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North American Sea Urchin Fishery Management Strategies: Their Applicability to the Maine Green Sea Urchin Fishery

Kate Sullivan
University of Rhode Island

NORTH AMERICAN SEA URCHIN FISHERY MANAGEMENT STRATEGIES: THEIR APPLICABILITY TO THE MAINE GREEN SEA URCHIN FISHERY

BY

KATE SULLIVAN

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KATE SULLIVAN

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Abstract

The Maine green sea urchin fishery has experienced dramatic growth since its inception in 1987. Landings have increased from 1.4 million pounds in 1987 to 41.6 million pounds in 1993 (NMFS, Fisheries Statistics). The reproductive gonads, referred to as roe or 'uni' are shipped fresh from Maine to Japan, where the uni is a delicacy item fetching high unit prices on the Japanese fish market. The green sea urchin from Maine, *Strongylocentrotus droebachiensis*, is the third highest priced sea urchin product imported in Japan (Anon., 1989). Country-wide, sea urchin fisheries are one of the fastest growing fishing industries (Phu, 1990). Total domestic landings have increased rapidly from approximately 7 million pounds in 1975 to almost 72 million pounds in 1990 (NMFS, Fishery Statistics).

An extreme increase in fishing pressure and landings has caused concern about the long term viability of the fishery. The Maine Department of Marine Resources (DMR), the agency responsible for managing and regulating marine living resources, began to impose regulations in 1990-91, long after the fishery had expanded. Due to the lack of scientific knowledge concerning sea urchin fisheries and the fact that sea urchin fisheries around the world follow a dramatic boom and bust pattern, it is important to begin managing these fisheries at the onset of fishing activity. The rapid increase in catch followed by a dramatic decline in landings indicates that urchins do not do well under unregulated, consistent fishing pressure.

Although several years are needed to acquire the necessary biological information on which to base sound management measures, looking at other sea urchin management measures may offer a solution for Maine's emerging sea urchin fishery. Unregulated sea urchin fisheries are inefficient as every unregulated sea urchin fishery shows the same rise and drastic declining trends. This thesis provides an overview of sea urchin fisheries from throughout North America. This overview illustrates a general trend that unregulated sea urchin fisheries tend to follow-one of rapid increase followed by a large, swift decline. This suggests that better management procedures need to be developed and implemented which take into consideration the unique characteristics of the sea urchin fishery (rapid increase in fishing pressure, low level of technology needed to harvest the resource, and transportation of product to international markets).

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CHAPTER 1

Introduction

Sea urchin fisheries have existed throughout the world for centuries. Most were small scale in tropical and temperate regions, supporting small, local delicacy markets. In the 20th century, these markets changed dramatically as sea urchins became high priced delicacies in Japan, western Europe, and large cities in the United States. Market prices rose and air freight routes were established, resulting in an international market.

All commercially exploited sea urchin species are epibenthic, shallow water grazers important in coastal benthic ecosystems (Sloan, 1984). Commercial landings consist primarily of species in the families *Echinidea* and *Strongylocentrotidae*. The sedentary nature of the urchin contributes to its easy fishing, resulting in easier access to the fishery in terms of start-up costs and gear. Sea urchin fisheries historically show rapid declines after intense fishing pressure. This is partially due to the market-driven nature of these fisheries. With a strictly market-driven fishery, technical innovations and excessive fishing pressure will often occur, leading to fishery resource damage.

This situation is especially true for sedentary species, which will be enormously affected by a small technical advancement, making them highly vulnerable to intensive exploitation (Caddy, 1989). With sea urchins, the establishment of routes to get urchins to market was the one advancement needed. As fresh uni is the most desirable product in Japan, air freight routes were the primary technological factor limiting the urchin industry in this country. Once this barrier was removed, however, urchin fisheries expanded.

The purpose of this research is to begin development of a management paradigm for the sea urchin fishery world-wide. Given its brief history and minimal data base, research of commonalties among urchin fisheries could supplant exhaustive and costly biological research, and provide a compelling model for early management strategies. The successful development of such a paradigm will prevent the potentially disastrous boom and bust cycles which unilaterally typify this fishery.

The case studies reviewed indicate that although management practices are being developed in the different management areas, they are being implemented after the problems are apparent.

This thesis describes sea urchin fishery case studies and management techniques from throughout the Americas. These histories, when considered as a whole, show the importance of management prior to the rapid decline phase of the fishery cycle. This work tests the hypothesis that there are sufficient similarities in recent sea urchin fisheries to permit the transfer of tried management techniques to new fisheries before the "bust" in the fishery is evident.

This overview of urchin fisheries and their management may benefit future sea urchin fisheries. Currently most managers of emerging sea urchin fisheries are at a loss for management strategies due to limited biological data. However, management must occur to avoid the trends illustrated in this paper.

The case study methodology will be utilized to accomplish the research objective. Sea urchin fishery management is a recent and evolving field and statistical data needed for quantitative analysis do not exist. The case study methodology is the best means of obtaining the desired information.

Background Information and the Japanese Fishery

Only a small amount of the overall urchin biomass is consumed. In sea urchins, there are five sacs of gonads which are referred to as "roe" and as "uni" by the Japanese. On average, only about 10% of the urchin biomass fished is consumed (Anon., 1989). This figure indicates a very small commercial recovery rate for urchins. (An overview of urchin biology is included in the following chapter). The best quality roe is consumed fresh as a sushi type product. Lesser quality roe is canned or processed for more generic uses in which appearance is secondary to taste. As the Japanese are the primary importers and consumers of sea urchin globally (Phu, 1990), their product demands determine this fishery. It is also this quality demand which makes sea urchins so highly prized and harvesting of urchins a lucrative business.

The Japanese sea urchin fishery dates to prehistoric times as evidenced in ruins and coastal shell mounds. Written records supporting the use of sea urchins date back to 718 AD. (Saito, 1992). Since the Second World War, edible sea urchins from all coastal waters have been exploited, and since the mid 1980's, Japanese urchin landings have decreased. In 1982, 26,000 tons were landed while in 1989, 20,400 tons were landed (Figure 1.1, Saito, 1992). Although this may not represent a significant decline, Saito (1992) and Takagi (1986), both indicate that the decrease is significant and continuing. The decline is accompanied by an increase in imports during the same period. In 1982, 2,400 tons were imported, increasing to 3,700 tons in 1987 (Saito, 1992). Imports and average price paid have increased since 1987 (Figure 1.2).

This decline is one of the primary reasons for increased urchin imports during the past decade. As domestic supply declined, Japan began to import large quantities of urchins. North and South American countries supplied approximately 33% of total imports during the period 1978-1983 (Takagi, 1986). In 1988, the Americas became even more important as exporters of sea urchins. The United States accounted for 49.4% of urchin exports to Japan, and the Americas combined accounted for 65.4% of the urchin export market (Figure 1.3, Saito, 1992). These imports are used to meet demand during the winter months when Japanese domestic urchins are spawning and of poor quality (Takagi, 1986). Imported roe is also utilized to satisfy an increasing consumer demand. Figure 1.4 shows total Japanese urchin imports and the U.S. contribution to these imports.

Sea urchins are an important artisanal fishery in Japan. The fishery is in part managed by general regulations such as fishing closures which correspond to the spawning season and urchin test size limits. The rest of the regulatory framework is determined and monitored by the Fishery Cooperatives established throughout Japan.

Each Cooperative sets fishing limits, gear restrictions, reserve areas among others. Reseeding, habitat enhancement, and mariculture are also practiced and regarded as an integral part of the sea urchin industry (Saito, 1992).

The best quality roe in Japan is obtained in February-April for some species, August-October for others, and June-August for the most valuable species (Takagi, 1986). Therefore, domestic supply is low at the peak holiday times in December-January, making the market lucrative for North American species, many of which are at peak quality at this time.

Most historic sea urchin fisheries are artisanal in nature, resulting in few records which correctly illustrate the total amount of urchins taken from oceans around the world (Sloan, 1984). For this reason, sea urchin fishery management has been reactive and slow starting, causing serious economic and ecological consequences (Sloan, 1984). In contrast, invertebrates such as mollusks have had better management historically due to the longevity and enormity of these fisheries.

Fishing pressure has increased rapidly as demand and prices paid rose. Large fisheries now exist in Japan, Korea, the United States, Canada, Chile, Mexico, and China, among others. Globally, fifty thousand metric tons of urchins were landed annually in the late 70's-early 80's (Conand and Sloan, 1989). As older fishing areas are fished down, new areas are opened to meet demand.

The expansion of North American sea urchin fisheries is an example of this pattern. Sea urchin fisheries began on the west coast where California was the center of activity. After several years of intense fishing and reactive management measures, yields declined and interest began in opening up a fishery for the green urchin common on the east coast, particularly in Maine.

In 1987 a large scale fishery for *Strongylocentrotus droebachiensis* began in Maine's coastal waters and within five years landings jumped from 200,000 pounds to over 24 million pounds. It took four years before the State actually started to regulate the fishery. Although little data exists concerning stock status in Maine, there has been a large shift in fishing pressure from western to eastern waters, indicating that fishers need to go further and to new areas to find urchin populations suitable for commercial exploitation.

As spin-offs to the Maine fishery, Massachusetts as well as New Brunswick, Canada, have emerging urchin fisheries. The Massachusetts fishery started within the last few years, possibly in response to the adoption of a Maine residency requirement. This has forced out-of-state fishers to go elsewhere. The New Brunswick fishery helps support the supply and demand nature of the Maine fishery (Robinson, 1994a). When Maine landings were inadequate to meet market demand, New Brunswick fishers would bring their landings to the Maine market. This has been especially true in December and January (Robinson, 1994a).

There are now sea urchin fisheries throughout North America, including Alaska, British Columbia, Washington, Oregon, California, Massachusetts, Maine, New Brunswick and Nova Scotia, while others are being considered. Although many of these fisheries have existed to support local or ethnic markets in Boston, New York, or Los Angeles, it has been within the past 15-20 years that these fisheries have become economically important fisheries. For example, the red sea urchin, *Strongylocentrotus franciscanus*, was the second most valuable fishery in California in 1990 with a value of 24.9 million dollars, while in Maine *S. droebachiensis* is second only to lobster in value for wild fishery products. Table 1.1 shows value of sea urchin products to US. states. Figure 1.5 shows the value of sea urchins to the U.S. at export time.

Table 1.1. Value of Sea Urchin Fisheries to U.S. States

State	1988	1989	1990	1991	1993
California	$19,474,699	$20,825,612	$24,976,829	$33,223,812	**
Maine	$1,758,805	$3,608,474	$5,955,975	$11,158,425	$26,816,313
Massachu-setts				$144	$338,829
New Hampshire		$41,051	$22,876	$33,457	$26,501
Oregon	$571,083	$2,728,272	$4,459,764	**	**
Washington	$3,008,996	$3,348,792	$1,697,720	**	**

Source: NMFS, Fisheries Statistics. **1993 data are preliminary and may be incomplete. Washington and Oregon data for 1991-1993 and California data for 1992-1993 are unavailable.

Both the number and magnitude of sea urchin fisheries has increased rapidly. People charged with managing these fisheries do not always know what measures to take or how to forecast the future of the fishery. Due to the newness of sea urchin fisheries, very little is known about urchin fishery biology, making management and conservation difficult. One exception is Japan, where urchin fishery biology has been well documented, primarily due to the longer history of the fishery as well as the Japanese commitment to manage this fishery (Sloan, 1984).

Unlike many fin and crustacean fisheries which have extensive records, sea urchin fisheries have little or no history of landings, stock status, or management. Therefore, when a sea urchin fishery begins, it is difficult to manage because no long term data has been collected. With lobsters, for example, Maine fishery managers have approximately 100 years of landing data which has been essential to manage the fishery. With sea urchins, managers have been unaware of the extent and importance of this fishery to the Maine economy. This has changed within the last year or two. With current landings and investments, it will be difficult to reactively manage this fishery on an economically and ecologically sustainable basis.

By using management measures from other sea urchin fisheries, the State may be helping to achieve the goals of fisheries management: sustainability of the resource, job creation, and benefit maximization. The following provides an overview of the statuses and management policies of several North American sea urchin fisheries with the aim of showing similarities that occur within these fisheries as well as what measures are working to sustain them. This perspective should help future and present managers better understand the global sea urchin market.

CHAPTER 2

Fisheries Biology and Ecology of Sea Urchins, With Particular Emphasis on Sea Urchins of the Genus *Strongylocentrotidae*.

Sea urchins have been widely studied by biologists since the early 1970's. Good indicators of environmental health, sea urchins are often used in bioassay studies. They are also used in studies related to fertilization and embryonic development as sea urchin eggs are easily manipulated under experimental conditions (Mottet, 1976).

Little research has, however, been conducted concerning the fishery biology of sea urchins prior to the mid-1970's, when urchin fisheries became important throughout temperate oceans. Japan, which has had a long term sea urchin fishery, has conducted the most detailed work concerning urchin biology (Sloan, 1984). In the United States, *S. franciscanus* is the commercial species most studied.

Although the Maine fishery focuses on a species for which little is known biologically, Mottet (1976), in his review of the biology of Strongylocentrotidae spp., indicates that as the classification of sea urchins is based solely on hard parts, the gonads of urchins from different orders may be the same. Moreover, from a fisheries point of view, differences between orders, families, and genera may not be any more significant than differences between species. Therefore, using general fishery biology for urchins is useful and may be applicable to the Maine fishery and to *S. droebachiensis*.

Sea Urchin Anatomy

Sea urchins have a symmetrical, five fold, starlike shape. They are most noticeable for their spines, which extend outward from the exoskeleton, or test. The test is composed of many small plates and each plate is composed of a single calcite crystal. The primary function of the spines, which in some species contain poison, is to discourage predation. Spines are also used for locomotion and generally, fast moving urchins are using their spines for movement rather than tube feet (Mottet, 1976). The spines vary in length according to whether they are located on the ambulacral or interambulacral section of the test (Figure 2.1). Ambulacral spines are shorter than interambulacral spines.

The small holes that are visible on a cleared test are pore arcs through which the tube feet extend or withdraw. The tube feet are found only on the interambulacral areas of the test. The ends of the tube feet shape into suction discs, which help urchins remain attached to substrate, to resist wave action, or to climb vertically on rock walls and crevices. Tube feet are also important tactile and chemical sensors which act to absorb oxygen, catch drifting algae for food, and to keep the test clean (Mottet, 1976).

Urchins also have small pincers, pedicellariae, which act to deter predators. In non-threatening times, pedicellariae act to clean the test or to hold shells, rocks, and various debris over the test for camouflage or shade. Pedicellariae may also collect drifting seaweed and algae and pass it to the mouth. When pedicellariae are used to deter predators, the spines closest to the threatening animal are moved and the pedicellariae extend out and group together toward the predator.

The internal anatomy is also radially designed in a five armed, star like pattern. The gonads, which are the commercially valuable portion of the urchin, are located in the aboral (top) half of the test. Each sac of gonads is centered within one of the interambulacral areas, which are separated by the hole filled ambulacral areas. Figure 2.2 shows the internal structure of *Strongylocentrotus droebachiensis*, the green sea urchin.

The mouth is located on the bottom of the test and consists of five teeth and many muscles which are part of an overall mechanism called Aristotle's Lantern. Around the mouth is the peristomal membrane, which is the weak point in the urchin's skeletal defense as there is no hard test covering this membrane. Food is chewed by teeth and passed from Aristotle's Lantern to the esophagus, stomach and then to the intestine. In the intestine, food is formed into round pellets which are eliminated as waste through the anus which is located on the top of the shell and looks like a small black dot. Wastes that get stuck on the shell are cleaned using spines, pedicellariae, and tube feet. The rate at which pellets are eliminated depends partially upon the food supply available.

The gonads are important for reasons other than their reproductive capacities. Gonads are the main nutrient storage organs in sea urchins and starved urchins will reabsorb their gonads to stay alive (Tegner, 1989). Underfed urchins will not grow and may even shrink in size. When food is abundant, urchins will store nutrients in their gonads, which can expand up to one-fourth of an urchin's overall body weight (Mottet, 1976).

The sex of gonads are indistinguishable until sex products are produced during the spawning season. Gonads are converted into gametes and released into the sea, resulting in a corresponding decrease in the size of the gonads. Due to seasonal and cyclical nature of urchin spawning, the quantity and quality of gonads changes throughout the year. This change is probably one of the most focused on in terms of fishery management and in most places, fishing seasons are designed to prohibit fishing when gonads are of poor quality or during spawning.

Mottet (1976) describes the five stages of the gonad cycle as translated from the Japanese study of Miwa, (1970). Stage one is considered a resting stage. During this stage, gonad size is the smallest, due either to the immaturity of the urchin or because it has recently spawned. In Stage 1, a well-fed urchin may have gonads which make up 5-10% of its body weight, most of which is due to high water content. Stage 2 is a growth stage in which the urchin actively feeds and stores excess nutrients in the gonads. During this stage, water content is minimal and there are no taste or coloration differences between male and female gonads. It is during the end of this stage and the beginning of Stage 3 in which urchins have the highest market value.

Stage 3 is referred to as the pre-mature stage, during which gonad weight approaches its maximum. Eggs and sperm are produced and coloration changes occur which allow the sexes to be visually distinguished. Stage 4 is the mature stage during which gonads may account for 25-30 % of total body weight. However, the quality of male gonads is commercially poor; coloration is whitish and water content is higher. Therefore, this is the least desirable phase for harvesting urchins as males will be of low to unmarketable quality. Fishing during this phase results in resource waste.

The final stage, Stage 5, is the spawning stage. Gametes are dispersed into the water and a rapid drop in gonad weight occurs. To compensate, perivisceral fluids surrounding the gonads increase in volume. Again, this is a poor time to harvest as urchins taken now will either be inhibited from spawning, or if just spawned, will have little or no marketable gonads. Spawning occurs when gonads become so full that leakage occurs or when something stimulates spawning. The exact stimulus varies by species and by geographic region. Spawning may also be triggered by the presence of the opposite sex's spawn in the water column.

Water content is an important market feature as gonads with a high water content tend to partially liquefy during processing and shipping. Gonad texture is important and liquefication greatly reduces the texture's quality and therefore, value. Further, urchins with a high water content tend to have less fat, protein, and glycogen concentrations, all of which are considered desired attributes of a good urchin.

Sea urchin gonads are very nutritious. A 100 gram serving of fresh, high quality gonad provides 148 calories, is 71.5% water, 15.8% protein, 8.5% fat, 2% sugar and 2.2% ash. Mineral content per 100 grams is 20 mg. calcium, 300 mg. phosphorous, and 2 mg. iron.

Vitamin content is 3,000 IU vitamin A, 7,500 IU carotene, 0.30 mg. B1, 0.40 mg. B2 and 2.5 mg. nicotinic acid (Mottet, 1976).

A spawning female sheds between 100,000-2,000,000 eggs. Fertilized eggs drop to the ocean floor where they remain until the end of the blastula stage. The larvae then rise and float near the ocean surface until settlement. Urchins prefer rocky or gravely bottoms and will seldom settle on sandy or muddy bottoms. If a desirable substrate is not available, the larvae will continue to float and feed on phytoplankton until a suitable settlement area appears (Hinegardner, 1969 as used in Mottet, 1976). After settlement, metamorphosis is rapid and within an hour, a tiny urchin appears from the larva. Feeding and behavior are similar to that of adults; however, smaller food sources are eaten.

The stages discussed above outline gonad development and changes which are essential to determine a fishing season. However, one problem is that urchins have demonstrated both regional and annual fluctuations to these cycles (Dowling, 1994, Urchin Workshop). Therefore, if a fishery season is established with the aim of protecting urchins during the spawning season, the closure must be flexible to accommodate changes in the cycle.

Other factors which affect gonad quality include the presence or absence of food, which is the primary environmental factor affecting gonad growth. Another environmental factor which limits growth is wave action. In areas of high wave energy, spines may be frequently broken, resulting in more energy being used for growth and repair than for test growth (Mottet, 1976). Other environmental factors which will affect growth include pollution, unsuitable temperature, salinity, or water depth, each of which are important variables affecting the marketability of urchins.

Sea Urchins as part of sub-tidal coastal benthos.

Sea urchins are considered to be important members of any marine community (Mottet, 1976, Bernstein et al, 1983, for example). As grazers they can determine the plant community in a region, especially in the absence of predators. Lobsters, crabs, star fish, sea anemones, several fishes, sea otters and sea birds all prey on urchins to various degrees (Mottet, 1976). On the west coast, sea otters are their largest predator. However, due to human-induced reductions of sea otter populations, the otters' ability to control urchin populations has been greatly reduced over the past several decades.

Due to a lack of strong predation, urchin populations exploded along both coasts, greatly changing benthic communities. One of the largest changes which is brought about by urchins is the conversion of kelp beds and seaweed areas to barrens-areas mostly devoid of any plant life. In a healthy kelp bed ecosystem with small urchin populations, a community of predominantly *Laminaria* kelp species grows high into the water column while smaller algaes and seaweeds such as *Chondrus* grow closer to the bottom (Bernstein et al., 1983). Lobsters, mollusks, and other invertebrates as well as fish commonly inhabit the kelp ecosystem which provides shelter and ample food supplies.

When sea urchins enter a kelp bed region, however, this system can be greatly altered to one where only dense mats of urchins exist on barren rocks and ocean bottom. Sea urchins graze on kelp in very destructive manners. In some instances, urchins attach to the kelp steadfast and eat the point of attachment only, allowing the bulk of the kelp stalk to float away (Kato, 1972). Not only does this eliminate the plant as a food, nutrient, and shelter source, but it also increases the risk of further kelp loss. In times of storms, these free floating kelp strands may entangle attached, living kelp and dislodge it (Mottet, 1976). In other instances, sea urchins, working as a group, have been observed to pull down and hold a plant in place until it has been consumed.

In contrast to this rich kelp bed ecosystem is the barrens, characterized by few, if any, microalgaes, and an abundance of encrusting coralline algaes (Bernstein et al., 1983). Sea urchin densities are much higher than in kelp systems and they act to maintain the barrens by grazing on any plants that attempt to resettle the area. Barrens are generally large mats of clumped urchins eating detritus, small plants, and other wastes.

Bernstein et al. (1983) explain how the transformation from healthy kelp bed to barren is accomplished. In low densities, urchins in kelp beds tend to remain in hiding and spaced apart. However, after a critical density is achieved (about 20 individuals per square meter), urchins begin to form small clumps in the open, attracting predators such as lobster. In response to potential predation, urchins have defensive aggregating responses, leading to the formation of larger clumps and ultimately to destructive grazing on kelp and formation of a barren.

Although a reproducing population of urchins can remain in barren areas for years by eating encrusting corraline algae and detritus (Lang and Mann, 1976), the urchins will generally have lower quality gonads. Low densities of sea urchins living in healthy kelp beds have greatly increased growth and gonad capabilities (Lang and Mann, 1976). Therefore, within a management context, removal of urchin conglomerates in barrens may be desirable from an ecological viewpoint, and also makes sense economically by helping to restore original kelp beds.

CHAPTER 3

THE MAINE SEA URCHIN (*Strongylocentrotus droebachiensis*) FISHERY: HISTORY AND CURRENT STATUS

The Emergence of the Maine Fishery: The Shift From California

A small scale sea urchin fishery has existed in Maine since the mid-twentieth century (Scattergood, 1963). This fishery primarily supported local consumption needs and a small domestic market. Between 1933-1963, this small boat dip-net fishery landings averaged 3.2 metric tons (Scattergood, 1963). The primary impetus of this fishery was to remove this species, considered a nuisance, from sub-tidal waters. The fishing season was December-April (Scattergood, 1963). There was no attempt to develop this fishery into a large scale operation supporting both a growing domestic and international market (Kato, 1972).

In the 1980's, however, interest in expanding this fishery began to grow, primarily as an offshoot of the booming California sea urchin industry. The California urchin fishery has a somewhat unique history in that it started as a way to reduce populations of this nuisance bottom dweller. The founding of the California fishery is due to efforts by the National Marine Fisheries Service.

In 1968, the National Marine Fisheries Service started to actively develop a sea urchin fishery in California essentially as a means of eradicating the abundant red sea urchin, *S. franciscanus*. Fishing methods were researched and markets were established to assist in starting the fishery. Sea urchin grazing was seen as a primary cause in the demise of economically important kelp resources. Increased urchin populations were competing with abalone for food and habitat, threatening this important fishery resource as well (Kato, 1972).

Further, in 1970, North and Pearse (1970), found that a direct cause and effect relationship existed between increased sea urchin populations and the decline of sea plants. In response, the State of California and various fishing groups began large scale eradication programs ("urchin kills") that included the application of such chemicals as calcium oxide to areas with high urchin densities (Kato and Schroeter, 1985). Sport divers would carry hammers and smash urchins. Overall, these types of eradication programs were unsuccessful.

The efforts to establish a fishery by the National Marine Fisheries Service, however, were successful and by the late 1970's-early 1980's, California was experiencing a booming sea urchin fishery. Due to the newness of this fishery as well as to the lack of importance placed on conserving sea urchins, stock problems arose and concern over possible fishery collapse began (Muraoka, 1990).

Although NMFS started to develop the fishery in the early 70's (the first commercial landing of 200 pounds was recorded in 1971 (CA. Fish and Game)), several factors would inhibit development until the mid-to late-1970's (Muraoka, 1990). The value of the dollar in relation to the yen was probably one of the main reasons that the fishery was initially unsuccessful. In the early years, it was not economically feasible to ship fresh urchins by air to Japan, thereby eliminating the Californian product from its potentially most lucrative market. Another factor was that air routes were not yet established to transport urchins quickly from Los Angeles or Santa Barbara to Tokyo.

Biologically, the largest factor contributing to the fishery's success in the late 70's was the explosion of urchin populations to record levels as a result of sharp decreases in both sea otter and abalone populations (Muraoka, 1990). Concern about increasing populations of this nuisance species led fisheries biologists to support this budding industry, regardless of the lack of biological information about the urchin or its role in benthic ecosystems.

By the late 1980's, the sea urchin fishery was one of the most valuable fisheries in the State and business owners and exporters were concerned about future profitability and sustainability of the industry. While some in the industry moved north to look for new stocks, others began to speculate on the harvestability of the common green sea urchin along the Maine coast, *Strongylocentrotus droebachiensis*. *S. droebachiensis* is more similar to the natural species found in Japanese waters than is *S. franciscanus* so market value prospects were good (Phu, 1990).

At the same time as this shift took place from the west coast, a group from the University of New Hampshire (Child et al., 1985) conducted a feasibility study for harvesting sea urchins in the Gulf of Maine. The focus of the study was to find ways of increasing lobster harvests by reducing the extent of urchin barrens as increased areas of barrens reduce food available to lobsters. The group concluded that a small scale sea urchin fishery would help to reduce barrens and thereby hopefully increase lobster landings. They also concluded that such a fishery would likely be economically feasible. Thus, the impetus for proposing a sea urchin fishery in Maine was similar to that of California-to enhance an economically important fish stock by eliminating a pest. While in California the economically important fish stocks were abalone and kelp, in Maine it was lobster. It is unlikely that either of these proposals could have forecasted the multi-million dollar international market that resulted.

In 1984, Maine recorded landings of 50,800 pounds and by 1993 had landed 41.6 million pounds (NMFS, Fisheries Statistics), making this a rapidly developing fishery. In terms of value, this is an increase from a $4,000 fishery in 1984 to a $26.8 million fishery in 1993. These figures represent drastic increases in just ten years. Figure 3.1 illustrates Maine sea urchin landings and value.

As with *S. franciscanus* in the California fishery, very little is known of the biology and ecological role of *S. droebachiensis*. Most responsible for fishery management were initially unaware of this fishery's magnitude. While some within the industry believed that urchins were limitless and that large scale harvesting was beneficial to the benthos, others became concerned about the status of the stock and the consequences of large scale urchin removal to the coastal ecosystem.

Although numbers seem to indicate that landings are climbing consistently and stock levels are healthy, this may not be the case. Over the past few years, the number of permits granted by the

State's Department of Marine Resources (DMR) has increased sharply, as illustrated in Table 3.1. Therefore, although landings are climbing, effort has increased threefold which would indicate that catch per unit effort (CPUE) is most likely declining. Figure 3.2 shows landings and value by county to illustrate shifting and rising effort.

Table 3.1. Permits Issued in the Maine Fishery: 1992-94

Year	Hand Harvesting	Boat Harvesting
1992	807	232
1993	1439	568
1994 **	1654	947

Source: Creaser, T., 1994, Maine DMR. ** In 1994, in addition to the hand and boat harvesting licenses indicated above, approximately 600 boat tender licenses were granted.

The Regulatory Framework in Maine

The State was reluctant to impose restrictions or regulations during the first four years of the fishery. The State blamed the lack of regulation on its then budget crisis, which prohibited it from getting the funds necessary to collect data to determine what the management needs were for the fishery. Lack of action by the State made some within the industry feel that the State did not consider the fishery important and industry leaders began to ask the State for more assistance (Griffin, 1993).

Regulations were adopted by the State legislature in 1993 and went into effect in January, 1994. These regulations, 'An Act

Concerning the Taking of Sea Urchins,' called for a three month summer closure of the fishery from June 15 through September 15, 1994 to limit urchin removal during the period when roe is of lowest quality and therefore low market demand. Urchins harvested in the Gulf of Maine from November to March have the best quality roe. Removal of urchins prior to this time results in economic losses in the form of lowered market value and the subsequent losses incurred by not having these urchins available during the time of peak roe quality and marketability.

The regulations also impose a minimum size limit of two inches on test diameter, excluding spines. This figure was established arbitrarily and does not reflect any known biological feature of *Strongylocentrotus droebachiensis* (Creaser, 1993, personal communication). The intent of the size limit is to help insure that urchins are allowed to spawn at least once prior to being harvested. However, the effects of this size limit remain speculative. Studies to determine the most effective minimum test size still need to be conducted.

Culling at sea is another requirement of the 1993 regulations. Culling at sea helps return undersized urchins to sea as quickly as possible, thereby reducing discard and fishing mortality rates. With sea urchins, however, little is known about survival rates of urchins culled at sea versus those brought to shore, primarily because there was little demand for such research prior to this fishery's expansion. Some biologists remain speculative as to whether on-board culling will have any effect on discard survival rates (Harris, 1994, Urchin Workshop).

Both divers and draggers must obtain permits from DMR and they must be Maine residents. A person is eligible for a resident license if s(he) has lived in Maine for six months preceding the date of application (Maine Marine Resource Laws, 6301:1). Prior to 1991, there were no residency requirements and divers would come from all over the country to work in the fishery (Creaser, 1994, Urchin Workshop). There are only estimates concerning the number of people actually involved in the fishery prior to 1991 due to a lack of management and record keeping(Chenoweth, no date).

The 1993 regulations were met with concern and opposition for various reasons and from various interest groups. Seasonal closures drew opposition from processing companies concerned about being shut down for three months which would make them unable to meet their customers' demand on a year-round basis. Processors instead favored a zonation program in which Maine waters would be divided into two fishing zones. With zonation, closures could be rotated and overlapped so the overall fishery closure time of three months could be staggered, reducing down-time in the processing plants. As of the fall of 1993, DMR was not willing to consider this option as it would be impossible to enforce (Creaser, 1993, personal communication).

With respect to the two inch minimum size limits, opposition has come from the dragging community. Dragging gear is not selective and draggers have little control over what size urchin is brought aboard. Further, due to the force of dragging, more damage is done to urchins, reducing the likelihood that undersized urchins can be returned to the sea unharmed.

The above regulations went into effect in January, 1994. However, in the interim period, concern over increased fishing pressure, stock status, diver safety, and lack of biological knowledge about urchins prompted the State to revise the 1993 regulations. Approved in the spring of 1994, two new legislative acts superseded the previous legislative regulations. In effect July 1, 1994, H.P. 1459-L.D. 1984 'An Act to Conserve Sea Urchin Resources,' substantially changed previous regulations.

The brevity of the 1993 regulations illustrates the rapidity with which this fishery is evolving. The difficulty is to enact regulations that will best conserve the resource while allowing those in the industry to earn a living. The 1994 regulations were in response to this issue. However they are again based on a severe lack of biological and ecological information, which makes it likely the new regulations will need to be changed shortly. Data on landings, fishing effort, CPUE, location of high and low fishing pressures, and stock status are still lacking and needed to really fine tune regulations.

The 1994 Legislation: 'An Act to Conserve Sea Urchin Resources' and 'An Act Concerning Commercial Divers'

The 1994 sea urchin legislation greatly changed the structure of the industry. In general, the 1994 legislation acted to restrict access to the fishery while increasing regulations which may conserve the resource. The specific measures of the Act are as follows:

The fishery is now a limited entry fishery. This is the first time Maine has used this management technique. In the April 1994 decision, a moratorium on new licenses was established, which took effect on July 14, 1994. By this statute, no new hand harvesting or dragging licenses will be issued in calendar years 1994-1998 unless the applicant possessed a license in the previous calendar year (Section 6749-0). A permit does not have to be used for it to remain valid (Creaser, 1994, Urchin Workshop) and there are no written regulations concerning transferability.

The announcement of a limited entry system caused many to enter the fishery before it was closed in July, 1994. While in 1993 there were 1439 hand and 568 boat dragger licenses, in 1994, when the fishery was closed, there were 1654 hand and 947 boat dragging licenses and approximately 600 tender licenses (Creaser, 1994, Urchin Workshop).

Permits and Fees: The permit structure also changed with the new regulations. A person now must not only be a resident of Maine to obtain a license, but must also obtain an individualized license depending on the type of fishing method (boat/dragger or hand harvesting). A surcharge of $160.00 is to be levied on license fees for all licenses issued in calendar years 1995, 1996 and 1997 (Section 6749-0). These funds will be designated for research needed to better understand urchin resources. With the surcharge, the overall cost of a dragger/hand harvesting license increased from $89.00 to $249.00. The industry supported this measure as the funds will be set aside in 'The Sea Urchin Research Fund' and used solely for urchin research (Creaser, 1994, Urchin Workshop).

Additional surcharges were added to the following permits as well: On the sea urchin boat tender's license, a $35.00 surcharge was established, raising the overall cost of this license to $124.00. A wholesale seafood license with a sea urchin buyer's permit was assigned a $500.00 surcharge and a wholesale seafood license with a sea urchin processor's permit was assessed a $2,500.00 surcharge.

These surcharges have been in place since January, 1995 and are designated for sea urchin research projects (Creaser, 1994). One uncertainty about this fund is who will be using it. Although the State Legislature has approved these funds, they did not approve the establishment of new positions at DMR with which to carry out research. Therefore, it is unclear whether DMR will obtain new job positions and carry out the research or whether the research will be contracted out to universities or other organizations (Creaser, 1994).

The State also adopted a zonal program requiring a licensee to choose either of the two zones in which to fish. Zone 1 includes all coastal waters west of Fort Point State Park on Cape Jellison and south to the boundary of the state's coastal waters. Zone 2 includes all waters east and north of Fort Point State Park to the boundary of Maine and Canadian waters. This boundary basically splits Maine waters through the middle of Penobscot Bay. A boat with a dragger license is not allowed to hold permits for both areas. Similarly, a hand harvesting license is valid for only one zone.

By adopting the zonal plan, the State has reduced the overall time in which processors and exporters are without product while increasing the overall time in which urchins are protected from fishing pressure. This is accomplished by overlapping the seasonal closures in each zone. Past regulations mandated a May-August state-wide closure. In the Act, Zone 1 is closed from April 1 to August 15 in calendar years 1995-1998 while Zone 2 is closed from May 15 to October 1 (Section 6749-N).

In addition to seasonal closures, DMR has also restricted the time of day in which harvesting may occur. Urchin harvesting is prohibited between sunset and sunrise in Maine territorial waters. Size regulations remain at 2 inches as established in 1993 and a 10% tolerance is allowed for unsorted piles on boats. This is to compensate for the non-selective catch of draggers. The tolerance is determined by numerical count of between 1/3 bushel and 4 pecks taken randomly from the bulk pile (Maine DMR Communication dated 12/10/93). Culling must be done at sea to reduce overall fishing mortality of undersized urchins. Culling tables have been designed which are reportedly imperfect but still helpful (Creaser, 1994, Urchin Workshop). A maximum width on dredge beams has also been established. This restriction was enacted due to the increased incidence of both larger and more dredges being used per boat (Creaser, 1994, Urchin Workshop).

Lastly, stipulations have been made concerning logbooks. Logbooks are useful in obtaining information about stock size, average urchin size, relative abundance, and roe quality. Although no formal guidelines and regulations have been made, the 1994 Legislation calls for the Commissioner of DMR to develop logbook guidelines. Log books will be required of any person holding a wholesale seafood license with a sea urchin buyer's permit or a wholesale seafood license with a sea urchin processor's permit

(Section 6749-S). License holders will be required to buy the appropriate logbooks from DMR and these fees will cover logbook development and data analysis costs. Operating and personnel costs associated with the logbook will be allocated from the 'Sea Urchin Research Fund.'

An Act Concerning Commercial Divers

The other significant change in the fishery related to diver safety. In 1993, four people were killed in Maine while harvesting sea urchins. In response to these fatalities, the Occupational Safety and Health Administration (OSHA) began to investigate the worker safety of those involved in this fishery.

The pressure from OSHA obviously had an influence on the Maine government as the issue of diver safety had been addressed and tabled in the 1993 legislation. In 1994, however, the Legislature decided that diver safety was indeed an issue and passed H.P. 973-L.D. 1304, 'An Act Concerning Commercial Divers.' The Act made it mandatory for holders of hand harvesting licenses to attend a diver safety workshop developed by DMR. Prior to this, any person could obtain a hand harvesting license without any proof of diver safety training.

One important stipulation of this Act is that a licensed hand harvester is ineligible for the course unless s(he) holds a valid open water diver certificate which meets the standards established by the American National Standards Institute (ANSI). The course is intended to train commercial harvesters in conditions similar to what they will experience when diving in rougher fall and winter weather.

Although the success of the new laws remains to be seen, some industry leaders feel the new legislation may actually cause more harm than good. Jim Bolen of the Maine Urchin Harvesters Association is concerned about the three month time window which allowed people to enter the fishery before the limited entry system began. He has also expressed concern about the new fishing zone program. Bolen feels that the zonal approach will result in greater fishing pressure east of Penobscot Bay in Zone 2 as urchin populations are more plentiful in this area (Maine Times, April 22, 1994). According to DMR, there are significantly more boats involved in Zone 2 as in Zone 1, indicating that there is in fact higher fishing pressure east of Penobscot Bay (Lewis, 1995, personal communication).

Another concern about the 1994 legislation is the seasonal closures. To satisfy processors, DMR opted to stagger closures to ensure year-round processing. By staggering harvest times, urchins in some regions may be harvested when their roe quality is poor. Regional variations are believed to exist in spawning times throughout the range of *S. droebachiensis* in Maine waters and staggered closures may reduce the reproductivity and market value of regional urchin supplies (Dowling, 1994).

Characteristics of the Green Sea Urchin Fishery in Maine

Most early fishery involvement consisted of lobster fishers trying to earn extra income during the winter months when lobstering is slow. Although still true, more people are now involved full-time in the sea urchin fishery. For fishers, income can be earned by dragging, acting as a platform for divers, acting as a tender, or being a commercial diver. Other revenue is generated by local dive shops which sell air and SCUBA equipment, and by exporters, distributors, and processors, among others.

The fishery has resulted in enormous economic gains for the State and provides sources of needed winter employment. As most coastal businesses operate for the late spring-early fall tourist industry, many people struggle through the winter months. As the primary urchin season is in the winter, the fishery alleviates job shortages in some areas.

Cooperation between State agencies and industry has been generally good, although some fishing industry/management conflicts have occurred. Examples are the initial opinion of industry that the State needed to do more to manage the fishery. This was followed by general dissatisfaction with State mandated management measures. Industry has generally done a good job of providing DMR with information concerning relative abundance and roe content. Response to impending mandatory log books has also been good (Creaser, 1994, Urchin Workshop).

The preferred gear selection for urchin harvesting in Maine has been draggers, primarily scallop draggers, and hand harvesting with SCUBA. Dragging provides a greater volume of urchins but also causes more damage to the catch (Cooperative Extension Service (CES), 1988). According to Japanese trading company representatives, spines are often scraped or broken off by the weight of the dragging equipment, allowing salt water to enter the shell and destroy the delicate membrane surrounding the roe (CES, 1988).

Destruction of this membrane could cause a market price decline or a complete product rejection. To minimize damage, use of a light weight dredge with a polypropylene type net with a maximum drag time of five minutes is recommended (CES, 1988).

Dragging is the preferred harvest method in areas of relatively flat, rocky benthos. In regions of irregular bottoms or frequent ledges, diving is preferred. Large urchin populations exist around kelp beds where draggers are not desirable due to the damage caused by pulling up kelp holdfasts. This will ruin the feeding area.

Divers typically use baskets or bags to collect urchins on the bottom. When a bag is full, the diver will attach it to a line which is then pulled up by people on the boat. The use of this line is helpful as it increases the amount of time a diver can spend picking up urchins, as well as minimizing the health risks associated with frequent ascents and descents. In general, diving is preferred in the western waters of the State where tidal ranges and forces are weaker than those in the eastern coastal sections (Chenoweth, no date). Generally urchins are taken from waters less than 50 feet deep.

Another method which can be used, but is not as common in the Maine industry, is the airlift. An airlift lifts urchins and the associated water mass are lifted to the surface by releasing compressed air underwater into a water filled pipe or tube. Although this method can be very effective, it has several drawbacks which include expense of the compression system, total amount of urchins lifted per minute, increased on deck sorting, and limitations of area covered due to overall length of hose and compression power (CES, 1988).

Sea Urchin Processing

Roe quality is very important as most of the product is used fresh in sushi restaurants. In general, there is a 10% recovery rate of harvested sea urchins. Therefore, for every 1,000 pounds of sea urchins caught, 100 pounds of salable roe is extracted. Once urchins are landed, there are two options open to processors and exporters: air freight the urchins whole to Japan or extract the roe within the State and air freight only the freshly picked roe. There are advantages and disadvantages with each method.

For air freighting whole urchins to Japan, the biggest benefit is a minimum of handling and labor costs. The largest disadvantage is the cost of shipping the entire urchin when only 10% of that weight is marketable. For air freighting the roe only, the benefits and disadvantages are reversed. The benefits of shipping only the roe are as follows: Air freight costs drop dramatically as only the salable part of the urchin is being shipped. Since more work is involved, there is also greater economic gain in the form of in-state jobs. Finally, there is assurance that only the best roe is being shipped, thereby increasing credibility and product satisfaction. One drawback to processing in Maine is that the Japanese are very particular about how their seafood is handled. This often results in dissatisfaction with American handling and a subsequent product rejection. Another drawback is that there is greater overhead in maintaining a 24 hour processing crew who work in cold, wet warehouses on an urchin supply basis performing very labor intensive, precise work.

In most cases where processing is done within the State, Japanese urchin specialists are hired to train workers and oversee plant processing. Improved roe processing will minimize product dissatisfaction in Japan. This is a useful option for American processors as it is difficult to understand a culture that values seafood quality as highly as the Japanese. With training by someone familiar with Japanese standards, workers learn exactly what skills are needed. Most Americans would be unable to provide this service without Japanese assistance.

The following chapters review a variety of sea urchin fisheries throughout North America. While the Maine fishery has already enacted many management measures, an overview of what other regions are doing is intended to serve as an additional source of information for Maine managers. Other sea urchin fisheries with longer histories of both fishing pressure and management offer invaluable and timely information about these fisheries.

CHAPTER 4

Sea Urchin Fisheries of the West Coast of North America-Histories and Management Techniques

Sea urchin fisheries have existed on the west coast of North America for decades. Most of the west coast, with the exceptions of Alaska and British Columbia, have already experienced intense fishing pressure and subsequent fisheries declines. Consequently, west coast managers have been researching and implementing management measures far longer than has Maine. Although most western sea urchin fisheries are for *S. franciscanus,* the sedentary nature and role of sea urchins in sub-littoral communities make analogies between fishery trends and management strategies for different sea urchin species applicable and valid.

Contemporary fisheries management often borrows strategies and ideas from other fisheries which have experienced similar problems or situations. The wealth of knowledge that exists can, if researched and applied correctly to the targeted fishery, provide data comparable to those provided by long-term fisheries studies. By researching and applying management strategies from other fisheries, managers are giving their fishery the best chance of reaching sustainability and avoiding the declines which so often occur in sea urchin fisheries.

This information is by no means perfect or complete. It does offer general guidelines to make the best decisions to meet the goals of individual fisheries. This is particularly true if the fishery has not had the benefit of specific, long-term research about the target species or the fishery in general. The best information for those managing emerging sea urchin fisheries is to look at what others have done before them.

The logic for this is twofold: First, managers can use the information obtained from other states with minimal cost and time, resources many states, especially Maine, do not have. Second, many past management objectives which seem reasonable in theory may accelerate the problem instead of solving it. If one sea urchin fishery has experienced negative effects from a specific management strategy, there is little to be gained from others trying the same strategy.

The following provides a review of the histories and management measures of west coast urchin fisheries. When known, the effectiveness of these measures is also reviewed. The case studies of the west coast sea urchin fisheries illustrate a general pattern which almost every sea urchin fishery follows. In the first few years of the fishery, there is little fishing effort and landings remain fairly small, generally small enough to give regulatory authorities a sense of not needing to regulate the fishery. By the third or fourth year, there is increased fishing effort and landings. With these developments, concerns grow about stock status and the future of the marketable stock, resulting in regulation and monitoring of the fishery. Finally, most fisheries opt for drastic, detailed limited entry and quota systems to further safeguard the stock. These options are usually enacted due to concern about the future fishery or because the fishery has actually started to decline.

The fishery usually starts in shallow coastal waters in one geographic region and spreads to new regions and deeper waters to find harvestable stock. In Oregon, for example, Orford Reef, the primary region of fishing effort, was able to sustain the fishery until 1990, when a broad expansion into several other regions took place in search of additional sea urchin resources. Moreover, an increasing market tends to extend the time which divers or draggers spend fishing after the first few unregulated years. CPUE also tends to be high initially and steadily declines as regulations increase in response to the declining stocks.

The Maine fishery has in many aspects followed this model. The fishery started out very small and was originally totally unregulated. It then expanded into a large, economically important fishery in which stocks and CPUE are believed to be in decline. Regulation likewise did not occur in Maine until well after the fishery began. It is hoped that by putting the Maine fishery in the context of other North American sea urchin fisheries, it will be clear to future managers and regulatory agencies that management and regulation must begin at the outset - not after the problems have emerged, by which time the fishers are reluctant to consider any controls on their activities. Also, by this time, measures may not work. The result is a fishery driven by market forces rather than by the sustainability of the resource.

The Oregon Sea Urchin Fishery

Commercial harvesting in Oregon of the red sea urchin, *Strongylocentrotus franciscanus* began in 1986 and in 1992 for the purple urchin, *S. purpuratus.* Like other sea urchin fisheries, Oregon's experienced enormous expansion and development. Fifty-five thousand pounds were landed in 1986, rising to over nine million pounds in 1990 (McCrae, 1993). In 1991 and 1992, Oregon began to experience a decline in pounds landed (Figure 4.1) as well as in CPUE.

In 1984, an Oregon State University researcher conducted an economic feasibility study for a sea urchin fishery. The study generated interest in the industry although logistical factors made development economically difficult. At that time, the only major distributors were located in Southern California, making it costly for fishers to market their catch at its best quality (McCrae, 1989).

The decline of the Southern California sea urchin fishery and the subsequent expansion to Northern California waters in 1986 is seen as the primary reason for the emergence of Oregon's urchin fishery. As this fishery expanded north, many processors and distributors also moved, making international urchin markets more accessible to Oregon harvesters (McCrae, 1989).

This northward movement also made urchin harvesters in Southern Oregon concerned about the possibility of the large California fleet moving into Oregon waters. Due to the extent of overcapitalization that had occurred within the California fishery, the motivation for harvesters to move north to continue making profits was high.

In response to the perceived threats, Oregon fishers lobbied to pass legislation to protect urchin resources. In the 1987 legislative session, HB 2934 was passed, authorizing the Oregon Fish and Wildlife Commission (OFWC) to establish a limited entry system for commercial harvesting of sea urchins. The bill was signed into law in June, 1987 under emergency provisions and OFWC developed regulations which were put into effect in January, 1988 (McCrae, 1989).

By the provisions of HB 2934, the maximum number of permits was set at 92, with biennial renewals. In order for permits to be renewed, a minimum of 20,000 pounds had to be landed over the previous two years. Unrenewed permits were reissued through a lottery system and permits were non-transferable (McCrae, 1993). Other regulations adopted were a minimum test diameter size of three inches, fishing depth of 10 feet or more measured from mean-lower-low-water, a logbook requirement, and a maximum of two divers in the water concurrently from the same boat.

There are no closed seasons in the Oregon fishery and in 1992 the number of harvesting days ranged from 16-31 days monthly, with highest numbers of days fishing occurring in the late spring-early fall (Figure 4.2). There was also a 10 fold increase in the overall number of fishing days from a total of 28 days in 1986 to a total of 280 days in 1992. The biggest factor cited for non-harvesting days was bad weather (McCrae, 1993).

In 1989, the fishery was reviewed by OFWC. Concerns about the status of the fishery led to a reduction of permits to 46 and an alteration in the biannual harvesting requirement of 20,000 pounds.

The new permit renewal requirement mandated that a permitee harvest 20,000 pounds annually in order to renew the permit each year. In 1989, 92 permits were issued and by 1993, the target of 46 permits had been achieved (McCrae, 1993).

In 1991, minimum size limits were increased from 3.0 to 3.5 inches based on findings that gonad index would be better from larger urchins and that a higher minimum size would help increase the probability that younger urchins would spawn prior to harvesting (Golden, McCrae, and Richmond, 1991). Along with the increased size limit, a tolerance of 100 urchins between 2.0-3.5 inches per diver was established. In 1992, this tolerance was reduced to 50 to further protect juvenile urchin resources.

Logbook requirements help a management agency obtain information about fishing effort, stock abundance and distribution, as well as vertical placement of urchins. The one drawback is that managers are forced to trust fishers to be honest about their recordings. Compliance with this type of regulation is always an issue of concern.

Logbook requirements have been viewed as a positive measure in Oregon. Compliance from divers has been good. Over 80 percent of trips are accounted for in the logbooks. Data collected from log books includes fishing area, average depth, dive time, and pounds harvested (McCrae, 1993). Data from logbooks indicate CPUE is declining, average depth of harvesting is increasing, and regional distribution of harvesting has greatly expanded. These indices illustrate how several years of fishing effort ultimately affects the overall resource and its future viability.

The Washington Sea Urchin Fishery

The *Strongylocentrotus franciscanus* fishery in Washington began in 1971, making it, along with California's, the oldest sea urchin fishery in North America. In the first four years of harvesting, less than 100,000 pounds were taken annually (White, 1993). During this time, there was little concern over stock status or overfishing. Consequently, management was passive, with only a license and landing records required by the State. The primary objective of these management policies was to provide statistical information to the Department of Fisheries and to prevent waste of the resource (Washington Department of Fisheries, 1978).

In 1975, a Japanese import company, in conjunction with a California processor and a number of divers arranged to work with a Port Townsend, Washington fish processor to begin sea urchin processing in Washington (Washington Department of Fisheries, 1978).

Establishment of processing capabilities made possible a significant expansion of this fishery. In 1976, landings jumped to 1.6 million pounds, raising concerns over the fishery. In January, 1976, 220,000 pounds were landed, more than double the landings of the previous fishing season. The landings were worth $125,000 to fishers and had an estimated export value of $400,000. Due to the dramatic increase in landings, the Washington Department of Fish and Wildlife (WA F&W) began to actively manage and research the fishery. The stated objective of the WA DOF in managing the fishery is to maximize the long-term net yield of urchin resources while minimizing the impacts of the fishery on other marine resources and the marine environment (Washington Department of Fisheries, 1979).

In 1977, WA F&W began underwater biological surveys of urchin populations. Information collected included urchin densities, size, gonad quality, substrate, associated animals, macrophytes, and based on these findings, whether the area was suitable for commercial harvesting (Washington Department of Fisheries, 1978).

During the period 1977-85, the fishery remained fairly stable in terms of effort and entry of new boats (White, 1993). Fishing was done by divers working from boats in waters of 25-45 feet. Hand removal of urchins was mandated in the 1976 regulations and divers generally use surface air compressors and carry bags which hold approximately 500 pounds of urchins each. Filled bags are hauled aboard by a winch and emptied bags are lowered to the diver. Divers can stay in the water for more than six hours per day and harvest rates can exceed 1000 pounds per hour per diver (WA DOF, 1979).

From 1985 to 1989, the number of boats in the fishery more than doubled annually from 12 boats in 1985 to 197 boats in 1989 (White, 1993, Figure 4.3). Landings also rose during this period, culminating in an emergency closure during the 88-89 season (Oct.-Feb.) when 8.1 million pounds were landed (Figure 4.4).

Prompted by the closure, the industry and state agencies agreed upon a limited entry system for the 1989-90 season. The limited entry system called for a reduction in the number of fishing boats by 68 percent. However, due to increased effort by the remaining boats, landings only declined by 35 percent, and yearly landings were still too high at 5.2 million pounds (White, 1993). Along with increased effort, the Court was allowing some fishers to return to the fishery due to claimed hardship, resulting in higher fishing pressure. These issues lead to further regulation in 1990-91 in which the fishing week was limited as was the number of divers in the water concurrently from any boat. Total time spent fishing was also reduced.

In 1993, results from five years of biological surveys indicated a significant decrease in landings was essential to keep the fishery viable. Based on survey findings and fisheries modeling to determine total allowable catch, WA F&G estimated that 1.1 million pounds was the maximum catch that should be taken to insure future recruitment (White, 1993). Therefore, in the 1993-94 season, a quota was established at 1.1 million pounds, representing an 80% decline from previous annual landings.

Studies are still being conducted on the Washington red sea urchin fishery and new management measures are being considered as needed. It is clear that Washington has followed the familiar pattern of starting small, increasing rapidly, and then needing regulation and management in order to limit or avoid fishery collapse.

The Washington Green Sea Urchin Fishery

Washington also began a fishery for the green urchin, *S. droebachiensis* in 1986. In the 1986-87 season, 65,000 pounds were landed, warranting little attention from the State. In the 1987-88 season, landings rose to 1/2 million pounds, and more than doubled again to 1.29 million pounds in the 1988-89 season, at which point WA F&G became involved in the fishery. Since 1989, the Washington green sea urchin fishery has followed the familiar pattern, with annual landings of *S. droebachiensis* declining consistently.

In 1988-89, several biological surveys were conducted, precipitated by that season's drastic rise in landings. Based on information gathered from these surveys and other data, a quota of 600,000 pounds was established which went into effect in the 1993-94 season. This represents a decrease on landings of over 50 percent in a few years. In Washington, licensed divers may still take red or green urchins.

In the Washington sea urchin fisheries, management and regulations did not occur until the fishery rapidly expanded. Although this is not uncommon in fisheries management, these cases illustrate the importance of beginning regulations in a proactive manner. This is particularly important in the sea urchin fishery as local Washington fisheries illustrate.

The California *S. franciscanus* Fishery

California's *S. franciscanus* sea urchin fishery is probably the best recorded and researched such fishery in North America. The fact that it is the oldest and the largest account for this. Much of what is known about sea urchin fisheries in America comes from trial and error and research results in this fishery, which began in Southern California in 1971, primarily by the efforts of NMFS. The objective was to start a fishery to eradicate urchins as they were destructive to kelp ecosystems and, therefore indirectly to valuable fish stocks (Kato, 1972). In the mid 1980's the fishery expanded to northern California.

For management purposes, the northern and southern California sea urchin fisheries have been subject to two distinct management strategies. The northern fishery as defined for management purposes by the California Department of Fish and Game (CDFG) is comprised of the coastal area between the California-Oregon border in the north and the Monterey-San Luis Obispo County Line to the south (Kalvass, 1992). The southern fishery management area includes all coastal areas south of this county line. In the earlier stages of these two fisheries management techniques were similar, but, in the past several years management has varied, as will be discussed below.

The southern fishery rose steadily from a few thousand pounds in 1971 to about 25 million pounds by 1981. After 1981, landings declined and by 1984 only 15 million pounds were landed. The following year (1985), the first landings in the northern fishery occurred. This fishery rose dramatically from less than 1 million pounds in 1984 to 31 million pounds in 1988 (CDFG, 1994), but has been declining steadily since that time to a low of 7 million pounds in 1993 (Figure 4.5). Southern California landings briefly rose during the period of 1985-1990, but then declined to approximately 17 million pounds by 1993.

In the 1988 season over 50 million pounds of sea urchins were landed in the combined fisheries, making them the second most valuable fish stock in the State. Between 1988 and 1993, however, landings for the combined fisheries dropped 55 percent to 23 million pounds (CDFG, 1994). The northern California 1993 landing of around 6.6 million pounds represents a decline of 24 million pounds in just five years (CDFG, 1994).

Fisheries indices support that the fishery is in danger of becoming non-sustainable. For example, the number of permits has dropped from 915 in the 1987-88 season, when a moratorium was established on the issuance of new permits, to 564 in the 1993-94 season. Despite this significant drop, the overall number of permits is still too high and there is concern whether this will further undermine the sustainability of the fishery. Surveys of the northern California fishery found declines in relative abundance of legal sized urchins ranging from 61-76% between 1988-1991 (CDFG, 1994). Further, CPUE figures are also substantially declining in the northern fishery. CPUE is measured in terms of pounds harvested per active diver hour. CPUE of 684 pounds per hour in 1988 has dropped to 250 pounds per hour in 1993 (Figure 4.6, CDFG, 1994).

The ex-vessel landed value of the sea urchin fishery peaked in 1991 at a high of 32 million dollars. The reason for the continued price increase after the decline in actual landings is probably due to the fact that immediately following the drop in pounds landed, the price increased in response to dramatic supply and demand conditions. However, by 1993, ex-vessel value had dropped to 20 million dollars, a net ex-vessel value decline of over one-third in two years.

In terms of management of the fishery, there have been many alterations and adaptations of management techniques. When the Northern California fishery began in 1985 a permit requirement was instituted. Landings in 1985 were 20 million pounds. In 1987, when landings jumped to 45 million pounds, a moratorium was placed on the issuance of new permits. In 1989, at the peak of over 50 million pounds landed, a minimum size limit of 3 inches was established.

In 1990, as landings decreased to 32 million pounds, the size limit was increased in the Northern fishery from 3.0 to 3.5 inches and the month of July was closed to fishing. Statewide regulations included the adoption of a four day week during September. A limited entry system was also established at this time. In 1992, with about 32 million pounds landed, the minimum size limit was increased to 3.25 inches and a two-day fishing week in July was established for the Southern fishery. Statewide regulations included a three day fishing week in June and August and a four-day week in April and October.

For the 1994 season, CDFG adopted more measures to facilitate red sea urchin resource recovery through the introduction of a three-tier management approach. Tier 1 includes the following measures: 1). Establishment of total allowable catch (TAC), 2). an October 1-May 31 statewide fishing season, 3). implementation of exclusive north/south permits (CDFG, 1994). Tier 2 includes the establishment of a maximum size limit of 4.75 inches and Tier 3 includes bay closures as part of the resource recovery studies program.

As is evident from the above discussion, management of this fishery is constantly changing as new information is obtained or as the fishery further declines. The need to alter management strategies so frequently is indicative of the difficulty of trying to protect an already heavily overfished and capitalized fishery. The following management strategies in Alaska and the Canadian provinces illustrate a more proactive approach which may ultimately lead to a different outcome for these fisheries.

The Alaska Sea Urchin Fishery

A fishery for the red sea urchin *S. franciscanus* has existed in Alaska since approximately 1981, with a peak harvest of over 600,000 pounds in 1987. A fishery for *S. droebachiensis* has existed since 1985 with average landings of approximately 70,000 pounds in the period 1985-1992 (Woodby, 1992). The red urchin fishery is located primarily in Southeast Alaska, while the green urchin fishery is located around Kodiak Island. The green sea urchin fishery requires a minimum size of two inches and has a fishing season of October-March (Munk, E.J., personal communication).

Management of sea urchin resources in Alaska is extremely conservative in comparison to the management strategies other sea urchin fisheries discussed. Although sea urchin resources are largely undeveloped in Alaska (Woodby, 1992), the Alaska Department of Fish and Game (ADFG) is aware of the potential fishing pressure that could be placed on these resources and has therefore decided to take proactive versus the generally followed reactive measures of California, Washington, and Oregon. ADFG hopes that proactive management will lead to orderly fishery development and future sustainability of urchin harvests while minimizing alterations to the nearshore marine environment and other associated species (Woodby, 1992). Concern is not unfounded as drastic regional increases have occurred in Alaska. In Cook Inlet, for example, 10,000 pounds were landed in 1991, and 25,000 in 1992. However, in 1993, 190,000 pounds were landed, prompting ADFG to close this region to fishing (Larson, personal communication).

By implementing management practices before major overfishing has occurred, the Alaska sea urchin fishery will provide valuable information about management alternatives as well as the associated impacts on both the fishery and fishers. In formulating management strategies measures were based on the assumption that the sea urchin fishery is a developing one in which little is known about biomass or productivity. Based on this and on initial surveys of urchin populations, a quota of three percent of total biomass per year was established. This figure represents the estimated natural replacement rate of a mature, virgin urchin stock (Woodby, 1992).

Specific management strategies in Alaska include seasonal limitations which correspond to seasons when roe is of marketable quality, use of a three year rotational harvest schedule, setting size limits, and harvest ceilings in areas of intensive harvesting. ADFG has been authorized by the Alaska Board of Fisheries to be the department in charge of sea urchin management and under this obligation, now requires a permit for all urchin harvesters. The permit may stipulate location and duration of harvest, limitation on gear and harvest procedures, and require periodic or annual reporting (ADFG, no date; 5 AAC 38.062). Currently, Alaska Commercial Shellfish Regulations limit gear to hand removal aided by SCUBA or an abalone iron (5 AAC 38.051).

Although these strategies are in place, ADFG admits to not knowing what season is best for roe quality, what size limits should be set at, and what overall urchin biomass exists. This lack of information is common in other sea urchin fisheries, however, ADFG has differed from other regulatory agencies in that it has acknowledged this lack of information and funding for research. Consequently, the ADFG decided that conservative measures were the best approach for sustaining the fishery (ADFG, no date).

Alaska is to date the only state which has managed their sea urchin fishery in a conservative manner from the outset. However, Alaska is not unique in North America. Canadian provinces have also taken a more cautious approach. New Brunswick and Southern British Columbia are two examples of this.

Sea Urchin Fishery Management in Canada

A *S. franciscanus* fishery has been active in British Columbia since 1970 and a *S. droebachiensis* fishery commenced in 1987 (Harbo and Hobbs, 1992). An experimental fishery for *S. purpuratus*, the purple urchin began in 1990. The federal Department of Fisheries and Oceans (DFO) is the agency charged with management of sea urchin resources in Canada. In British Columbia, the province has been split into two distinct management units: the South and North fisheries. Different management strategies exist in each region. Management of the southern fishery is seen to be more conservative than that of the north (Harbo and Hobbs, 1992).

In the south, 26 zones with individual quotas have been established. An overall biomass removal target of 5% has been established to limit potential over-exploitation. This appears conservative since little local data exists which indicates that this fishery is already operating at sustainable levels. Time, season, and size restrictions have also been established.

The northern fishery is year round and minimum and maximum size limits have been set, although no further measures will be implemented until more is known about stock status (Harbo and Hobbs, 1992). The North is also planning to establish a rotational fishing plan as a result of reduced numbers of urchins in the 4-5.5 inch range, the legal size range of red urchins in the North (Harbo and Hobbs, 1992). Once surveys reveal a significantly reduced number of red urchins in this range, the surveyed region would be closed for a minimum of three years.

Landings in the red urchin fishery remained fairly low throughout the 70's and began experiencing large growth in the 80's, peaking in 1991 with 14.8 million pounds in the south and 11.8 million pounds in the north. Landings for green urchins peaked in 1992 with approximately 20 million pounds (984 tons) landed (DFO, 1994). The fishery has been declining both in landings and in value in the past two years.

The green urchin fishery is a dive-only fishery, and due to patchy distribution there is heavier reliance on SCUBA than on surface air sources (DFO, 1994). A minimum size limit of 2.15 inches for green urchins is in force as is a fishing season of October 1 through February 28 (DFO, 1994). License limitations were introduced in 1991 but did little to reduce fishing effort as there has been an increase in both the number of divers and diver hours (DFO, 1994).

In 1994, DFO established a ceiling of 990,000 pounds (449 tons) for the South fishery. Twenty five percent (250,000 pounds) is the maximum amount which can be taken in the January-February fishing season, with the remaining 75% to be taken in the fall fishing season (DFO, 1994). This initial precautionary TAC for 1994 reflects a drastic decrease from 1993 fishing levels, and DFO feels landings may need to be further reduced in the south.

Open seasons and times vary among locations and between the North and South fisheries. Boat captains are required to report landings and fishing effort weekly. Harvest amounts must be recorded daily and records kept on board at all times for inspection and review. Additionally, many regions have been permanently closed to urchin fishing. Closures encompass Marine Parks, Research and Marine Reserve Areas, Ecological Reserves, native allocation areas, and study or research areas (DFO, 1994). Boat captains must also notify DFO within 24 hours of commencement and cessation of a fishing trip as to number of divers and area to be fished.

Catch reporting is required of processors as well as of fishers. Processors must report weekly landings and number of vessels in the previous weeks' activity (DFO, 1994; 8.9). Exporters shipping urchins to another province, territory, or country are required to provide written records of total weight to be exported, area of catch origination, export destination, and location and time of export (DFO, 1994; 8.10). If urchins are processed at federally registered plants, the above requirements do not apply.

Other Sea Urchin Fisheries of North America:

Similar to the Maine fishery, the New Brunswick green sea urchin fishery began in the 1960's as a small-scale local fishery (Robinson, 1994). The fishery began in the Grand Manan area and then spread toward Maine and the Campobello area. In neighboring Maine, where the urchin industry is booming and based on supply and demand, demand could not always be met. Therefore, Canadian fishers began to transport urchins to the Maine market, increasing effort in Canadian waters. The fishery has been extremely successful economically and fishers and regulatory agencies are working together to implement appropriate socio-environmental management practices. Urchins are collected by both divers and scallop draggers.

Regulations include an October1-May15 fishing season, a minimum size limit of 2 inches, sorting at sea, daylight harvesting, a maximum of two divers per boat in the water at a time, mandatory reporting of catch in logbooks, refuge closures for research purposes, and maximum limits on the size of scallop drag.

To the south of Maine, another green urchin fishery has developed. The Massachusetts urchin fleet is primarily composed of draggers. Most are either lobster fishers looking for winter income or finfishers seeking an alternative to the declining finfish and collapsed groundfish fisheries (Carr, H.A., 1994 Urchin Conference). The regions of largest fishing pressure are Beverly/Salem and Boston Harbor, where catch is lower but, surprisingly, of better quality and quantity of roe (Carr, H.A., 1994). Figure 4.7 shows Massachusetts landings in the past few years, illustrating the rapid emergence of this fishery. The Massachusetts Department of Marine Fisheries

(MADMF) is the state agency charged with management and is currently investigating management needs and areas of concern with the urchin fishery.

Sea Urchin Fisheries of the Caribbean: St. Lucia and Barbados

Many Caribbean nations have had strong local markets for sea urchin roe and the economies derived from these fisheries are considered very important to local communities. Eastern Caribbean fisheries are by law open access, although a few community-based access restrictions do exist for specific fisheries (Smith and Berkes, 1991). For the most part, however, eastern Caribbean governments encourage participation in fisheries, increases in gear use and technology, and entrance of new participants into the fisheries. The primary objective of eastern Caribbean governments has been to obtain self sufficiency in fish production (Smith and Berkes, 1991).

Two examples of sea urchin fisheries in the Caribbean region include those of Barbados and St. Lucia, which have very different fishery characteristics. They are also the only two eastern Caribbean countries to have taken measures to regulate their urchin fisheries (Smith and Berkes, 1991). Also, as global demand and prices paid for urchins have increased drastically in the past decade, sea urchin fisheries in this region have been influenced by these increased economic opportunities.

The Barbados fishery for *Tripneustes ventricosus* has been active for more than a century and government management in the form of a closed season during spawning (May to August) has been in effect since 1879 (Scheibling and Mladenov, 1987). The fishery was quite stable until the mid-1980's, experiencing only minor variations in catch. However, during the past decade, declines have been so drastic that the fishery has virtually collapsed (Scheibling and Mladenov, 1987).

In Barbados, *T. ventricosus* inhabit patch reefs composed primarily of coral rubble which is interspersed with live corals, algae consisting mostly of *Dictyota* spp., or the sea grass *Thalassia testudinum* (Scheibling and Mladenov, 1987). Most urchins are taken in depths of between 5-8 meters from these patch reefs on the landward side of the offshore reef which runs along the southeast-east coasts of Barbados.

Skin diving is the primary method used to harvest sea urchins in Barbados. Divers generally swim from shore with a floating log to which are attached net bags. Urchins are scraped off the bottom with iron rods and deposited in the bags, which when full are brought back to shore by the diver. Twenty five percent of the total fishing effort is by this method alone. Sixty five percent combine the above method with the use of boats to transport divers and full urchin bags to and from reef areas (Scheibling and Mladenov, 1987).

Although quantitative fishery statistics documenting the decline do not exist, qualitative surveys of fishers and of stocks corroborate the observed decline of the industry. Fishers felt the primary reason for stock declines and fishery collapse was pollution and the secondary reason was overfishing. However, Scheibling and Mladenov (1987) believe that the spatial and temporal patterns of *T. ventricosus* depopulation suggest overfishing as the primary cause of or contributing factor to the demise of sea urchins. Declines were noted initially in the most accessible areas and spread as fishing pressure moved from primary fishing grounds. Further, since declines were observed in areas remote from major pollution sources, pollution was seen as secondary, well behind fishing pressure.

As a small scale, artisanal fishery, Barbados provides an interesting contrast to the large-scale, market-driven commercial fisheries to the north. It demonstrates that sea urchin resources are vulnerable to a wide range of harvesting pressures. Many of the management issues facing this fishery are similar to those facing the large, international market fisheries: recruitment protection; necessary size for reproduction; controlling fishing effort during spawning while keeping the market viable.

Recommendations for rehabilitation of the Barbadian fishery included a complete fishing moratorium for at least one year, the establishment of reserve areas closed to urchin fishing and strict enforcement of the closed season at the moratorium's end (Scheibling & Mladenov, 1987). In 1987, the fishery was closed to enable stock recovery. Another method considered a viable alternative, which involves little or no enforcement or compliance, is artificial stock enhancement through the development of sea urchin aquaculture.

The St. Lucian Sea Urchin Fishery

Similar to the Barbados fishery, the St. Lucian sea urchin fishery harvests *T. ventricosus*. Fishing method is free diving, either by swimming from shore or from dugout canoes. Most urchins are captured in waters less than 6 meters, the area of highest urchin distribution. Until the past decade, the fishery was seen as operating at sustainable levels. Fishing was conducted by families and harvesting occurred mainly during school vacation months. This meant that the resource was under pressure for approximately 1-2 months and had 10-11 months to recover. However, as urchin roe became more highly priced and in demand, commercial ventures tended to replace family- and community-based operations, placing greater year-round stress on the resource. Demand eventually exceeded supply and many more began to fish for urchins. Urchin fishers can earn several times the daily wages earned in other labor-intensive industries (Smith and Berkes, 1991).

In 1987, due to heavy fishing and stock decline, the St. Lucian government closed the sea urchin fishery to protect remaining stocks. Three interesting research approaches were taken to determine the best methods for managing the fishery once it reopened. The first two involved placing the resource under a state property regime or a communal, open access regime. The third and best solution found for St. Lucia was a system in which local communities worked with government agencies to formulate, regulate, and enforce management measures. This solution was successful in that individuals felt they had some control over the fishery and consequently, could exert influence to make others comply with government regulations.

This is a significant change from previous attempts at regulation in which laws were passed without provisions for enforcement which resulted in non-compliance. This led to a situation in which each fisher would take what they could, before another fisher did. By integrating users and managers throughout the management process, St. Lucia has developed an interesting community based management approach to a local fishery problem.

The Chilean *Loxechinus albus* fishery

The Chilean *Loxechinus albus* fishery has been in existence for several decades. Although the fishery has developed all along the 6000 km coast, many areas in the north are inaccessible due to a lack of roads across the Coastal Range or due to the thawing of the Bolivian altiplano which destroys existing roads in the summer. In the south, access is also limited due to the extensive islands that form the Austral-southern and South-Patagonian fjords. Consequently, fishing pressure has remained highest in the central part of the country (Vasquez and Guisado, 1992).

Chile and Japan are the largest consumers of roe (FAO, 1980, as used in Vasquez and Guisado, 1992). Due to high commercial value in international markets, the urchin industry is important to the Chilean economy. In 1985, for example, Chilean sea urchin landings of 30,577 tons were the second largest in global fish markets (Vasquez and Guisado, 1992). During the period 1985-1990, 76% of landings were frozen, 11.2 % dehydrated in alcohol, 6.8% canned, and 6.6% were consumed locally as a fresh product. During the past ten years, Japan has imported 90% of total Chilean exports (Vasquez and Guisado, 1992).

In 1987, the fishery was worth US $15.8 million in foreign currency and declined to US $7.4 million in 1988. The decline is still occurring, probably due to overfishing (Vasquez and Guisado, 1992). During the period 1949-1980, sea urchin landings did not exceed 2,500 tons per year. Landings were sustainable from 1975 until 1985 when over 30,000 tons were landed. Since 1985 landings have been declining and fishing levels non-sustainable. In 1990, only 15,648 tons were landed, representing a 50% decline in the total catch in just five years. Figure 4.8 illustrates sea urchin landings since 1970.

Management measures have included the establishment of a 2.75 inch minimum size limit, closures of fisheries concurrent with spawning seasons, and research into the establishment of non-use zones. Although these measures have been established, compliance has been a problem: at 18 processing locations, only 37.6% of the catch was of legal size (Sloan, 1984).

Another problem with management measures has been the establishment of a closed season which does not directly correspond to the spawning season (Vasquez and Guisado, 1992). According to fishing regulations established in 1981, sea urchin fishing is prohibited from November 1 to February 15. However, spawning seasons vary greatly along the Chilean coast, allowing fishing to occur during times of low roe quality or during the spawning season. Spawning has been recorded to occur between November and April in the north, from July to December in Central Chile, in November and December in South-Central, and from August to September in the South (Vasquez and Guisado, 1992).

Currently, Chile is researching the use of aquaculture in both controlled and natural environments as a means of repopulating urchins. Although reseeding may be promising, raising individuals to fishable size is not viewed as the best option for immediate reversal of the decline. Instead, coastal management in the form of establishing both no-use zones and rotational fishery zones is seen as the best option for Chile. In one recent experiment in establishing no-use zones in central Chile (Duran et al.,1987), reported that after two years of area closures, sea urchin populations had increased 25 fold. Similar results have also been reported in the northern experiment (Moreno and Vega, 1988, as reported in Vasquez and Guisado, 1992). The most important aspect of a future management plan for Chile is the concept of establishing the no-use zones and rotational fishery zones concurrently. This is considered critical for the future of the sea urchin fishery.

CHAPTER 5

Discussion

The fisheries previously described illustrate general trends and management techniques being utilized in sea urchin fisheries. The following is a general discussion of those methods and trends. The most notable management strategies being used include seasonal closures, size limits, area closures and rotation of harvest areas, establishment of marine reserves, gear restrictions, limited entry, quotas and logbooks. Although each of these techniques has different parameters, they provide a general set of sea urchin fishery management techniques.

Each technique can be adapted for use in new fisheries and the approximate outcomes can be projected from what has happened in other areas. However, if techniques are used prior to complete biological and socioeconomic studies, careful attention should be paid to any known differences between the region from which the management strategy has been taken from and where it is going to be introduced. Without complete studies, it is impossible to use management techniques from another region without any risk of adverse social, economic, or biological impacts.

The fisheries reviewed also indicate that not taking any management measures is economically, socially, and biologically destructive. All fisheries that initiated management after heavy fishing pressure had occurred have experienced economic and biological losses, not to mention increased costs of manpower to research, formulate, and enforce reactive measures. As this trend is evident, instigating management measures at the inception of fishery activity is the best option for both the sea urchin resource and the fishing community.

Although in some instances management without research is not advised, the sessile, easily accessible nature of sea urchins coupled with high demand and economic value, makes implementation of management essential to avoid overfishing. Otherwise, the concept of the "Tragedy of the Commons" will characterize this fishery (Hardin, 1968). Applying management guidelines from previous fisheries that have already experienced the rise, boom, and decline of an urchin based economy to more recent fisheries, such as in Maine, provides the best chance of avoiding economic and biological losses. Due to the many variables affecting any fishing economy and ecology, it is possible that negative impacts could result from management. It is clear, however, that negative impacts occur without management.

Seasonal closures are one of the most effective management measures. With the exception of Southern British Columbia and Oregon, all sea urchin management strategies include a seasonal closure which corresponds completely or in part to the spawning season. The benefits of fishery closure during spawning are to protect spawning populations and to allow spawning to occur prior to capture. This helps insure recruitment and also minimizes resource waste as urchins harvested during spawning are of low quality

(Mottet, 1976). Seasonal closures must be flexible to accommodate annual variation in spawning times or to accommodate varying spawning times within a management region. Although altering closure times to protect spawning may make enforcement difficult, there is little to be gained in having a closure that does not correspond to spawning seasons.

The disadvantage of a seasonal closure is primarily economic. This is especially true for the processors and export companies who are forced to shut down due to lack of a product. Overhead costs continue without income and more effort is needed to hire and train help on a seasonal basis. However, due to the lowered roe quality during spawning, potential economic gain is reduced. For fishers, the economic impact is probably less as in many regions, urchin fishers will seek other seasonal employment or work in other fisheries.

Test diameter size limits are a management measure employed by most sea urchin fisheries. Minimum size limits act to protect juveniles as well as to insure individuals spawn at least once prior to reaching fishable size. Maximum size limits are used primarily with *S. franciscanus* to protect large individuals which are important in providing a spine canopy under which juveniles may live and avoid predation. Maximum size limits have not been used for other urchin species of American fisheries as shorter spined urchins do not exhibit this canopy behavior.

There may be reasons other than canopy behavior to protect larger urchins. One reason is that larger urchins may be important in minimizing Allee effects, which are demonstrated by sea urchins. According to Allee effect theory, sea urchin spawning is density dependent and if low densities of urchins exist, reproductive success declines (Quinn et al, 1993). Release of spawn into the water is triggered either by water conditions or by the sensing of spawn from the opposite sex. In the second case, if low population densities are present, spawning success declines, reducing future recruitment. There has been either little or no research conducted on the importance of large individuals in terms of their role in aggregate behaviors which induce other urchins to aggregate. Protection of large urchins may be important for resource management until their role is better understood.

The other reason protection of large short spined urchins may be warranted is reported by Paul and Paul (1984) in which they review the work of Kawamura (1973). Kawamura reported several important biological characteristics of *S. intermedus*, which is morphologically similar to *S. droebachiensis*. One important biological characteristic described which is relevant to maximum size limits for the Maine fishery is that larvae produced by newly mature females have lower survival rates than those produced by older females (Kawamura, 1973, as used in Paul and Paul, 1984). This is significant information with direct relevance to management. If older females produce more viable larvae, they are more important for reproductive success. This is especially true in areas where urchin populations are already reduced due to overfishing.

Gear restrictions are also commonly practiced. While in some fisheries, diving is the only method allowed, in others dragging or a combination of the two are utilized. With diving, restrictions include a maximum number of divers per boat in the water at the same time as well as the total diving time allowed. Use of draggers may be limited to specific regions, may have maximum beam sizes, and minimum mesh sizes.

The largest controversy about gear selection is whether dragging is overly damaging to urchins and other benthic species of commercial value. Divers tend to have lower impact as they can be highly selective, taking primarily legal sized urchins with a minimum of juvenile mortality and non-target species capture. Drags, on the other hand, are highly unselective, taking urchins of all sizes above the minimum mesh size, if there is one. All other benthic organisms in the path of the drag are also susceptible to harvesting. This factor becomes important when species such as lobsters or abalone are affected by the fishing method.

Juvenile lobsters live in regions populated by urchins and dragging may damage habitat to a point where lobster recruitment is disrupted. Although the effects of dragging for sea urchins on other commercially valuable species have not been well documented, there is still reason for concern. An urchin researcher from the University of New Hampshire, feels that dragging should be avoided due to the environmental damage it causes (Harris, 1994, Sea Urchin Workshop). On the east coast, Maine, Massachusetts, and New Brunswick allow dragging.

The use of regional closures and fishing area rotations offer another management technique. In many instances closures and rotations have been used reactively in response to an overfishing situation in which these measures were seen as necessary to halt a regional resource collapse. If these techniques are used as general management policy and not as a crisis measure, they may be extremely effective.

Area closures are specific geographic locations that are closed to fishing. They are charted and can be stipulated as part of permit agreements. The purposes and benefits of area closures are numerous. The most important being that they provide an area where juvenile urchins can grow to legal size without any fishing pressure mortality. This enables the largest number of juveniles to reach recruit size. Grown urchins may move out of the closed area on their own or can be taken and seeded in open fishing areas (as is done in Japan). In the first instance, there is little capital investment in moving legal urchins to fishable areas while in the second there is capital investment and increased risk of disrupting the habitat in the closed area.

Area closures can be large with only one or two within a given fishery management area or can be small and well-spaced throughout the management region. The benefit of fewer closed areas is easier enforcement. The disadvantage is that they may attract a large number of fishers to fish around the perimeter for newly settled adult urchins, causing highly concentrated fishing pressure. Fewer closed areas also tend to benefit the fishers in the immediate coastal ports as the cost of getting to the vicinity of the closed area will be less. Fishers in far away ports would therefore be at a disadvantage. Regardless, based on closed area research in the Chilean fishery, this method is excellent for sustaining urchin populations.

The use of smaller, frequent closed areas has almost opposite impacts. The primary disadvantage is that enforcement will be difficult unless fishers act to regulate themselves. The advantages are that they will help to keep effort spread out within the fishery management area, will benefit more fishers by providing urchin recruits throughout a region, and will minimize potential losses if there is a regional disease outbreak or natural disaster. For example, if there is one fishery closure area and fishing pressure is high in this region, economic losses would be greater if a natural shift occurred such as a storm which wiped out stocks in that closed area. By having smaller closed areas, if one region undergoes a natural change disfavoring urchins, then the rest of the reserves may still be productive. Biologically, smaller, multiple reserves are beneficial as they minimize Allee effects, which are displayed by urchins (Quinn, Wing, and Botsford, 1993). If reserves are closer together geographically, densities of reproducing urchins will be maintained, resulting in increased reproductive success. Lastly, many small protected areas may be more efficient in reseeding surrounding waters than would be fewer and larger reserves as larvae can spend several weeks in the water column prior to settlement.

Rotation of fishing areas is a variation on closure schemes in which the management area is split into distinct fishing zones that are opened and closed on a rotating basis. Some sea urchin fisheries utilizing this technique operate on a four region rotation schedule as three years is the common time needed to allow most urchins to reach market size. Therefore, a four region system would allow fishing in region 1 in the first year, region 2 in the second, region 3 in the third, and region 4 in the fourth. In the fifth year, region 1 would again be opened, after three years of closure.

This management method offers an effective way of insuring that a portion of the juvenile urchin population reaches marketable size. A few parameters of this method must be addressed. The first is that fishing regions should not be so large as to force fishers and their families to migrate to ports accessible to the fishery area on an annual basis. In large fishing areas, such as the Maine fishery, the management regions may need to be subdivided to allow rotation on a smaller scale. The second issue which must be addressed is whether the effort (i.e. number of permitted fishers) is so great as to make rotation ineffective. If there is excessive fishing pressure prior to initiating a rotational scheme, an individual fishing region may not be able to support the increased pressure. This would be counter to the rationale for using a rotational fishing scheme.

Another management tool very common in sea urchin fisheries is the use of a limited entry system. Some fisheries, such as the Washington fishery, limited entry and then started reducing the overall number of allowable permits based on annual catch quotas. This method is used to more accurately match effort to overall removal rates of the resource. Other fisheries, such as Maine's, limited entry but do not have reduction plans or catch requirements/use requirements for renewal (Creaser, 1994, Urchin Workshop).

Limited entry can be beneficial as it reduces or controls the overall effort that can be exerted in the fishery. With limited entry, other variables such as time allowed fishing, number of divers per boat, etc., can be manipulated to better control effort once the net effort (i.e., number of permitted fishers) is known. Without limited entry, it is difficult to forecast and manage fishing effort in an already active fishery.

There are however several drawbacks to using limited entry systems. One of the largest is that limited entry systems do not by themselves restrict effort. Limited entry must be combined with effective limitations on gear, fishing time, etc. in order to work. Furthermore, limited entry systems are usually not established until after fishing effort is excessive. Initially, this results in fleet size in the limited entry system being the same size, or larger as in Maine, as the fleet was under open access (Andrews, B., 1990). Therefore, when limited entry is a reactive measure, it may do little to reduce or control effort in the initial stages. Historically, almost all fisheries which utilized limited entry systems have initially allocated permits which are well beyond the biological and economic sustainability of the fishery (Andrews, B., 1990). Limited entry does little to reduce overcapitalization as the incentive remains high for permitted fishers to upgrade or change gear or boat style to catch more of the target species.

A quota on the overall number of urchins that may be taken in the fishing year is also used. Although quota systems may regulate the overall annual biomass removal of a resource, general problems are common. The largest is high grading, in which less desirable individuals are discarded for better individuals with a greater market value. This results in high fishing mortality and causes more harm to the overall resource. Although there may be little incentive to high grade with urchins as it is difficult to determine quality by external appearances, the possibility still exists. For example, if a sample of a catch reveals poor quality, a fisher may discard the entire catch, resulting in large fishing mortality. A quota may also force fishers to concentrate effort directly in kelp beds and regions with good urchin food sources as best quality urchins come from these areas. This could cause greater kelp bed and plant-community damage.

Recommendations for the Maine *S. droebachiensis* fishery

Although Maine has already enacted a number of management measures, the following management recommendations may help sustain the fishery. Recommendations include a reduction in the number of permitted fishers, establishment of biological reserves, harvesting closures, expansion of use of urchins, limitations on the use of draggers, among others.

The largest problem facing the Maine fishery is the number of people legally allowed to utilize the resource under a limited entry system. In the 1992 season, 807 hand and 232 dragging licenses were granted, in 1993, 1439 hand and 568 dragging. In 1994, these numbers increased to 1654 and 947 respectively. Most of the new 1994 permits were granted after the limited entry system law was passed but prior to the July deadline (Creaser, 1994, Urchin Workshop). DMR does not plan on decreasing these numbers (Creaser, 1994, Urchin Workshop). Clearly, Maine is starting a limited entry system with too many participants in the fishery, which poses potential problems.

One problem with over-participation is that the resource is placed in greater danger of being depleted. With a large profit motive and eager market, urchin fisheries move quickly to a point around MSY and then quickly decline, unless effort is adjusted. With such high involvement, management becomes difficult and other sound measures may become ineffective as they are undermined by the sheer number of fishers.

An example of this is the Pacific halibut fishery of the 1920's. As managers tried to control this fishery and prevent it from crashing, a closed season of November 15 - February 15 was initiated. The purpose was to help stock re-enhancement but it did not work; despite the fact that closures have been helpful in numerous other fisheries. One reason indicated for closures being ineffective was that effort was so intense and high that the closed season could not correct for overfishing in the remainder of the open season (Keen, 1988).

Halibut are free swimming and therefore somewhat less susceptible to fishing pressure. As urchins are sessile, shallow water resources, they are especially susceptible to overfishing and depletion (Caddy, 1989, Overview of Part II, p. 399.). In Maine, over-involvement in the fishery coupled with sea urchins' already increased susceptibility to overfishing makes lessening of permitted fishers imperative.

Another potential problem with over-involvement is political. As so many fishers are dependent upon this fishery for a livelihood and are now legally granted a right to fish the resource, they may be more influential in the political and policy making process. Although fisher involvement in policy making is a desired thing, it can also have its drawbacks, especially when the industry is economically important and capitalized.

For example, if after the 1995 season it becomes apparent that urchin landings will need to be reduced to ensure biological sustainability, the fishers may be able to lobby to have this number increased. A lower catch might prohibit them from paying for new boats, crew, or equipment and licenses, making a biological necessity an economic issue as well. Further, because the government granted fishers exclusive rights to exploit this resource, their concerns become more important in the decision-making process. This could result in a situation in which a biological parameter might be bent to satisfy economic and political reasons, and ultimately may make the entire measure ineffective (Nixon, 1994).

Due to high effort, overcapitalization will continue to occur as there is no sense of protection for fishers in a fishery when the limited entry system has expanded beyond what it was under the open resource regime. New boats and mechanical equipment are bought, usually beyond the buying power of the fishers. This is sometimes accomplished by using future catches as collateral for future repayment of loans. In the Stonington, Maine area, an inordinate amount of fishing pressure is occurring (Creaser, 1995, personal communication), and overcapitalization of this sort may be happening. Fishers need to travel more quickly and to as many spots as possible in the course of a day to get urchins. Prior to this, many fishers used their lobster boats or whatever boats they had in the water. However, with many from western waters now fishing in this region due to zonal permit requirements, competition is high and may be forcing fishers to alter gear and boat types. In the 1994-1995 fishing season, effort as indicated by permits, has shifted to the east. This is particularly true of boat dragging licenses: 188 permits in zone 1 (west) and 307 permits in zone 2. Diver permits were fairly equal with 487 in zone 1 and 465 in zone 2 (Lewis, 1995, personal communication).

Due to the overall number of permitted fishers, the benefits of limited entry are minimized. One important benefit is the change in attitudes of fishers that occurs with limited entry. Usually, when a fisher has some type of ownership of a fishery resource, that individual will want to fish only what can be taken without hurting the future of the resource.

This factor is extremely important in whether a fishery succeeds but is the result of fishers feeling some sort of protection. When DMR allowed so many to enter the fishery, it actually reduced the security fishers had under the open access system. Therefore, the imperative of common property resource harvesting is still active - harvest the resource before someone else does (Keen, 1988). DMR needs to reduce the number of permitted fishers. Currently, the Maine fishery has many more fishers than the California fishery did in its peak years. California has since had to drastically reduce its entry and has targeted even further reductions for the future (CDFG , 1994).

One management technique available to allocate harvest is the use of individual transferable quotas (ITQ's). In an ITQ system, a total allowable catch (TAC) is established and then individual boats or fishers or even companies are allocated an individual quota of the TAC. ITQ's are generally established based on historical catch levels or on the average catch over a few fishing seasons (Rettig, 1986). ITQ's insure that active fishers are protected within the fishery and can be helpful to manage effort in a fishery with many participants. The use of ITQ's could also help to reduce overall numbers of fishers if permitted fishers are not utilizing their licenses.

A second management recommendation for the Maine fishery is to establish harvest refugia/biological reserves. These areas can be beneficial to all benthic invertebrate resources and can also provide excellent research and educational opportunities. Establishment of reserves offers a valuable point of comparison between the harvested and unharvested state as well as a place for juvenile invertebrates to mature to fishable size. Reserves may also provide invaluable insights into urchin stock recovery rates.

The use of reserves is especially important for sea urchin fisheries due to the limited knowledge of their fishery biology and the limited control of fishing pressure in the Maine fishery. Many decisions in the Maine fishery have been made with the premise of buying time until biological and population studies can be conducted. Reserves have been found to greatly increase the potential of correcting future policy by extending the time a resource has before reaching extinction, or even severe depletion (Quinn et al., 1993).

Reserves can be of any size and number. Fewer, larger refuges will tend to disrupt fishing and catch rates less, but are considered less effective in the long term. In cases of low fishing pressure, more reserves maintain the highest average populations and catches

(Quinn et al., 1993). With high fishing pressure, which characterizes the Maine fishery, short term catches will be substantially reduced primarily because many reserves prevent complete regional depletion of the resource.

The amount of time required before catch increases using the many reserves with high fishing pressure scenario makes this option difficult for the Maine fishery. However, the use of reserves may be an important factor in making the urchin fishery sustainable. It will also help other fisheries by providing protected habitat.

Modeling for the Maine fishery should be done to determine the optimal number of reserves based on successful spawning distances. Pennigton (1985), as used in Kalvass (1992), found that egg fertilization success rates for *S. droebachiensis* dropped from 60-95% when females were within 20cm from spawning males to less than 15% when at a distance greater than 20cm. This indicates that successful reproduction occurs in a very small spatial range. Since reproductive success is based upon density and geographic closeness, smaller reserves that are closer together will maximize reproductive success. Further, with many smaller reserves, settlement will occur more evenly throughout the management area as urchin larvae can remain suspended for several weeks prior to settlement.

The creation of one or two larger reserves, although better than establishing none, is probably suboptimal in Maine and should be avoided. Establishing one or two large reserves may cause fishers to congregate around the edges of reserves, causing greater 'spot' fishing pressure. It would also benefit local fishers over those from further away and may cause some fishers to migrate to the reserve areas. This will have both social and economic impacts.

Due to the length of the Maine coast and the distribution of effort which is now occurring along the entire coast, the establishment of smaller, frequent reserves appears to be the best option, even if catches are reduced for a while. The time to increased harvests under this reserve regime may be shorter if the number of fishers is also reduced. If reserves are successful, then permits may be expanded in conjunction with growth in urchin populations. Smaller, more densely distributed reserves affect fishers in all locations equally.

If fishing/harvesting effort remains high and reserves are not created, the fishery will likely decline, resulting in a much larger time period for stock restoration. Although the estimated time of twenty years may seem long for low catches under the small reserve regime (Quinn et al., 1993), this same scenario may happen without reserves, but with an outcome of worse resource depletion, not resource enhancement.

To answer the question of whether few/larger or many/smaller reserves is the best management strategy for the red sea urchin fishery in California, Quinn et al. ran a number of modeling tests (1993). In all the cases examined, the use of smaller, more numerous reserves protected larger populations of urchins and in situations with high fishing pressure or low reproductive rates, appear to have been better in preventing localized extinction.

The purpose of establishing harvest reserves is to protect reproduction and recruitment. The successful use of reserves may eliminate the need for some of the more conventional management measures which attempt to limit harvest efficiency. If reserves are able to adequately protect reproductive stocks, then both money and manpower will be saved, without the use of other management tools such as gear restrictions or size limits (Quinn et al., 1993). Reserves promote conservation without placing technical restrictions on the fishers and with minimal overhead costs.

Rotation of fishing areas is the second most valuable option. Due to the length of the coast and the possible social disruptions that could occur by having large rotational areas, the State should be split into small management zones and within those zones, fishing regions should be established, as is done in British Columbia. The current estimate on the number of years it takes for *S. droebachiensis* to reach fishable size in the Gulf of Maine is four years (Chenoweth, no date). Therefore, a five year rotational plan would be adequate and would allow undersized urchins in unfished regions to reach market size. This would also limit disruption to other resources.

The one drawback of rotational harvests versus the use of reserves is that while urchin fishers may not be fishing in a region, other invertebrates are being fished. Therefore, determining fishing mortality of urchins as a bycatch in other fisheries may be warranted. Regardless, the lack of direct fishing pressure will most likely benefit the reproducing stock of urchins.

Another recommendation concerns fishing method. Currently, both dragging and diving are allowed in Maine. Although it may not be feasible to ban dragging altogether, it should be limited to areas unsuitable for diving due to current, wave or tidal action. Diving, due to its probable lower impact on the marine environment, should be considered the primary means of urchin harvesting. Dragging should be utilized only in designated areas where diving is not advised or where damage to the benthos will be minimal.

In conjunction with this change in fishing method, reseeding programs may prove beneficial. Two types of reseeding recommended include moving individuals from densely populated, poor feeding areas to regions with better food. The second possibility is artificially rearing seed stock and releasing them into reserve areas or areas of high food quality and low urchin densities. The Japanese have had great success with both methods which are considered an integral part of urchin resource management (Saito, 1992).

Lastly, Maine needs to better define its closed season. At the 1994 Urchin Workshop in Boothbay Harbor, Ted Creaser of the DMR discussed the issue of the closed season and how processors and exporters played a part in the establishment of a staggered closed season. The staggered closed seasons between the eastern and western waters of the State minimizes the down time for this segment of the industry. However, in implementing such a system, part of the population in both regions may not be protected for spawning. Furthermore, if physical variables change within a given year, spawning may be delayed and may not occur until after the fishing season is open. Regional spawning variations are believed to occur throughout the range of *S. droebachiensis* in the Gulf of Maine. Closed seasons should be established to provide maximal protection to spawning stocks.

The issue of establishing a closed season becomes one of balancing economics with inflexible biological parameters. One avenue Maine may consider researching is utilizing the unused portions of sea urchins for non-human consumptive uses. Currently, only about 10% of the urchin biomass is utilized. In Maine, where over 40 million pounds were harvested last year, approximately 36 million pounds were discarded. Although most of this biomass is shipped to Japan, the unutilized portions of urchins processed in the state could be utilized. Two potential uses for the remainder of the urchin include grinding the shell and spines for a quicklime product for fertilizer and using the intestinal tract/digestive tract for fish feed. Both would have practical uses in Maine.

Most of northern Maine is dominated by potato fields and other harvestable crops. Urchin-based limes are potentially good garden fertilizers and this use would reduce overall urchin waste. The fish feed option is also of potential benefit in the Maine economy as it could be used in the salmon aquaculture industry. A fish feed of urchin base suitable for this industry should be researched. For urchins processed in the State, these parts could be frozen and then processed during the summer months when the fresh product is unavailable. This would help alleviate the down time for processors and thereby, some of their opposition to a longer closed season.

The above discusses only some of the bigger management tools which may be of benefit to the Maine fishery and is based on how similar management procedures succeeded in other fisheries or in modeling studies. The true test of the relative success or failure of these measures can be attained only from extensive field testing and experimentation. While the paring down of permit numbers is a reactive measure, and unavoidable, the other measures provide the State with ways to act proactively and for the best interest of the long term sustainability of this multi-million dollar fishing industry.

CHAPTER 6

Conclusions

Sea urchin fisheries, like many other fisheries, seem to follow a general pattern regardless of geographic location or extent. This is due to two factors associated with this fishery. One is the market-driven nature of the fishery. The other concerns the traditional attitude of fishers who perceive sea urchins as a nuisance species, not as a resource that was worth over $130 million in 1994 when it left US ports (NMFS, United States Exports Statistics).

The descriptions of the previous two chapters illustrate a general trend which all sea urchin fisheries seem to follow. There is first a period of low fishing pressure and low capital investment in which aspects such as routes to market may inhibit development of the fishery. During these first few years, little attention is paid to managing the fishery.

This first stage is followed by a phase of rapid increases in fishing pressure and landings which are usually external to the actual fishery and related to processing and transportation of the finished product to the market. During this phase, everyone involved in the fishery is making large profits and the fishery gains attention from managers and the general public. Managers start to research urchins and their fishery biology, usually concluding that little is known about the biology and that most fisheries in other areas have been unsustainable. However, due to this lack of knowledge, most managers delay measures until more biological research is conducted. During this time the fishery enters a third stage in which entry into the fishery takes on drastic proportions, as do landings.

At this stage, those charged with managing the fishery quickly realize that something must be done and often based on little or no existing research. This is commonly accomplished through emergency State legislation. Landings are peaking and possibly starting to decline. The third phase is characterized by continuous decreases in landings and the introduction of management measures which often have little significant effect on stock and harvest levels. Throughout these case studies, with the partial exceptions of the Alaskan *S. franciscanus* and Southern British Columbian sea urchin fisheries, management is not addressed until about the same point in the fishery. It is not until landings and involvement in the fishery are alarming that regulation is finally enacted.

Existing fisheries provide invaluable information concerning the very nature of sea urchin fisheries. They make it evident that one of the biggest downfalls in sea urchin fishery management is the delay in implementing management strategies until after the fishery is peaking.

It is understandable that managers are reluctant to enact potentially unpopular measures without adequate biological data to support such measures. However, until that data exists in amounts useful and acceptable to base management decisions, those in charge should look at these trends and use the information to better protect their resources.

Since much of the data presented in these case studies is anecdotal and descriptive, it should be used with some caution. The sea urchin fishery shows a very rapid spatial diffusion and a comparatively short development time, probably due to the simple gear used (drags and hand harvesting). The principal obstacle to an even faster and more widespread spatial distribution appears to be related to the transport of product to market, however, this barrier has been greatly diminished.

Market access and the great demand for sea urchin products will trigger an endless chain of new sea urchin fisheries emerging in temperate regions. To an extent, this has been the case in North America. As the California fishery peaked and began to show signs of overfishing, urchin companies began exploring new markets and Maine became the next big fishery (Chippello, 1988). Also, as the Maine fishery peaks, an urchin industry is established in Massachusetts and more interest in improving marketability of the Alaska green urchin may be expressed. Moreover, Oregon experienced growth as the Southern California market moved to Northern California waters. A pattern of movement to regions with large urchin resources is likely to continue for the foreseeable future.

The Maine fishery is at a critical juncture in its development. Landings, effort and investment are high. Although strong management measures have been taken in the past two years, these measures were not enacted until after the fishery was booming. Based on what has happened in other fisheries enacting management in the boom phase of the fishery, it is likely that the Maine fishery will be entering a stage of decline within the next few years.

The sea urchin fishery illustrates the shortcomings of basing management solely on known biological data. In most urchin fisheries, managers were reluctant to implement actions until conclusive scientific data existed to support the proposed measures. As Gulland (1974) has pointed out in his groundbreaking work in the field of fisheries management, relying on biological data is too narrow and restrictive when focusing on a fishery. While waiting for scientific data, a fishery may face dire social and economic losses which are compounded by the fact that scientific data to support management may be difficult to obtain or may take so long to establish in fast growing fisheries, such as sea urchins, that the fish stock and its fishery are badly harmed before data is conclusive and the appropriate remedial action can be taken (Gulland, 1974).

This work supports the notion that fishery management not be based solely on scientific evidence. This is particularly true in sea urchin fisheries as urchins are susceptible to overfishing and have little scientific data concerning their fisheries biology. Until this exists in useful amounts, managers must broaden their techniques and use other information for management. Left unregulated, or regulated well after fishing pressure is high, sea urchin fisheries will collapse, causing economic and social losses for local and national economies.

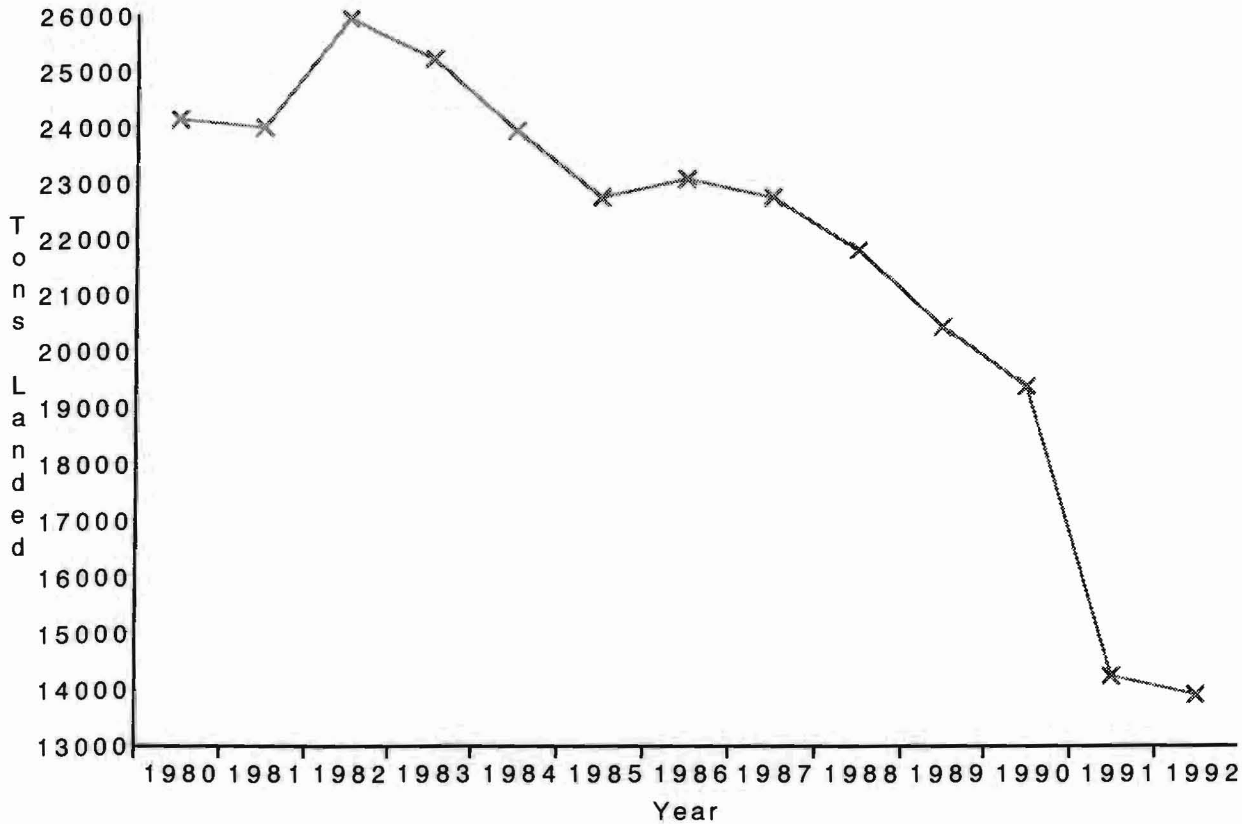


Figure 1.1. Japanese Sea Urchin Landings: 1980-1992.
Source: FAO Yearbook: Fishery Statistics: Catches and Landings. Vol. 74, 1992.

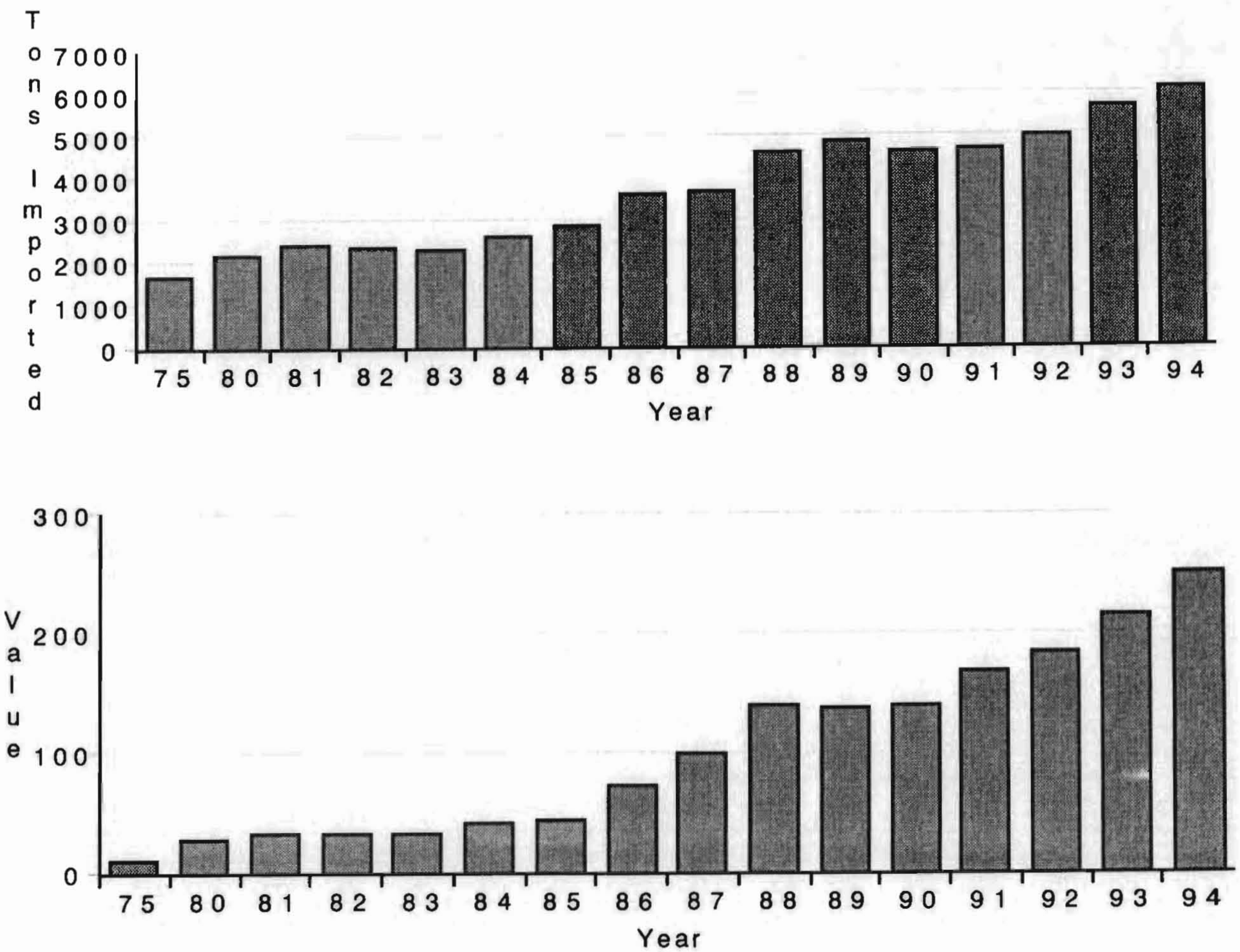


Figure 1.2. UPPER: Japanese Sea Urchin Product Imports. LOWER: Value of Japanese Sea Urchin Product Imports, 1975-1994 (in $US millions. Source: Japanese Marine Products Importers Association, 1976-1995.

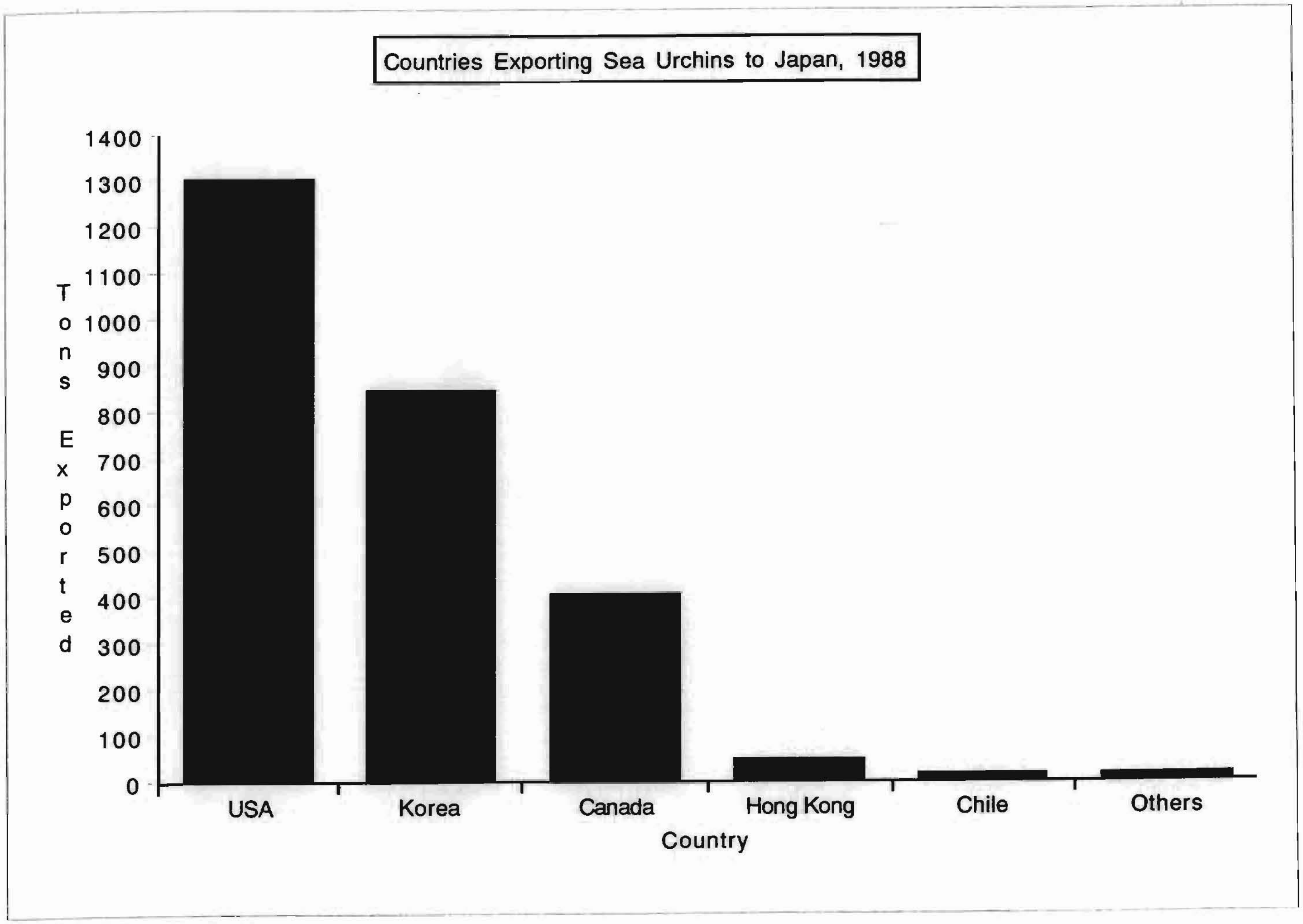


Figure 1.3. Leading Fishing and Exporting Countries of Sea Urchins in 1988.
Source: Saito, 1992.

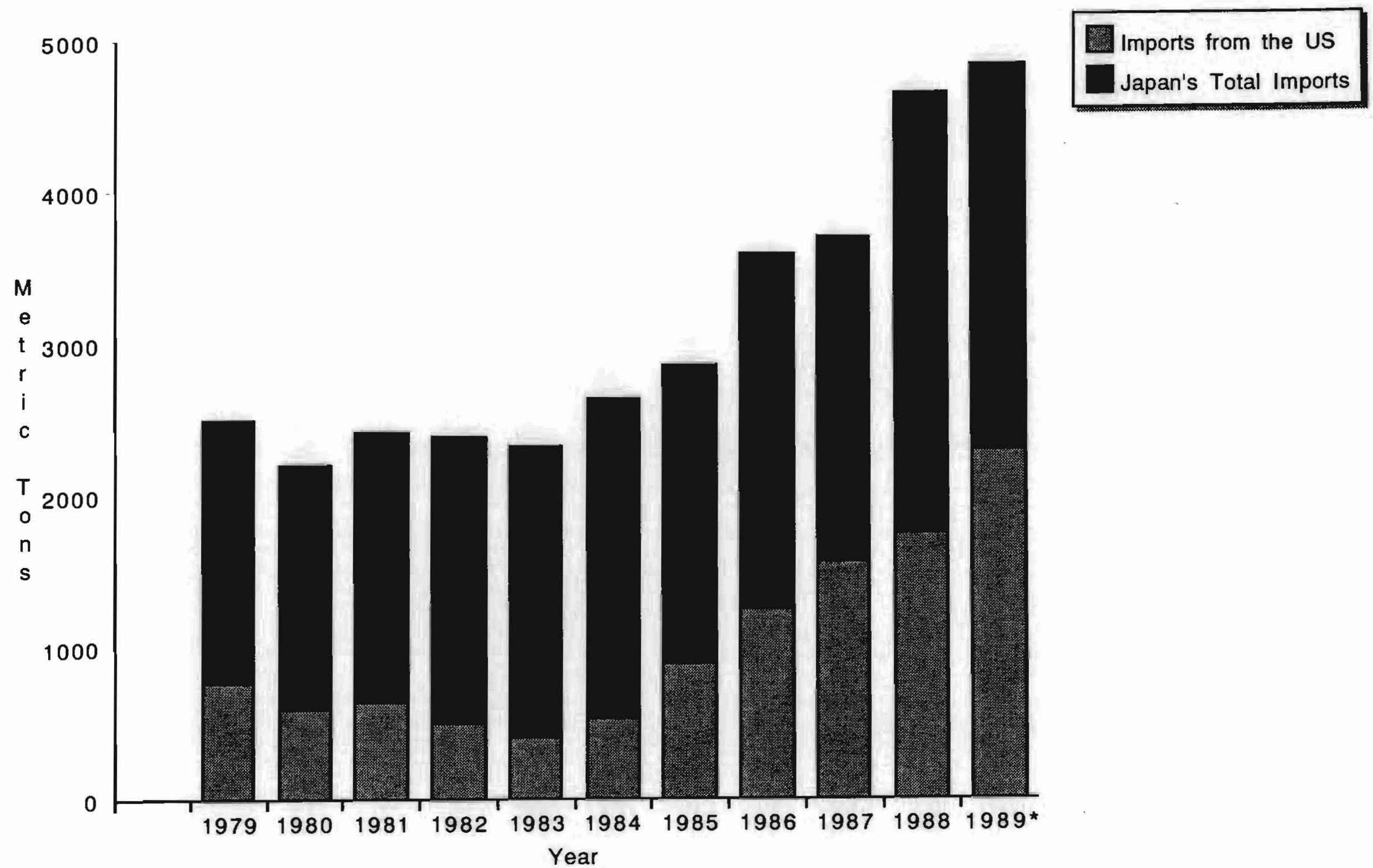


Figure 1.4. U.S. Contribution to Total Japanese Urchin Imports. 1989 figures are estimated. Source: Phu, 1990.

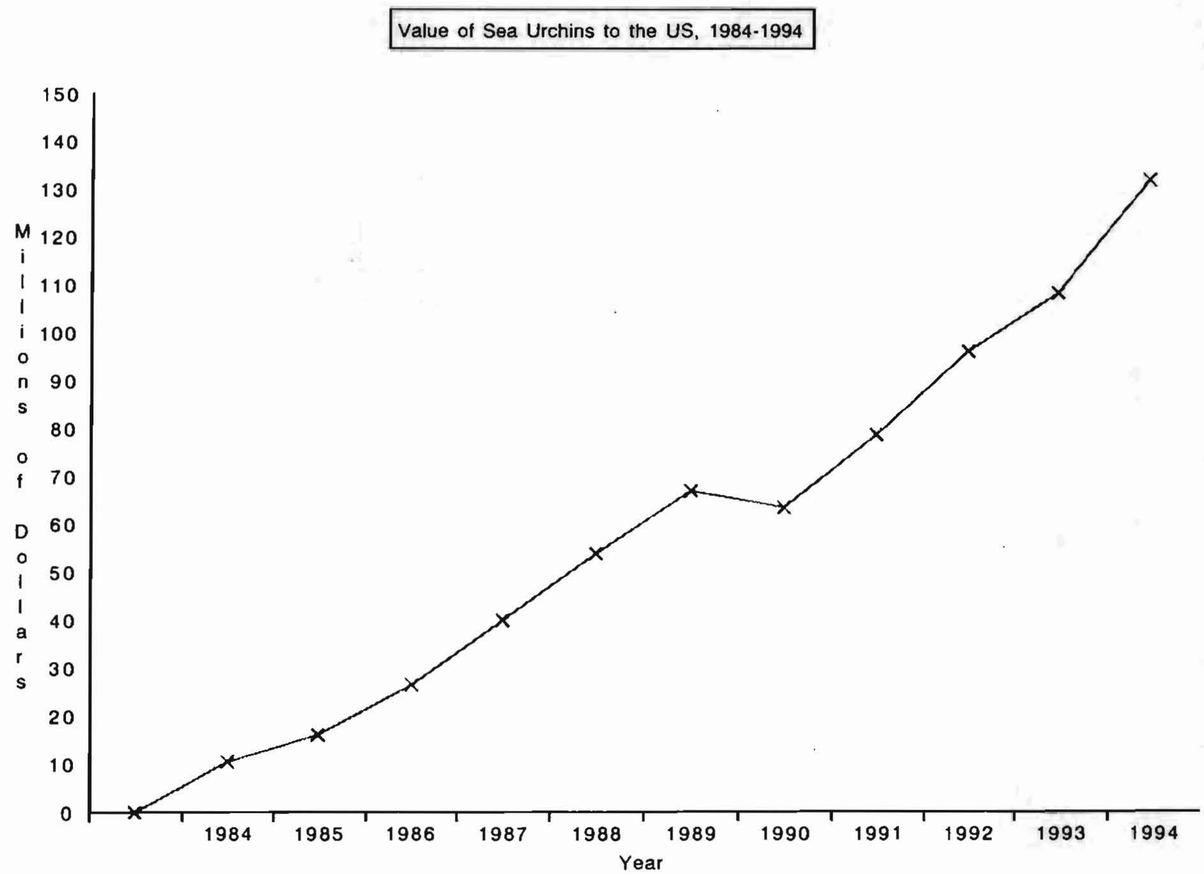


Figure 1.5. The value of sea urchin products exported to Japan to the United States at the time of export. Source: National Marine Fisheries Service, United States Export Statistics, by Country and product.

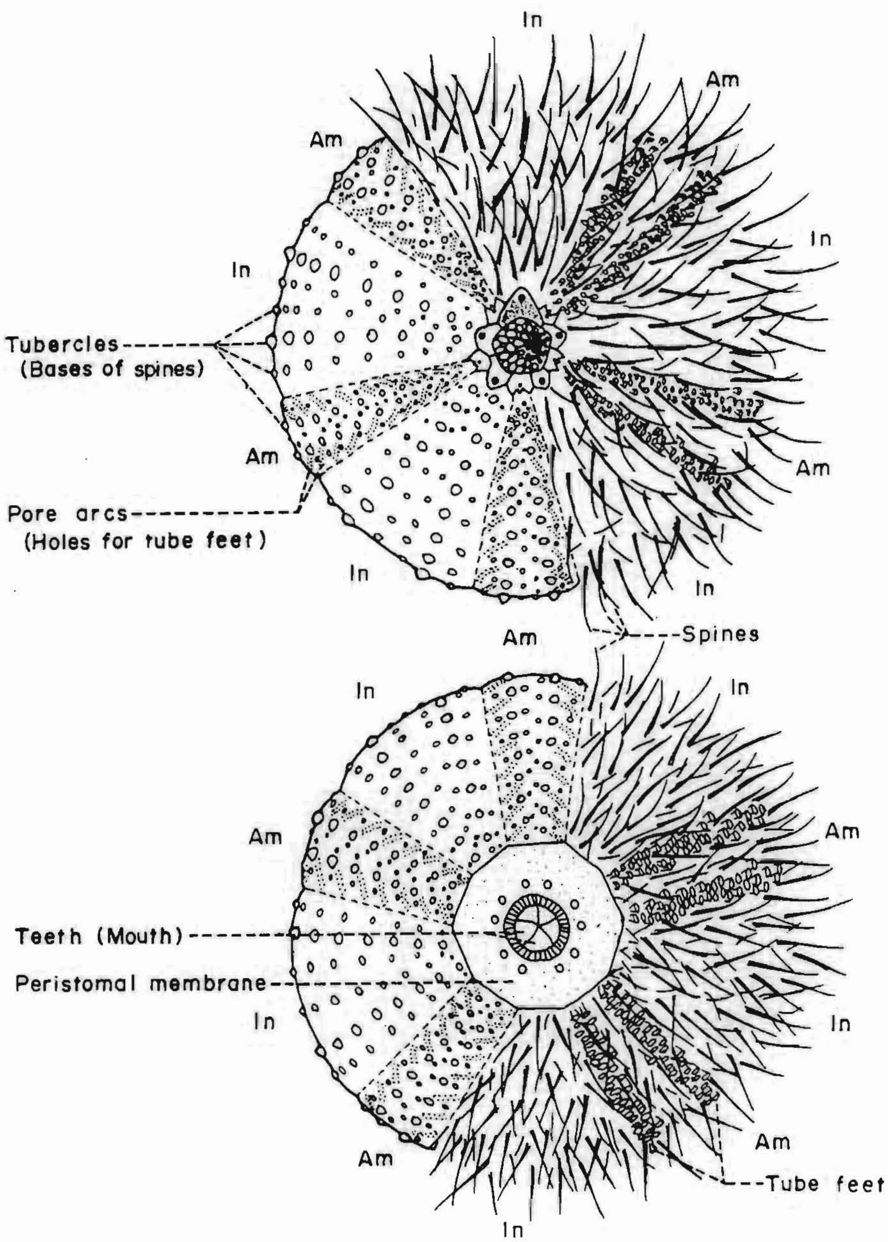


Figure 2.1. External Anatomy of a *Strongylocentrotus droebachiensis* sea urchin. The upper figure is the aboral, or top side of the urchin and the lower figure is the oral side, or bottom of the urchin. Source: Mottet, 1976.

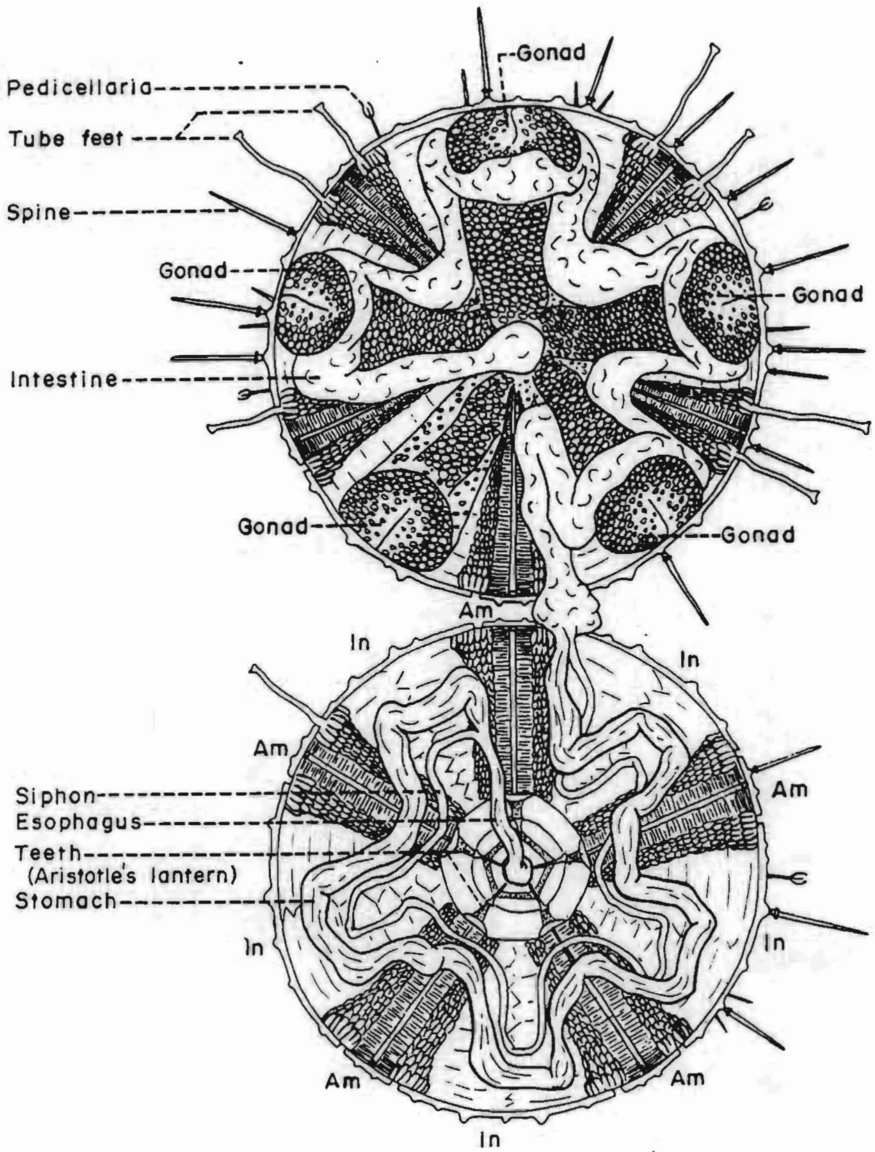


Figure 2.2. Internal Anatomy of a *Strongylocentrotus purpuratus* sea urchin. The upper figure illustrates the aboral half of the urchin and the lower figure the oral half of the urchin. 'In' and 'Am' are used to indicate the ambulacral and interambulacral areas.
Source: Mottet, 1976.

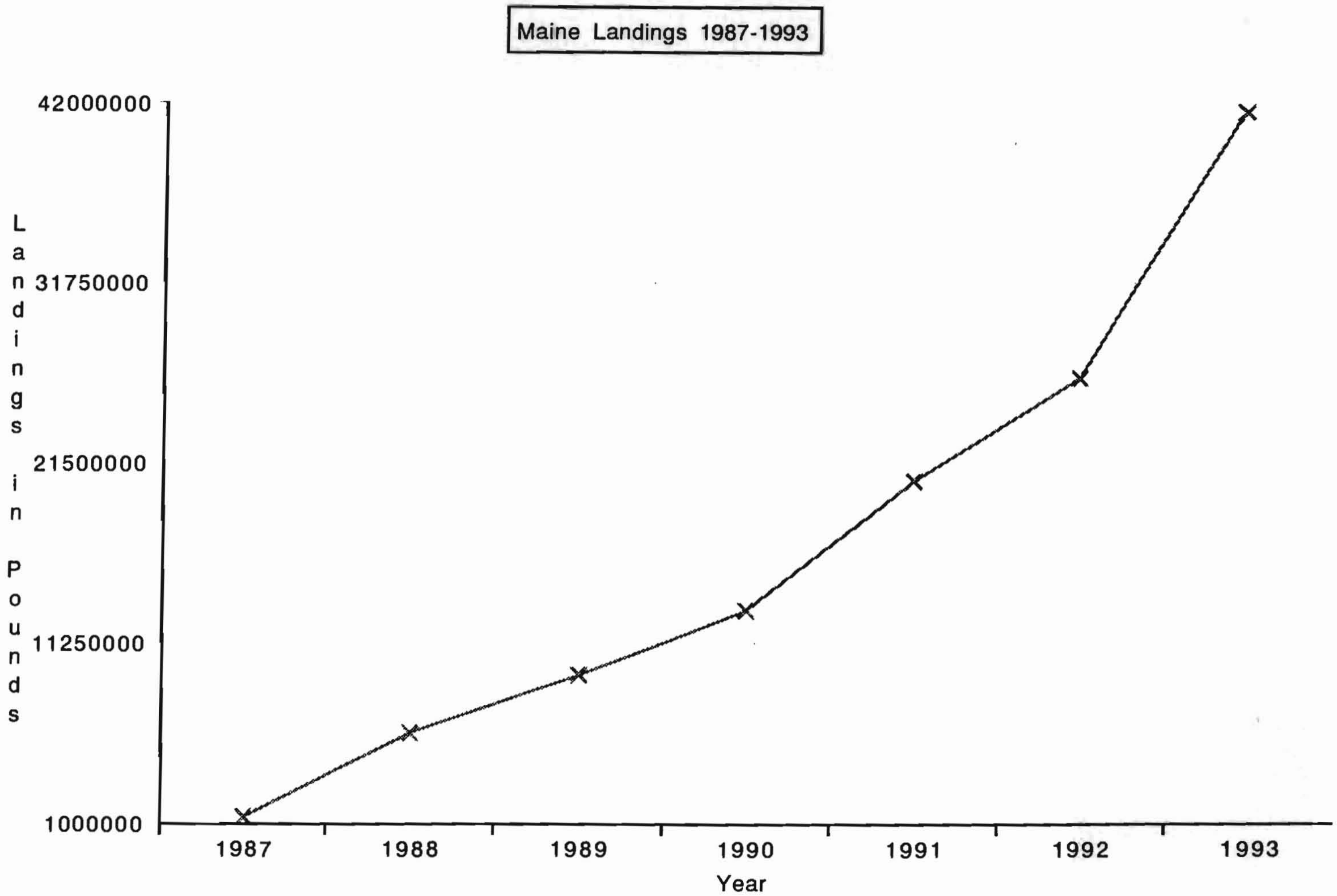
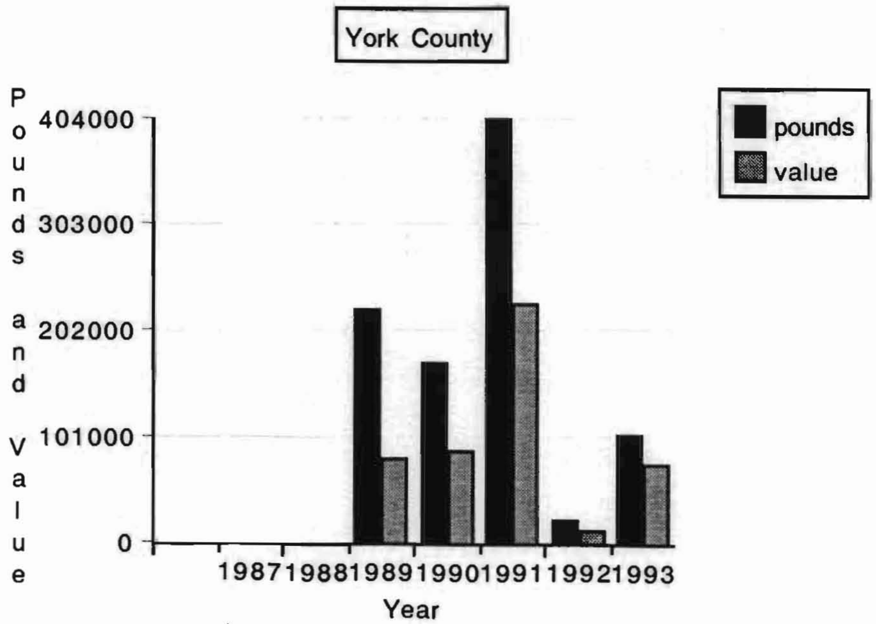


Figure 3.1. Maine Landings of Green Sea Urchins, 1987-1993.
Source: Maine Department of Marine Resources.

Figure 3.2. Maine Sea Urchin Landings and Value by County, 1987-1993. Source: National Marine Fisheries Service.



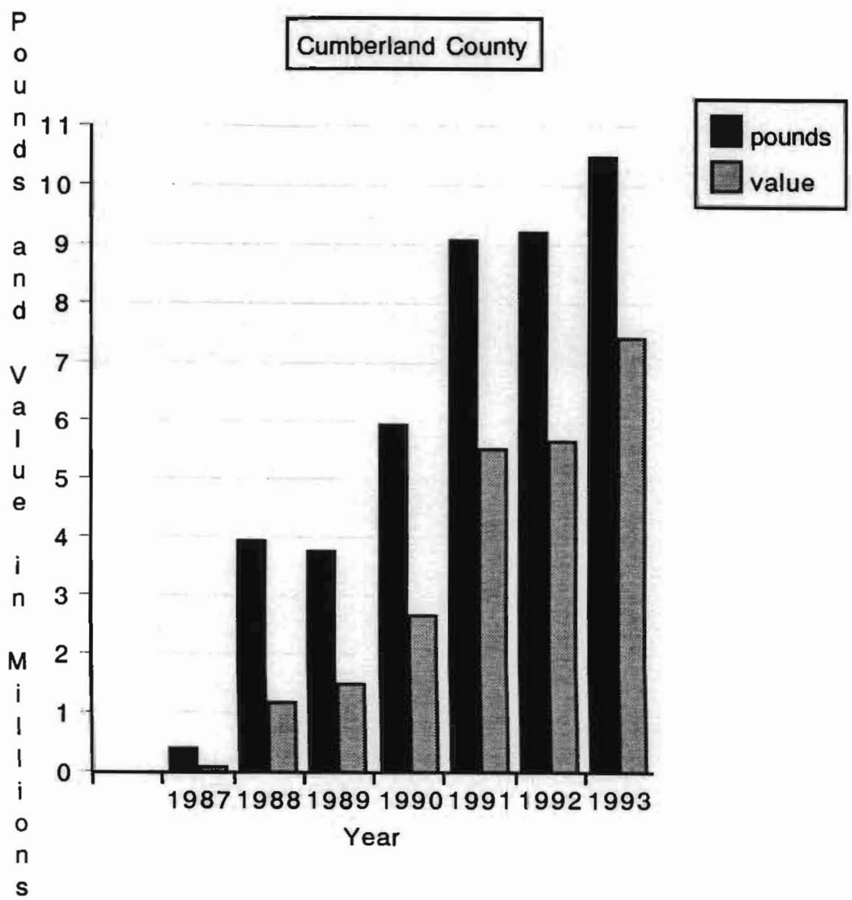
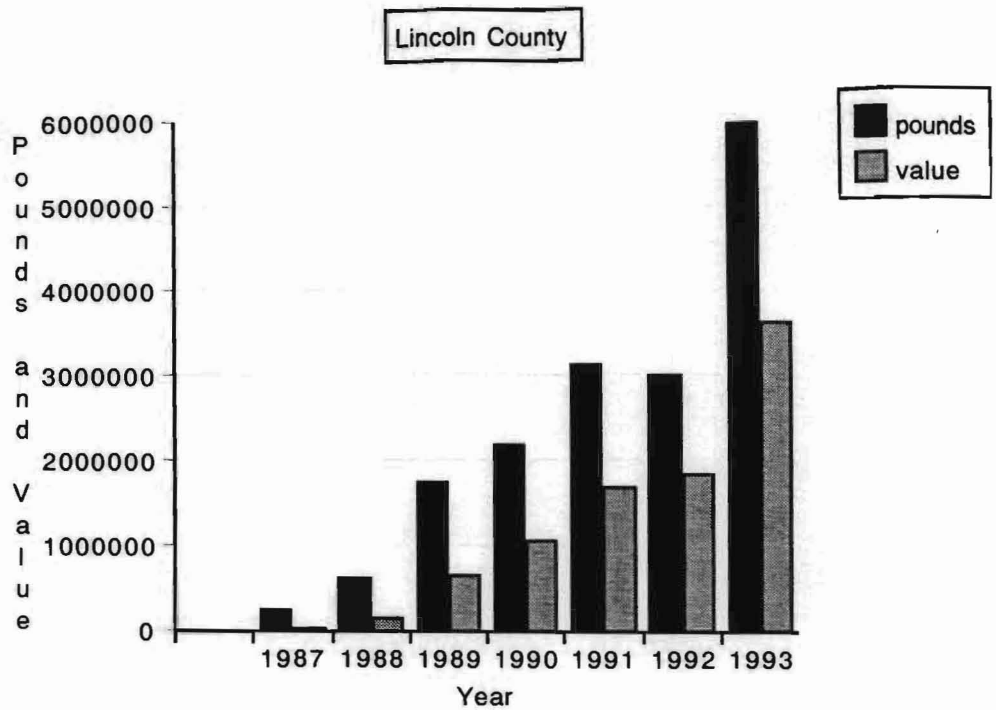


Figure 3.2. Continued.



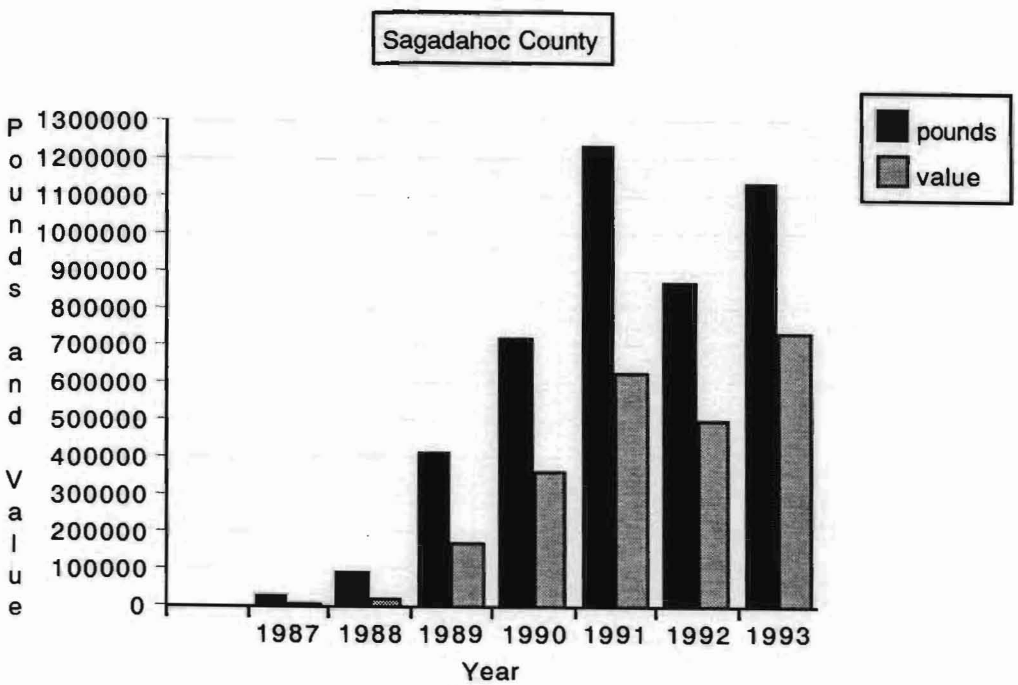
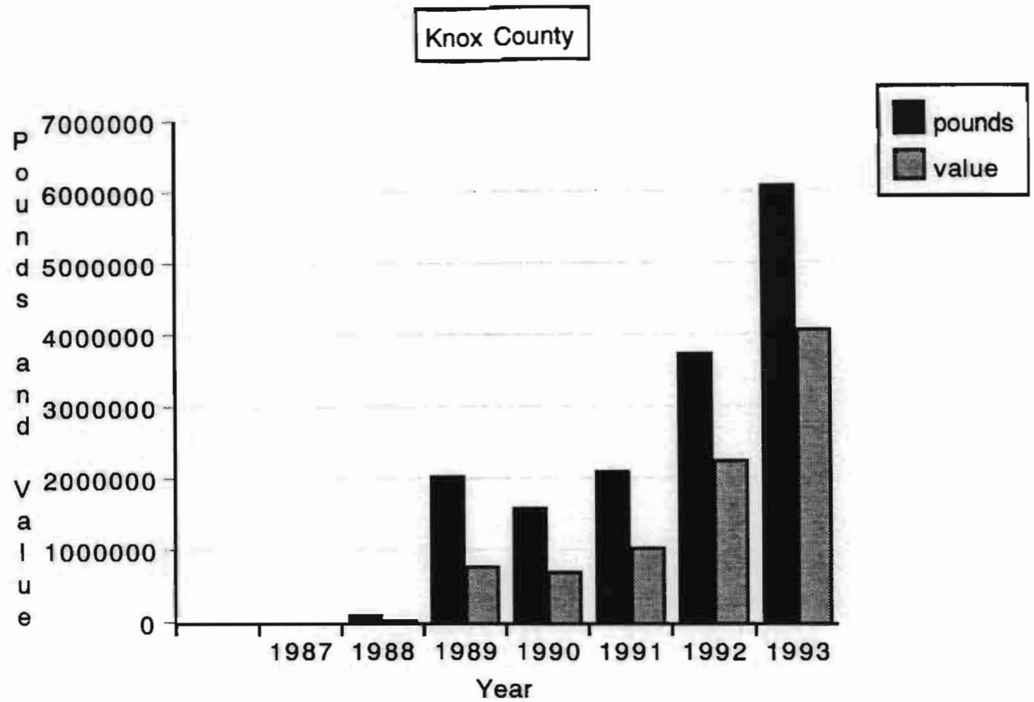
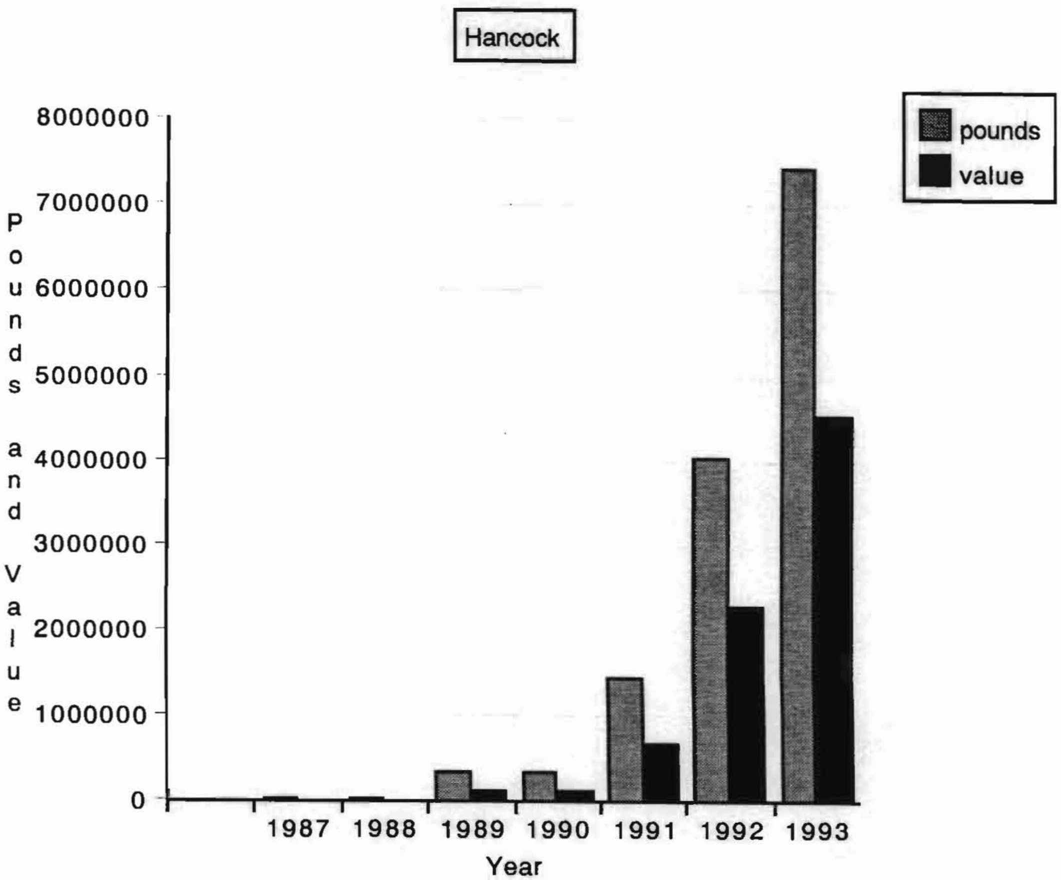


Figure 3.2. Continued.





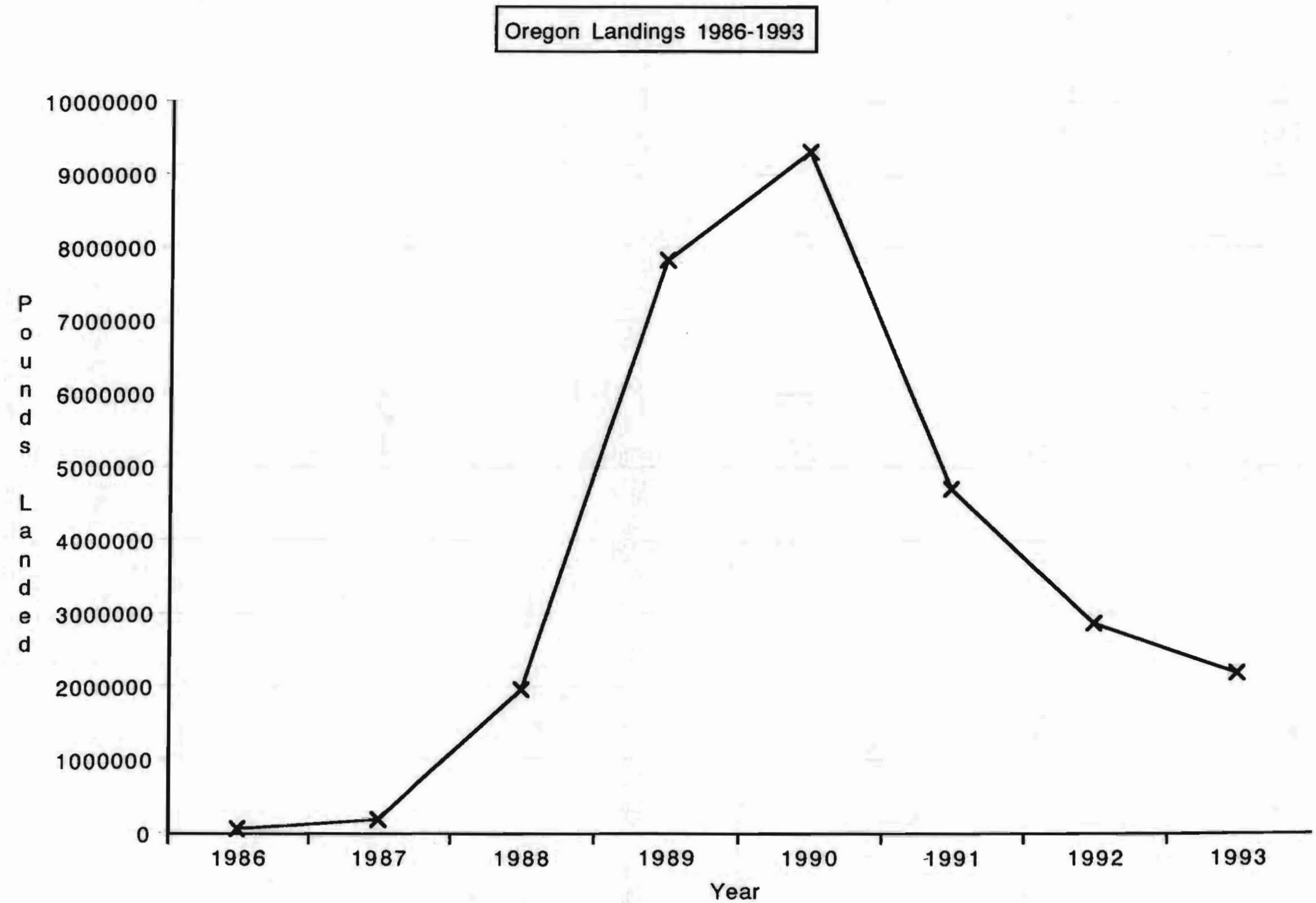


Figure 4.1. Oregon Sea Urchin Landings, 1986-1993.
Source: McCrae, 1993.

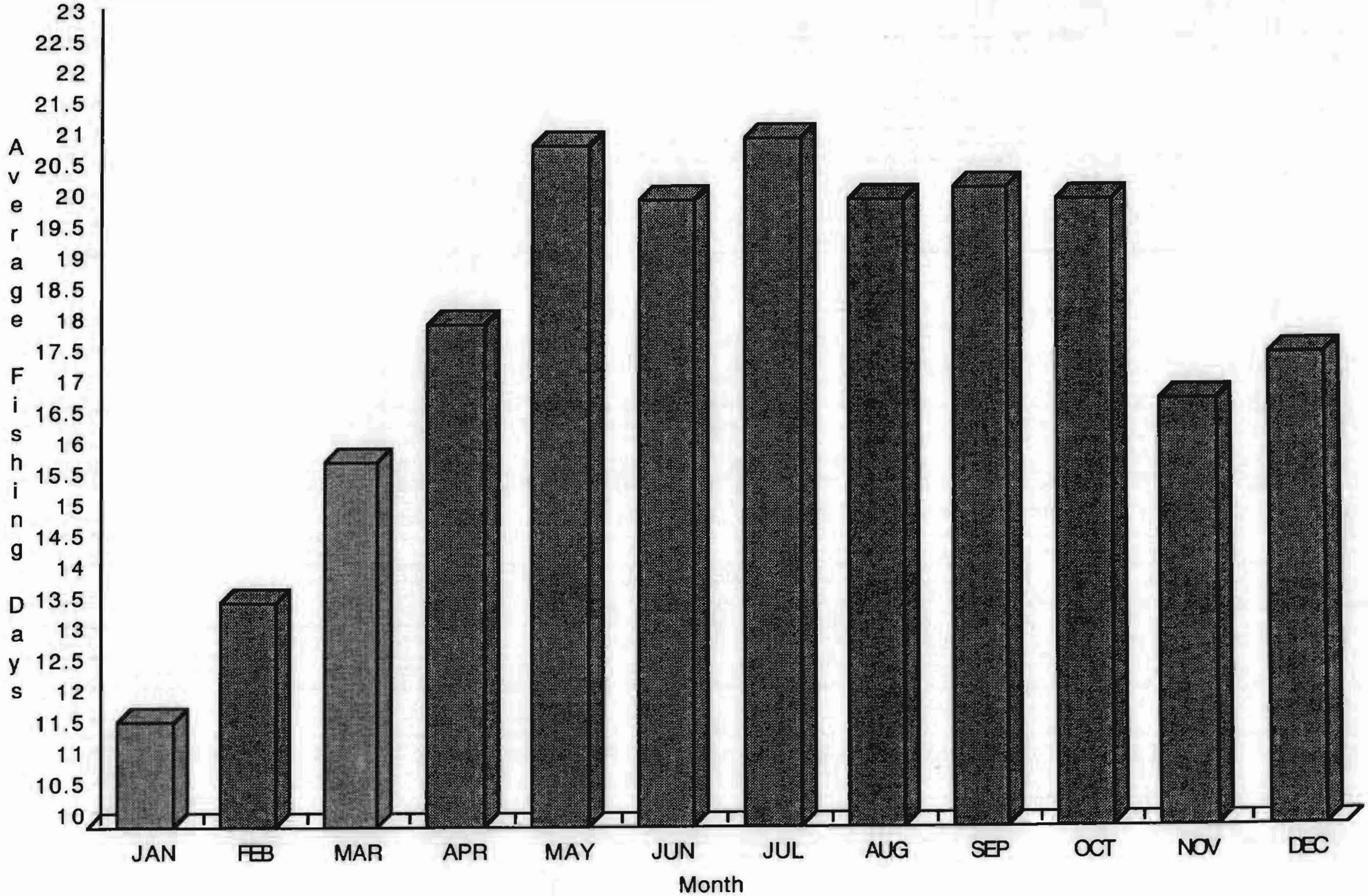


Figure 4.2. Oregon Average Fishing Days Per Month, 1986-1992.
Source: McCrae, 1993.

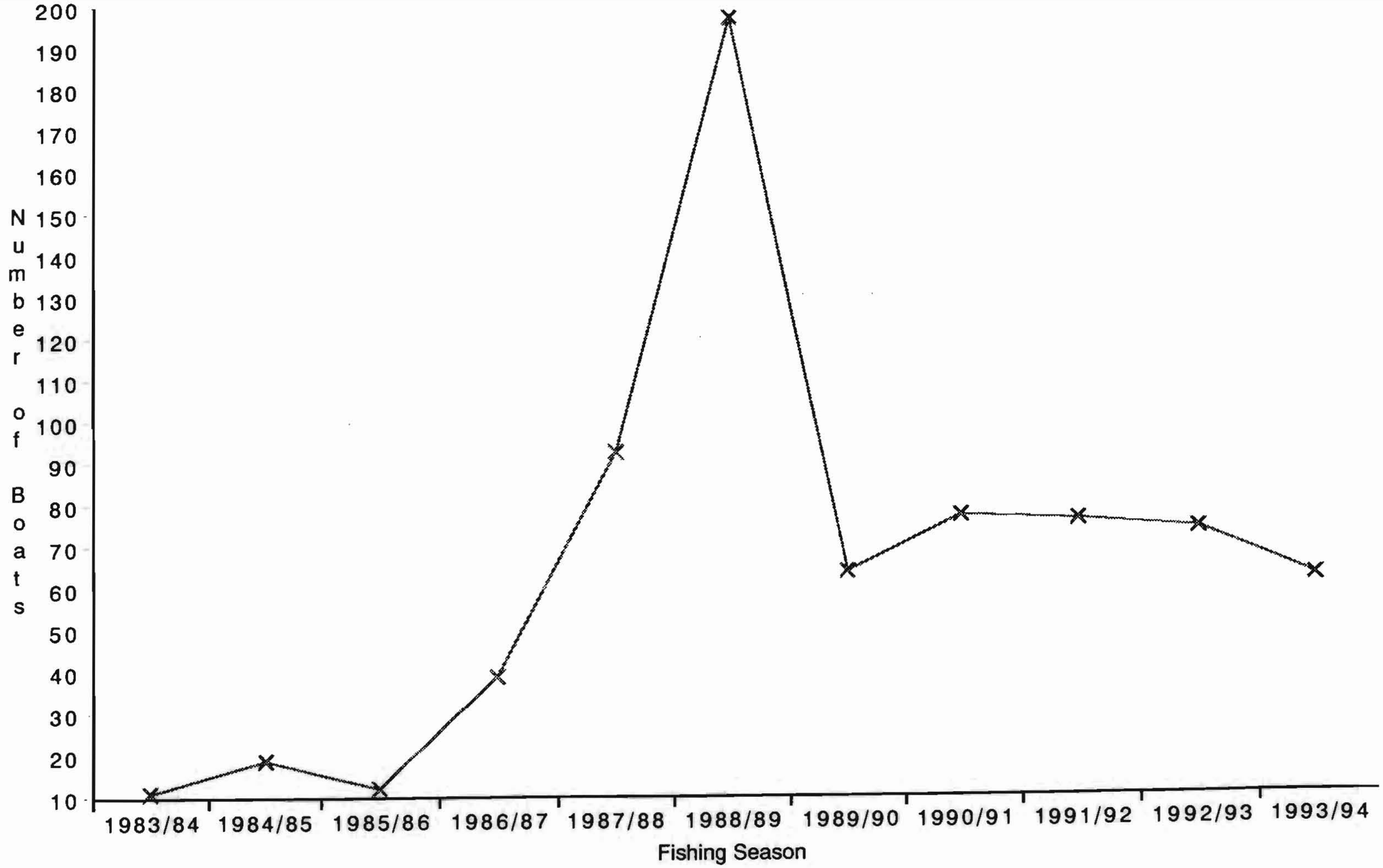


Figure 4.3. Change in effort in the Washington fishery as indicated by number of permitted boats. Source: White, 1993.

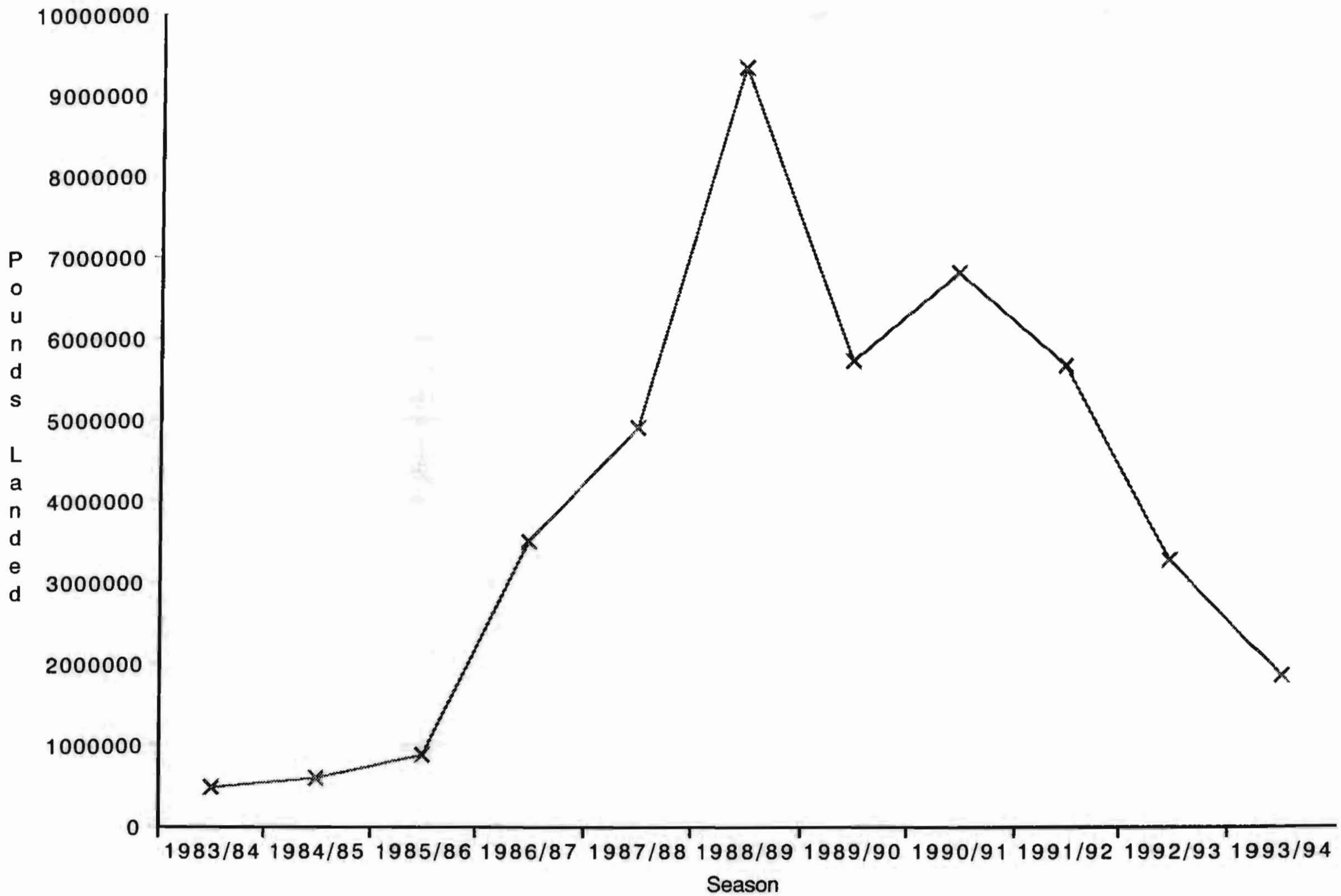


Figure 4.4. Combined red and green sea urchin landings in the Washington fishery, 1983-1994. Source: White, 1993.

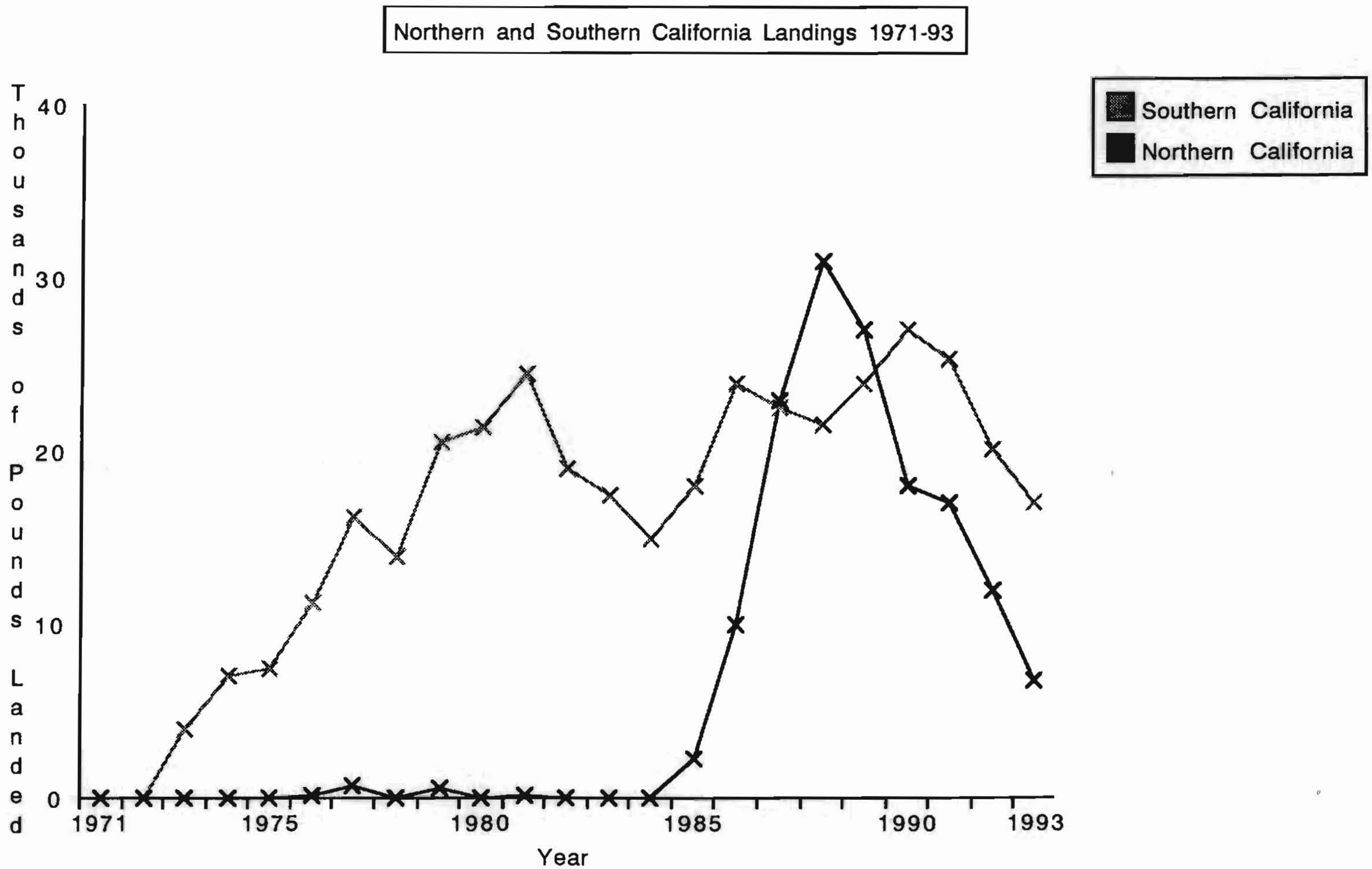


Figure 4.5. Northern and Southern California Sea Urchin Landings, 1971-1993. Source: Kalvass, 1992.

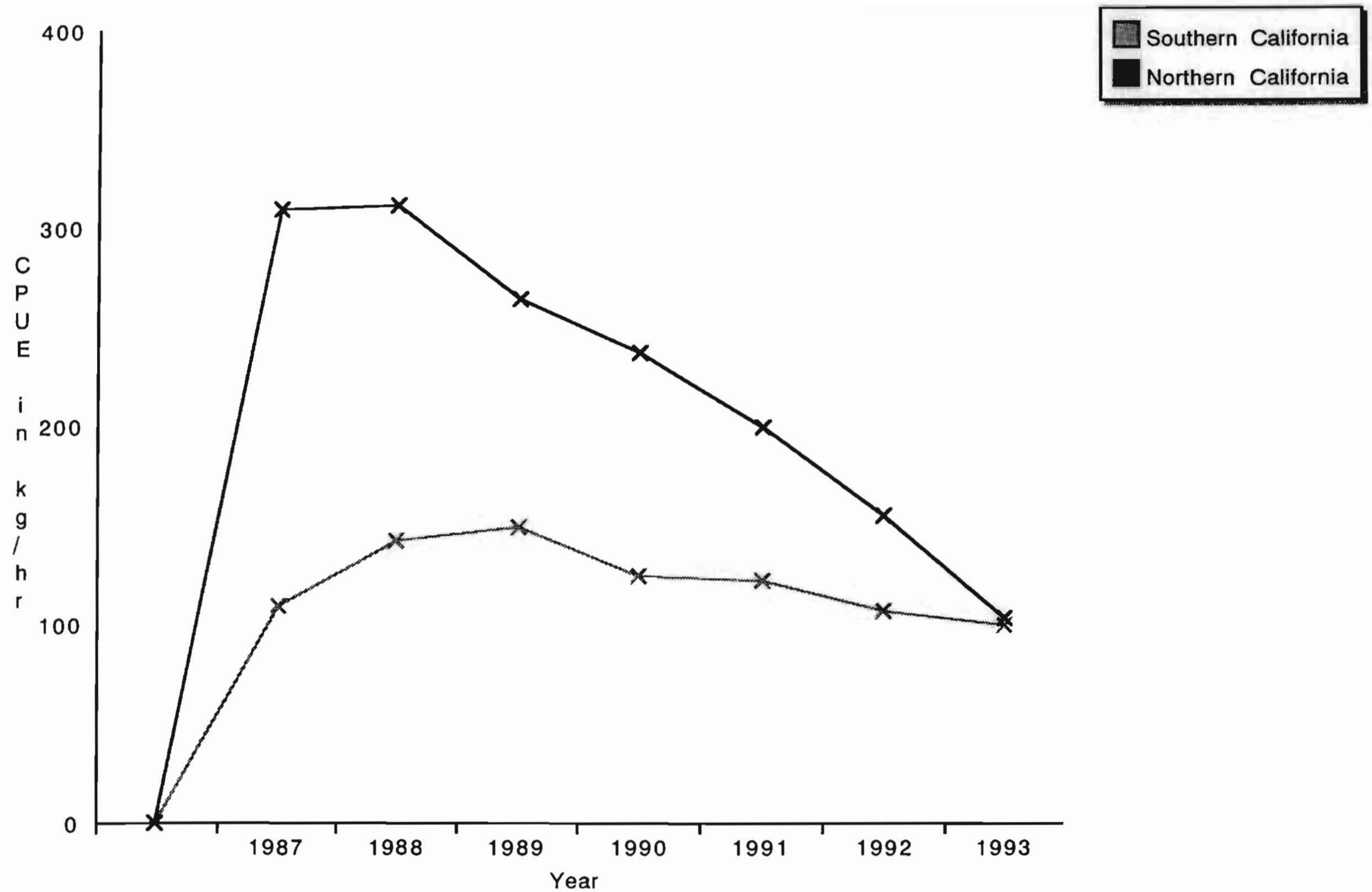


Figure 4.6. Change in CPUE in the California Fishery, 1987-1993.
Source: CalCOFI Rep., 1994.

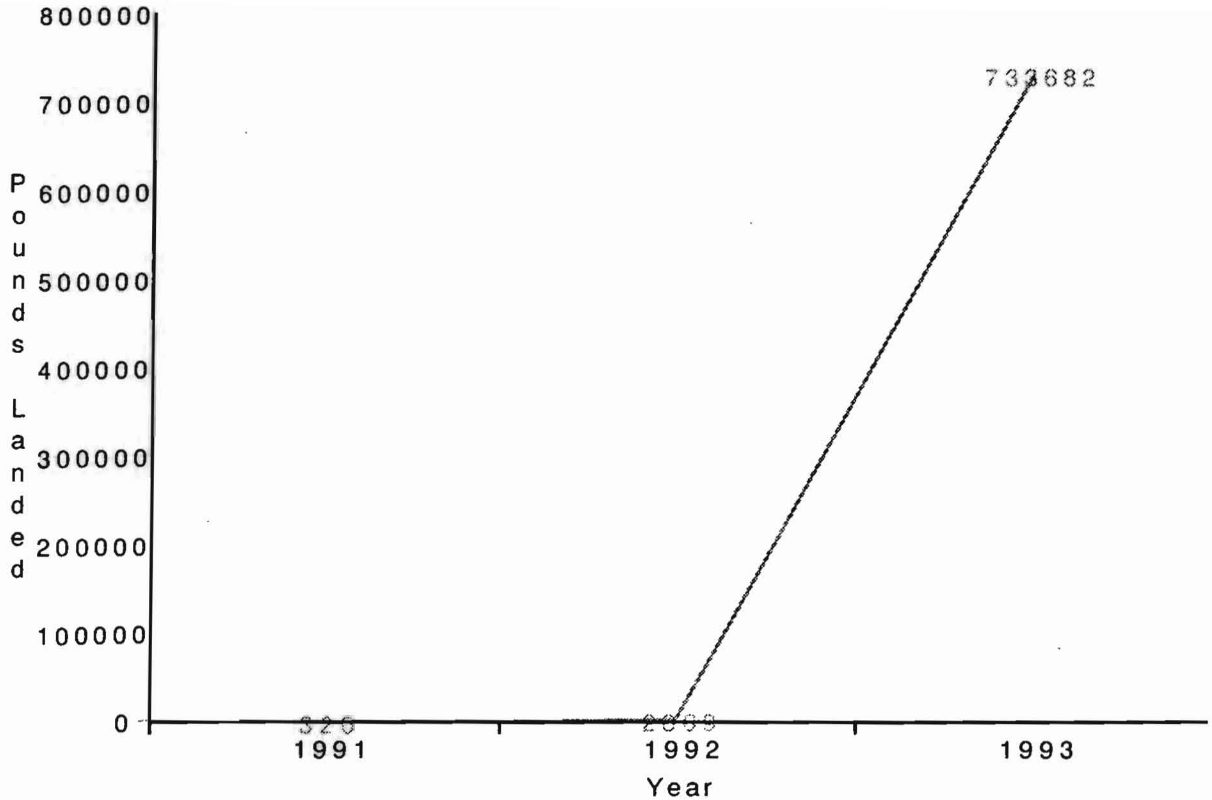


Figure 4.7. Massachusetts Green Sea Urchin Landings, 1991-1993.
Source: Harris, 1994.

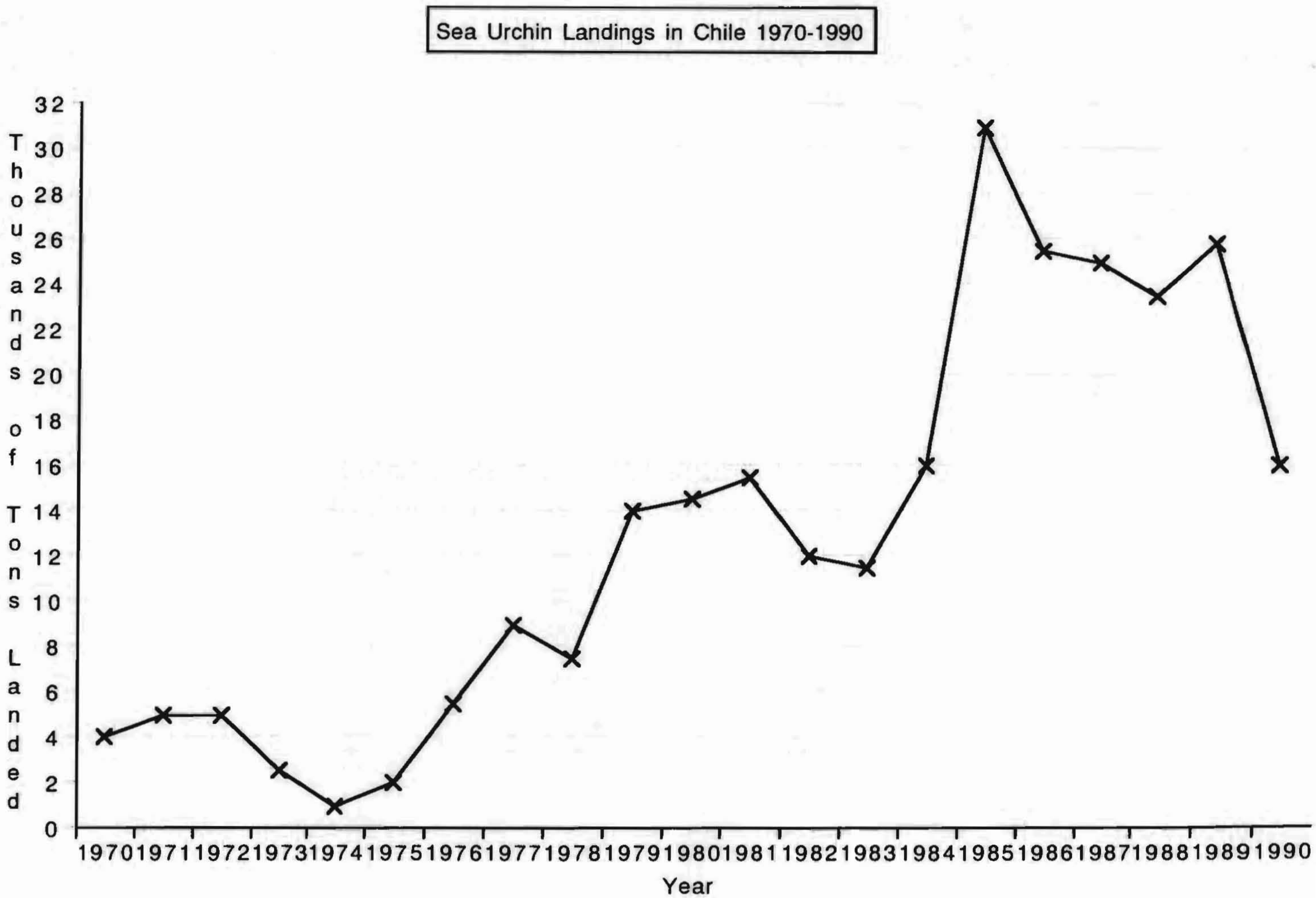


Figure 4.8. Chilean Sea Urchin Landings, 1970-1990.
Source: Vasquez and Guisado, 1992.

BIBLIOGRAPHY

ADFG (Alaska Department of Fish and Game). no date. Southeast Alaska Sea Urchin Harvest Management Plan. ADFG, Alaska.

Andrews, B. 1990. Limited Entry. In: Dewees, C.M. and E. Ueber, eds. Effects of Different Fishery Management Schemes on Bycatch, Joint Catch, and Discards. Summary of a National Workshop, January 29-1, 1990. California Sea Grant Rept. No. T-CSGCP-019.

Anon. 1989. The sea urchin market in Japan. Marine Fisheries Review. 51(3): 63.

Anon. 1994. "Will new urchin laws do more harm?" The Maine Times. April 22, p.7.

Austin, P. 1993. "The urchin fiasco illustrates a failure of state policy". The Maine Times. 25(22): 2-7.

Bernard, F.R. and D.C. Miller. 1973. Preliminary Investigation on the Red Sea Urchin Resources of British Columbia (*Strongylocentrotus franciscanus* [Agassiz]). Fisheries Research Board of Canada Technical Report No. 400. Fisheries Research Board of Canada, Pacific Biological Station, Nanaimo, B.C.

Bernstein, B.B., Schroeter, S.C., and K.H. Mann. 1983. Sea urchin (*Strongylocentrotus droebachiensis*) aggregating behavior instigated by a subtidal multifactorial experiment. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 40: 1975-1986.

Bruce, C.A. 1988. Sea Urchins. Infofish Int. no.3, 32-34. Canadian Translations of Fisheries and Aquatic Sciences. no 5528.

Caddy, J.F., ed. 1989. Marine Invertebrate Fisheries: Their Assessment and Management. John Wiley and Sons, New York.

CalCOFI Rep. 1994. Fisheries Review: 1993. Vol. 35, p.14-15.

CDFG (California Department of Fish and Game). 1994. Draft fishery management plan for the 1994 California commercial red sea urchin fishery. CDFG, Sacramento.

Chenoweth, S. no date. The green sea urchin in Maine: Fishery and biology. Maine Department of Marine Resources, W. Boothbay Hbr.

Chipello, C.J. 1988. "A Miracle in Maine: Sea Urchin is Turned Into the Golden Uni." The Wall Street Journal, March 18, 1988, p.1.

Conand, C. and N.A. Sloan. 1989. World fisheries for echinoderms. Chapter 29 in: Caddy, J.F., ed. Marine Invertebrate Fisheries: Their Assessment and Management. John Wiley and Sons, New York.

Cooperative Extension Service (CES). 1988. The green sea urchin industry in Maine: Guidelines and ideas for harvesting. Maine DMR, Boothbay Harbor.

DFO (Department of Fisheries and Oceans). 1994a. Conservation harvesting plan: Sea urchin. 1994-1995, Southwest New Brunswick. DFO, St. Andrews, N.B.

DFO. 1994. Pacific region 1994 management plan: Green sea urchins. DFO, B.C.

Duran, L.R., Castilla, J.C., and D. Oliva. 1987. Intensity of human predation on rocky shores at Las Cruces in central Chile. Environmental Conservation. 14(2): 143-149.

Gonzales, L.P., Castilla, J.C. and C. Guisado. 1987. Effect of larval diet and rearing temperature on metamorphosis and juvenile survival of the edible sea urchin *Loxechinus albus*. Journal of Shellfish Research. 6(2): 109-115.

Griffin, N. 1993. Maine weighs green sea urchin regulations. National Fisherman. October, 1993:22-23.

Gulland, J.A. 1974. Management of Marine Fisheries. University of Washington Press, Seattle.

Harbo, R. and K. Hobbs. 1992. Sea urchin fisheries of British Columbia, Canada. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

Hardin, G. 1968. The tragedy of the Commons. Science. 162: 1243.

Himmelman, J.H. 1978. Reproductive cycle of the green sea urchin, *Strongylocentrotus droebachiensis*. Canadian Journal of Zoology. Vol. 56, 1828-1836.

Himmelman, J.H., Y. Lavergne, F. Axelsen, A. Cardinal, and E. Bourget. 1983. Sea Urchins in the Saint Lawrence Estuary: Their abundance, size-structure, and suitability for commercial exploitation. Canadian Journal of Fisheries and Aquatic Sciences. Vol. 40, No. 4, 474-486.

Japanese Marine Products Importers Association. 1976-1995. Japanese import statistics.

Kalvass, P. 1992. The northern California commercial sea urchin fishery: A case study. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

Kato, Susumu. 1972. Sea urchins: A new fishery develops in California. Marine Fisheries Review. 34(9/10): 23-30.

Kato, S. and S.C. Schroeter. 1985. Biology of the red sea urchin, *Strongylocentrotus franciscanus*, and its fishery in California. Marine Fisheries Review. 47(3): 1-20.

Keats, D.W., South, G.R. and D.H. Steele. 1985. Ecology of juvenile green sea urchins(*Strongylocentrotus droebachiensis)* at an urchin dominated sublittoral site in Eastern Newfoundland. In: Keegan, B.F. and B.D.S. O'Connor, eds. Echinodermata. Proceedings of the Fifth International Echinoderm Conference Galway/24-29 September 1984. A.A. Balkema, Rotterdam.

Keen, E.A. 1988. Ownership and Productivity of Marine Fishery Resources. McDonald and Woodward Publishing Co., Blacksburg, Virginia.

Kramer, D.E. and D.M.A. Nordin. 1978. Physical data from a study of size, weight and gonad quality for the green sea urchin (*Strongylocentrotus droebachiensis*) over a one-year period. Fisheries and Marine Service Manuscript Report No. 1476. Fisheries Research Board of Canada, Vancouver.

Kramer, D.E. 1980. Outlook for establishing a fishery for the green sea urchin (*Strongylocentrotus Droebachiensis)* in the St. Lawrence River. Canadian Industry Report of Fisheries and Aquatic Sciences 114. Department of Fisheries and Oceans, Vancouver.

Lang, C. and K.H. Mann. 1976. Changes in sea urchin populations after the destruction of kelp beds. Marine Biology: 36, 321-326.

Larson, B.R., Vadas, R.L. and M. Keser. 1980. feeding and nutritional ecology of the sea urchin *Strongylocentrotus droebachiensis* in Maine, USA. Marine Biology: 59, 49-62.

Lawrence, J.M. 1985. The Energetic Echinoderm. In: Keegan, B.F. and B.D.S. O'Connor, eds. Echinodermata. Proceedings of the Fifth International Echinoderm Conference Galway/24-29 September 1984. A.A. Balkema, Rotterdam.

Maine Department of Marine Resources. 1978. Towards a fisheries development strategy for Maine. C.E. Maguire Inc., Portland, Me.

Maine, State of. 1993. An Act Concerning the Taking of Sea Urchins. H.P. 98-L.D. 140.

Maine, State of. 1994. An Act to Conserve Sea Urchin Resources. H.P. 1459-L.D. 1984.

Miller, R.M. 1989. Commercial culture of the giant red sea urchin *Strongylocentrotus franciscanus* in Hawaii. Journal of Shellfish Research: 8(2): 414.

McCrae, J. 1989. Oregon sea urchin fishery 1986-1988. Annual progress report. Oregon Dept. Fish and Wildlife. 13 pp.

McCrae, J. 1993. Oregon sea urchin fishery 1986-1992. Draft report for Oregon Dept. of Fish and Wildlife.

Mottet, M.G. 1976. The fishery biology of sea urchins in the family *Strongylocentrotidae.* State of Washington Department of Fisheries, Shellfish Division. Technical Report No. 20.

Munk, J. E. 1992. Reproduction and growth rate of green urchins *Strongylocentrotus Droebachiensis* (Muller) near Kodiak, Alaska. Journal of Shellfish Research. Vol. 11, No. 2, 245-254.

Muraoka, D.D. 1990. Managing the sea urchin fishery: An economic perspective. Natural Resources Journal. 30: 139.

National Marine Fisheries Service (NMFS). 1993. Fishery Statistics on Sea Urchin Landings by State, 1980-1993.

NMFS. 1994. United States Exports by product and country. Fisheries Statistics Division.

Nichols, D. 1966. Echinoderms. Hutchinson and Co., London.

Nixon, D. 1994. Why Fishery Management Has Failed. Maritimes. 37(1): 15.

North, W.J. and J.S. Pearse. 1970. Sea urchin population explosion in southern California coastal waters. Science. 167: 207.

Ojeda, F.P. and J.H. Dearborn. 1989. Community structure of macroinvertebrates inhabiting the rocky subtidal zone in the Gulf of Maine: Seasonal and bathymetric distibution. Marine Ecology Progress Series. Vol. 57: 147-161.

Paul, J.M. and A.J. Paul. 1984. Reproductive cycle and gonad yield of green sea urchins in lower Cook Inlet, Alaska. Alaska Sea Grant.

Phu, C.H. 1990. The U.S. sea urchin industry and its market in Tokyo. NOAA-TM-NMFS-SWR-025.

Prince, J.S. and W.G. LeBlanc. 1992. Comparative feeding preference of *S. droebachiensis* for the invasive seaweed codium fragile ssp. tomentosoides and four other seaweeds. Marine Biology. 113(1):159-163.

Pringle, J.D., G.J. Sharp, and J.F. Caddy. 1980. Proceedings of the Workshop on the Relationship Between Sea Urchin Grazing and Commercial Plant/Animal Harvesting. Canadian Technical Report of Fisheries and Aquatic Sciences 954. Canadian Department of Fisheries and Oceans, Halifax.

Quinn, J.F., Wing, S.R., and L.W. Botsford. 1993. Harvest refugia in marine invertebrate fisheries: Models and applications to the red sea urchin, *Strongylocentrotus franciscanus*. American. Zoologist. 33, 537-550.

Rettig, R.B. 1986. Overview. In: Fishery Access Control Programs Worldwide: Proceedings of the Workshop on Management Options for the North Pacific Longline Fisheries. Alaska Sea Grant Report No. 86-4.

Rudie, D. The Southern California red sea urchin fishery 1972-1992. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

Saito, K. 1992a. The sea urchin fishery of Japan. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

Saito, K. 1992. Japan's sea urchin enhancement experience. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

Scattergood, L.W. 1961. The sea urchin fishery. U.S. Fish and Wildlife Service, Fishery Leaflet #511.

Scheibling, R.E. and P.V. Mladenov. 1987. The decline of the sea urchin *Tripneustes ventricosus*, fishery of Barbados: A Survey of fishermen and consumers. Marine Fisheries Review. 49, No. 3, 1987.

Sebens, K.P. 1985. The ecology of the rocky subtidal zone. American Scientist. Vol. 73: 548557.

Sloan, N.A. 1984. Echinoderm fisheries of the world: A review. In: Keegan, B.F., and B.D.S. O'Connor, eds, Echinodermata: Proceedings of the Fifth International Echinoderm Conference. Galway, 24-29 September, 1984. A.A. Balkema Publishers, Rotterdam.

Smith, A.H. and F. Berkes. 1991. Solutions to the 'Tragedy of the Commons': Sea-urchin management in St. Lucia, West Indies. Environmental Conservation: 18, no. 2, 131-136.

Stein, M.A. 1987. "Urchin message. State petitioned to set harvesting rules as spiny shellfish gains popularity as food." The Los Angeles Times. March 10, 1987. p.3.

Stephens, R.E. 1972. Studies on the development of the sea urchhin *Strongylocentrotus droebachiensis*. I. Ecology and normal development. Biological Bulliten: 142: 132-144.

Swan, E.F. 1961. Some Observations on the growth rate of sea urchins in the genus *Strongylocentrotus*. Biological Bulliten. Vol. 120, No. 3, 420-427.

Takagi, K. 1986. Aspects of the sea urchin fishery in Japan. Proceedings of the Gulf and Caribbean Fisheries Institute: 37:41-53.

Tegner, M.J. 1989. The feasibility of enhancing red sea urchin, *Strongylocentrotus franciscanus*, stocks in California: An analysis of the options. Marine Fisheries Review: 51, no. 2, 1-22.

Trinidad-Roa, M.J. 1989. Mariculture potential of giant clams and sea urchins in the Lingayen Gulf area. Proceedings of an ASEAN/ UN Coastal Resources Management Project Workshop. ICLARM Conference Proceedings. #17:133-137.

Vadas, R.L., Elner, R.W., Garwood, P.E. and I.G. Babb. 1986. Experimental evaluation of aggregation behavior in the sea urchin *Strongylocentrotus droebachiensis*. A reinterpretation. Marine Biology: 90, 433-448.

Vasquez, J.A. and C. Guisado. 1992. Fishery of sea urchin (*Loxechinus albus)* in Chile. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

Washington DOF. 1978. Development of mangement techniques for a sea urchin fishery. Project progress report. Washington DOF, Olympia.

Washington DOF. 1979. Development of techniques for a sea urchin fishery. Project Completion Report. Washington DOF, Olympia.

White. 1993. An Overview of Washington's Sea Urchin Fisheries. Draft Report, Washington Dept. of Fish and Wildlife.

Woodby, D. 1992. Red sea urchins in SE Alaska: Status of research and management. In: The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective. March 19-21, Bodega Bay, California. Report No. T-CSGCP-028. California Sea Grant College, University of California, La Jolla.

CONFERENCES AND PERSONAL COMMUNICATIONS

Personal Communications:

Bradbury, Alex. Washington Department of Fish and Game. Telephone conversation. March 31, 1995.

Creaser, Ted. Maine Department of Marine Resources. Telephone conversation. April 14, 1993.

Creaser, Ted. Telephone conversation. June 28, 1994.

Creaser, Ted. Telephone conversation. March 31, 1995.

Kalvass, Peter. California Fish and Game. Telephone conversation. June 28, 1994.

Larson, Robert. Alaska Dept. of Fish and Game. Telephone conversation. June 28, 1994.

Lewis, Robert. Maine Department of Marine Resources. Telephone conversation. April 14, 1993.

Lewis, Robert. Telephone conversation. March 31, 1995.

Munk, Eric. Fishery biologist, NMFS, Kodiak, Alaska. Telephone conversation. June 24, 1994.

Thomas, Greg. Department of Fisheries and Oceans, Northern sea urchin fishery, British Columbia. Telephone conversation. July 19, 1994.

Conferences

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THE FOLLOWING IS A LIST OF SPEAKERS AT THIS CONFERENCE.

Carr, H.A. 1994. The Sea Urchin Fishery in Massachusetts, current trends, concerns, and research.

Creaser, T. 1994. Discussion concerning management strategies.

Dowling, T. 1994. Discussion concerning Maine urchin fishery.

Harris, L. 1994. Studies on the effects of depth, water flow and diet on settlement, recruitment and growth of the green sea urchin, *Strongylocentrotus droebachiensis*.

Lawrence, J.M. 1994. Strategies and life history characteristics as criteria for evaluating the suitability of sea urchin species for fisheries and aquaculture.

Robinson, S. 1994a. The green sea urchin fishery in southern New Brunswick.

Robinson, S. 1994b. The impact of scallop drags on sea urchin grounds.

Steneck, R. 1994. Spatial and temporal patterns in sea urchin populations, herbivory and algal community structure in the Gulf of Maine.

Vadas, R.L. 1994. Spatial and temporal variability in reproduction and spawning in green sea urchins in Maine.