the expansion of an established and successful company to deep water will be a good test of the viability of such future leases. Ecomar, a Santa Barbara Channel operation with a state lease, but the primary source of harvest for the company is from oil platforms. The actual lease is often used to hold mussels for future sale or for depuration. Ecomar harvests two species of mussels, bay (Mytilus edulis) and Mediterranean (M. Gallo Provincialis). A technological barrier that both firms have had to overcome is the development of an effective means to clean the mussel shells after harvest. Removing barnacles and other substances from the shell is essential for marketing the product to restaurants. Each company uses a machine similar to ones used in Europe but adapted for the thin-shelled species of mussel typically raised in California (Ecomar and Seafarms West, personal communication). [For a brief summary of the potential for culturing a wild, thicker-shelled species, see Yamada and Dunham (1987). For additional information on mussel culture, see Brown (1983), Korringa (1976) and Minchin and Duggan (1989).]

In addition to these two dominant growers, mussel harvests were reported at eight other lease sites in 1988, four of which are located in the Central Coastal segment. The others are scattered throughout the Santa Maria, Santa Barbara Channel, and San Diego Coastal areas. Production from these smaller operations totalled 17,326 pounds, or about 9% of the harvest statewide. Four other leases are being used for experimental mussel cultivation.

The wholesale price of mussels ranges from $.70 per lb. for wild varieties to $1.40 per lb. for premium, "farmed" animals. An average price for cultured bay mussels is $1.29. The value of the 1988 harvest is at least $250,000. We believe, however, that the production figures for 1988 understate the production potential for the industry. Seafarms West expects to at least double its production within a couple of years, by taking advantage of (1) an ever-growing stock, and (2) the economy of scale afforded by their investment in cleaning equipment. The winter of 1988 was uncharacteristically rough in the Santa Barbara Channel, and Ecomar reported heavy losses to their stock that period. It appears that 1989 output will be at least twice the figure for 1988. Assuming that the other eight growers remain in business and maintain their output at current levels, we predict total mussel production of at least 500,000 pounds for the year 1990. If prices remain stable, the value of the 1990 harvest could reach up to three quarters of a million dollars (Ecomar, Seafarms West, personal communication.)

C. Abalone

Abalone, which are large marine snails, are the most difficult animals to produce commercially. They are slow-growing grazers, and, as adults, depend on a diet of giant kelp (Macrocystis pyrifera). A seven-inch abalone -- the minimum size that one can take from the wild legally -- is about 12 years old. The following species grow in the wild off the coast of California: red abalone (Haliotis rufescens), pink abalone (H. corrugata), black abalone (H. cracheroddi), green abalone (H. fulgens) , pinto abalone (H. kamtschatkana), threaded abalone (H. kamtschatkana assimillis), white abalone (H. sorenseni), and flat abalone (H. walallensis) (California Department of Fish and Game, 1980). [Information on the size and distribution of native red abalone in selected areas can be found in California Cooperative Extension (1977), and California Department of Fish and Game (1986 and 1988).] Red abalone (Haliotis rufescens) are the largest and fastest-growing of the eight different species found in U.S. coastal waters, and they are also regarded as one of the best-tasting species. Therefore, red abalone are the focus of extensive research by the University of California (Lynch, 1982) and are thus far the only species being cultured and raised commercially in California waters. The typical animal still grows only about an inch per year, however. This slow growth rate results in a lag between the settlement of abalone larvae (at 4 to 10 days old) and their eventual harvest later (Hooker and Morse, 1985). Such an extended growing period may be unprofitable for abalone cultivators due to high operational expenses.

Recently, one-and-a-half to three-inch animals have been marketed as "cocktail abalone" by growers in Ventura County (in the Santa Barbara Channel Coastal Segment). "White tablecloth" restaurants typically serve them by pounding a three inch abalone into a one-ounce steak, the size of an orange, and serving them four to a plate. Whereas full grown abalone have a wholesale value of $38 per pound, dressed weight, cocktail abalone range from $.75 for a one inch animal to anywhere between $2.00 and $4.50 for the 3 inch size, at wholesale prices (Abalone Unlimited, Pacific Mariculture, personal communication).

Abalone can be cultured by two methods. The first method uses land-based facilities throughout the life of the abalone while in the second method the abalone are released to the natural environment after initial cultivation in a tank. A land-based facility is connected to a sea water source through a system of inflow pipes, filters, outflow pipes and electric pumps. Raising the animals in tanks allows constant monitoring and treatment of the water to prevent bacteria and viruses from threatening the health of the abalone. During the early stages of growth, the abalone are fed diatoms and microalgae. At about six months old they are weaned to macroalgal species such as <u>Egregia</u> (feather boa kelp) and <u>Macrocystis pyrifera</u> (giant kelp). At that time, they are kept at specific densities and repositioned as little as possible, since the mortality due to handling can be as high as 30 percent. Water quality deterioration brought about by surface water pollution is of little concern using this method, since water intake pipes are often positioned 60 feet or more below the ocean surface. Bacteria can be filtered from the water before it reaches the tanks. Research is being conducted to ascertain whether constituents of drilling muds and produced water would be removed using current filtration methods. The biological effects of drilling discharges on abalone is also being studied. As abalone are not filter feeders, as are oysters and mussels, the public health problems associated with coliform bacteria and the bioaccumulation of contaminants are believed to be less for abalone than for shellfish.

The advantages of cultivating abalone in tanks include the ease of monitoring the animals and control over the water supply. The problems of predation by sea otters (Enhydra lutris) and competition with sea urchins (Strongylocentrotus franciscus) for a limited food source are eliminated. However, this method is both capital- and labor-intensive. Start-up costs include acquiring land close to a source of sea water and financing the purchase of a tank and pumping system. Maintaining the operation is also quite expensive, as it requires constant supervision and feeding of the animals, energy to run the pumping system, and periodic monitoring of water quality. The annual expenses must be covered for many years while the "crop" grows to marketable size. These costs have thus far limited profits in the industry to a few established mariculturists.

The alternative to raising abalone in tanks throughout their lifetime is an approach called "ocean ranching" (Hooker and Morse, 1985). Ocean ranching has been practiced for decades in the cultivation of certain species of anadromous finfish, like salmon and steelhead, which return to their original release site each year to spawn. [See Bjorndal (1988) for an economic model of the optimal harvest decision for ranched, or "farmed," salmon and turbot.] For abalone culture, growers raise young animals in tanks from seed until they have been weaned to kelp, at which time they are transplanted to the ocean floor. This process avoids the costly maintenance associated with several years of feeding and housing adult animals until harvest. The chief drawback is that although abalone migration is limited to a narrow area surrounding the release site, animals left in the wild are subject to predation and must compete for kelp with other species, especially the sea urchin. Mariculturists in Japan have had greater commercial success with the sea ranching of abalone when the ranch site has first been cleared of most predators and competitors prior to the release of the abalone (Hooker and Morse, 1985). Predation by human poachers may also become a problem as natural populations of abalone become more scarce and the price for the animals remains high. Ocean ranching as an alternative, or supplement, to tank systems is currently in the experimental stage in California, but shows considerable promise. However, the large number of protected sea otters in the waters off the central and northern California coast preclude any type of ocean ranching in those areas.

It is unknown what effect byproducts of oil production have on the growth rate and overall health of abalone. Nine years ago John Perkins of Abalone Unlimited raised 5,000 red abalone, ranging in size from 1 to 3 inches, beneath Arco's oil drilling platform Holly. Although many of the animals and part of the surrounding kelp beds were often coated with crude oil, he reported that the exposure to the oil had no apparent adverse effects on the health of the abalone (Perkins, personal communication). Other growers argue that reliable data on the long-term effects on abalone of exposure to crude oil, as well as to produced waters and drilling muds, is inadequate. They maintain that it is extremely difficult to filter heavy metals from the sea water intake. In addition, there is concern that even if the abalone themselves may be protected by careful positioning of water intake pipes, filter systems, and pump shut-offs in emergency situations, the animals may still be exposed to potentially harmful levels of hydrocarbons through contamination of their food sources (The Abalone Farm, Abalone Unlimited, and McCormick and Associates, personal communication). Kelp productivity may be affected by oil and gas drilling discharges thus jeopardizing the supply of food for abalone. In addition, petroleum-related contamination of kelp may affect abalone health directly.

Currently, all commercial, and most experimental, abalone culture operations are limited to three areas. There is one lease holder raising abalone for commercial sale near Santa Cruz, in the Central Coastal Segment. However, most of the annual harvest comes from leases far to the south, with about half of the State's production generated at three Santa Maria Basin lease sites and over a third from three lease holders in the Santa Barbara Channel Segment. The annual production of adult abalone, ranging in size from 1.5 to 5 inches, is just over 1.1 million animals, in addition to a significant number of seed abalone raised at the Ab Lab (Santa Barbara Channel Coastal Segment). Prices vary considerably with season and size of the abalone, so an exact measure of the value of the industry is impossible. Assuming that most animals are harvested when they reach "restaurant size," about 2-3 inches, a conservative estimate of the yearly wholesale value of the product is $2.2 million. However, this figure could be revised upwards to over $5 million, depending on price and size.

The future of the abalone industry seems quite promising at this time. Certain factors have resulted in a reduction in the stock of wild abalone available for harvest by commercial divers. These include a thriving population of sea otters, which break open the shell of various species of abalone using rocks as primitive "tools," (Cicin-Sain et al., 1982), and the over-harvesting of wild populations of valuable abalone by commercial and recreational divers (Santa Barbara Mariculture Foundation, 1975). At the same time, demand for abalone is increasing, especially as the small "restaurant size" animals become more popular with consumers. Such an increase in demand, coupled with a reduction in the supply of wild abalone, has caused an increase in price and created an incentive for local entrepreneurs to enter this infant industry. In expectation of future profits, most current abalone growers are now tending stocks of young abalone that are much larger than current production figures might suggest. For example, one lease holder in the Santa Maria Basin Segment harvested only 60,000 red abalone last year, but maintains an inventory of one-and-a-half million more animals which he expects to put on the market in the next couple of years. In addition to increased output from existing commercial growers, production will probably be expanded to a number of experimental leases located in the Central, Santa Maria Basin, Santa Barbara, and San Diego Coastal segments.

D. Industry Summary

The California mariculture industry is relatively small compared to other portions of the agricultural sector. Revenues for cultured shellfish in 1988 were only about $6.5 million while total crop receipts in California were $12 billion that year. More than 50 individual agricultural crops had a higher market value than cultured oysters, mussels, and abalone combined (U.S. Department of Agriculture, 1989). The future for a healthy mariculture industry will depend on the availability of high quality water and suitable growing locations. Additional shallow water sites in bays, estuaries, and lagoons are scarce, so industry expansion may have to take place in deeper water. Demand for shellfish and other marine products will continue to grow and it is likely that many natural populations will decline. Further development of the mariculture industry will help to alleviate the excess demand for seafood. Both technical and institutional constraints will have to be overcome, however, before such development can be realized.

IV. CO-DEVELOPMENT MODEL

There are many pathways that chronic effects of oil and gas development on the mariculture industry might take, and those effects may differ markedly between species and even between life cycles of a single species. With abalone, for instance, drilling discharge might affect sperm production or larval development. More indirectly, contamination of kelp beds might destroy the primary food source for adult abalone. Filter-feeding bivalves may bioconcentrate some constituents of drilling wastes while depurating others. Any change in the food chain either above or below the commercial species will affect the population of that animal and hence affect profitability. The complexity of all of the possible permutations of the effects of oil production on marine species makes predicting economic consequences difficult. However, economists can make predictions if they have certain scientific information. In this section of the report, a theoretical model is presented to address the second project objective -- to suggest the scientific information necessary to assess the economic consequences to the California mariculture industry of chronic exposure to oil and gas development.

In the past, resource development has tended to favor a single use. When resources are plentiful, dedicating areas to the "highest and best use" will not cause many conflicts. Coastal areas suitable for development are becoming increasingly scarce. There are many valuable uses for society's resources and some of these uses have negative impacts on others. State and federal agencies as stewards of these resources must devise development schemes to jointly maximize the value of the United States' natural assets (optimal co-development).

The potential for the joint production of oil and mariculture products is the example that is discussed in this report, but the theoretical framework can be used to assess the tradeoffs inherent in any co-development plan. Currently, oil lease areas are not jointly leased for mariculture. If potential operational or safety conflicts such as support boat and fire-fighting access are adequately addressed, there may be no reason why the offshore area could not be co-developed to maximize the joint value of oil and mariculture assets.

The following discussion reviews the economic theory of externalities and shows the benefits of government action as compared to allowing the "free market" to work. In addition, the placement of mariculture leases as a function of distance from oil and gas development is discussed.

A. External Effects

Any chronic or acute effects of oil production on commercial mariculture species will be reflected in the costs of operation. "Externalities" occur when the actions of one economic agent unintentionally affect the utility or production possibilities of another economic agent and the latter is not compensated for the damage or benefits (Mills and Graves, 1986, p. 32). The costs of operation will reflect any chronic or acute effects of oil production on commercial mariculture species. The costs of a mariculture operation would decrease if oil development had a positive external effect on commercial mariculture species. For instance, if mussels grew more quickly in the presence of hydrocarbons, then the profitability of the mariculture enterprise would increase. The analysis works just as well for this case, but the following analysis assumes that oil development imposes a negative externality on mariculture. If biomass is reduced either through reduced size per animal or through fewer animals, then the cost of achieving any production level will increase. One may have to grow animals for a longer period or expand the size of the growing area so as to achieve output goals. Production costs may be affected directly. For instance, one may have to depurate shellfish in purified water after harvest so as to cleanse them of contamination, and this will increase costs. Or, produced water contamination might harm oysters cultivated on the bottom sediments more than oysters grown on suspended trays, which are more expensive.

For this hypothetical analysis, assume that two "firms" exist in an area. The first produces oil and is not directly affected by other resource uses. The second firm is a mariculture enterprise that grows a species sensitive to oil drilling wastes. Oil production negatively affects the production of the species, but that negative effect declines with the distance from the effluent outfall. Therefore, the costs of the mariculture firm are positively related to the level of oil production and negatively related to the distance from the source of the externality.

In a free market (competitive) situation in which one does not consider externalities, the oil producer would choose the quantity of production Q_o to maximize the firm's profits. Profits for the oil firm are

$$\Pi_o = P_o\, Q_o - C_o(Q_o) \qquad [1]$$

where P_o is the market price of oil and $C_o(Q_o)$ is the cost of producing Q_o. We assume that the market price accurately reflects the benefits to society of that oil. Profits are maximized when production equals Q_o^* where the benefits to be gained from an additional unit of production is equal to the cost of producing that unit. This marginal efficiency condition is

$$P_o = \partial C_o(Q_o^*)/\partial Q_o \qquad [2]$$

where $\partial C_o(Q_o^*)/\partial Q_o$ is the private marginal cost of production -- i.e., the additional cost to the petroleum firm of producing one more unit of oil. We assume that standard economic conditions hold -- that marginal costs are positive and increasing with output.

The mariculture firm has costs that are positively affected by oil production. That firm would choose the production level Q_m to maximize profits, but, in this case, profits are directly related to the level of oil production over which the mariculturist has no control. Profits for a mariculture firm that can be earned when a negative externality is imposed are

$$\Pi_m = P_m Q_m - C_m(Q_m, Q_o) \qquad [3]$$

where P_m is the market price of the mariculture product and $C_m(Q_m, Q_o)$ is the cost for the mariculture firm of producing Q_m given that the oil firm produces Q_o. The firm faces a different cost function for each level of oil production. When profits are maximized, the marginal efficiency condition for the mariculture firm is to produce where

$$P_m = \partial C_m(Q_m^*, Q_o)/\partial Q_m. \qquad [4]$$

$\partial C_m(Q_m, Q_o)/\partial Q_m$ is the private marginal cost to the mariculture enterprise for producing Q_m, but the firm faces a different private marginal cost curve for each level of oil production. Since mariculture costs will increase as more oil is produced for a negative externality [$\partial C_m(Q_m, Q_o)/\partial Q_o > 0$], the more oil that is produced, the less mariculture output will be forthcoming. Figure 1 shows a hypothetical marginal cost structure where the lowest costs are associated with no oil production. The graph is presented to illustrate the conceptual framework and is not meant to imply an order of magnitude. The free market solution is shown as the highest cost curve where the optimal level of mariculture production (Q_m^*) depends on the independent decision of the oil producer (Q_o^*) who maximizes his or her firm's profits without considering the impact of oil production on the mariculture firm.

In the theory of welfare economics, one finds the optimal allocation of resources when an externality is present by maximizing the aggregate (joint) profits of the firms (Mills and Graves, 1986). Both firms (or industries) produce goods that are valued by society, so society as a whole would be best off if joint resource profits were maximized. One would obtain the same solution if a single profit-maximizing enterprise directed both oil production and mariculture. Formally, the objective to society is to

$$\text{Max } [\ P_o\ Q_o + P_m\ Q_m - C_o(Q_o) - C_m(Q_m,\ Q_o)\ ]. \qquad [5]$$

The first order conditions of this maximization problem are

$$P_o = \partial C_o(Q_o^{**})/\partial Q_o + \partial C_m(Q_m^{**},\ Q_o^{**})/\partial Q_o \qquad [6]$$

and

$$P_m = \partial C_m(Q_m^{**},\ Q_o^{**})/\partial Q_m \qquad [7]$$

which must be solved simultaneously to obtain the level of production for both resources, Q_o^{**} and Q_m^{**}, that will maximize social profits. As described above, $\partial C_m(Q_m, Q_o)/\partial Q_o$ is the addition to costs for the mariculture firm that results from more oil being produced. This is the external cost imposed on the mariculture firm by oil development. The marginal efficiency condition would be to choose the level of oil output such that the benefit (P_o) of producing the last unit equals the social marginal cost of that unit. The entire right-hand side of equation [6] represents the social marginal costs of producing oil. The social marginal costs include the private marginal costs of operation for the oil company plus any external costs imposed on mariculture. The external costs are "internalized" through the maximization procedure. By comparing equations [2] and [6], it can be seen less oil would be produced when one accounts for externalities since marginal costs are positive and are increasing with output -- i.e., $Q_o^{**} < Q_o^{*}$ because $\partial C_o(Q_o^{**})/\partial Q_o < \partial C_o(Q_o^{*})/\partial Q_o$. Figure 2 graphically depicts a hypothetical private and social marginal cost structure for the oil producer. The amount of oil production when external effects are ignored (Q_o^{*}) is chosen when oil price equals the private marginal cost of production. The optimal production (Q_o^{**}) is chosen when price equals the social marginal cost.

Equations [4] and [7] for the mariculture firm are the same in that the level of production is chosen such that the price is equal to the private marginal costs of producing the good. In the joint maximization, the level of oil production is less, so the output of the mariculture firm would be more. Figure 1 depicts the marginal costs of producing mariculture products for several levels of oil production and shows how the socially optimal level of mariculture production would be chosen at the intersection of price and the marginal cost curve associated with the level of oil production at which the external effects are internalized (Q_o^{**}). In the absence of internalization, "too much" oil is produced and "too little" mariculture is produced.

much" oil is produced and "too little" mariculture is produced. The private profits for the oil producer would be less and the private profits for the mariculturist would be more at this optimum than in the free market case. The social (i.e., combined) profits would be equal or higher (they will be the same if the external cost is zero). Government intervention to achieve the optimal co-production would lead to more efficient resource development as long as the costs to achieve such levels did not outweigh the net benefits.

One may never eliminate the external effects of energy development on mariculture, but one would reduce the effects to the level most favorable to society -- at the point that would jointly maximize the profits of both valuable enterprises. To choose the optimal levels of oil and mariculture development, both public and private decision makers must know the characteristics of the external effect $[\partial C_m(Q_m, Q_o)/\partial Q_m]$. If the scientist can quantify the effect of contamination on the animal -- e.g., the growth rate of oysters decreased by 30 percent -- then one can estimate the increase in costs. If the government wanted to internalize the negative external effects of petroleum development on the mariculture industry, then it could impose a tax on harmful effluents. For economic efficiency, the government should base the tax on actual external costs so that the oil producing firm would face costs (actual charges plus taxes) that equal the true social cost of oil production. The oil producer could reduce effluents by reducing production or by installing abatement equipment and paying the tax on the residual. The oil producing firm would choose the least-cost way of reaching the optimal level of petroleum output. The mariculture firm would choose its production level based on the optimal production of oil.

B. Spatial Variation

The analysis of external effects has assumed that each firm is spatially fixed. In reality, one can choose lease and production sites. The mariculture firm's profits will be positively related to its distance from the effluent discharge, but profits will increase at a decreasing rate with distance. Of course, distance is not the only factor of concern in the marine environment. Current, temperature, depth, and other factors also will determine the external effects on mariculture species. The analysis here assumes that one can include these characteristics within a linear index, but for simplicity, refer to this as distance. The magnitude of the effects also will differ depending on the species. For cultivated abalone, the location of the saltwater intake pipe would be the variable of interest since most growing tanks will be land based. In addition, oil

Once the external effect to the commercial species is known, one can calculate optimal production levels as described above) and subsequent profits for each distance. Firms growing different species or choosing among species will pick the activity making the highest profit at any location. This form of sequential decision making -- i.e., finding the profit maximizing output level for each activity and then choosing the activity that yields the highest profits -- is known as "putty-clay" since the first-stage decision is changeable during the production cycle while the second-stage decision is not (Just et al., 1980). Among firms, the one making the highest profit at any point would be able to outbid the other at that location. If the government was leasing the tract without bids, the agency would want to grant the lease for the most valued use. This analysis could also be applied to leasing near municipal sewage outfalls once the marginal effects of the effluents on commercial species and the relationship between the magnitude of the effects and distance were known. Cumulative impacts of both sewage and oil development effluents is not discussed here, but may be significant.

Species specific restrictions may be optimal when allocating leases for joint uses. Figure 3 shows an example in which the distance from the oil-producing unit influences the per acre profits for two mariculture firms. More than two species can be included in the analysis, but the number was limited here for notational ease. The figure assumes that the optimal level of oil production already has been chosen according to the socially optimal criteria described above. For the firm growing one species -- e.g., Pacific oysters -- profits (Π_{m1}) increase rapidly. In this example, profits for the second firm (Π_{m2}) which grows a species such as bay mussels are less affected by distance -- i.e., $\partial\Pi_{m1}/\partial d \geq \partial\Pi_{m2}/\partial d \;\; \forall \;\; d$, where d denotes distance. This scenario was chosen arbitrarily, and one would have to test the actual effect on profits for each species. The point d* is the "switching distance," and it represents the point at which profits for the two firms are equal. Formally,

$$\Pi_{m1}(d^*) > \Pi_{m2}(d^*) \quad \text{when } d > d^*,$$

$$\Pi_{m1}(d^*) = \Pi_{m2}(d^*) \quad \text{when } d = d^*,$$

and

$$\Pi_{m1}(d^*) < \Pi_{m2}(d^*) \quad \text{when } d < d^*.$$

Other distances of note are the d^0_is which are the zero profit levels -- i.e., $\Pi_{m1}(d^0_1) = 0$ and $\Pi_{m2}(d^0_2) = 0$. As illustrated in Figure 3, there may be a range of distances for which mariculture would not be profitable (0 to d^0_2. This may not be the case for a species such as mussels that appear to thrive in proximity to oil production. For distances from d^0_2 to d*, social profits would not be profitable (0 to d^0_2. This may not be the case for a species such as mussels that appear to thrive in proximity to oil production. For distances from d^0_2 to d*, social profits (welfare) would be the highest if the firm growing the least sensitive species (#2) locate in this range. The other mariculture firm would be more profitable at distances further than d*. From d^0_2 to d^0_1, only firms producing the least sensitive species would be able to make a profit. The more sensitive species would yield a profit at distances from d^0_1 to d^*, but growing the other species would be more profitable. The opposite is true for distances greater than the switching one -- both species would be profitable to grow, but species #1 would yield the highest profit.

The analysis above was based on fixed prices and costs. Changes in these economic parameters will affect the level of profitability and the optimal distances. When product price increases, profits will increase and profits will decline when input costs increase -- i.e., $\partial\Pi_{mi}/\partial P_{mi} > 0$ and $\partial\Pi_{mi}/\partial C_{mi} < 0$. The zero profit distance d^0 for a firm will decrease when the price of that firm's product increases and d^0 will increase as costs for growing that product increase -- i.e., $\partial d^0_i/\partial P_{mi} < 0$ and $\partial d^0_i/\partial C_{mi} > 0$. The switching distance (the optimal lease boundary) will also be affected by changes in the economic parameters. If the output price (input cost) of species #1 increases, the switching distance will decrease (increase). The opposite will occur if the conditions change for species #2. Formally,

$$\partial d^*/\partial P_{m1} < 0,\ \partial d^*/\partial C_{m1} > 0,\ \partial d^*/\partial P_{m2} > 0, \text{ and } \partial d^*/\partial C_{m2} < 0.$$

Depending on forecasts for industry prices, lease boundaries could be designated to preserve flexibility. For instance, if demand is predicted to be increasing for a species over time, the optimal extent of the lease area might be greater than what would be warranted by current profit conditions.

One could base the design of an optimal co-development leasing scheme on this type of analysis. Firms with perfect information also would choose the following outcome. For instance, no mariculture leases would be considered in the area from the effluent source (0) to d^0_2. Leases for a particular species -- e.g., mussels -- would be granted at distances between d^0_2 and d*, and oyster growers might dominate farther away.

As noted above, if mariculture leases were granted to the highest bidder, the most profitable use of the resource would prevail. The only reason to restrict lease locations would be for public safety. For instance, if it was found that a commercial mariculture species bioaccumulated harmful constituents of drilling muds, animals grown in certain locations might pose a health threat even though they could be profitably grown. Despite public concern for food safety, only 11% of the fish and shellfish sold in the United States is subject to voluntary federal inspection. Current regulations require periodic meat sampling from shellfish beds, but the primary concern is for coliform and pesticide contamination (the main threats to shellfish production at this time). If certain areas were deemed to pose a potential problem, the relevant mariculture leasing agency could restrict leasing in that area while opening other areas for production.

The scientific information one would need to establish the optimal location of the lease is the relationship between the magnitude of the negative external effect and distance. Once one has quantified that physical connection, then one can estimate the spatial characteristics for profits and determine the lease boundaries. If the government wishes to internalize the external cost through imposing effluent taxes on oil producers, then it should base such a policy on the locational variation of the externalities.

V. CONCLUSION

Valuable coastal resources are becoming increasingly scarce. Single-use development can be wasteful and may lead to unproductive conflicts among resource users. External effects may exist between uses, and one should not ignore such effects when designing a co-development scheme. This report has discussed the possible chronic effects of oil and gas development on the growing mariculture industry. Current and likely conditions for the California mariculture industry also were included. The report has presented a theoretical model of economic externalities showing the parameters one must estimate before designing a joint lease development plan.

The California mariculture industry is not large currently. There are 66 leases totalling almost 5,000 acres, but prime shallow water growing sites are becoming increasingly scarce. Deep water production is being tried on an experimental basis and there are plans to expand the coastal leasing program. Since much of the California coastline has been divided into oil and gas leasing tracts, leasing expansion for mariculture may require cooperative arrangements between oil and gas interests and the mariculture industry. State and federal agencies could facilitate co-development schemes in order to maximize the net return on society's coastal resources.

The greatest California mariculture revenues are earned by oyster growers. The annual production of 15 million oysters has a value of around $4 million. Although only 1.1 million cultivated abalone were sold, they had a value of $2.2 million. Mussels are a relatively low value product, so production was only about 190,000 pounds earning a revenue of $250,000. No other species are currently being produced in significant market quantities. In total, the California mariculture industry earns revenues of about $6.5 million. If current expansion plans are realized, the value of the industry would double by the year 2000. To put the value of the mariculture industry in perspective, however, the values of more than 50 agricultural crops in California are significantly greater than the revenue earnings of cultivated oysters, mussels, and abalone combined. Annual revenues from offshore oil and gas development probably far outweigh the current and future earnings potential for mariculture, but precluding the latter industry from oil leasing areas based on the lesser value might be wasteful.

One must assess the marginal effect of oil production effluents -- e.g., hydrocarbons, drilling muds, and produced water -- on the production function for each important commercially harvested marine species so as to estimate the marginal effect of the effluents on mariculture costs. In addition, one must evaluate the way the effects are moderated by distance so as to establish the optimal location of the lease from any effluent discharge. Future analyses must include the concomitant effects of municipal and agricultural pollution loads. Interdisciplinary cooperation is essential for designing a leasing or allocation scheme that maximizes the social welfare gained from developing multiple costal resources.

FIGURE 1
Marginal Costs of Producing Mariculture Products
for Several Levels of Oil Production

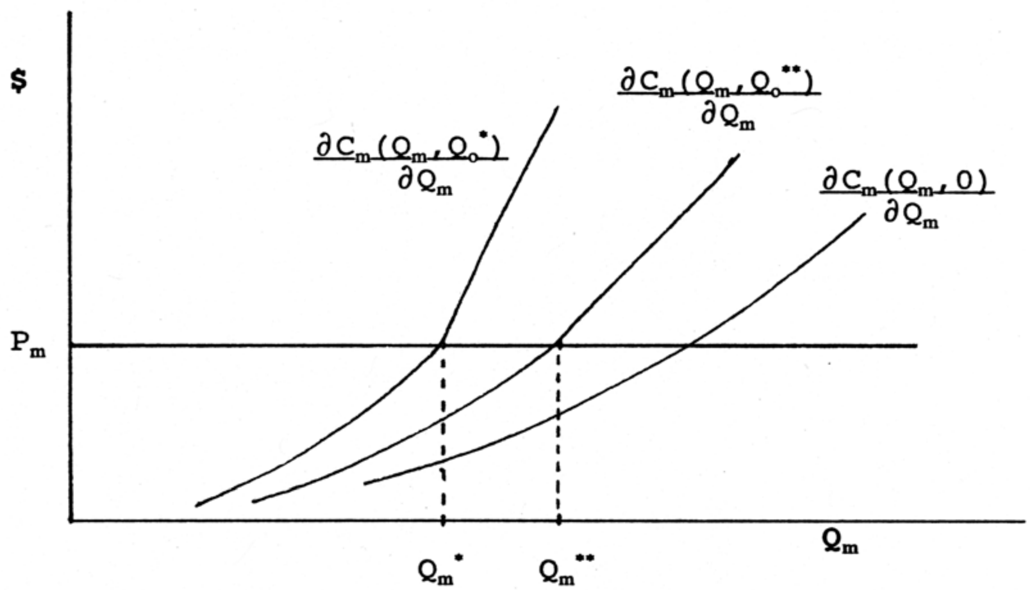


FIGURE 2
Private and Social Marginal Costs
for Producing Oil

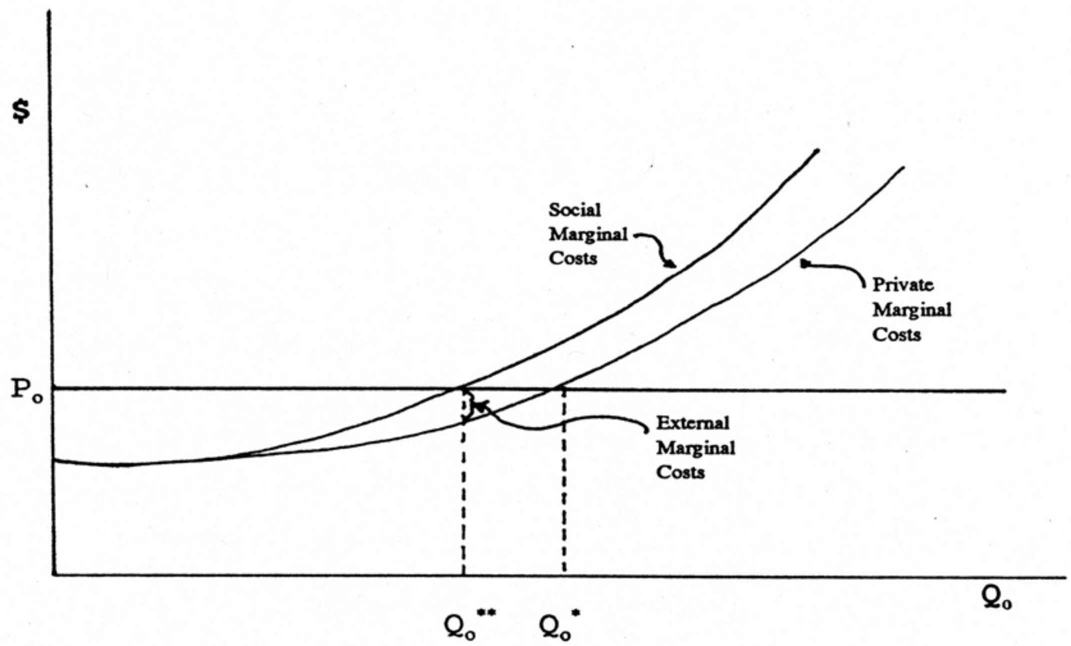
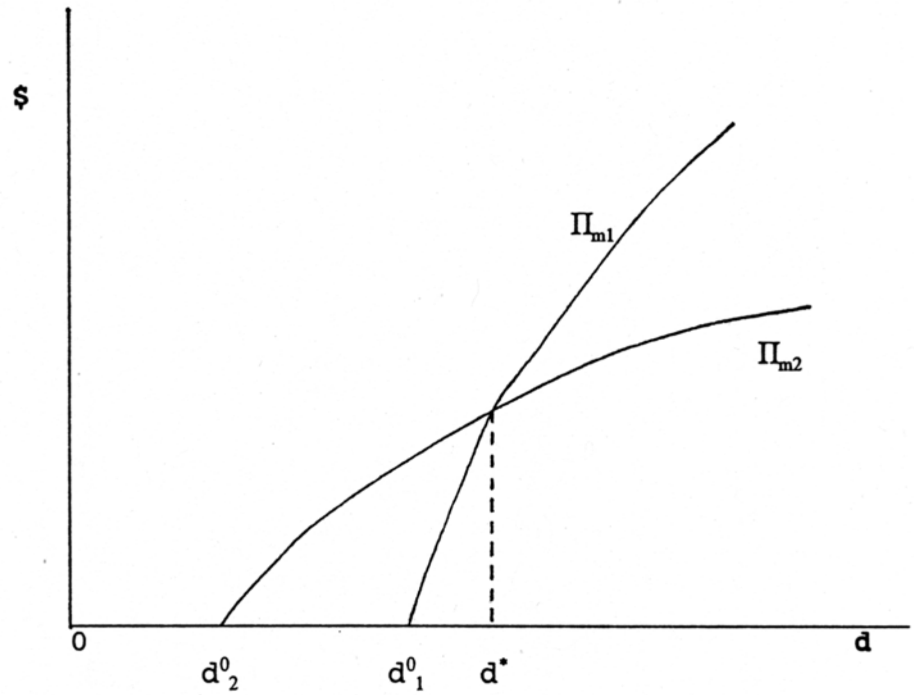


FIGURE 3
Profits from Mariculture Leasing
as a Function of the Distance from Oil Production Effluents.



REFERENCES

Ambrose, Richard F., Daniel C. Reed, John M. Engle, and Margriet F. Caswell, California Comprehensive Offshore Resource Study: Summary of Biological Resources, submitted to the California State Lands Commission by the Coastal Research Center, Marine Science Institute, University of California Santa Barbara, 1989.

Berck, Peter and Jeffrey Perloff, "The Commons as a Natural Barrier to Entry: Why There Are so Few Fish Farms." American Journal of Agricultural Economics, v. 67, May 1985, p. 360-363.

Bjorndal, Trond, "Optimal Harvesting of Farmed Fish," Marine Resource Economics, v. 5, n. 2, 1988, p. 139-159.

Brown, Evan E., World Fish Farming: Cultivation and Economics, Second Edition, AVI Publishing, Westport, Connecticut, 1983.

Brown, Lester R., "Maintaining World Fisheries," State of the World - 1985, W. W. Norton & Co., 1985.

California Cooperative Extension, The Value of an Abalone Industry to San Luis Obispo, Santa Barbara, and Ventura Counties, Misc. Publication, 1977.

California Department of Fish and Game, Atlas of California Coastal Marine Resources, Misc. Publication, Sacramento, 1980.

_________, Densities and Size Compositions of Red Abalone (Haliotis rufescens) at Five Locations on the Mendocino and Sonoma County Coasts, September 1986, Marine Resources Technical Report no. 88-5, Sacramento, 1988.

_________, Red Abalone Size Data From Johnsons Lee, Santa Rosa Island,From 1978 to 1984, Marine Resources Technical Report no. 53, Sacramento, 1986.

California Interagency Committee for Aquaculture Development, A Guide to California State Permits, Licenses, Laws and Regulations, Affecting California's Aquaculture Industry, Sacramento, 1988.

California Water Resources Control Board, California Ocean Plan: Water Quality Control Plan, Ocean Waters of California, Sacramento, 1988a.

_________, Marine Bioassay Project, Third Report, Protocol Development: Reference Toxicant and Initial Complex Effluent Testing, Sacramento, 1988b.

Cicin-Sain, Biliana, Phyllis M. Grifman, and John B. Richards, Social Science Perspectives on Managing Conflicts Between Marine Mammals and Fisheries, Proceedings From a Conference on Management of Sea Otters and Shellfish Fisheries in California, University of California Cooperative Extension, 1982.

Ebert, Earl E. and J. L. Houk, "Elements and Innovations in the Cultivation of Red Abalone (Haliotis rufescens)," Aquaculture, v. 39, 375-392, 1984.

Ebert, Earl E., Mariculture in California, Marine Resources Technical Report no. 18, California Department of Fish and Game, Sacramento 1973.

Glenn, Richard, "European Techniques of Oyster and Mussel Farming Applied to a Southern California Coastal Lagoon," in West Coast Mollusc Culture: A Present and Future Perspective, Proceedings of a California Sea Grant Workshop in Cooperation with the Pacific Sea Grant College Program, Rosemary Amidei, ed., University of California, Berkeley, 1988.

Hooker, Neal and Daniel E. Morse, "Abalone: The Emerging Development of Commercial Cultivation in the United States," in Crustacean and Mollusk Aquaculture in the United States, Jay V. Huner and E. Evan Brown, eds., Van Nostrand Reinhold, New York, 1985.

Huguenin, John E. and John Colt, Design and Operating Guide for Aquaculture Seawater Systems, Elsevier, New York, 1989.

International Council for the Exploration of the Sea, Report of the Ad Hoc Study Group on Environmental Impact of Mariculture, 1988.

Iversen, E. S., Farming the Edge of the Sea, Second Edition, Whitefriars Press, London, 1976.

Johnson, Ronald N., "Commercial Wild Species Rearing: Competing Groups and Regulation," Journal of Environmental Economics and Management, v. 19, September 1990, p. 127-142.

Just, Richard E., David Zilberman and Gordon C. Rausser, "A Putty-Clay Approach to the Distributional Effects of a New Technology Under Risk," in Operations Research in Agriculture and Water Resources, D. Yaron and C. Tapiero, eds., North-Holland Publishing, 1980.

Kanter, Robert, Susceptibility to Crude Oil With Respect to Size, Season, and Geographical Location in Mytilus Californianus (Mussels), USC-SG-4-74, Sea Grant, University of Southern California, 1974.

Korringa, P., Farming Marine Organisms Low in the Food Chain: A Multidisciplinary Approach to Edible Seaweed, Mussel and Clam Production, Elsevier, New York, 1976a.

_________, Farming the Flat Oysters of the Genus Ostrea: A Multidisciplinary Approach, Elsevier, New York, 1976b.

_________, Farming the Cupped Oysters of the Genus Crassostrea: A Multidisciplinary Treatise, Elsevier, New York, 1976c.

LaBelle, R. P., Oil Spill Risk: Aspects of Assessment and Perception, Minerals Management Service, Pacific OCS Region, Information Transfer Meeting, 1989.

Lynch, Teresa, "Award-Winning Research Team Continues Advances in Mollusk Culture Techniques," Aquaculture Magazine, September-October, 1982.

Magoon, Charles, "Introduction to Shellfish Aquaculture in the Puget Sound Region," Division of Marine Land Management, Department of Natural Resources, State of Washington, 1985.

McConnell, Kenneth E. and Ivar E. Strand, "Benefits from Commercial Fisheries When Demand and Supply Depend on Water Quality," Journal of Environmental Economics and Management, v. 17, 284-292, 1989.

Mills, Edwin S. and Philip E. Graves, The Economics of Environmental Quality, Second Edition, W. W. Norton and Co., Inc., New York, 1986.

Milne, P. H., Fish and Shellfish Farming in Coastal Waters, Whitefriars Press, London, 1972, reprinted 1979.

Minchin, D. and C. B. Duggan, "Biological Control of the Mussel in Shellfish Culture," Aquaculture, v. 81, n. 1, 97-100, 1989.

National Research Council, Drilling Discharges in the Marine Environment, National Academy Press, Washington, D.C., 1983.

_________, Oil in the Sea: Inputs, Fates and Effects, National Academy Press, Washington, D.C., 1985.

Neff, J. M., N. N. Rabalais, and D. F. Boesch, "Offshore Oil and Gas Development Activities Potentially Causing Long-Term Environmental Effects, " in Long-Term Environmental Effects of Offshore Oil and Gas Development, D. F. Boesch and N. N. Rabalais, eds., Elsevier Applied Science, New York, 1987.

Norgaard, Richard B., "The Oyster Beds of Ao Ban Don," Land Economics, v. 64, n. 1, 83, 1988.

[OECD] Organization for Economic Cooperation and Development, Aquaculture: Developing a New Industry, Washington, D.C., 1989.

Pauley, Gilbert B., Birgitta Van Der Rey and David Troutt, Pacific Oyster: Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest), Biological Report no. 82 (11.85), US Department of the Interior, Fish and Wildlife Service, Washington Cooperative Fishery Unit, University of Washington, 1988.

Santa Barbara Mariculture Foundation, Proposal for the Development of a Mariculture Facility at the Ellwood Pier, Santa Barbara County Park Commission, 1975.

Smith, Gordon, "Aquaculture Musseling in on Wild Mollusks," Los Angeles Times, December 14, 1986.

Spies, R. B. and P. H. Davis, "Toxicity of Santa Barbara Seep Oil to Starfish Embryos: Part 3 - Influence of Parental Exposure and the Effect of Other Crude Oils," Marine Environmental Research, v. 6, 3-11, 1982.

Straughan, Dale, Analysis of Mussel (Mytilus Californianus) Communities in Areas Chronically Exposed to Natural Oil Seepage, American Petroleum Institute, Washington, D.C., 1980.

Teal, J. M. and R. W. Howarth, "Oil Spill Studies: A Review of Ecological Effects," Environmental Management, v. 8, 27-44, 1984.

[UN-FAO] United Nations Food and Agriculture Organization, Economic Aspects of the Effects of Pollution on the Marine and Anadromous Fisheries of the Western USA, no. 162, 1976.

__________, 1983 Yearbook of Fisheries Statistics, 1983.

U.S. Committee on Merchant Marine and Fisheries, Coastal Waters in Jeopardy: Reversing the Decline and Protecting America's Coastal Resources, US Government Printing Office, Washington, D.C., 1988.

U.S. Department of Agriculture, Economic Indicators of the Farm Sector: State Financial Summary, 1988, Economic Research Service, Washington, D.C., 1989.

Yamada, Sylvia B. and J. Dunham, "Mytilus Californianus: A New Aquaculture Species?," in Program / Abstracts, Western Society of Naturalists Convention at California State University at Long Beach, Dec 26-30, 1987.

Yonge, C. M., Oysters, Collins, London, 1960.

APPENDIX I
MARICULTURE LEASES IN CALIFORNIA

The identification numbers listed for each lease below (ID #) can be used to locate the lease on the maps shown in Appendix II. Registration numbers are those assigned by the California Department of Fish and Game (DF&G) to identify all registered aquaculturists in California. The lease grantor may be a local government, private landowner, or the State. State leases are designated by the letter M, followed by a three digit number used to identify the DF&G Fishery areas, and a two digit number representing the lease holder. In addition, the duration of each state lease is reported below the lease number when available. The number of acres contained in the lease site has been rounded to the nearest integer. Commercial production is identified by species and indicated as follows:

BM = Bay Mussels (Mytilus edulis)
MM = Mediterranean Mussels (M. gallo provincialis)
PO = Pacific Oysters (Crassostrea gigas)
RA = Red abalone (Haliotis rufescens)

Non-commercial (experimental) production is indicated as "Exp:", and followed by the names of the species. NP indicates no production, "New" denotes state leases issued in 1989, and NA refers to information not available at this time. All leases have been grouped into six geographical areas, or segments, which are ordered from north to south (See Figure 1 in Appendix II). This table is adapted from Ambrose et. al. (1989) and supplemented with information obtained from our survey of registered mariculturists.

ID #	Registration #	Lease Grantor	Lease Holder	Acres	Production
			Humboldt Segment		
1	00525	Private	Sea Harvest Shellfish	NA	PO
2	00329	City of Arcata	Arcata Wasterwater Aquaculture Project	2	Exp: PO, Salmon
3	00091	Humboldt Conservation District	Northbay Shellfish	349	PO, Exp: BM

ID #	Regis-tration #	Lease Grantor	Lease Holder	Acres	Production
		Humboldt Segment (continued)			
4	00103	Humboldt Conservation District	Coast Oyster Co.	1,744	PO
5	00134	Humboldt Conservation District	Kuiper Mariculture, Inc.	NA	Seed (PO)
6	00445	Humboldt Conservation District	Pacific Brucite	1	NP
		Central Coastal Segment			
7	NA	M-430-15 1989-2014	Shellfish International	129	New
8	NA	M-430-16 1989-2014	Half-Shell Oyster Co.	132	New
9	00356	M-430-02 1982-2007	Bay Bottom Beds	5	PO
10	00265	M-430-11 1983-2008	Hog Island Shellfish Farms	5	PO
11	00030	M-430-10 1981-2006	Great American Shellfish Farms	5	PO
12	00256	M-430-17 1989-2014	Shellfish Unlimited	124	New

ID #	Regis- tration #	Lease Grantor	Lease Holder	Acres	Production
			Central Coastal Segment (continued)		
13	00028	Private	Spengers Fish Grotto	1	PO, BM
14	00527	Private	Aquatech	NA	NA
15	00426	M-430-08 1989-2014	Point Reyes Oyster Co.	18	New
16	00416	M-439-14 1984-2009	Point Reyes Oyster Co.	5	PO, BM
17	NA	M-430-07 1989-2014	Shellfresh International	11	New
18	00311	M-430-06 1978-1988	Cove Mussel Co.	10	PO, BM
19	00650	M-430-09 1989-2014	Blue Garden Shellfish Co.	10	New
20	00607	M-430-18 1989-2014	Chandler Shellfish Farm	5	New
21	00256	M-430-13 1989-2014	Shellfish Unlimited	50	New
22	00364	M-430-12 1984-2009	Intertidal Aquafarms, Inc.	50	PO, BM
23	00330	M-430-05 1976-2001	Tomales Bay Shellfish Farms, Inc.	156	PO

ID #	Registration #	Lease Grantor	Lease Holder	Acres	Production
			Central Coastal Segment (continued)		
24	00024	M-438-01 1979-2004	Johnson Oyster, Inc.	1059	PO
25	00024	M-438-02 1979-2004	Johnson Oyster, Inc.	1	PO
26	00229	Private	Lee Marine Enterprises	0	Storage (live sale)
27	00223	M-489-01	First Venture Capital Corp.	5	Exp: PO
28	00490	Private	Pacific Mariculture	0	RA
29	00427	Private	Abalone West	1	Exp: RA
30	00328	Moss Landing Harbor Dist.	Danny Burns Shellfish	2	NP
31	00278	Moss Landing Harbor Dist.	Monterey Bay Marine Farm	7	PO
32	00385	Moss Landing Harbor Dist.	Sea Life Supply	7	Exp: PO,BM
33	00370	Moss Landing Harbor Dist.	Pacific Mariculture	4	NP
34	00446	M-526-01 1986-1991	Pacific Abalone Farms	1	Exp: RA
35	00200	City of Monterey	Monterey Abalone Farms	0	NP

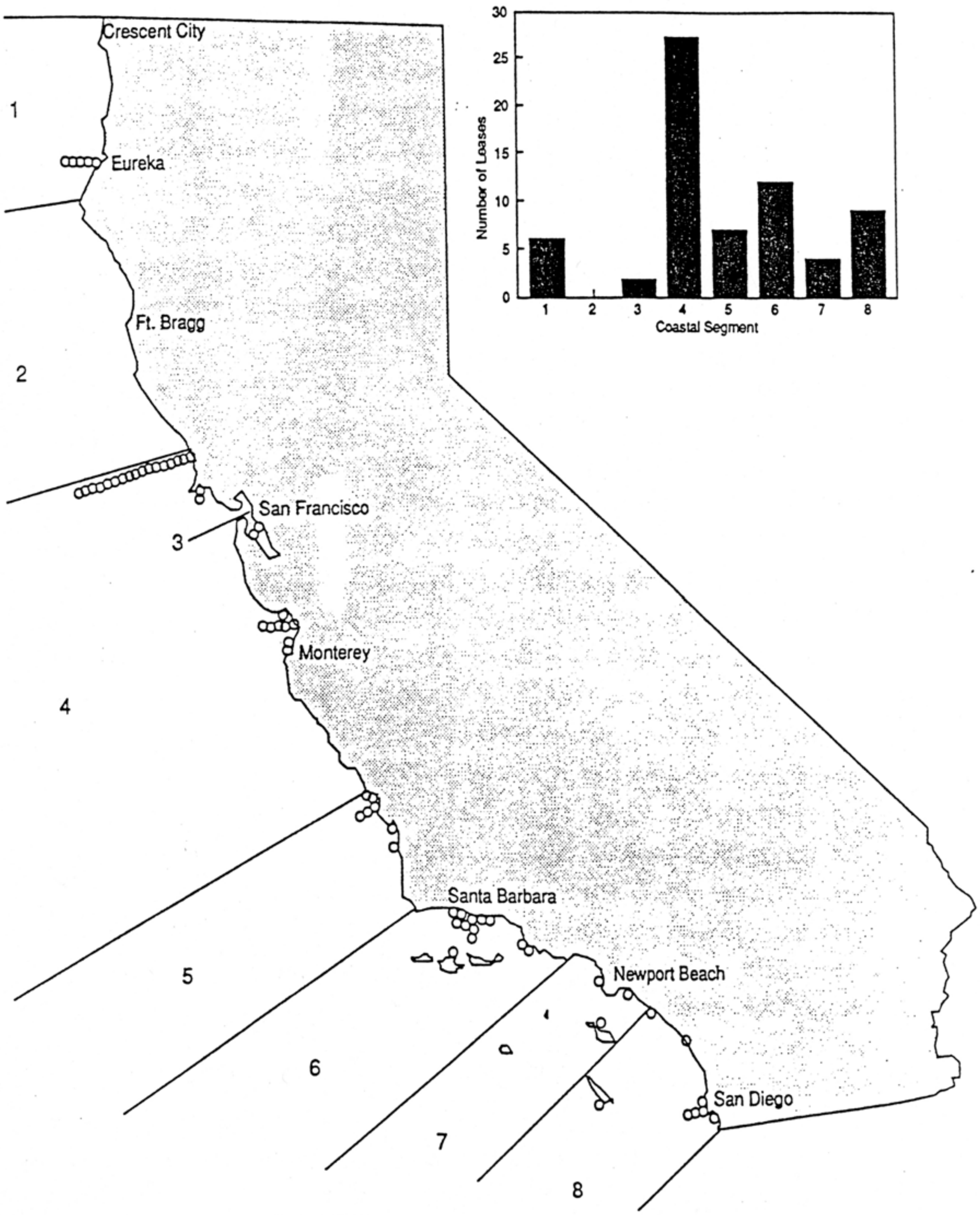
ID #	Regis-tration #	Lease Grantor	Lease Holder	Acres	Production
			Santa Maria Basin Coastal Segment		
36	00029	Private	The Abalone Farm, Inc.	2	RA
37	00473	Private	Western Aquaculture Enterprises	NA	NP
38	00275	M-614-01 1983-2028	Estero Oyster Farms, Inc.	743	PO,BM
39	00228	M-614-02 1983-2028	Estero Oyster Farms, Inc.	15	PO, BM
40	00544	Private	Orata Aqua Farms	NA	NP
41	00365	Port San Luis Harbor Dist.	Pacific Mariculture Unlimited	1	RA
42	00415	Private	Abalone Unlimited, Inc.	50	RA
			Santa Barbara Channel Coastal Segment		
43	00289	M-711-01	California Abalone Association	1	NP
44	00015	M-654-03 1980-1985	Neushul Mariculture, Inc.	25	Exp: Macroalgae
45	00015	M-654-02 1978-1983	Neushul Mariculture, Inc.	2	Exp

ID #	Regis-tration #	Lease Grantor	Lease Holder	Acres	Production
		Santa Barbara Channel Coastal Segment (continued)			
46	00322	M-653-04	The Cultured Abalone	1	RA
47	00499	M-653-08 1988-1993	Western Pacific Mariculture Co., Inc.	5	Exp: BM, Rock Scallops
48	00428	M-653-05 1985-1990	South Coast Shellfish Co.	1	Exp: RA, Rock Scallops
49	00039	M-653-02 1984-1989	Pacific Seafood Industries, Inc.	78	PO, Exp: Rock Scallops
50	00441	M-653-06 1986-1991	Henry's Sea Ranch	5	BM
51	00355	M-653-03	Sea Ventures Enterprises, Inc.	5	NP
52	00025	M-652-01 1982-1987	Ecomar, Inc.	1	MM, BM
53	00325	So. Cal. Edison Co.	McCormick & Associates	0	RA
54	00321	U.S. Navy Civil Eng. Lab	Ab Lab	0	RA

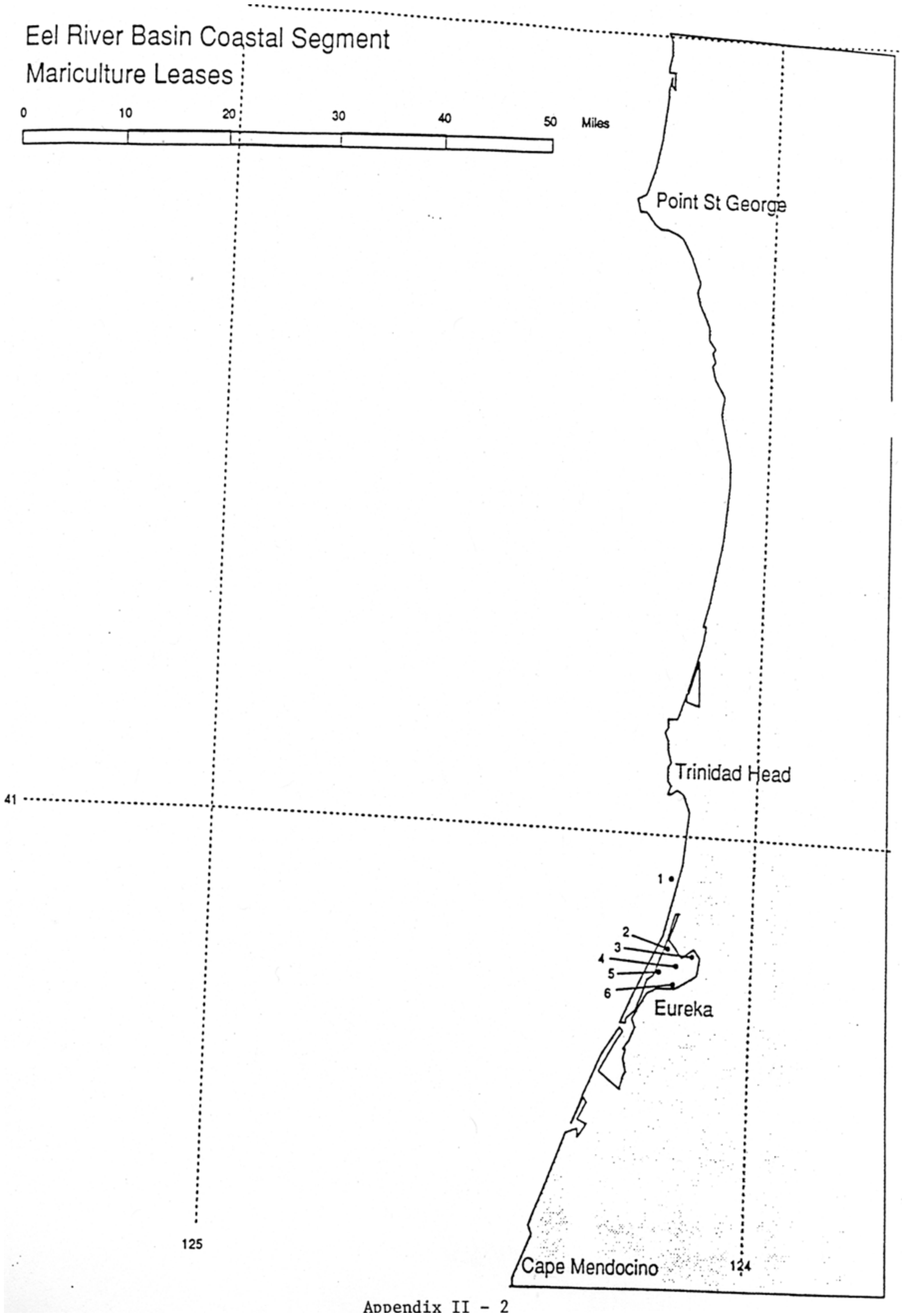
ID #	Regis-tration #	Lease Grantor	Lease Holder	Acres	Production
		Santa Monica / Newport Coastal Segment			
55	00357	So. Cal. Edison Co.	LACM Fish Hatchery	2	Exp: Halibut
56	00450	M-718-01 1986-1991	Gregorio Aquatech	1	Exp
57	00450	M-761-01 1986-1991	Gregorio Aquatech	2	Exp
		San Diego Coastal Segment			
58	00498	M-738-02	Marine Forests Corp.	10	Exp
59	00027	San Diego Gas & Electric	Aquatic Systems, Inc.	0	Exp: RA, Lobster
60	00220	San Diego Gas & Electric	Seafarms West	5	BM, PO
61	00233	M-867-01 1982-1987	Maritech	3	BM
62	00280	M-860-12	Seahorse Enterprise, Inc.	10	BM, PO
63	00233	M-860-01 1982-1987	Maritech	3	BM
64	00383	Private	Hubbs Marine Research Institute	0	Exp: Algae, Sea Bass
65	00300	Mission Bay	David Lapota	1	Exp
66	00280	M-877-01 1979-1994	Seahorse Enterprise, Inc.	10	BM, PO

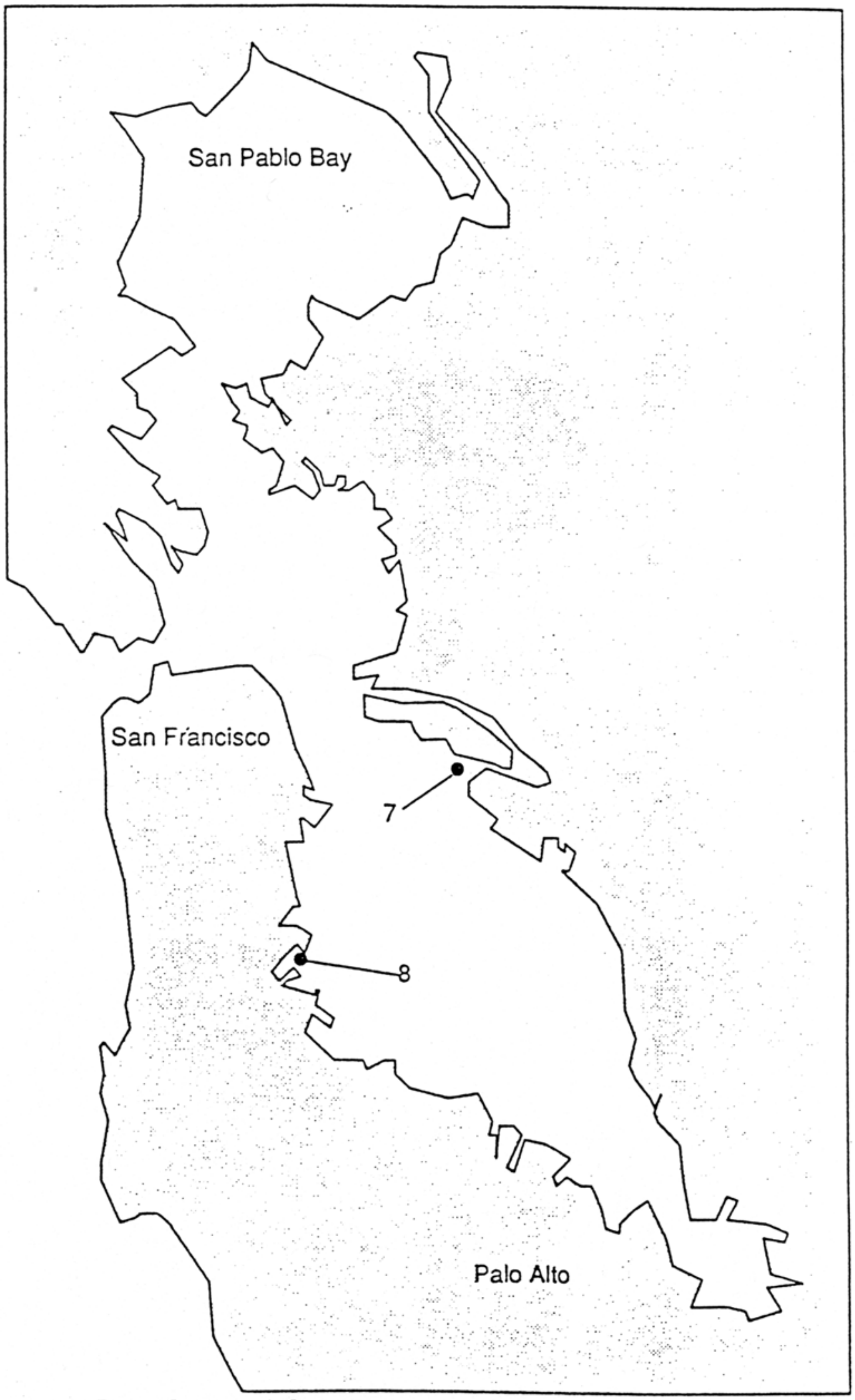
APPENDIX II

Overview of Mariculture

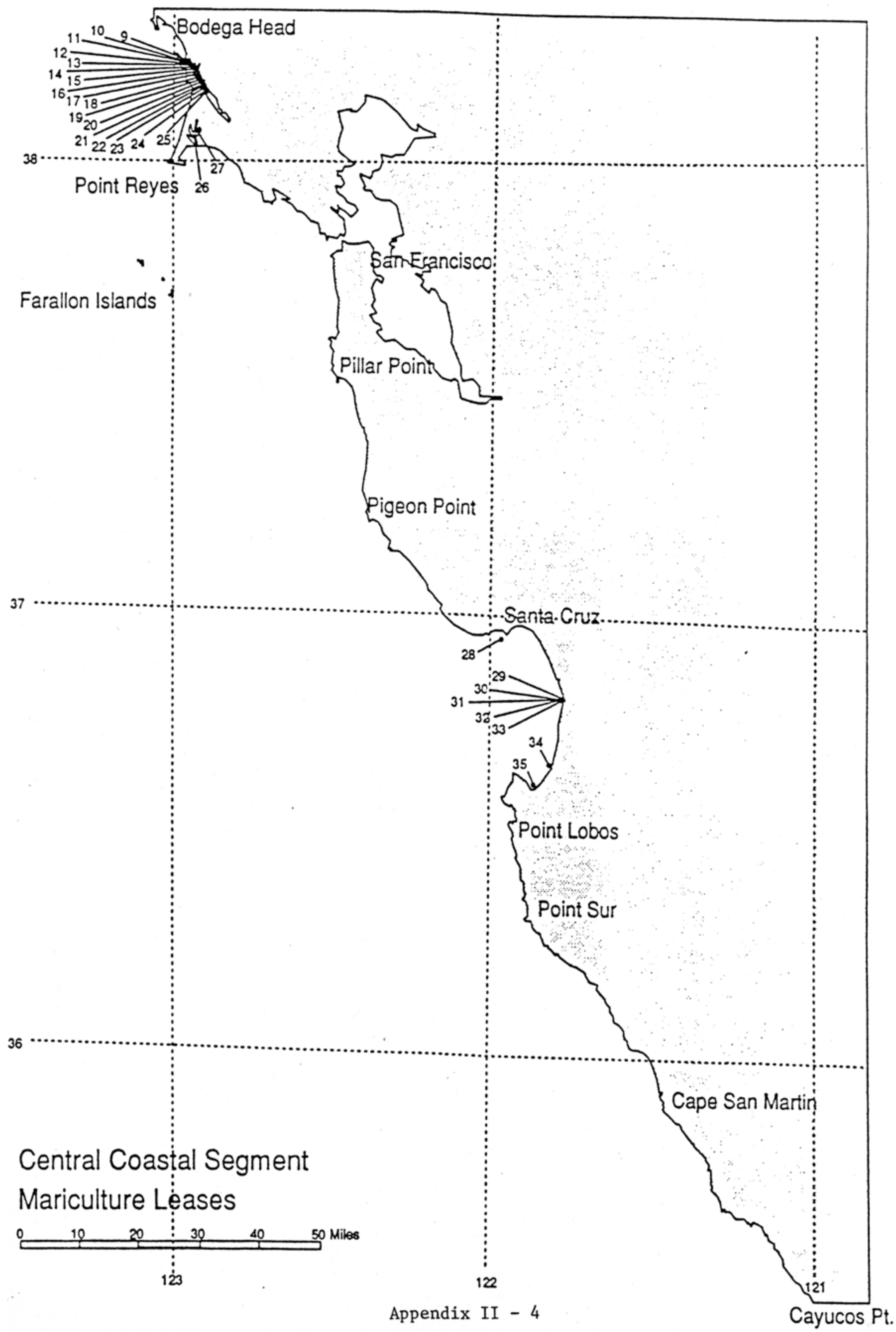


Source: Ambrose et. al. (1989)

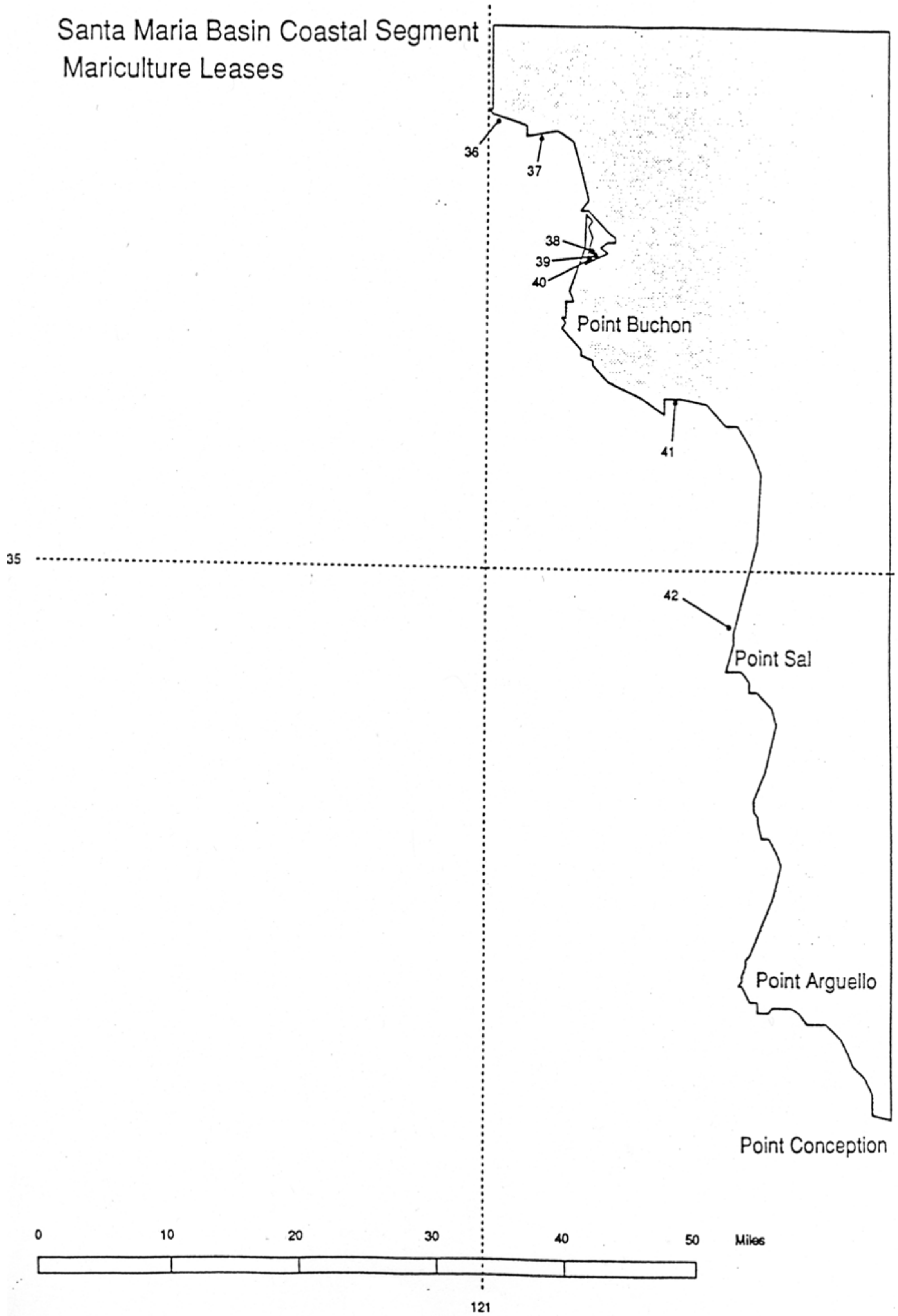

Eel River Basin Coastal Segment
Mariculture Leases
0
10
20
30
40
50
Miles
Point St George
Trinidad Head
41
1
2
3
4
5
6
Eureka
125
Cape Mendocino
124



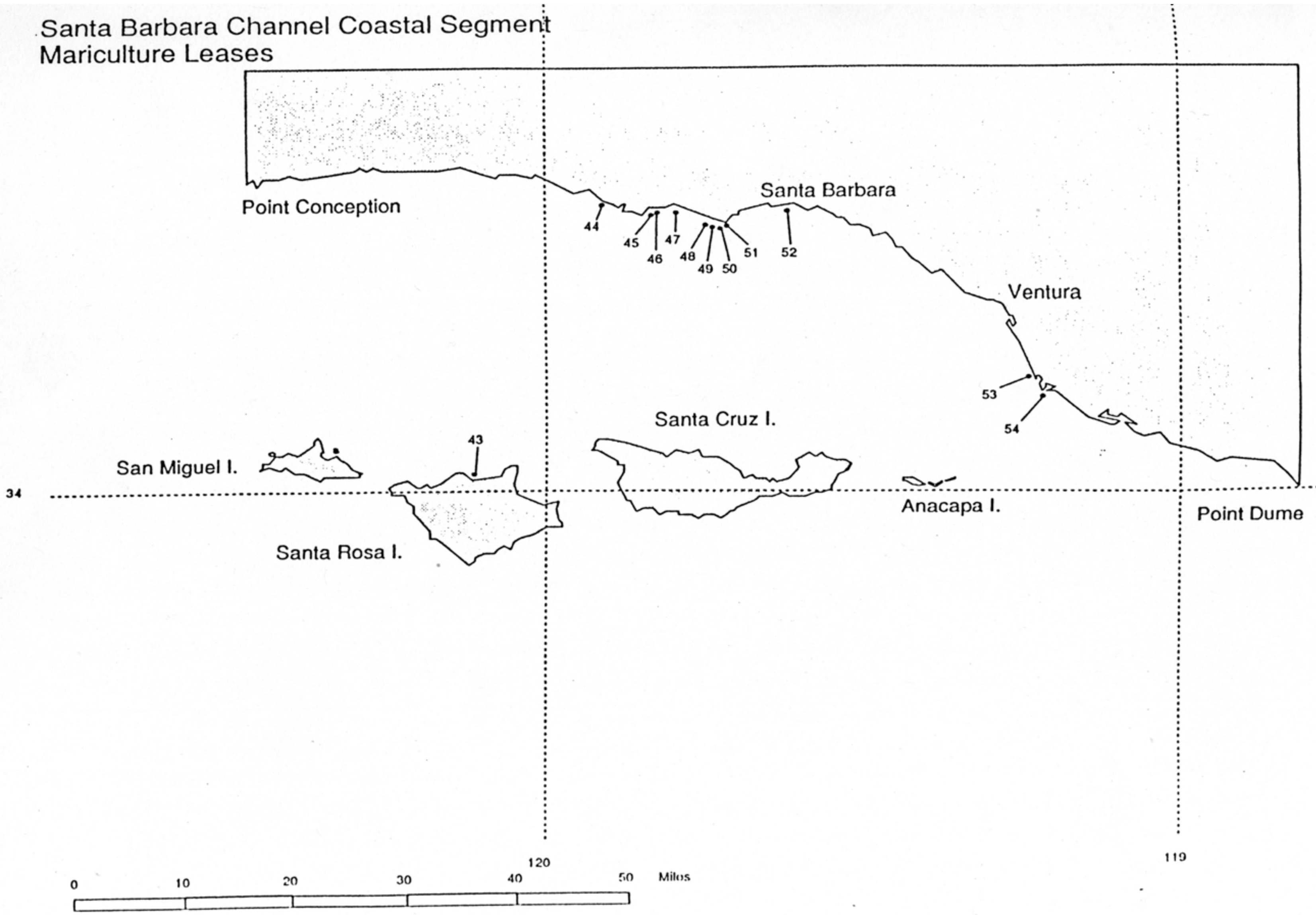
San Francisco Bay Coastal Segment
Mariculture Leases


Bodega Head
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
38
Point Reyes
Farallon Islands
San Francisco
Pillar Point
Pigeon Point
37
Santa Cruz
28
29
30
31
32
33
34
35
Point Lobos
Point Sur
36
Cape San Martin
Central Coastal Segment
Mariculture Leases
0
10
20
30
40
50 Miles
123
122
121
Cayucos Pt.

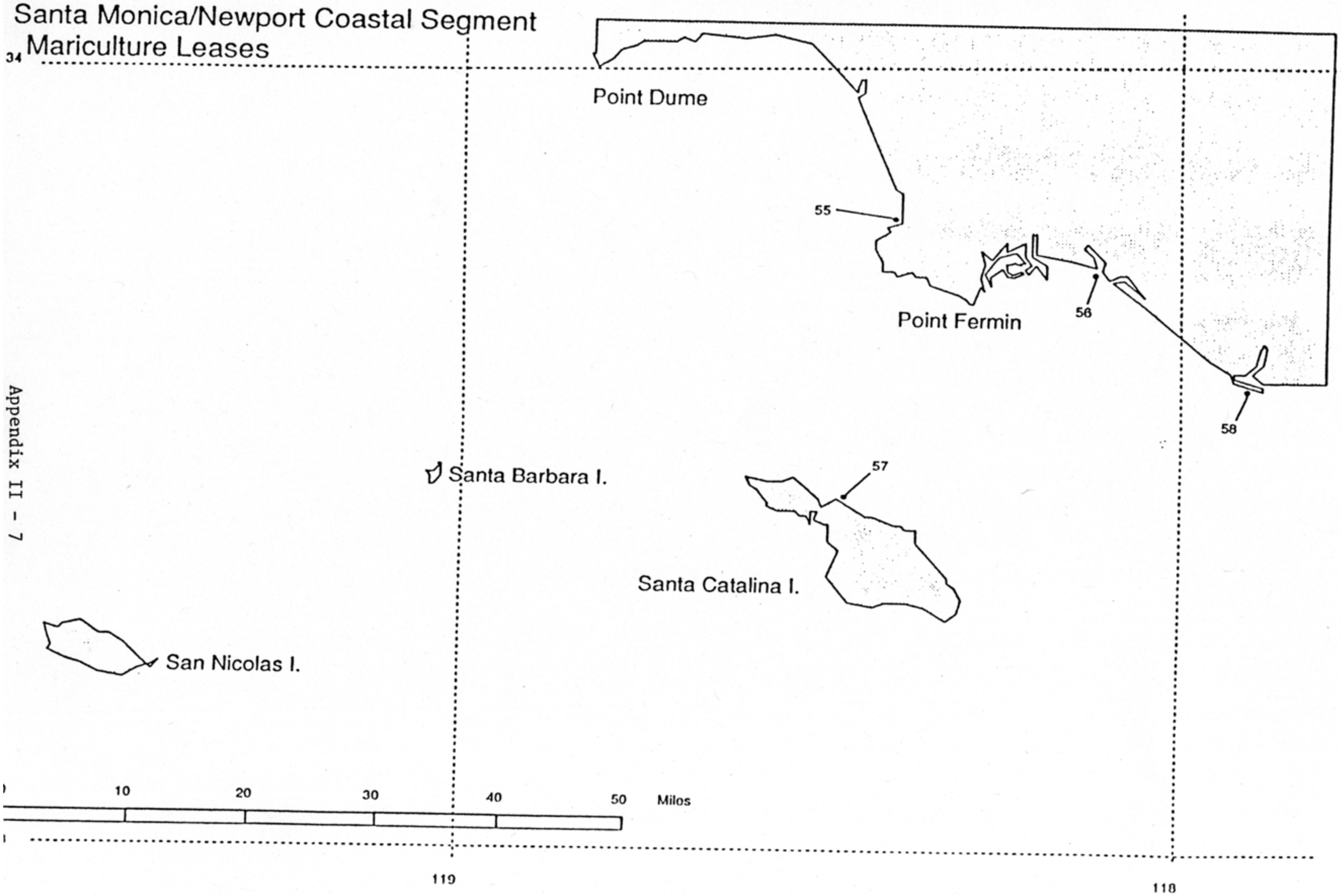
Santa Maria Basin Coastal Segment
Mariculture Leases



Santa Barbara Channel Coastal Segment Mariculture Leases



Santa Monica/Newport Coastal Segment Mariculture Leases



San Diego Coastal Segment
Mariculture Leases