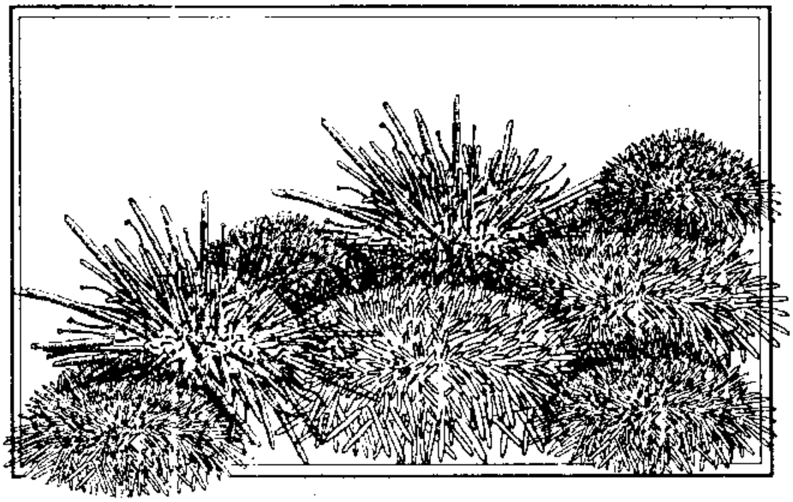
The Management and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective

A Collection of Papers from a Conference Sponsored by the California Sea Grant College



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INTRODUCTION

Though there is clear evidence that the Japanese were eating sea urchins in prehistoric times, the animal was regarded as little more than a pest in most of the Western Hemisphere until the 1970s. At that time, some of the vast sea urchin beds of the West began to be harvested, and the animal's roe shipped to Japan, where it is highly prized as a delicacy.

In California, the fishery for red sea urchins grew rapidly from its beginnings in 1972 to become by the 1980s one of the state's most lucrative fisheries. But concerns about possible over-exploitation of the resource grew rapidly, voiced in large part and with considerable urgency by the urchin industry, the environmental community, and the California Department of Fish and Game. (CDFG). As a consequence, since 1987, the CDFG and its director's Sea Urchin Advisory Committee (made up primarily of industry participants) have negotiated an increasingly restrictive management system in an attempt to maintain a sustainable fishery. In addition, a landing tax has been established to fund research needed for wise management. Nonetheless the resource remains highly vulnerable.

In order to obtain a broad perspective on utilization of California's kelp bed resources, and particularly sea urchins, the California Sea Grant College, in cooperation with the Sea Urchin Advisory Committee, sponsored a major Pacific Rim conference on sea urchins, kelp, and abalone in March 1992.

The conference, which was held at Bodega Bay, California, was organized by Professor Wallis H. Clark, of the University of California, Davis, and Dr. Christopher M. Dewees, Marine Fisheries Specialist with the Sea Grant Extension Program, University of California, Davis.

Approximately 140 people from universities, fishery agencies, fishing industry, and conservation organizations listened to papers on the status of knowledge about and current research on the biology, enhancement, and management of sea urchins, kelp, and abalone. These participants came from six U.S. states, Canada, Mexico, Chile, New Zealand, Australia, and Japan. They also participated in three series of discussion groups on current research and management needs where much of the emphasis was on sea urchins.

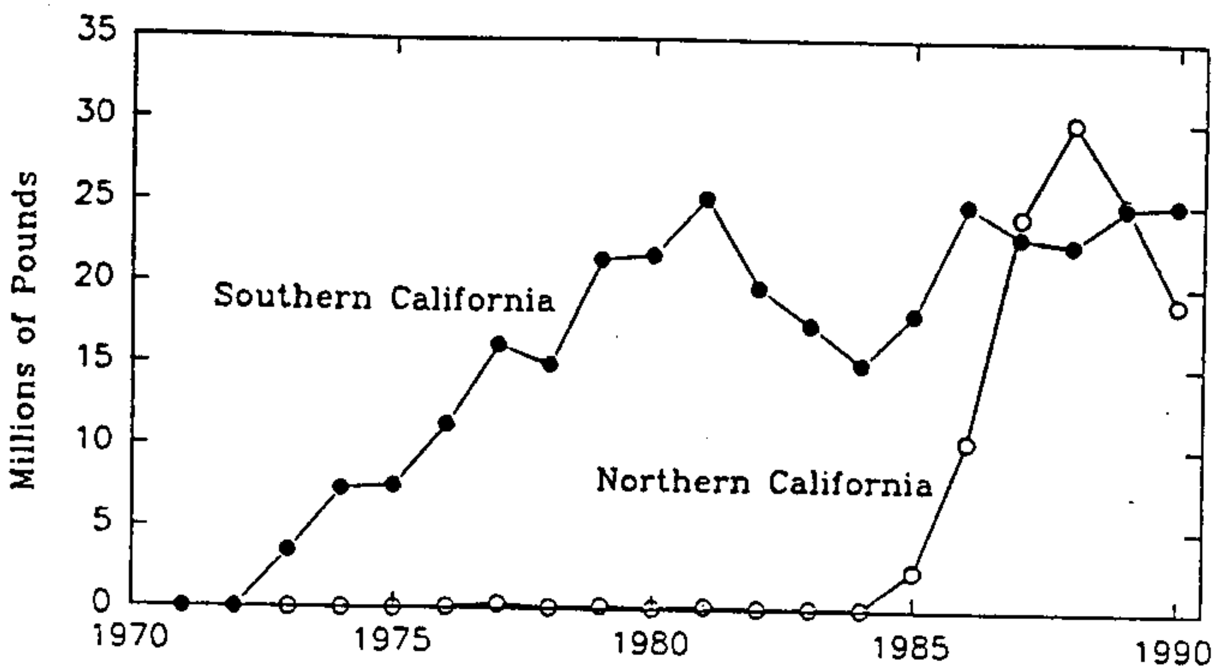
California Sea Grant is publishing summaries of the conference presentations and discussion group recommendations as a separate publication: *Sea Urchins, Abalone, and Kelp: Their Biology Enhancement, and Management*. In the interests of promoting information dissemination throughout the Pacific Rim, however, we are also making available this collection of full, unedited papers related to resource management. The first two papers describe the development of the commercial fisheries in northern and southern California, respectively. Subsequent papers describe the situation in British Columbia, Chile, Japan, and southeast Alaska. Also included is a review of the experiences of Australia, South Africa, and New Zealand in managing their respective abalone fisheries by quota.

Through both its Extension Program and its International Technology and Information Transfer Program, California Sea Grant will continue to seek opportunities to promote international communication among those interested in kelp bed resources.

James J. Sullivan
Director
California Sea Grant College

State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

The Northern California Commercial Sea Urchin Fishery - A Case Study



by

Peter Kalvass

MARINE RESOURCES

1992

Northern California is defined, for purposes of sea urchin management, as the coastal area between the California-Oregon border and the Monterey-San Luis Obispo county line. The center of the northern California fishery, which began to accelerate in 1985, extends from Shelter Cove, southern Humboldt county, south to Half Moon Bay, San Mateo county, a distance of about 220 miles, and includes the Farallone Islands, located about 25 miles west of San Francisco (Figure 1). This area, except for occasional stretches of sandy beach, is characterized by alternating small coves and headlands of exposed bedrock extending subtidally. Tidal areas are dominated by lush seasonal growths of large-bladed brown algae. The primary port for the fishery has been Fort Bragg in Mendocino county, though the ports of Point Arena in southern Mendocino county and Bodega Bay in Sonoma county have become increasingly important.

North of Cape Mendocino in California, the harvest of sea urchins has been relatively low, accounting for less than 200,000 pounds (round wt.) out of the estimated northern California total of 16.4 million pounds in 1991 (Figure 2). To the south, the area between San Mateo and San Luis Obispo counties contains urchin populations that are inadequate to support a commercial fishery due primarily to the established presence of the southern sea otter (Enhydra lutris nereis) (Kato and Schroeter 1985).

The northern California sea urchin fishery, like its southern counterpart, targets on the red sea urchin (Strongylocentrotus franciscanus), but there has recently been a developing interest in its smaller relative, the purple urchin (S. purpuratus). Though red and purple urchins are both found in the nearshore, they usually occupy separate niches or zones, with purples being found in the intertidal or shallow subtidal. These are the only urchin species found in the nearshore in northern California. Sea urchins in northern California are usually confined to intertidal and subtidal rocky habitat to a depth of about 100 ft, primarily depending on the availability of food. The fishery has been centered between 10 and 70 ft of depth on the northcoast (CDFG, unpublished report 1990). Within the fishery area there are a number of locations totalling several miles of coastline where commercial fishing is prohibited, these include marine ecological reserves and two special commercial sea urchin fishery closure zones.

In the recent past, prior to the early 1970s, small numbers of red and purple urchins were harvested for local consumption of the reproductive organs, the edible portion of these animals (called 'uni' by the Japanese). It was not until the Japanese export market began in 1972 for southern California urchin that a small commercial fishery began in northern California, remaining insignificant until 1977 when 386,000 pounds were harvested in the Albion/Ft Bragg region. The fishery fell to under 100,000 pounds in 1978 and again in the period 1982-1984.

An exponential increase in landings began in 1985, due partly to a more favorable monetary exchange rate for U.S. exported goods. Northern California landings jumped from 1.9 million pounds in 1985 to 30.4 million pounds in 1988. Northern California landings eclipsed those of southern California in the years 1987 through 1989. Northcoast urchin landings were worth an estimated $7.9 million exvessel in 1990. Virtually all of the northern California urchin landings have been reds, until 1990 when a small purple fishery began, with about 53,000 pounds landed for the year. Purple urchins have been less economical to process because of their small size and less uniform gonad quality, though this fishery will probably increase as red urchin stocks become increasingly depleted. At present there is only a very minor sport fishery for urchins in California.

Southern California divers and processors began arriving on the northcoast in a migratory wave in 1985, augmenting an increasing number of local divers. At the height of the northern California fishery in the late 1980s there were about 220 vessels spending at least a portion of their fishing year in the north, though a relatively small percentage of vessels landed a high percentage of the catch; in 1989 17% of the vessels landed 50% of the catch (CDFG unpublished report 1990).

STATUS OF STOCKS

Sea urchin stock assessment methods in northern California follow four strands which include:
1) direct censusing of subtidal stocks,
2) the CDFG market receipt database,
3) the CDFG sea urchin fisherman logbook (daily activity records) database, and
4) market sampling of catches as they are landed.

Subtidal Stock Assessment

The subtidal direct stock assessments include a recently completed three year study funded in part by a special $0.005 per pound sea urchin landing tax. The CDFG has been conducting annual subtidal investigations of urchin abundance on the northcoast since 1988. The survey has a two-phase approach, a wide ranging 'broadscale survey' in Mendocino and Sonoma counties and a 'finescale survey' over sites situated near Fort Bragg. Between the spring of 1988 and the last survey period in August 1991, 663 1x30m transects representing 19,890 m^2 were examined (2x30m bands were used in 1991). SCUBA divers surveyed transects at various sites along the Mendocino-Sonoma county coasts at three different depth zones representing a variety of subhabitats, with sites located within commercial sea urchin closure zones, the Point Cabrillo Marine Reserve (PCMR), and areas subject to harvest.

Collected data included the number, canopy condition and test diameters of red sea urchins, the number of purple urchins and red abalone, counts of certain sea stars, and percent cover of algae and substrate by type.

Relative Abundance Indices (Broadscale Survey)

In 1988, the overall mean density of red sea urchins at the 22 broad scale subtidal survey sites was 1.3/m^2 (SE 0.083). This declined to 1.1 (SE 0.098) by 1989, which was a significant decline (ANOVA $p<0.0000$) (Kalvass, Taniguchi and Buttolph 1990, Kalvass et al 1991). By the 1991 surveys, results showed a further drop to 0.71 (SE 0.09) (in an abbreviated survey excluding the Sonoma county sites) (CDFG, unpublished data), representing a 45% decline from the initial 1988 survey.

Juveniles (<=50mm test diameter) as an index of recruitment, accounted for 13.1% of the population in the 1988 broadscale surveys, declined to 7.3% in 1989, and increased to 28.4% in 1991. Though this is an apparent increase in relative numbers of juveniles, when applied to the overall decline in density, the relative change in juveniles from 1988 to 1991 becomes less significant (0.17/m^2 in 1988 versus 0.20/m^2 in 1991).

Size Distribution (Broadscale Survey)

The mean test diameter (MTD) of red sea urchins in the 1988 broadscale survey was 92mm (SE 0.66), MTD was 90mm (SE 0.66) in 1989, and in 1991 MTD dropped dramatically to 77mm (SE 1.33). In 1988, 53.5% of measured red urchins were greater than 90mm (the present legal minimum size), in 1989 47.4% were legal, and in 1991 only 38.0% were in this category (Figures 3 and 4a). When combined with density data, this apparent decline in abundance becomes more alarming, since in 1988 there were 0.70/m^2 legals compared to only 0.27/m^2 in 1991.

Relative Abundance Indices (Fine Scale Surveys)

Red sea urchin densities along transects within the PCMR, the Caspar Closure Zone and sites within areas subject to commercial fishing are summarized in Table 1. Densities within the PCMR and the Caspar Closure Zone are fairly stable, while the apparent steep decline within the fished sites (82%) may be misleading since the south Caspar site was removed from the fished sites analyses (having been closed for two years) in the 1991 surveys. Additionally, several sites were either not revisited or new to the survey within the combined fished sites in 1991. It is important to note that the highest densities of juvenile red urchins are found at PCMR where the highest densities of all size categories are found (Figure 4b). It appears that juvenile urchin recruitment may be enhanced by high adult urchin densities.

Size Distributions (Fine Scale Surveys)

In 1991, red sea urchin MTDs were 94mm (SE 1.4) and 91mm (SE 1.4) at PCMR and fished sites, respectively. In 1988 MTDs were 87mm (SE 1.2) and 85mm (SE 0.87) at these locations. Juvenile red sea urchins comprised 17.8% of the sampled PCMR population compared to 13.3% at the fished sites in 1988. In 1991, these percentages were 15.4% and 12.4%, respectively. Notably, the high percentage of juveniles seen in the 1991 broad scale survey was not evident in this survey. Legal-sized red sea urchins at PCMR comprised 64% of the population compared to 61% of the population at fished sites in 1991 (Figure 5).

Distribution and Migration

Red and purple urchins occupy shallow water from the mid-intertidal to depths in excess of 125 ft, with purples more dominant in the shallower zones. Sea urchins prefer rocky substrate, particularly ledges and crevices and avoid sand and mud (Kato and Schroeter 1985). They occur in patchy distributions within and around stands of large bladed brown algae. Typically sea urchins are most abundant near the outer edges of kelp beds forming in some locations a kelp-urchin mosaic. Recent recruits appear to be more abundant outside of kelp beds in southern California (Tegner and Dayton 1981). Northern California kelp communities are quite different from those in southern California, primarily in lacking significant stands of <u>Marcrocystis</u>, with kelp canopies consisting almost exclusively of <u>Nereocystis luetkeana</u> (bull kelp). This algae, unlike <u>Macrocystis</u>, consists of a single unbranched stem from holdfast to the surface at maturity, with a terminal set of blades. Recent CDFG northcoast sea urchin surveys did not find an obvious pattern of sea urchin distribution associated with stands of bull kelp, there were high densities of red urchin found both within and outside of bull kelp beds, urchin abundance being perhaps more dependent upon substrate and the density of lower growing algaes (Kalvass et al 1991). Rowley (1989) found similar settlement densities of purple urchins within kelp beds and sea urchin barrens (areas of high urchin concentration) near Santa Barbara and postulates reduced post-settlement mortality of newly settled urchins in barrens to explain the higher concentration of adult sea urchins in those areas.

Purple urchins are more abundant than red urchins in harsher habitats (intertidal and exposed to waves and surge), while red urchins dominate in less extreme habitats, apparently because purples are outcompeted here by reds (Kato and Schroeter 1985). Selective removal of red urchins, as in the commercial fishery, seems to be a mechanism for allowing purples to colonize formerly red urchin dominated habitats, a phenomenon particularly noted in areas of southern California (Davis et al In Press).

Sea urchins, like many other semi-sessile benthic invertebrates, exhibit a contagious or patchy distribution. These patches vary in size and distance apart, variables which in northern California are under the influence of an intense commercial fishery, substrate type and the availability of cracks and crevices. Sea urchin patch size can vary from a few urchins to up to several hundred, but more commonly is considerably under 50 or so individuals. In addition to size and species specific harvesting, sea urchin distributions can be affected by predation, both post-settlement and later, and by food availability (Kato and Schroeter 1985).

A relatively high percentage (46%) of juvenile red sea urchins in the 1989 broad scale survey were found under the spines or tests of larger urchins (canopy), while in comparable fine scale areas 66% of juveniles were canopied (Kalvass et al 1991). Most canopy groups consisted of one canopy provider per sheltered conspecific. Breen, Carolsfeld and Yamanaka (1985) studied juvenile red urchin social behavior in coastal British Columbia as well as in the laboratory. They concluded that juvenile red urchins are found under canopies as a result of preferential juvenile behavior, presumably to avoid predation and to benefit from the superior food capturing abilities of the adults. This kind of adult-juvenile relationship can exert a strong influence on sea urchin distribution patterns.

Distribution can also be affected by larval supply which in turn is determined in part by spawning success and nearshore currents and eddies which can move larvae to or from favorable habitats at the critical settlement stage. Variations in recruitment success of many marine organisms has been attributed to annual and geographical differences in upwelling intensity and its associated offshore transport of larvae (Tegner 1984). Upwelling index values at 39N latitutude characterize the area between Cape Mendocino and Point Arena as the most vigorous upwelling region in the California system (Bakun and Parrish 1980).

Catch and Effort Analyses

The market receipt database forms the foundation of the stock assessment system and provides landings data by port, species, vessel and time period as well as exvessel value. The commercial fishery for red sea urchins in northern California exhibited exponential growth prior to its recent decline. In 1985, 1.9 million pounds were landed; landings peaked at 30.4 million pounds in 1988, followed by a 40% reduction to the 18.3 million pounds landed in 1990 (Figure 1). Declines in landings are an index of the health of the population and can be attributed to a combination of factors, including most importantly a decline in fishable stock, more restrictive management measures as a response to that decline, and a reduction of fishing effort in part due to the former two developments.

Fishermen are required to maintain daily records of their fishing activity (logs). Though mandatory since 1987, logbook data compliance has only been about 60-70% in northern California in recent years. This data is valuable in that it provides managers with important fishery indices at a minimum of cost. These include catch per unit of effort (CPUE) data such as red sea urchin pounds landed per diver hour, number of divers per fishing vessel, and location of fishing activity which can be converted to one nautical mile intervals along the coastline.

An analysis of catch per unit of effort (CPUE), as average number of fishing days per week (Sunday through Saturday), for the top 20 northern California urchin boats (ranked by landings in 1991) submitting logs, showed that during the period April through October (the period subject to current or proposed time closures) days fished never exceded 3 days per week, though the present regulation mandates 4 legal fishing days per week during the open periods between May and September. Additionally, of the 16 boats reporting landings during this time period (April through October), only 7 averaged more than 3 days fished/week, and none 4 or more (Figure 6).

CPUE as pounds per hour has been on the decline in most fishery areas since 1989 and has dropped by almost 40% in the Fort Bragg area during that period (Figure 7). The increased size limit (from 3.0 to 3.5 inches test diameter) in June 1990 has undoubtedly contributed to that decline.

Decreases between 1990 and 1991 in the percentage of catch by catch area ocurred throughout the principal fishing areas, with exceptions at the Westport, Sea Ranch and Fort Ross areas and more recently exploited areas to the north and south (Figure 8). Harvest depth patterns have also been monitored via logbook data since 1987. In both 1989 and 1990 the 30-39ft depth interval accounted for more red sea urchins harvested than any other depth interval.

Dockside market sampling provides managers with information relating to the size distribution of the catch as well as a system for validating some of the logbook information via direct fisherman interview.

The vast majority of market sampling in Northern California has been done in the Mendocino county ports. Before the new minimum size limit of 89mm (3.5in) became effective on June 7, 1990, 35.1% of the 1990 sampled catch fell below 3.5 inches. Market sample data for 1991 shows 11.6% of sampled urchins under 3.5 inches (Figure 9).

Age and Growth, and Recruitment

The availability of size-specific age data has been limited in part due to the difficulty associated with tagging sea urchins with physical external tags capable of identifying individual urchins. The biggest problem with using hard parts (jaws, spines or test plates) to age sea urchins is that while growth lines are found in urchins, Strongylocentrids do not have an annual or semiannual burst of growth and subsequently these growth lines or zones are not useful for ageing (Kato and Schroeter 1985, Mottet 1976).

A technique developed by Ebert (Ebert and Russell 1991 Draft) uses tetracycline to bind to calcium ions and become incorporated into sea urchin skeletal elements. Sea urchins are injected with OTC and upon recapture, ultraviolet light reveals tetracycline marks from which the size of the skeletal element at the time of tagging can be determined. Knowledge of this original size, final size and time interval are sufficient to estimate growth.

Studies funded by the Pacific States Marine Fisheries Commission are presently underway to determine size-specific ages of red and purple sea urchins at several locations in northern California. A preliminary study conducted at PCMR in 1988 and 1989 on a limited sample size lacking small individuals revealed that large animals were growing very slowly. Above a jaw length of 18mm, correlating to about 99mm TD, annual jaw growth increments are only 0.1 to 0.2mm. At this rate it might take longer than 20 years to attain a jaw length of 21mm, which correlates to a TD of 113mm. Ebert (unpublished data) concludes that northern California populations with large animals have individuals in excess of 30 years old.

While there are not yet published ageing studies of northern California red sea urchins, field studies in British Columbia suggest that red sea urchins probably attain harvestable size in 4-5 years, on the average (Kato and Schroeter 1985). Tegner and Barry (1989) developed a growth curve from a study on red sea urchins in the Pt. Loma kelp forest near San Diego. That relationship, in contrast to one described by Bernard and Miller (1973), exhibits more rapid growth initially but becomes asymptotic more quickly. Visually combining both analyses produces an estimate of 3.5 to 4.0 years to reach 90mm and subsequent recruitment to the northern California commercial fishery (Kalvass et al 1991). Bradbury (1989) estimates about 4-8 years to reach the various legal sizes in Washington State.

Northern California recruitment levels appear to fall within the ranges described for Washington, British Columbia and Alaska. Mean recruitment rates for urchins <= 50 mm in British Columbia studies ranged from 5.5 to 16.0% (Sloan, Lauridsen and Harbo 1987, Breen, Miller and Adkins 1976, Bernard and Miller 1973). Recruitment rates (based upon urchins < 50 mm) for two commercially harvested districts in Washington were 10.7% and 6.6%, respectively, in 1988 (Bradbury 1988). Based upon a 1990 survey by the Alaska Department of Fish and Game in Sitka Sound, the proportion of red urchins in the population under 50 mm was 10.8%. The annual recruitment for 1990 was estimated as 3.2% (Woodby 1991).

Natural Mortality

Estimates of total mortality (Z) have been made for red and purple sea urchins at various west coast locations. Total mortality is composed of fishing mortality (F) and natural mortality (M) (Ricker 1971). As noted by Bradbury (1989), red sea urchin populations in the Pacific northwest exhibit low recruitment rates and size distributions that are negatively skewed, indicative of domination by larger, older individuals. Populations with low death rates and relatively fast growth in the early stages can exhibit this type of distribution. The instantaneous rate of natural mortality (M) in a British Columbia population was estimated from size frequency data as 0.057 (Bradbury 1989). Based upon this estimate and others, and the relative lack of natural predators on red sea urchins in the Pacific northwest, Bradbury (1989) postulates a relatively low M of 0.1 for Washington's Puget Sound.

Woodby (1991) calculated a Z of 0.16 for a Southern Sitka Sound red sea urchin population, this is equal to an approximate annual rate of 15% (annual mort. rate = $1 - e^{-Z}$).

Central California Stocks

Densities of red sea urchins at Hopkins Marine Reserve near Monterey were monitored over a 10 year period from 1972-1981 and remained very low ($0.1/m^2$) (Pearse and Hines 1987). Additionally, this population did not experience a major recruitment event during the 10 year period, while the purple sea urchin population experienced a substantial recruitment event. This area is in the present sea otter range, and red and large purple sea urchins are preferred food items of the sea otter (Miller 1974). There is presently no commercial sea urchin harvest within the sea otter range, and virtually no commercially fishable stock (Tegner and Barry 1989).

RESOURCE MANAGEMENT

The status of northern California sea urchin stocks are evaluated by assessing abundance and size distribution trends both directly with dive surveys and indirectly using the methods listed previously. Abundance indices developed for this fishery enable managers to follow a 'points of concern' approach to management. As problems develop, managers can suggest changes in fishery regulations to address them.

Fishery management regulations in northern California were virtually identical to those in southern California until March 1989 when the Caspar and Salt Point Closure Zones were established to study the recovery of previously fished areas subject to closure. Further differences in management between the regions came about in June 1990 when the complete July closure and the 3.5 inch minimum size limit were established in northern California.

Sea urchin fishery management strategies require an understanding of the interplay between the impact of harvest upon yield, or biomass production via growth, and the impact of harvest upon recruitment, expressed as egg and larval production (Botsford, Quinn and Dewees Sea Grant Proposal 1989).

Partly because marine populations do not exist in equilibrium due to annual variations in recruitment, growth and mortality, the fishery management concept of MSY (maximum sustained yield) has come under close scrutiny as an acceptable management goal in recent years (Larkin 1977, ADFG 1990). Because of highly variable environmental conditions, management schemes based on MSY can lead to recruitment overfishing in which the recruitment potential of the stock is impacted. It is therefore important to consider the effect of management measures designed to maximize yield upon the number of fertile eggs produced by a stock (Sluczanowski 1984). Approaches to fishery management traditionally have evaluated the lower size limit and fishing mortality rate on yield-per-recruit (YPR). In order to account for the effects of fishing on recruitment, analysts have begun computing eggs-per-recruit (EPR) (Botsford, Quinn, Dewees Sea Grant Prop. 1989).

For a hypothetical population in an equilibrium condition, we can let MSY = 0.5 M B_O, where the amount available for harvest (F) in a given year would be equivalent to that amount of virgin biomass (B_O) lost to natural mortality (M) in the absence of fishing, less the proportion under the legal size limit (unavailable to the fishery and set to 0.5 in this example) (Gulland 1977, ADFG 1990). Despite the inherent limitations of this type of simplistic yield modeling, it can assist managers in developing harvest rate guidelines in the absence of a long time-series of catch and effort data and growth and mortality rate estimates. Using an expected natural mortality of 10-15% for northern California red sea urchin stocks, a scaling factor of 0.38 to account for the percentage available to harvest (percent legals based on 1991 northern California broadscale surveys), yields a range in harvest rate of 0.04 to 0.06 which translates to a conservative annual yield of 4% to 6% of the northern California virgin red sea urchin biomass.

Management to date has followed a reactive 'points of concern' approach by tracking the various indices described in the previous section. In 1989 the DFG decided to reduce the harvest by 20-30% from that of the 12 month period preceding adoption of new regulations designed to decrease harvest pressure, in an effort to address the declining abundance. The harvest reduction goal was achieved as northern California landings declined by 24% to 17.7 million pounds in the 12 months following regulation changes. However, it is doubtful whether this level represents a sustainable yield because of the continued relatively low population recruitment rates compared to areas in southern California. Additionally, annual landings in southern California have remained fairly steady over the last decade, and at around 20 million pounds they maybe near MSY. This harvest is gathered over an area at least twice as large as the principal available fishery areas in northern California, when using miles of shoreline of the Channel Islands and mainland as the means of comparison.

The fishery implications of reduced urchin densities are multifaceted. They mean fewer refuges for juvenile urchins, a factor in increasing mortality. Lowered adult densities also could have serious impact on the success rate of fertilization. Pennington (1985) in both laboratory and field experiments with green sea urchins (S. droebachensis) found that egg fertilization success rates at distances greater than 20cm from spawning males were less than 15% compared to 60-95% within 20cm. The naturally occurring aggregations of adult and juvenile urchins are therefore important for a variety of reasons, but may also make urchins more vulnerable to recruitment overfishing.

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Table 1. Red Sea Urchin Mean Densities (number/m^2) at Finescale Survey Sites, 1988-1991.

Site *	Survey	1x5m Quads	Mean Density	SE
PCMR				
	Summer 88	132	6.7	0.60
	Summer 89	102	5.4	0.57
	Summer 91	115	7.0	0.58
Caspar Closure Zone	Summer 88	114	4.5	0.52
	Summer 89	102	2.3	0.32
	Summer 91	246	3.7	0.33
Commercially Fished Sites	Summer 88	312	2.2	0.24
	Summer 89	210	1.7	0.21
	Summer 91	372	0.3	0.06

* Caspar closed to fishing in March 1989, data are included in fished sites in Summer 88 and Summer 89 surveys.

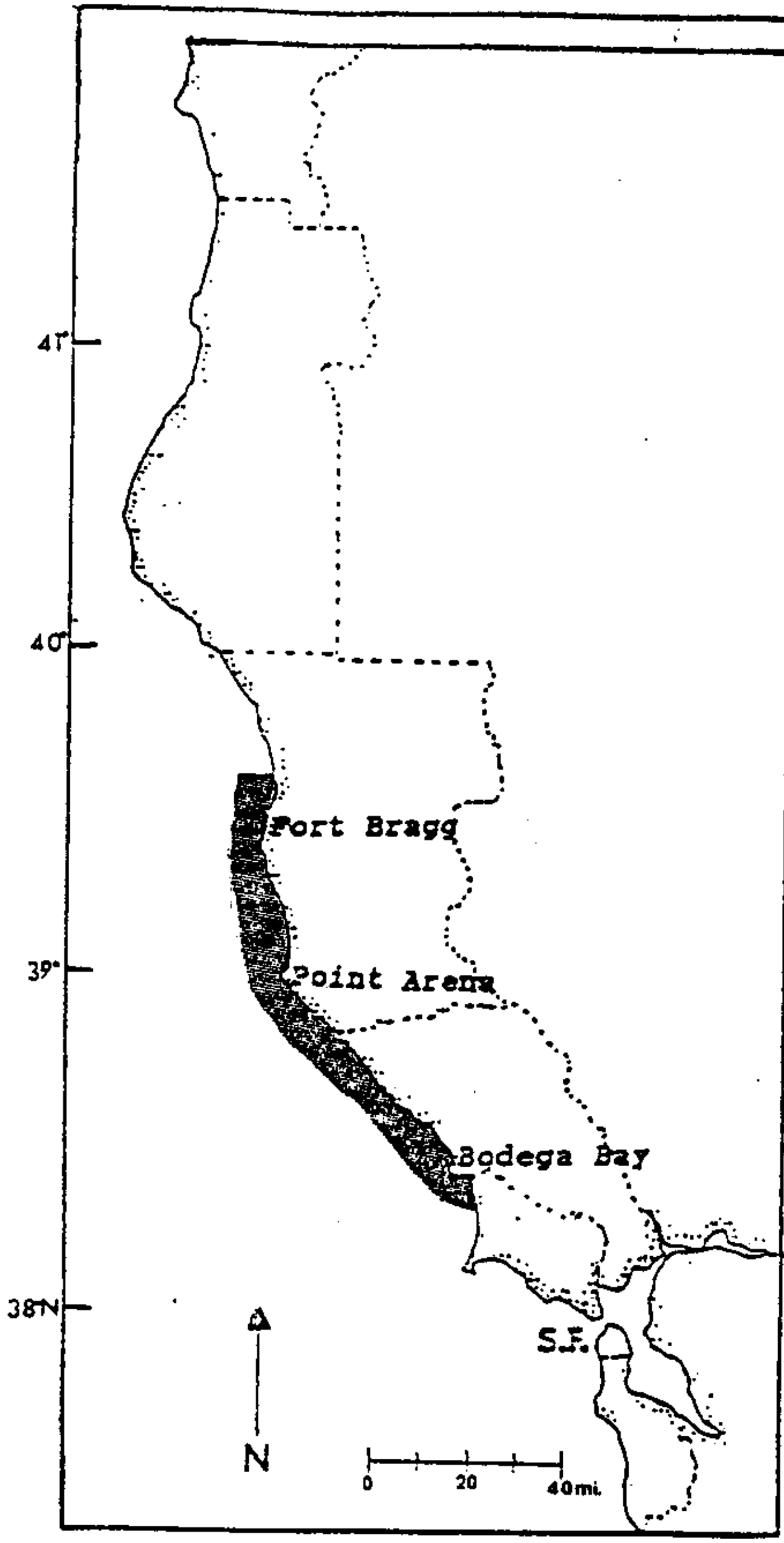


Figure 1. Principal northern California red sea urchin harvest area.

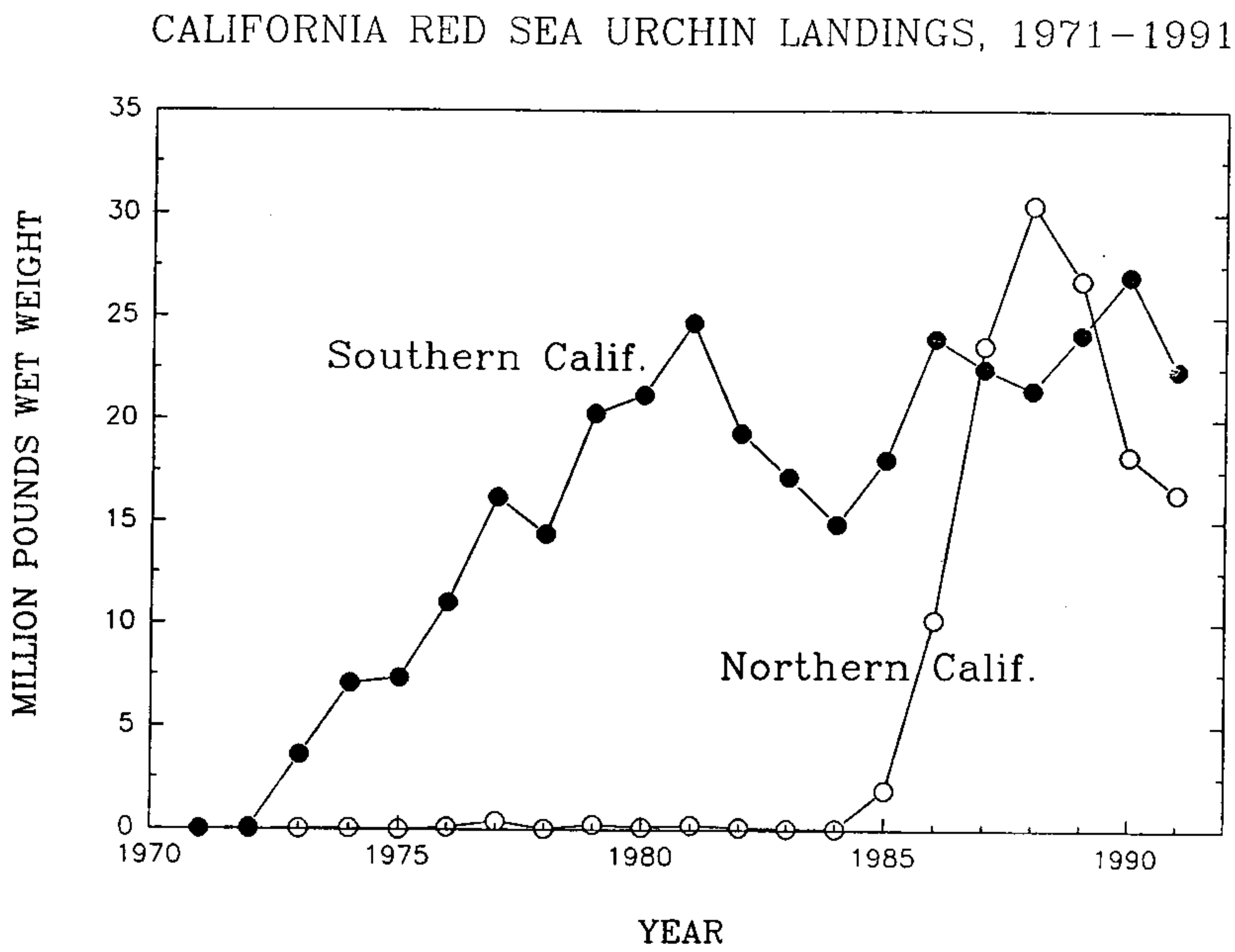


Figure 2. Commercial red sea urchin landings in northern and southern California, 1971-1991.

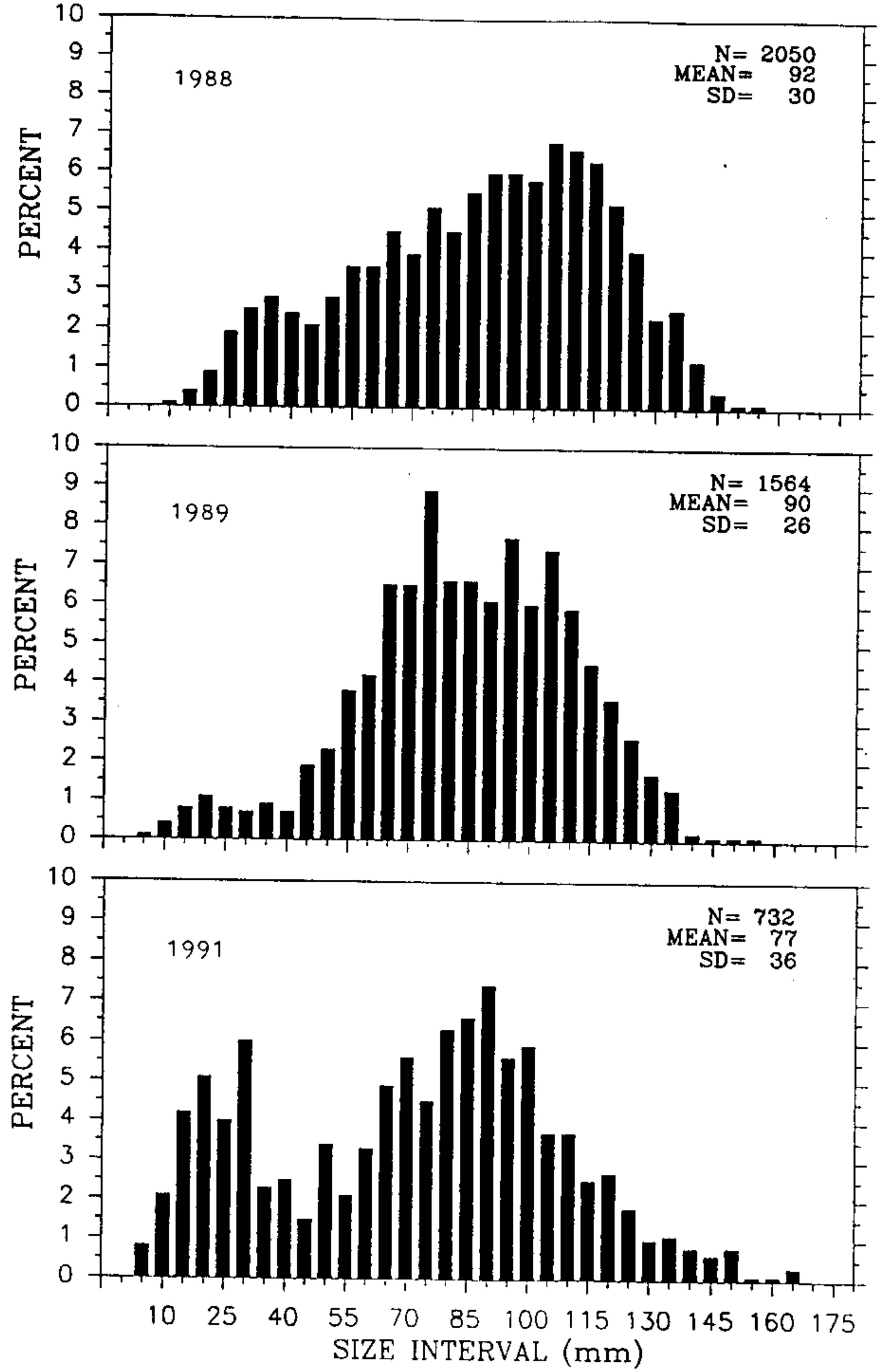
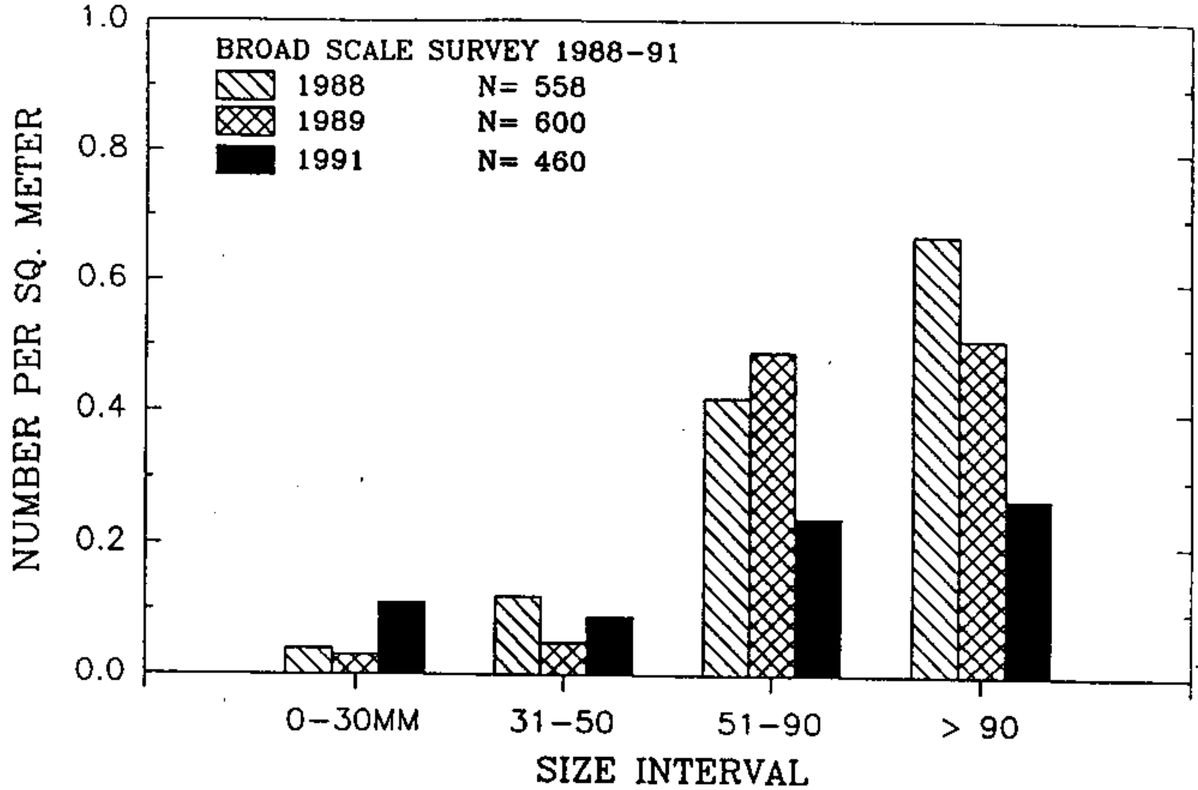


Figure 3. Frequency distributions of red sea urchin test diameters for 1988, 1989 and 1991, northern California broad scale subtidal surveys.



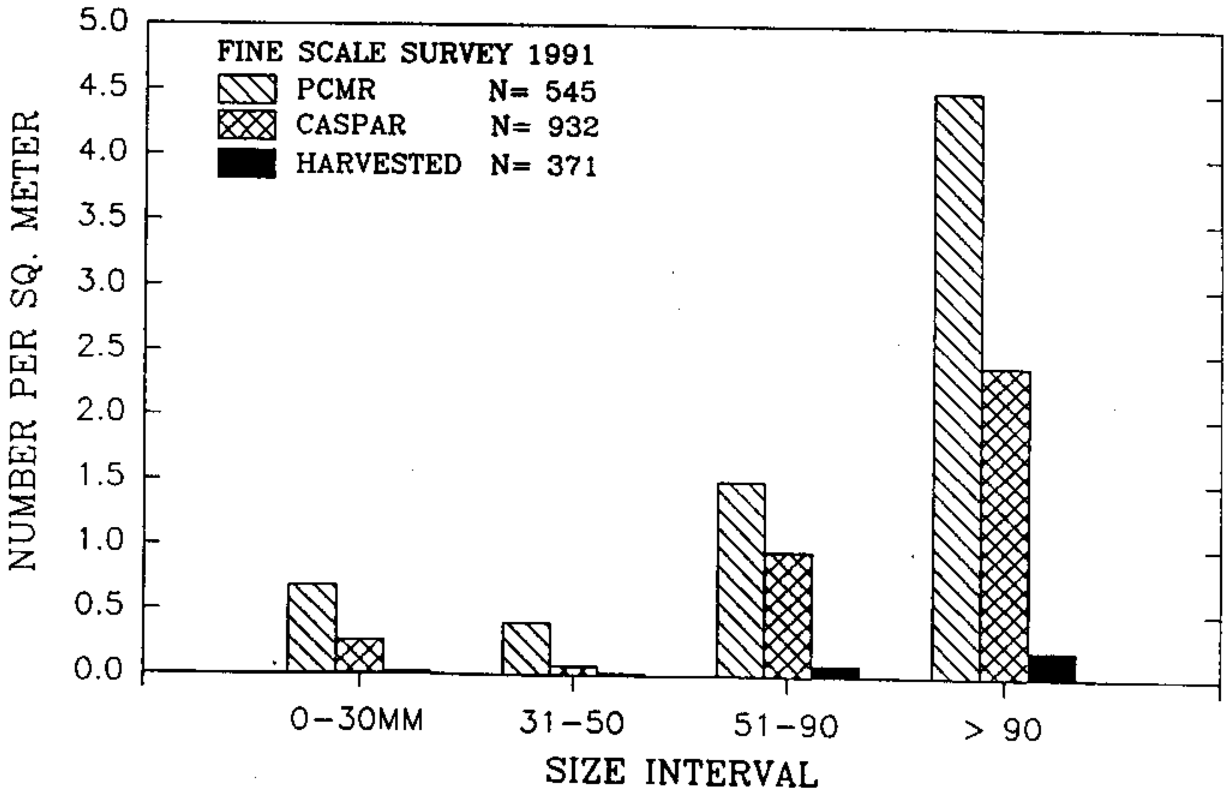


Figure 4. Red sea urchin densities by size category for broad scale survey, 1988-1991 (A), and for PCMR, Caspar and combined fished sites, fine scale survey, summer 1991 (B).

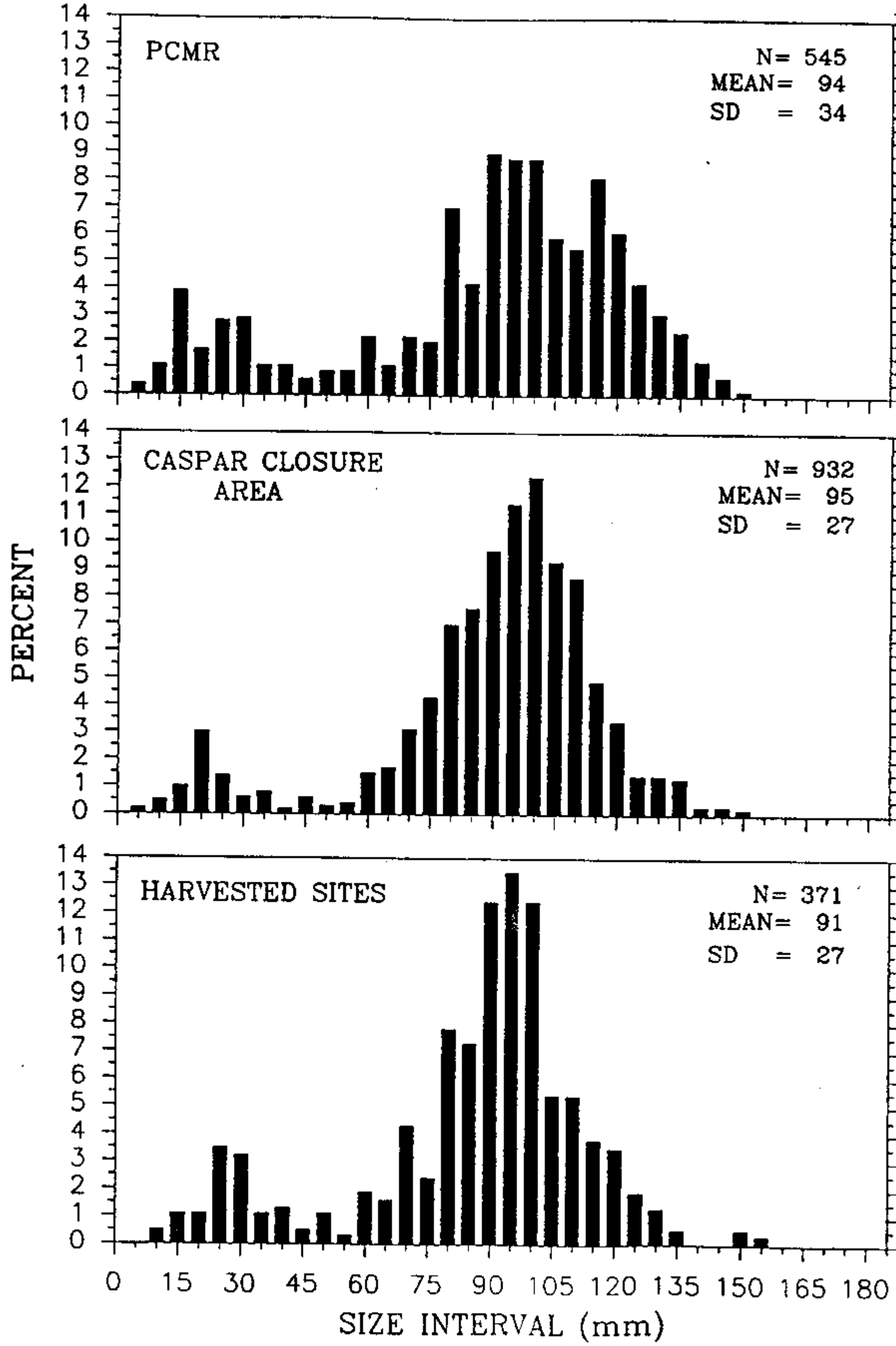
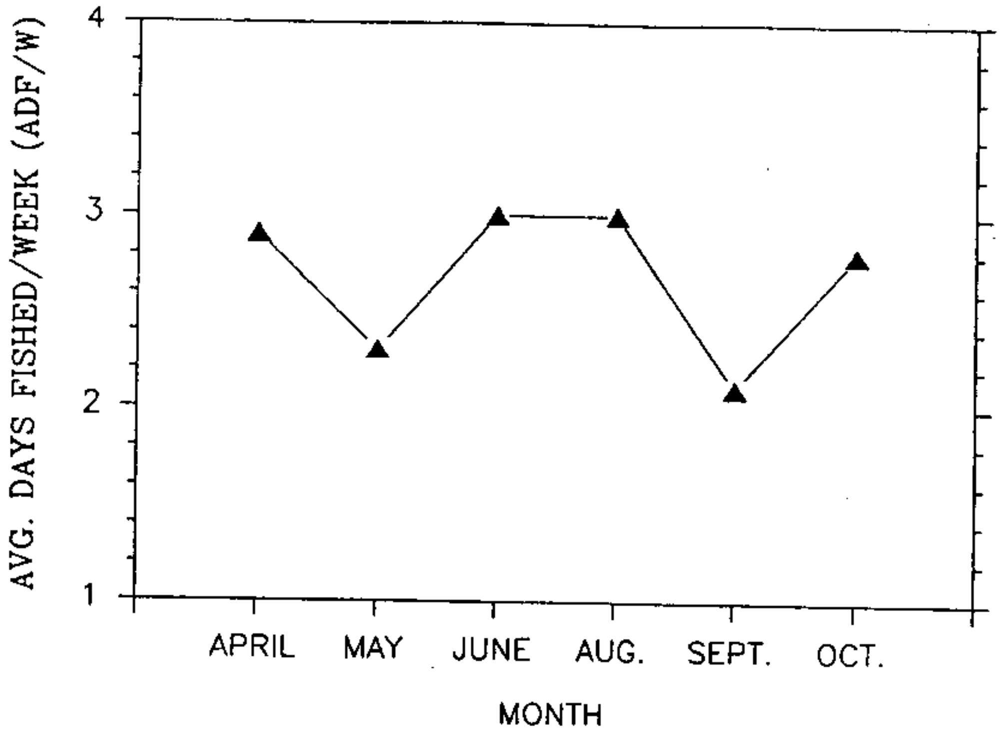


Figure 5. Frequency distributions of red sea urchin test diameters for PCMR, Caspar Closure Area and combined fished sites, fine scale survey, summer 1991.



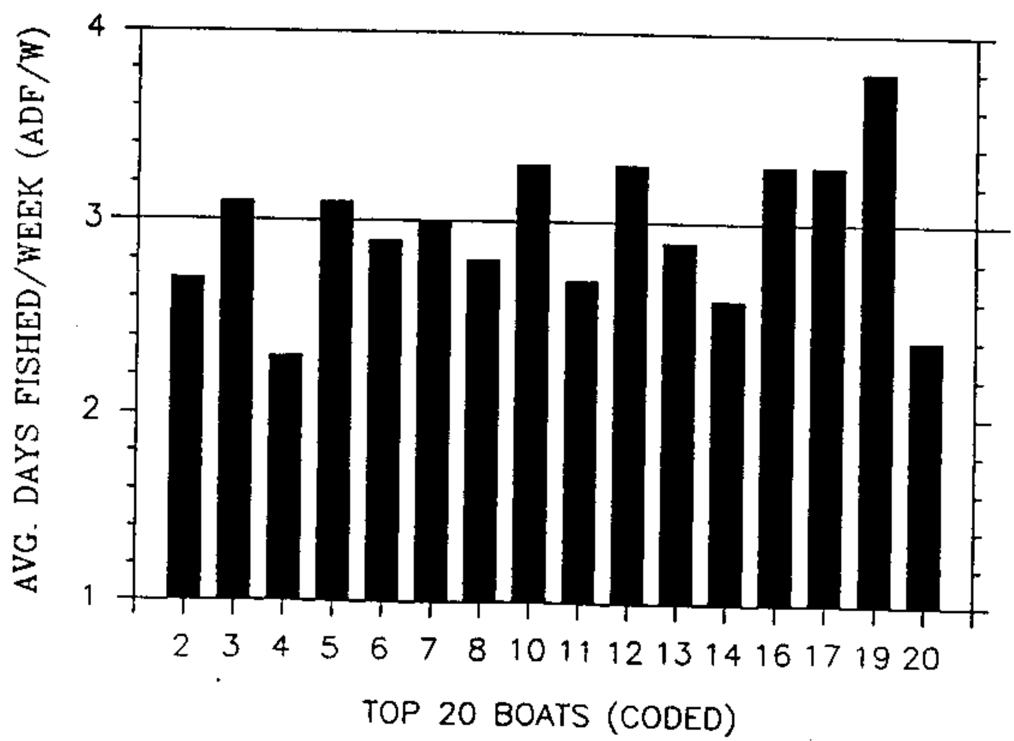


Figure 6. Average days fished per week by month and vessel for the top 20 northern California sea urchin vessels, April through October 1991.

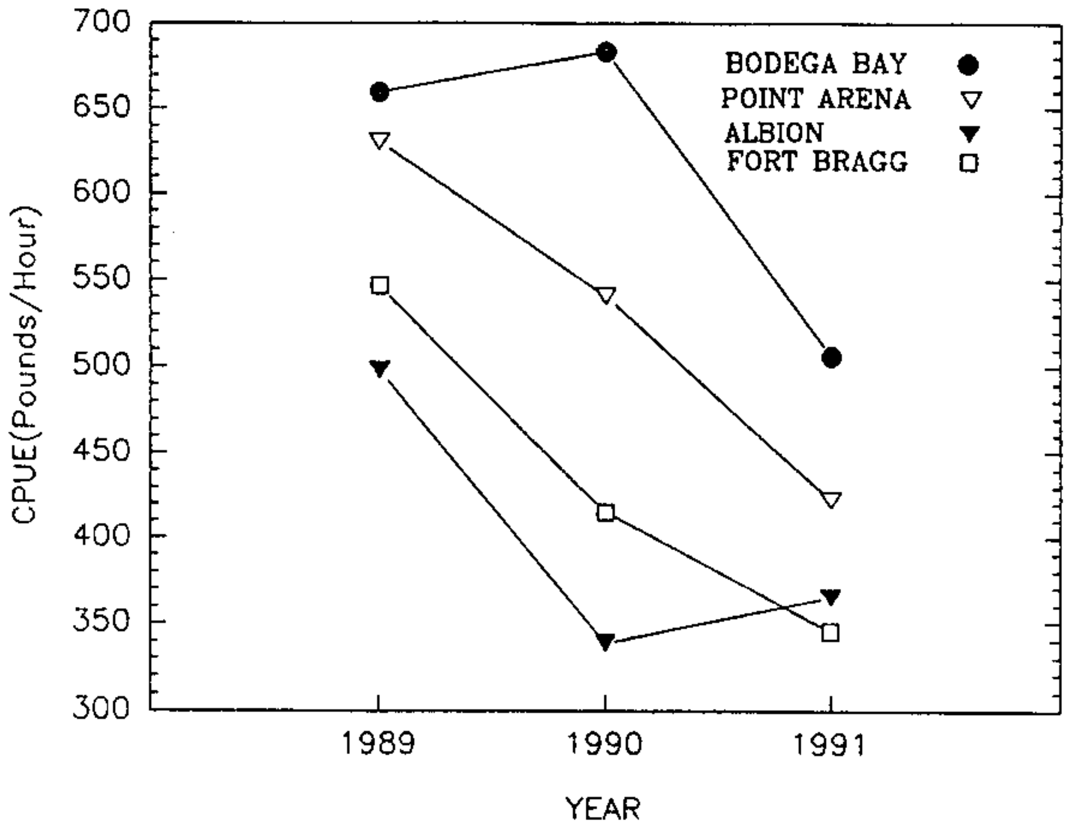


Figure 7. Northern California commercial red sea urchin CPUE by major port, 1989-1991.

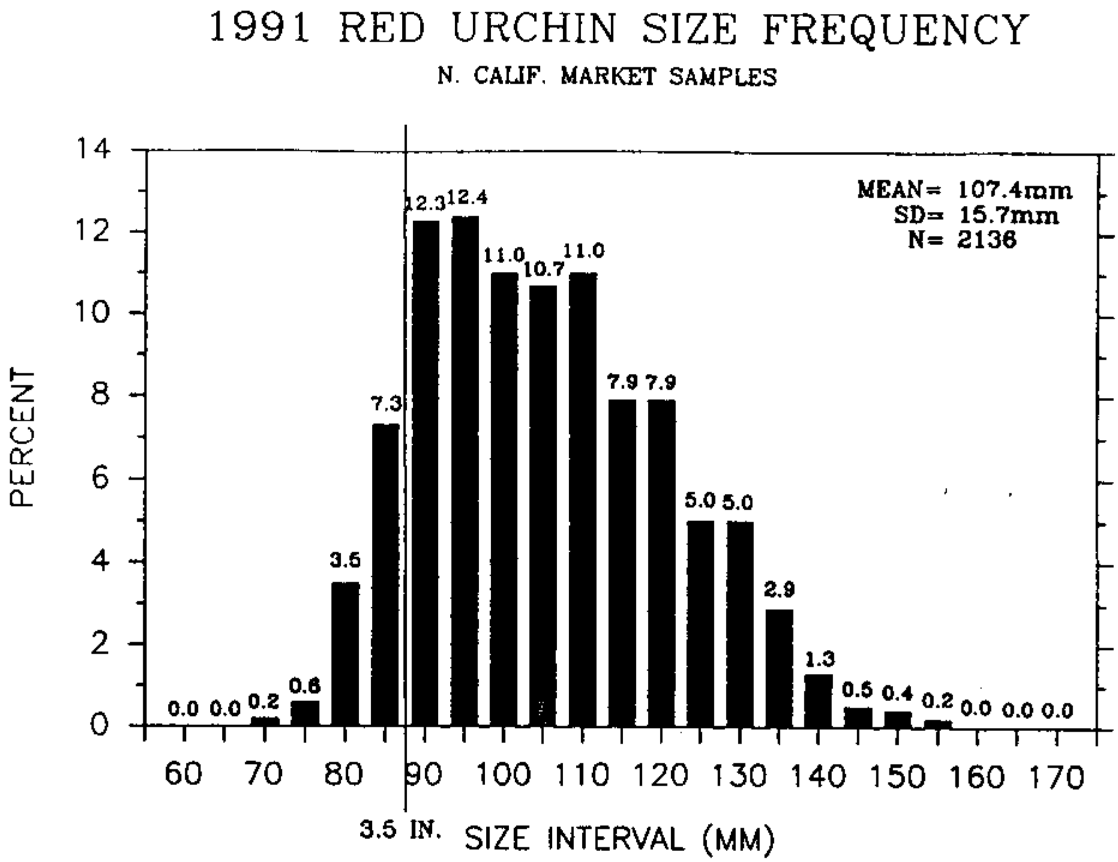


Figure 8. Frequency distributions of red sea urchin test diameters from northern California commercial catch, 1991.

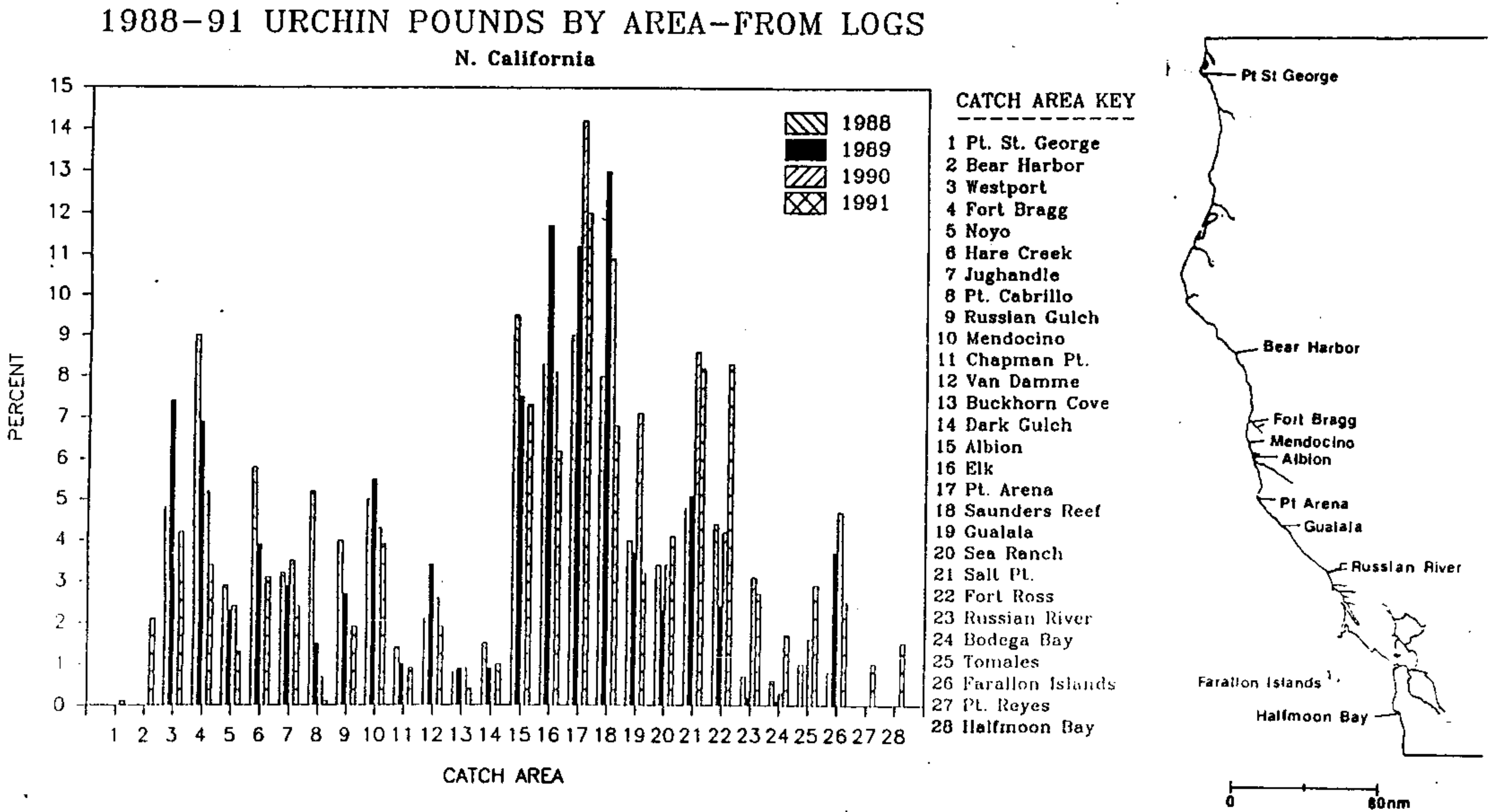


Figure 9. Northern California percent commercial sea urchin catch by area, 1988-1991.

The Southern California Red Sea Urchin Fishery 1972-1992

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and
Pete Halmay, Diver
Lakeside, California

THE SOUTHERN CALIFORNIA
RED SEA URCHIN FISHERY
1972 - 1992

ABSTRACT

The El Nino event around 1958 wiped out the Southern California kelp beds. Sea urchin grazing was considered the factor precluding the re-establishment of the kelp beds. The harvest of red sea urchins began in 1972 as a means of controlling sea urchin grazings.

The unique nature of the Southern California Bight and its effect on the life cycle of the red sea urchin is described. Fishery data is presented describing the catch and effort variations.

The San Diego based red sea urchin fishery is described in detail. The kelp-urchin interactions has been extensively studied, since 1960, in the San Diego area.

Economic factors relating to the red sea urchin fishery and its primary market in Japan are described.

The management of the Southern California red sea urchin fishery is described. The management started with few regulations as a market driven fishery harvesting the large standing stock of relatively old, poor quality red sea urchins. This evolved to a more controlled fishery with management based on sustaining the standing stock by a minimum size limit and controlling effort by reducing the number of fishing days per week during the summer months.

Management decisions are recommended by an advisory committee made up of members of the California Department of Fish and Game, sea urchin divers, sea urchin processors and a representative of the Sea Grant Program. The recommendations are based on fishery data provided by the California Department of Fish and Game, empirical data and anecdotal evidence provided by the divers, and marketing information provided by the processors.

Implications for further management schemes, including enhancement programs; mitigating seeding, habit-improvement quality enhancement, are discussed. The need for fishery independent data for management decisions is presented.

THE SOUTHERN CALIFORNIA RED SEA URCHIN FISHERY 1972-1992

A case study of the Southern California red sea urchin fishery will look at the following topics:

1. KELP ECOSYSTEM
2. SEA URCHIN RESOURCE AND FISHERY
3. FISHERY ECONOMIC VIABILITY - THE MARKET
4. SEA URCHIN MANAGEMENT
5. THE FUTURE

1. KELP ECOSYSTEM

The viewpoint that macrocystis forests are the key component of the kelp ecosystem was advanced as early as 1834 by Charles Darwin who noted. . .

> "Yet if in any country a forest was destroyed, I do not believe nearly so many species of animals would perish as would here, from the destruction of the kelp."

When severe deterioration of the Southern California kelp beds was observed in 1958, scientific studies were performed to determine the cause of this deterioration. (North W. Hubbs 1968, KHIP 1963-1974). The viewpoint in all these studies was that macrocystis forests are desirable, and are the unvarying natural state of coastal waters (Foster M.S. Schiel D.R. 1985).

The domination effect of sea urchins on the distribution and abundance of macrocystis plants led the idea that sea urchins were to blame for the loss of the kelp beds. The kelp-sea urchin interaction is illustrated in Figure 1 - Sea urchin dominated area.

Scientific literature, when discussing sea urchins was replete with words such as :

"Sea urchin population explosion (North), "overgrazing", "Control & Regulating" "Sea urchin barrens."

These studies all stated that the sea urchin population has caused an "unnatural" shift from natural community dominated by a large macro algae to a community where large macro algae was absent in large patches (Foster & Schiel 1985 Tegner & Dayton 1981).

This led to assaults on the lowly and meddlesome sea urchins that took on epic proportions; from the destruction of tests with quicklime to mechanical maceration (Foster & Schiel 1985).

In the midst of all this destructive activity it was noted that Japanese people actually used sea urchins as a source of food. It was discovered that there existed a market in Japan for sea urchins served as paste or as "sushi". The establishment of the sea urchin fishery in California was advanced as a means of reducing the grazing activities of sea urchins (Kato 1972).

The effect of the sustained red sea urchin harvest was to reduce the red sea urchin population and grazing potential to allow the recruitment of macrocystic and the reforestation of areas barren of kelp plants.

Sea urchins and kelp in equilibrium are shown in Figure 2, Sea urchins and kelp. Although the red sea urchin harvest appeared to have benevolent effect on the kelp ecosystem, resource managers advocated additional sea urchin control measures as late as 1985. The annual harvest of red sea urchin had reached 21 million pounds in 1980.

The changes in kelp canopy during this period is shown in Table I, Kelp Canopy Planimeter Areas. It can be seen that the size of the kelp beds remained stable from 1967 to 1989 with the exception of two areas. These areas are S. Nicolas Island and the portion of the mainland coast from the city of Santa Barbara to Point Conception.

EL NINO

The El Nino is a warming of the ocean waters that has occurred cyclically for more than a century. El Nino events have considerable influences on atmospheric conditions. The changes in wind patterns influence the degree of upwelling and thereby the transport of plankton. This is illustrated in Figure 3 Satellite Image using Coastal Zone Color Scanner.

The CZSC measures irradiance from the ocean to a depth of 10 to 50 fathoms. This gives an estimate of how much chlorophyll is in the water, shown in mg of chlorophyll per cubic meters of water.

The strong California current, whose influence normally extends past San Diego is all but absent and replaced by a push of warmer water from the South.

The reduced productivity would have severe effects on the sea urchin larva transport and therefore on settlement and recruitment of sea urchins. The El Nino of 1958 and 1983 reduced the kelp canopy in Southern California by 90%.

HYDRODYNAMIC FORCES

The Southern California Bight is subject to unique hydrodynamic forces which affect the larval distribution of sea urchins. This has profound effects on sea urchin recruitment volume and occurrence (Kato, Schroeter 1985). The hydrodynamic forces are illustrated on Fig. 3, Currents.

Sustainability of the red sea urchin resource is dependant on the recruitment of sea urchins into the population. The recruitment rates are much higher in Southern California than in British Columbia and Canada (Bernard & Miller 1973, Tegner and Dayton 1981).

SANTA BARBARA ISLAND

Santa Barbara Island supported a large harvest of prime quality red sea urchins from 1978 to 1985. Since that time the harvest has decreased dramatically. At this time only a very small harvest of generally poor quality urchins exists.

The kelp beds have been greatly reduced and urchin dominated areas are common.

These events may be cyclical and conditions will reverse.

2. SEA URCHIN RESOURCE & FISHERY

GENERAL

The red sea urchin fishery in California is divided into two parts; the Northern California fishery and the Southern California fishery. The dividing line is the San Luis Obispo County and Monterey County Line.

The Southern California fishery includes a part of the sea otter range. The foraging habits of sea otters do not leave any animals large enough or in sufficient quantities to allow for any human exploitation. There is no commercial harvest north of Pismo Beach (Rebok, Radon).

The entire red sea urchin harvest occurs from Point Conception to the Mexican border.

This area is shown on Figure 5, Southern California Kelp Beds. This area consists of approximately 200 miles of shoreline along the coast and eight offshore islands.

Red sea urchins are landed at four major ports: Santa Barbara, Ventura-Channel Islands, San Pedro and San Diego. These ports are shown on Figure 5.

RED SEA URCHIN GROWTH RATE

The growth rate of red sea urchins are very important to the management of the fishery. A composite graph of growth rate is presented in Figure 6 - growth curve.

This curve included studies by various researchers to 1980. The first year stage of the curve is presently being questioned by some researchers who believe that growth rates are much slower in the first two years (Schroeter, Dixon, Ebert).

The growth rates may vary considerable from one area to another.

RECRUITMENT

An important measure of the ability of the sea urchin resource to sustain itself is the rate of recruitment of young urchins into the population.

It was considered by Tegner (Tegner Barry 1990) that juveniles under 35 mm had settled within the past year and were therefore one years recruitment.

Various recruitment rates for the Channel Islands is shown in TABLE II Red sea urchin Recruitment.

Another method of measuring recruitment is by determining how many urchins entered the fishery in one year.

The minimum size limit for red sea urchins was taken as 74 mm. Using the growth curve in Figure 6, it was estimated that red sea urchins would grow from 74 mm to 94 mm in one year.

By calculating the percentage of harvested urchins between 74 and 94 mm we could determine the recruitment into the fishery. This is illustrated in TABLE III Red sea urchin recruitment into the fishery.

If undersized urchins (under 74mm) are harvested the recruitment into the fishery would be offset. These percentages are shown in TABLE III.

Areas of high sea urchin recruitment into the fishery appear to coincide with sustained harvest areas, e.g., San Diego and Northern Channel Islands. This is illustrated in TABLE III and TABLE IV Spatial and Temporal variations in red sea urchin harvest areas.

CATCH AND EFFORT

The red sea urchin fishery began in 1972 (Kato 1972). The annual landings of red sea urchins in Southern California are shown in Figure 7, Southern California Red Sea Urchin Fishery.

It can be seen that the catch increased steadily until 1981 then declined for three years. Since 1986 the catch has been relatively steady.

Information regarding effort is somewhat sketchy. The number of participants in the fishery in the initial years is a matter of speculation. There was a large turnover rate as new divers came into the fishery and old divers left.

The number of divers peaked in 1986 when limited entry was established. However, the number of active participants or the number of divers in Southern California is not known since there was no distinction betwen North and South until 1988.

The number of boats in the fishery is another measure of effort. This is shown in Figure 7. It can be seen from the little information available that the number of boats has been steady between 200 and 250 since 1979.

The quality of the boats has largely improved in the last six years.

HARVEST AREAS

Changes in harvest areas is shown in Table IV.

It can be seen that roughly 80% of the harvest occurs at the Channel Islands and 20% along the mainland coast.

Other fluctuations need to be followed for more than three years to determine trends.

SAN DIEGO FISHERY

The sea urchin resource in the San Diego area has been studied in detail for over 20 years and the red sea urchin fishery has been well documented.

Although the San Diego fishery is only a small part of the southern California fishery some observations apply to the entire fishery.

The catch is shown in Fig. 8, San Diego Red Sea Urchin Fishery. The fishery started in 1974 and landings increased steadily to 1981-82. The El Nino of 1982 caused a severe decline in the fishery in the next two years.

For the next few years only two or three boats harvested urchins in San Diego. The fishery rebounded in 1988 and landings have been over 1 million pounds since then.

CPUE (SAN DIEGO)

Resource managers use catch per unit effort as an indicator of stock abundance. The effectiveness of CPUE as a measure of standing stock for diving fisheries has been questioned (Day, Leorke 1986).

Complete records from divers and a processing company in San Diego are available from 1977 to 1991. (Datz, Rudie, Catalina Offshore Products).

The variation in CPUE from 1977 to 1991 is shown in Figure 8. The unit effort used is pounds per diver per day. It can be seen that CPUE decreased dramatically in the period 1977 to 1980 from 1600 pounds to 700 pounds. The CPUE has remained constant to this date with the exception of a decrease in 1984-86 caused by El Nino.

The CPUE from Figure 8 can be compared to the CPUE from the California Department of Fish and Game records which use pounds per diver per hour as the unit effort:

1977	-	1983	210 lbs / hr
		1988	180 lbs / hr
		1989	230 lbs / hr

Although most resource managers use lbs/hr as unit effort, it can be seen that any conclusions drawn from these numbers would be questionable.

KELP AND RED SEA URCHINS (SAN DIEGO)

Sea urchin quality and recruitment is dependent on the kelp forest.

The kelp canopy and red sea urchin recruitment are show on Figure 9, Point Loma.

The loss in kelp canopy caused by the 1982 El Nino is evident. This lack of kelp coincides with reduced landings, number of boats and CPUE shown in Figure 8.

The percentage of small red sea urchins in the total population increased dramatically in 1986 in the south end of the Point Loma kelp bed (Fegner).

PROCESSED YIELD (SAN DIEGO)

There is a direct correlation between the processed yield and the gonad maturation cycle. The processed yield is the ratio of weight of roe removed during urchin processing to the total weight of sea urchin.

The annual cycle is shown in Figure 10, San Diego Red Sea Urchin Fishery Processed Yield.

It can be seen that the annual cycle has a peak in October in 1989, 1990 and 1991 and a low point in march in 1990 and 1991. The processed yield remained high through 1989 without any discernable cycle.

This valuable record can give us a great deal of information regarding the life cycle of the red sea urchin.

TEST DIAMETER (SAN DIEGO)

The variation in test diameters of harvested sea urchins is shown in TABLE V, Variation in Harvested Mean Red Sea Urchin Test Diameters, San Diego.

These changes in mean diameter may be used as indicators of the size of the standing stock. Removal of first growth of large old sea urchins is followed by successful recruitment and establishment of smaller size populations.

3. FISHERY ECONOMIC VIABILITY - THE MARKET

When it was discovered that there was a market for sea urchins in Japan, efforts were made in the early 1970's to establish a sea urchin fishery in Southern California.

In the early stages of the fishery, selling the California product in the Japanese market met with strong resistance. The California product was considered inferior to the Japanese and was considered only for the making of sea urchin paste. The value of the processed product in Japan in 1970 was $2,500 per ton (McPeak Pers. Comm.)

During the period 1972 to 1978 the harvested sea urchins were primarily large old urchins that were considered inferior to the younger small urchins.

Until the urchins are processed it is not possible to ascertain the quality. It is possible to obtain indicators by cracking urchins underwater and on the deck of the boat. However, in the initial years, diver training and the large variations in the population were problems that had to be overcome.

There was a high turnover rate among sea urchin divers and processors as both crept slowly up the learning curve.

In 1976 the fishery was aided by the weakening of the dollar relative to the yen. This is illustrated in Figure 11, Economics of California Red Sea Urchin Fishery.

Almost 90% of the red sea urchins were exported to Japan. The price for sea urchin roe (uni) on the Tokyo market in yen did not change appreciably but the price in dollars changed.

The increase in prices correspond to increase in harvest. These dramatic increases are illustrated in 1976 and 1985.

It is also interesting to note the similarity of the Chilean landings to the California landings. These landings are illustrated in Figure II. The Japanese landings are also shown in Figure II.

Market acceptance in Japan has increased with the improvements in the harvesting and processing techniques. The fishery is now harvesting a smaller, younger and much improved quality sea urchin than were harvested in the 80's.

Processors have by and large reduced middlemen and improved freshness and reliability of the shipments of red sea urchins in Japan.

The market acceptance in Japan is illustrated in Figure 12, Average High Price for Large Uni Tray in Tokyo Tsjuki.

It can be seen that the California price as an indication of market acceptance is much greater than the Canadian price. There also appears to be room for improvement to reach the Japanese prices.

In 1990 The Directors Sea Urchin advisory Committee recommended lowering effort by reducing the work week to 4 days during the summer months. The differences in price of uni on the Japanese market from a 7 day work week in 1989 to a 4 day work week is shown in FIGURE 13, Japanese market average high price for large box uni. The effect on ex vessel prices of urchins is similar as shown in Figure 14, San Diego sea urchin prices

4. SEA URCHIN MANAGEMENT

Red sea urchin fishery management can be divided into two periods. The first period 1970-1986 when the fishery was primarily a control on kelp grazing and the large population of old sea urchins was harvested. Restrictive regulations during this period would have led to the possible demise of a fishery trying to establish itself.

The result of the El Nino of 1982 on the Southern California fishery is an example of the resilience of the fishery as the landings were reduced by approximately 40% as a result of disturbances caused by the El Nino and rebounding to peak harvests in 1986.

In 1986 the sea urchin industry saw a need for fishery management and petitioned the State Legislature to pass a law requiring formal management.

A law was passed in 1986 requiring the establishment of an industry advisory committee and directing the California Department of Fish and Game to perform studies on the health of the red sea urchin resource. The studies would be funded by the industry.,

The law also required that studies relating to sea urchin enhancement be performed. These studies would also be funded wholly by the sea urchin industry.

The era of formal sea urchin fishery management started in 1986.

Regulations were promulgated by the California Department of Fish and Game working closely with the advisory committee. This mechanism allowed input into the users of the resource. Empirical data and anecdotal evidence from divers was melded with marketing information from the processors and fishery data from the resource managers.

The result has been a management scheme based on the following:

1) Limited entry program to reduce the number of fishermen
2) Minimum size limit to maintain sea urchin standing stock
3) Reduction in number of days per week allowed for harvesting to reduce effort and sfabilize marketing.

The progress of these regulations is shown in TABLE VI, Sea Urchin Management Southern California.

5. THE FUTURE

During the period from 1972-1992 the California red sea urchin fishery grew from zero to a fishery with an economic impact of over $380 million and employment impact of 124,000 people (CIF model 1982, NFI 1990 figures).

The sea urchin industry must take an aggressive role to ensure sustainability and balance in the kelp ecosystem. This encompasses sustainability of the resource, fishery, fishermen and processors.

The goal will be to develop a better understanding of the resource and fishery thought experimental designs that vary only one parameter to determine its influence on the resource or fishery.

We must not adopt the latest fads such as harvest refugia or transferable quotas and then spend years in trying to determine the effectiveness of the plan.

The objective would be to obtain the information first and use it to develop a comprehensive management plan including a long range enhancement program.

There exists a Directors Sea Urchin Advisory Committee established by law and extended by law to 1996. This committee is comprised of sea urchin divers, sea urchin processors, California state resource managers and a fishery biologist from Sea Grant.

This committee will work with university affiliated scientists to develope a program for the following:

1) Understanding red sea urchin life cycle
2) Improved fishery data
3) Fishery management
4) Long-range cooperative enhancement programs

RED SEA URCHIN LIFE CYCLE

The plan would be to develop a plan for studies to obtain information regarding the red sea urchin life cycle as a basis for resource management. Information regarding the following:

I) Recruitment
II) Growth
III) Mortality
    a) larval
    b) juvenile
    c) adult
IV) Stock assessment

IMPROVED FISHERY DATA

It is important for the industry and the resource managers to develop a program of fishery data gathering and dissemination.

Goals should be developed and the purpose for which the data will be used explained to the industry so their cooperation will be encouraged.

FISHERY MANAGEMENT

The industry must develop fishery management in an economically efficient manner. Since the California red sea urchin fishery is an example of demand side economics we must sustain the role of the California product in a global market. The effect of regulations on the market should be carefully studied.

ENHANCEMENT PROGRAMS

The Japanese model has shown us that if a fishery is to be sustained at an adequate level, enhancement programs are necessary.

The industry has funded studies on the following programs:

1) use of brushes for seed collection
2) outplanting of hatchery reared juveniles
3) enhancement of roe quality of purple sea urchins by supplementary feeding in cages
4) small scale hatchery
5) enhancement of roe quality of red and purple sea urchins by in-situ feeding

It appears that mitigating seeding using hatchery reared juveniles shows the most promise. Long range programs based on the Japanese experience should be initiated.

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TABLE VI

SEA URCHIN MANAGEMENT SOUTHERN CALIFORNIA

1971:	Experimental Gear Permit required (no fee).
1976:	Invertebrate Permit (no fee) required. Vessels had to be designated with letters "SU".
1977:	Log Books required.
1985:	Sea Urchin Permit (Cost: $25.00)
1986:	Sea Urchin Permit (Cost: $250.00).
1987:	Moratorium on new permits.
	Log Book requirement.
	Area closure (Salt Point Area).
	1/2¢ Tax for Management & Enhancement.
	Commercial Sea Urchin Advisory Comm. Est.
1988:	One week closed each month (May-Sept.).
	Minimum Size 3".
1989:	Limited Entry
1990:	4 days/week (May-Sept.)
1992:	Minimum size 3 1/4"
	2 to 4 days/week (April-Oct.).

LIST OF TABLES

KELP CANOPY PLANIMETER AREAS (IN SQUARE MILES)

LOCATION	YEAR		CHANGE
	1989	1967	
So. Cal. Islands	*20.68 sq mile	21.24	-2.6%
Pt. Conception To Mexican Border Mainland	**19.07	32.62	-41.5%

* Large losses in kelp canopy at S. Nicolas Island (= - 4.82 square miles)

** Large losses in kelp canopy in area from Santa Barbara to Point Conception (= 9.09 square miles)

TABLE I

RED SEA URCHIN
RECRUITMENT

LOCATION	DATE	% SIZE < 35 MM
San Clemente I	1977-1980	78 ± 6
Santa Barbara I	1976-1978	66 ± 6
Anacapa I	1976-1979	48 ± 21
Santa Cruz I	1977-1981	32 ± 19
Santa Rosa I	1976-1982	20 ± 4
San Miguel I NE Side	1977-1981	15 ± 9
San Miguel I South Side	1976-1980	30 ± 10
San Nicolas I	1977	14 ± 5

* 35 mm Considered as urchins that recruited the previous year.

SOURCE: Tegner & Barry 1990

TABLE II

RED SEA URCHIN RECRUITMENT INTO FISHERY

YEAR	% OF TOTAL BETWEEN 74-94 MM			
	San Diego	S. Ch. Islands	N. Channel Islands	S. Cal
1979	31	9		
1981	60	8		
1988	56	28	47	40
1989	52	30	57	51
1990	57	19	54	50
1991	50	42	70	62

SOURCE CDFG J. DUFFY D. PARKER

YEAR	% OF TOTAL UNDER 74 MM			
	SAN DIEGO	S.CHANNEL ISLAND	N. CHANNEL ISLAND	S. CAL
1988	6	6	36	17
1989	9	2	12	10
1990	3	1	6	5
1991	4	0	9	8

TABLE III

SPATIAL AND TEMPORAL VARIATIONS IN RED SEA URCHIN HARVEST AREAS

LOCATION	% OF TOTAL LANDINGS		
	1988	1989	1990
ISLANDS	81	79	81
Anacapa	2	1	1
** Santa Cruz	11	10	9
** Santa Rosa	17	19	21
** Santa Miguel	6	11	18
Santa Barbara	1	2	1
Santa Catalina	2	1	1
** San Nicolas	13	19	21
** San Clemente	29	17	9
COAST	16	19	20
Santa Barbara	4	5	4
Ventura	2	2	1
San Pedro	2	5	6
San Diego	8	7	9

* Total reported in daily logs
1988 - 8,406,836 lbs.
1989 - 13,056,059 lbs.
1990 - 13,279,287 lbs.

** Major fishing areas

SOURCE: CDFG Logbooks

TABLE IV

VARIATION IN HARVESTED MEAN RED SEA URCHIN TEST DIAMETERS
SAN DIEGO

YEAR	MEAN DIAMETERS
1978	122
1979	115
1988	92
1989	94
1990	95

SOURCE: CDFG

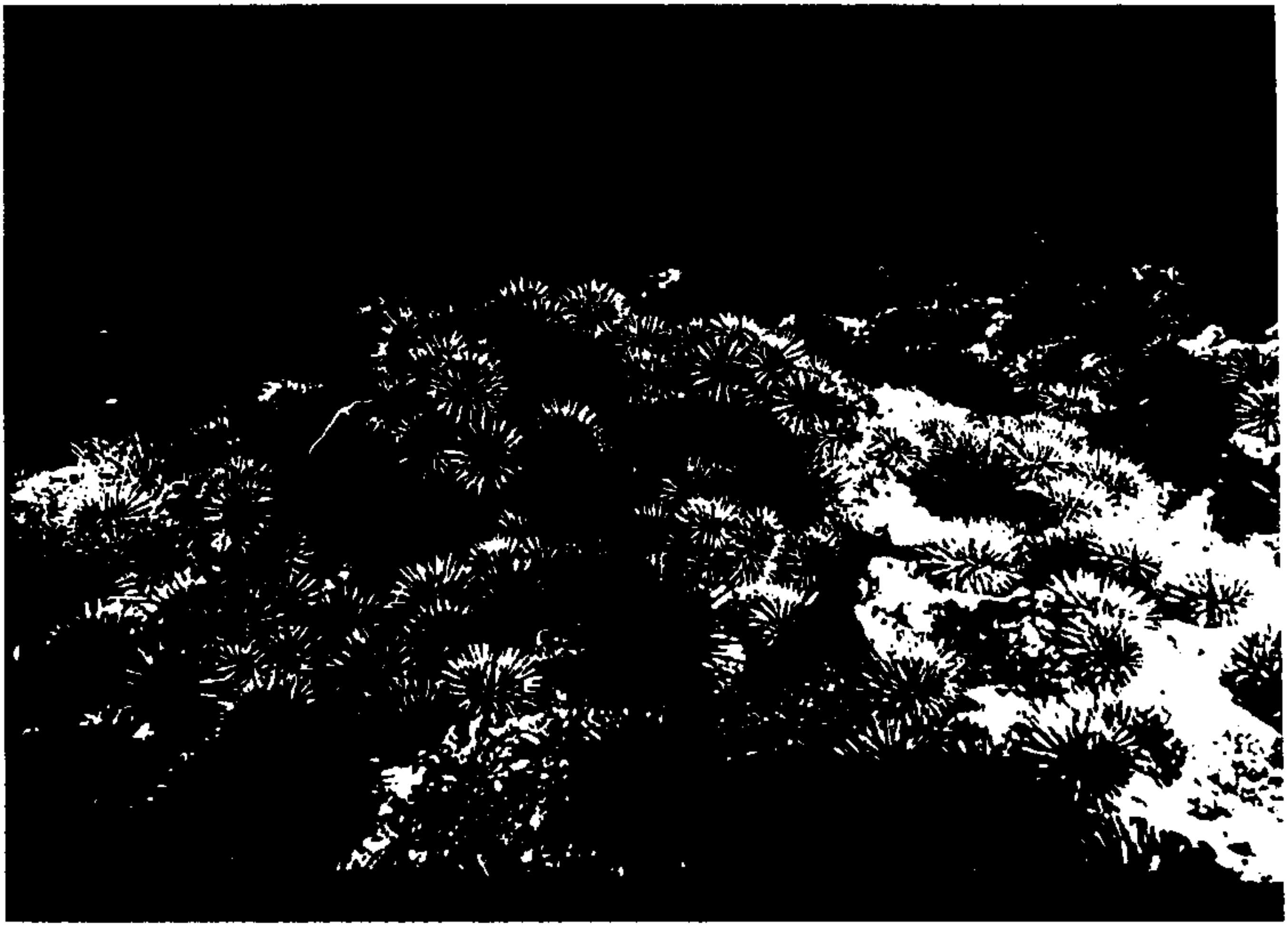
TABLE V

TABLE VI

SEA URCHIN MANAGEMENT SOUTHERN CALIFORNIA

1971:	Experimental Gear Permit required (no fee).
1976:	Invertebrate Permit (no fee) required. Vessels had to be designated with letters "SU".
1977:	Log Books required.
1985:	Sea Urchin Permit (Cost: $25.00)
1986:	Sea Urchin Permit (Cost: $250.00).
1987:	Moratorium on new permits.
	Log Book requirement.
	Area closure (Salt Point Area).
	1/2¢ Tax for Management & Enhancement.
	Commercial Sea Urchin Advisory Comm. Est.
1988:	One week closed each month (May-Sept.).
	Minimum Size 3".
1989:	Limited Entry
1990:	4 days/week (May-Sept.)
1992:	Minimum size 3 1/4"
	2 to 4 days/week (April-Oct.).

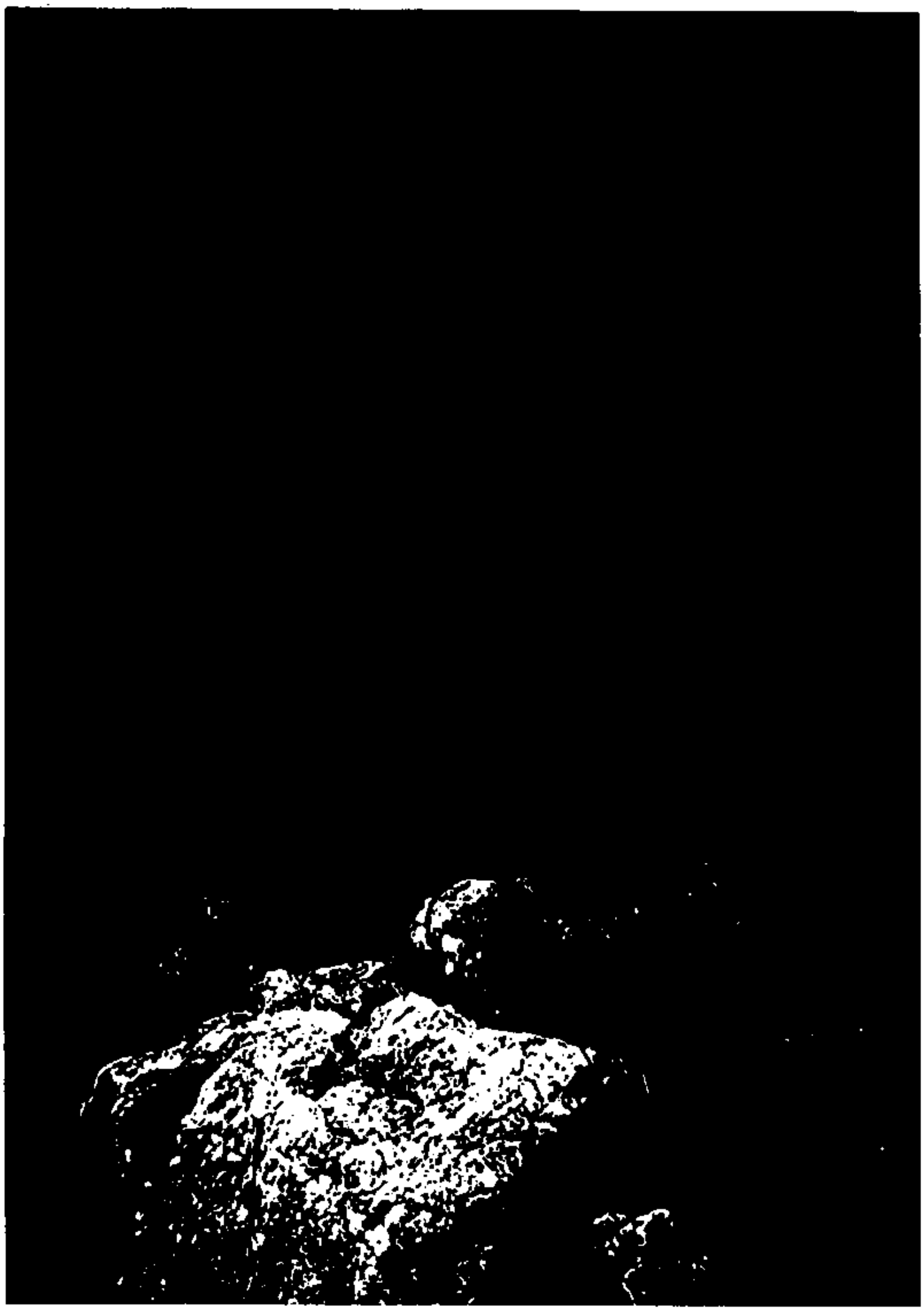
LIST OF FIGURES



SEA URCHIN DOMINATED AREA

A common feature is Southern California kelp beds prior to the start of sea urchin harvests.

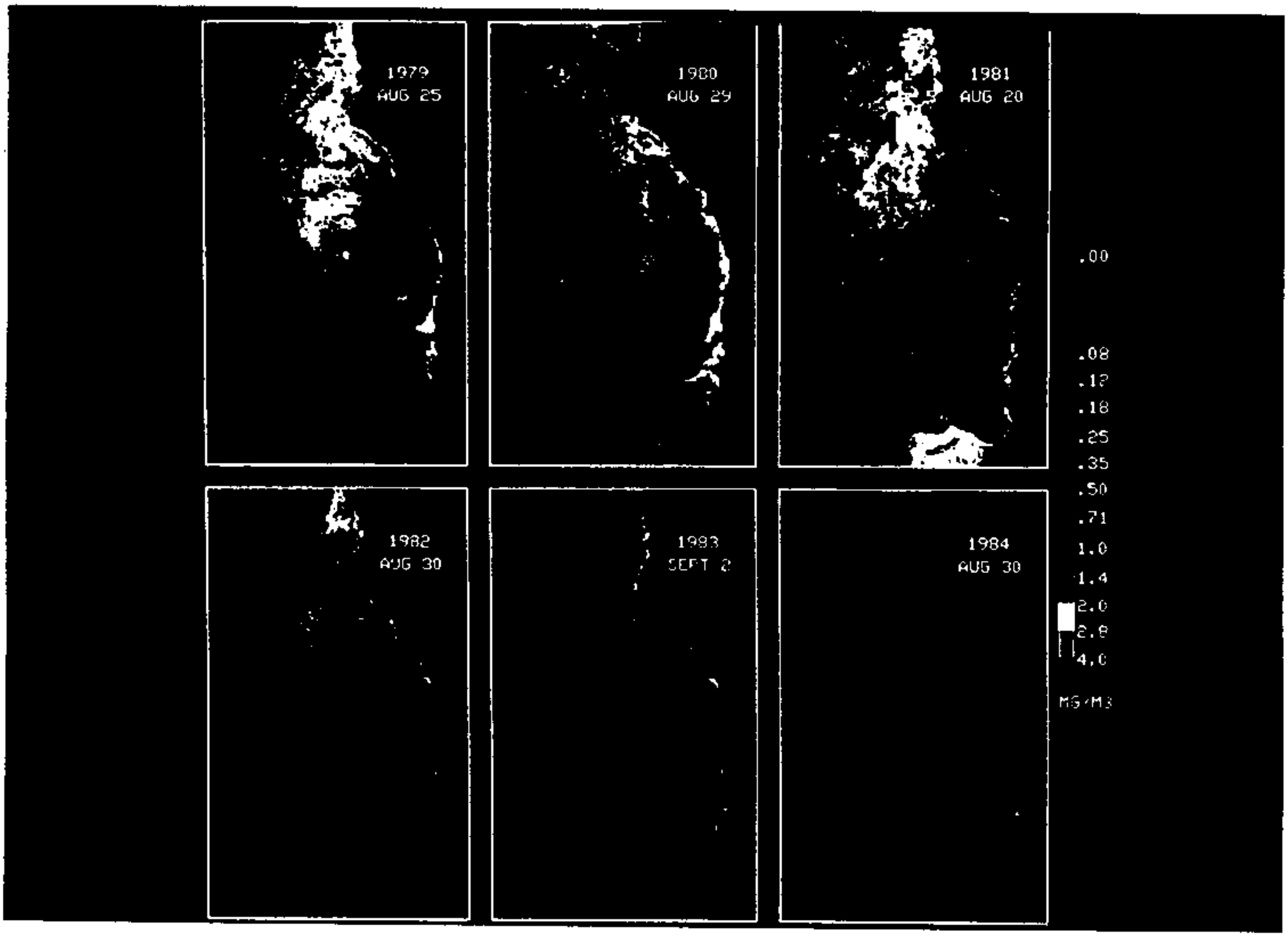
FIGURE 1



SEA URCHINS AND KELP

After harvest of red sea urchins grazing of kelp plant was reduced.

FIGURE 2



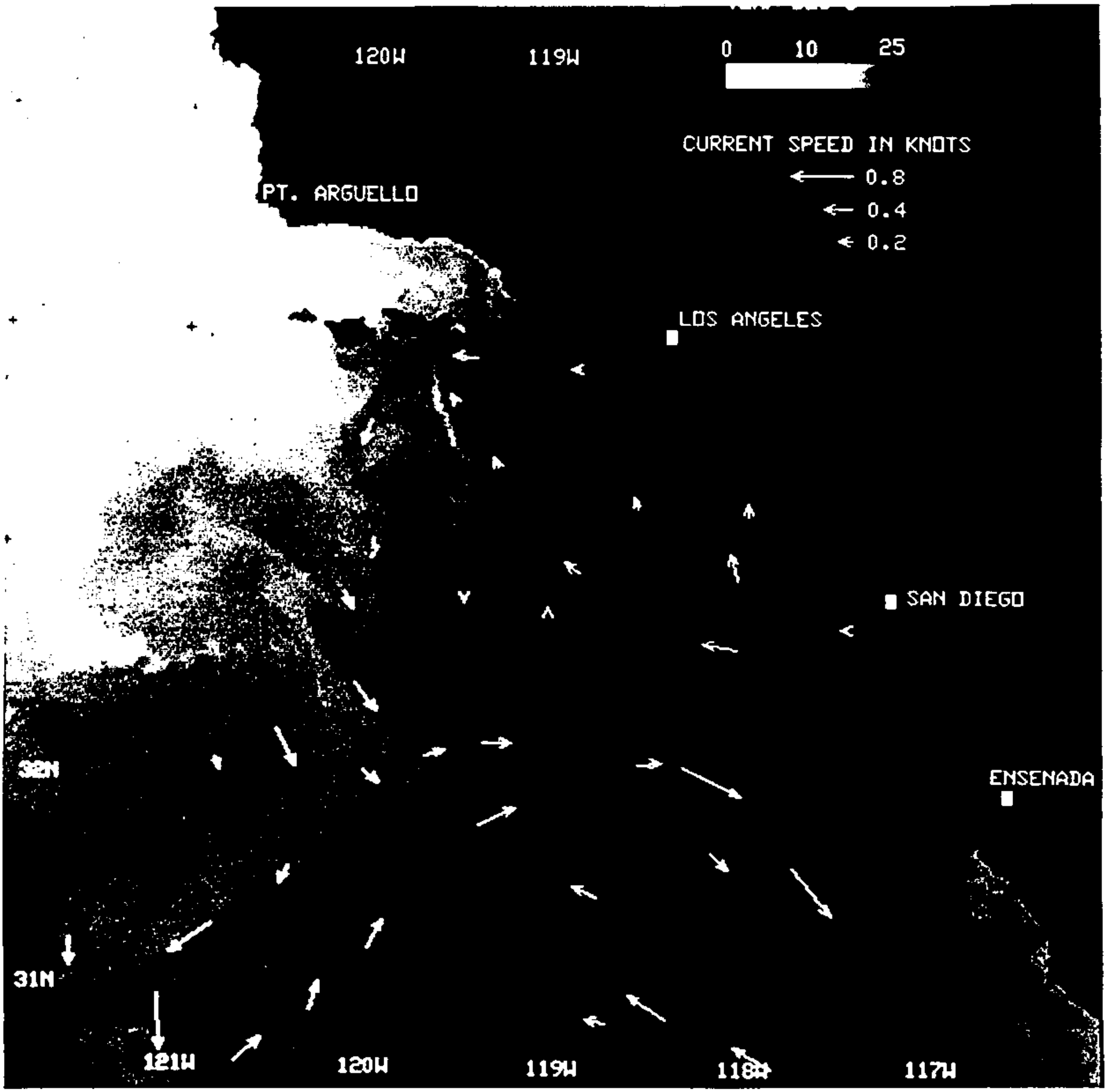
COURTESY OF OCEAN IMAGING

SATELLITE IMAGE
USING
COASTAL ZONE COLOR SCANNER

Ocean irradiance is measured and used to estimate mg. of chlorophyll/m3.

Changes in the California current during the El Nino event of 1983 are shown.

FIGURE 3



COURTESY OF OCEAN IMAGING

OCEAN CURRENTS IN THE SOUTHERN CALIFORNIA BIGHT

Currents are derived from changes in temperature between water masses.

FIGURE 4

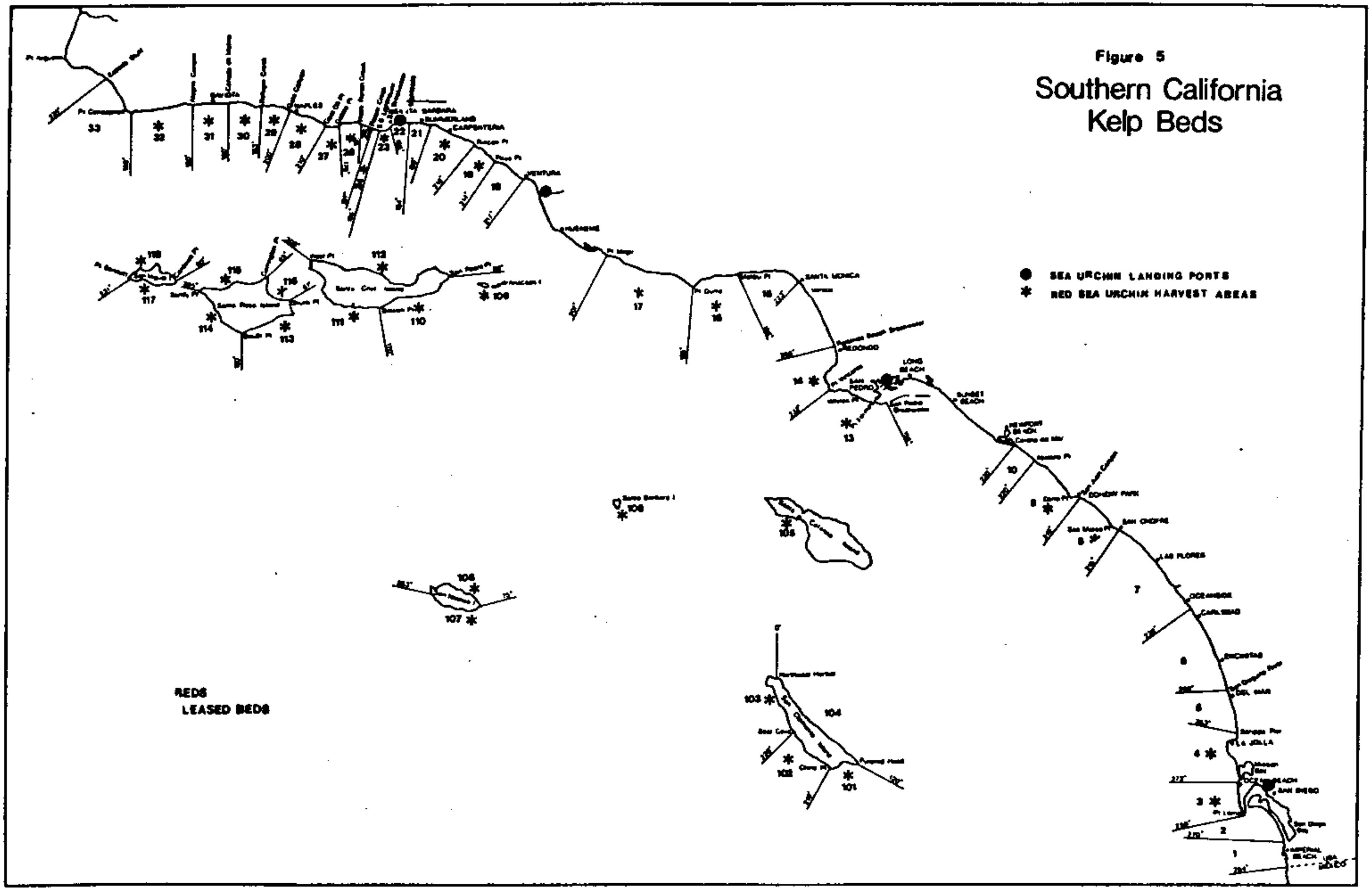
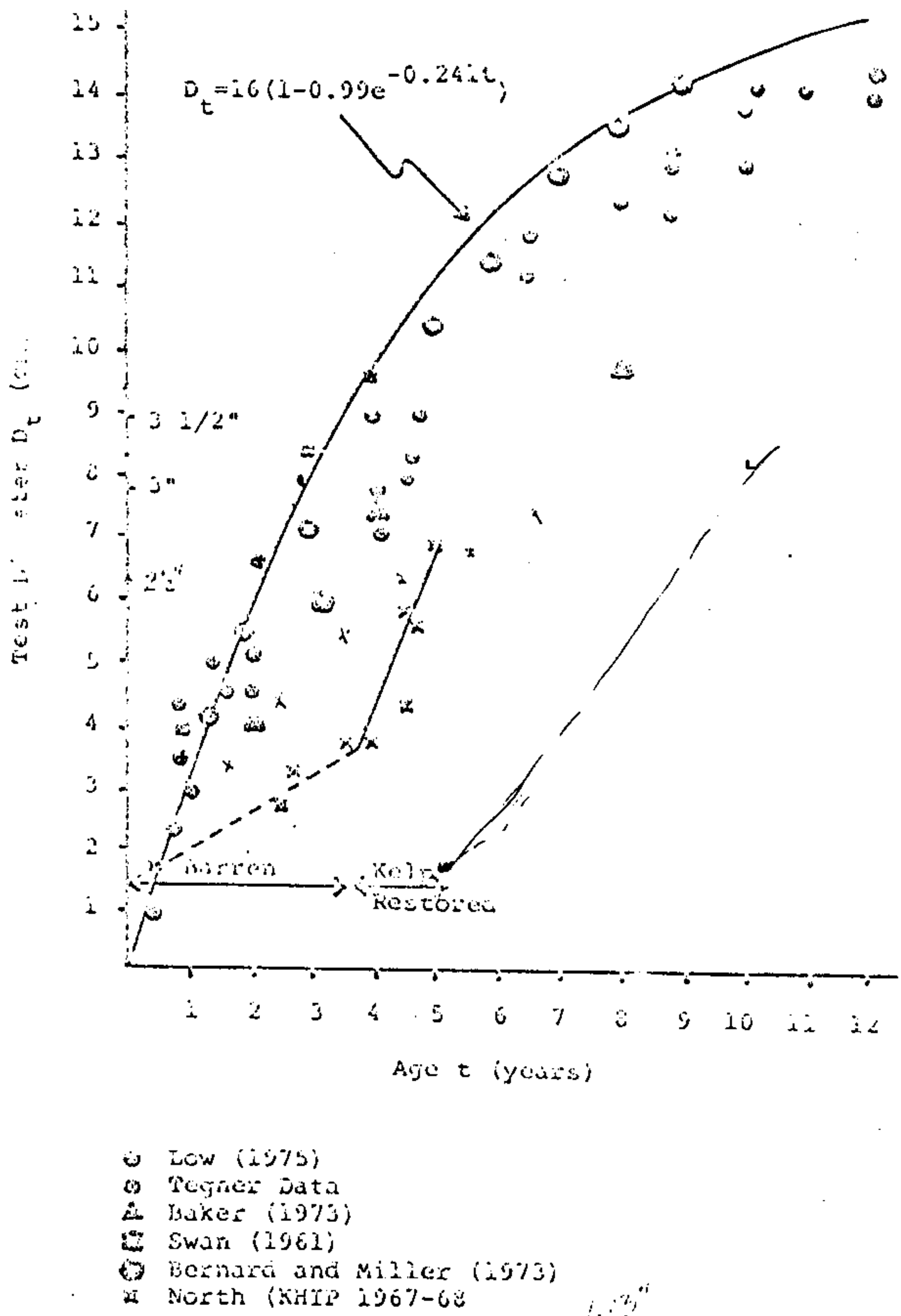


Figure 5
Southern California
Kelp Beds
SEA URCHIN LANDING PORTS
RED SEA URCHIN HARVEST AREAS
REDS
LEASED BEDS
SANTA MONICA
REDONDO
LONG BEACH
SAN PEDRO
SUNSET BEACH
NEWPORT BEACH
VENTURA
CARPINTERIA
DANA POINT
SAN ONOFRE
LAS FLORES
OCEANSIDE
CARLSBAD
ENCINITAS
DEL MAR
LA JOLLA
SAN DIEGO
OCEAN BEACH
IMPERIAL BEACH
USA
MEXICO



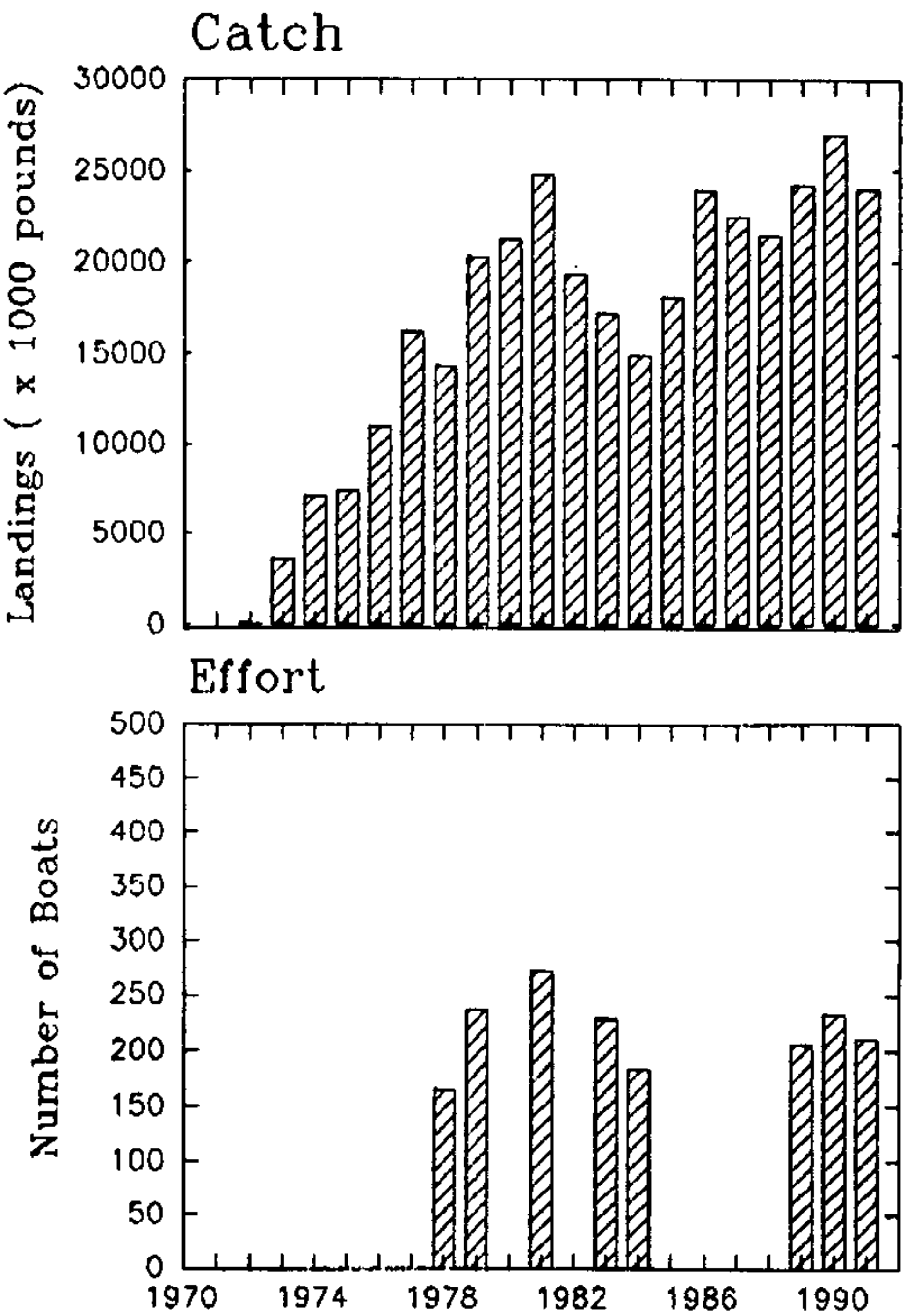
RED SEA URCHIN GROWTH CURVE

A compilation of various growth rates. The Brody-Bertalanffy growth curve was fitted to the growth data.

FIGURE 6

Figure 7

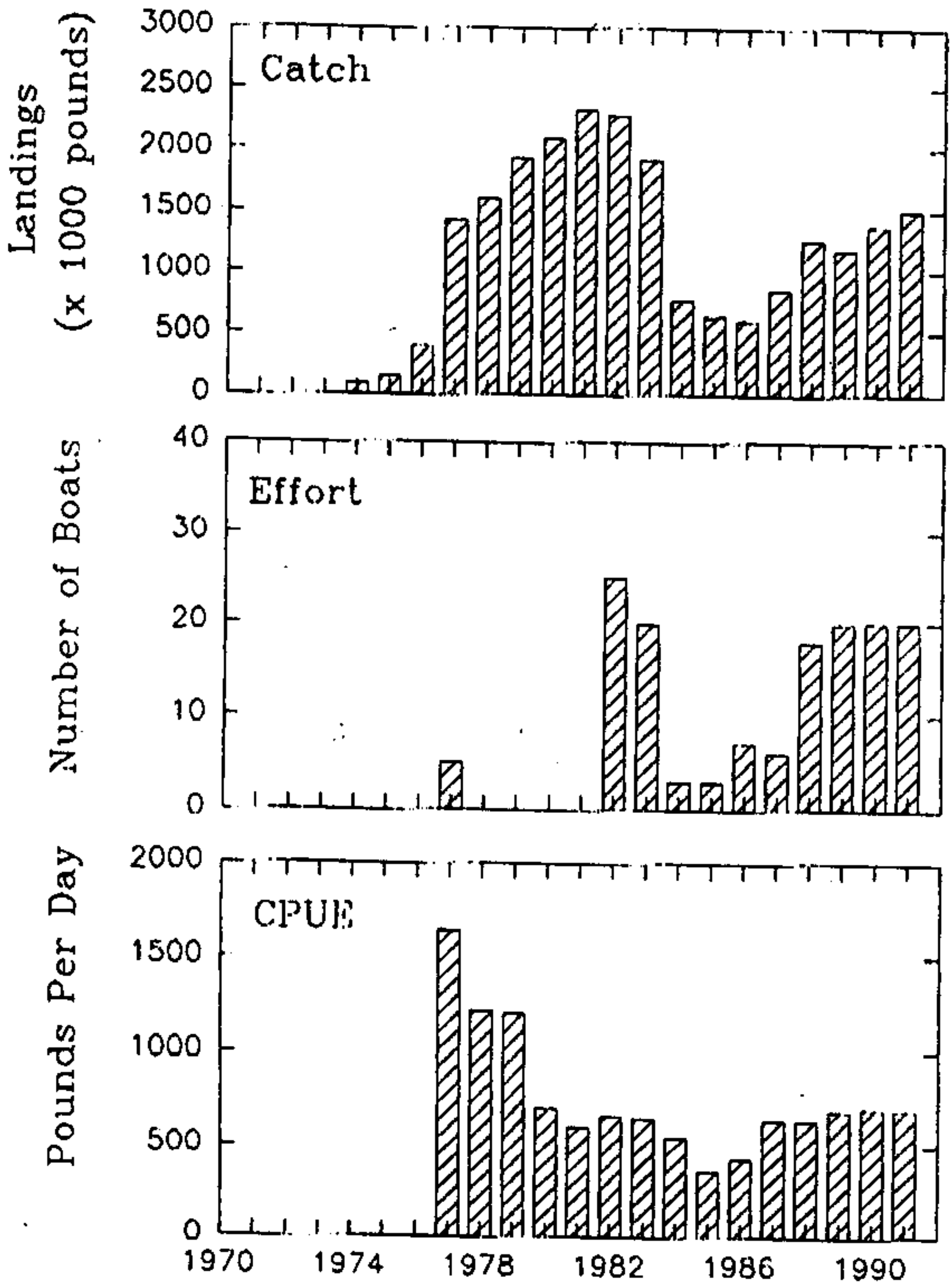
Southern California Red Sea Urchin Fishery



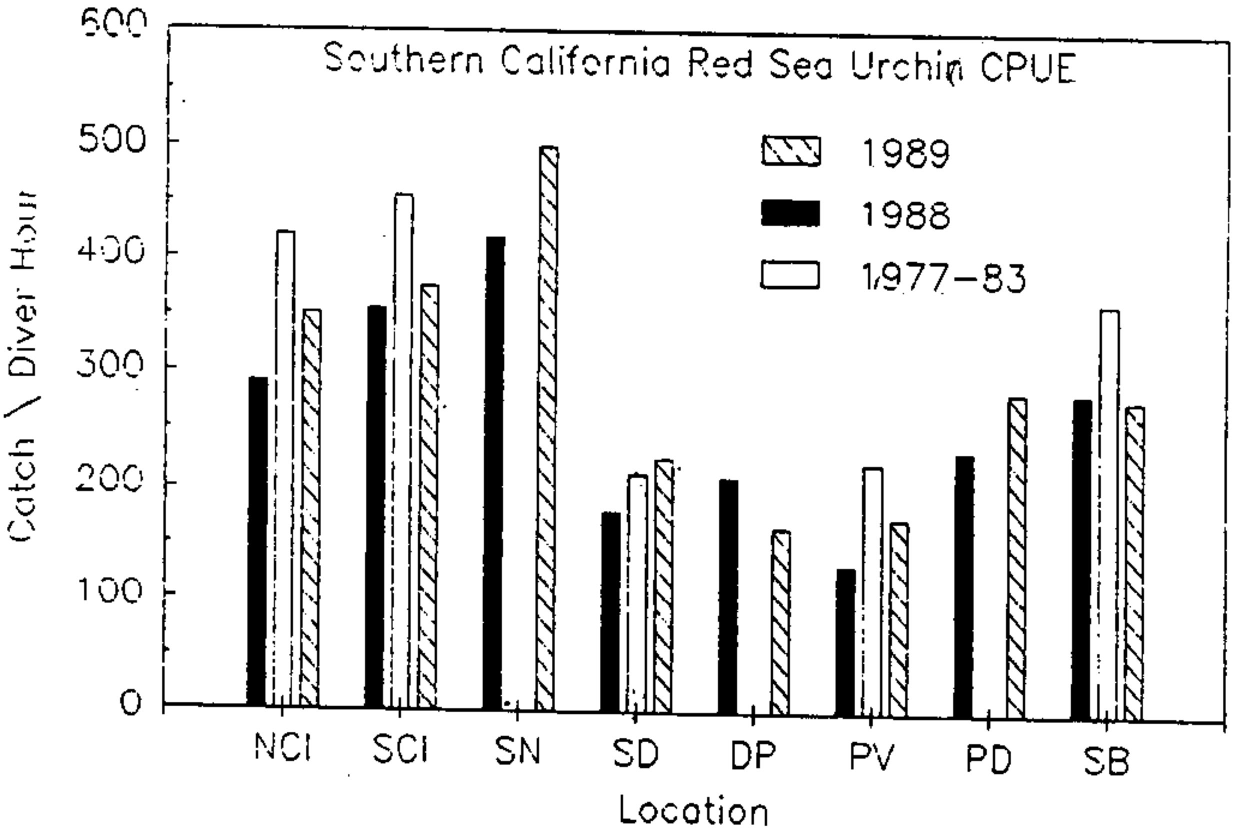
Source: CDFG

Figure 8

San Diego Red Sea Urchin Fishery



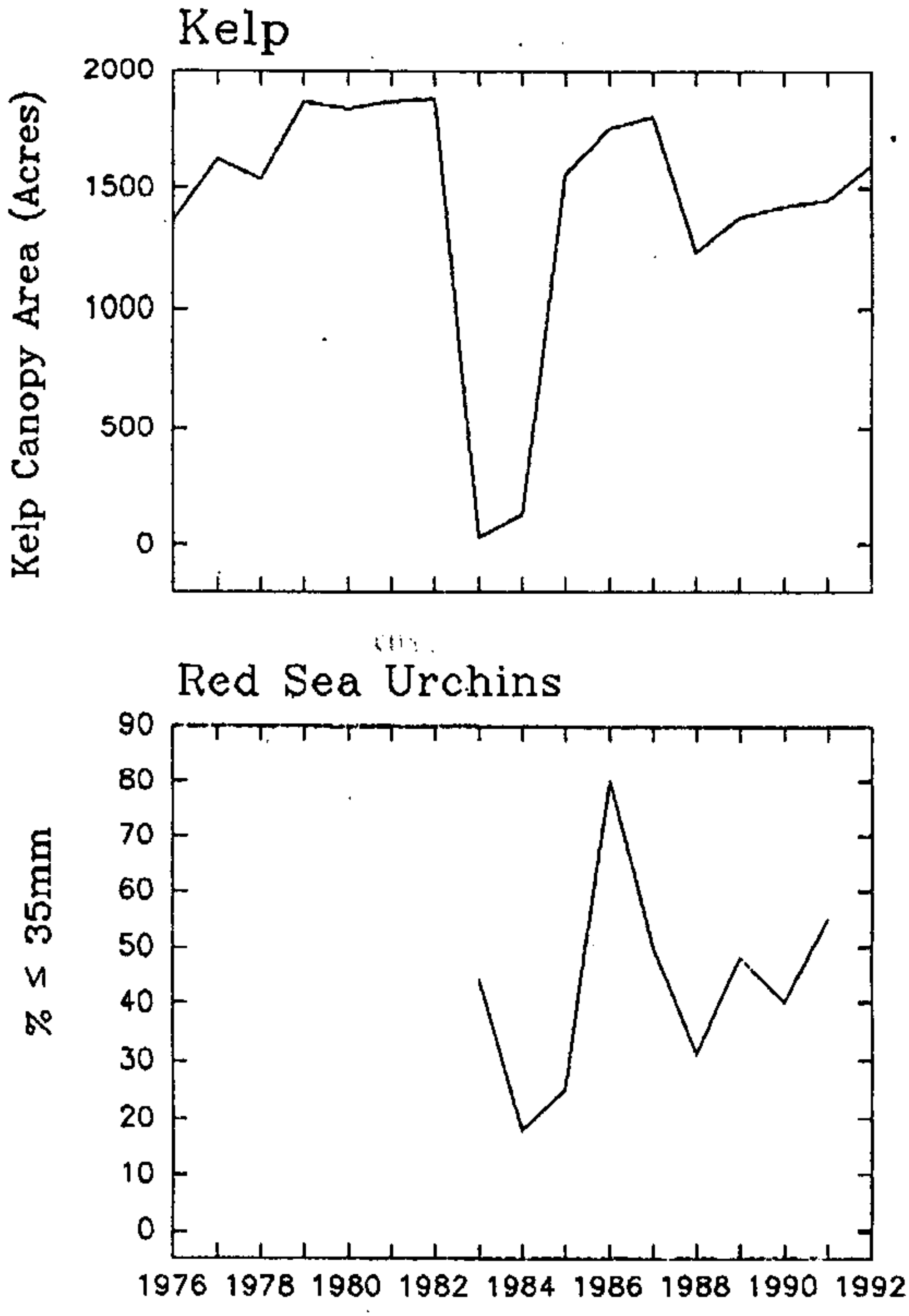
Sources:
Catch - CDF&G
Effort - 1977-86: Tegner & Barry, COP
1987-91: COP
CPUE - 1978-86: Datz, COP; 1987-91: COP



Southern California Red Sea Urchin CPUE
1989
1988
1977-83
Catch \ Diver Hour
600
500
400
300
200
100
0
NCI
SCI
SN
SD
DP
PV
PD
SB
Location

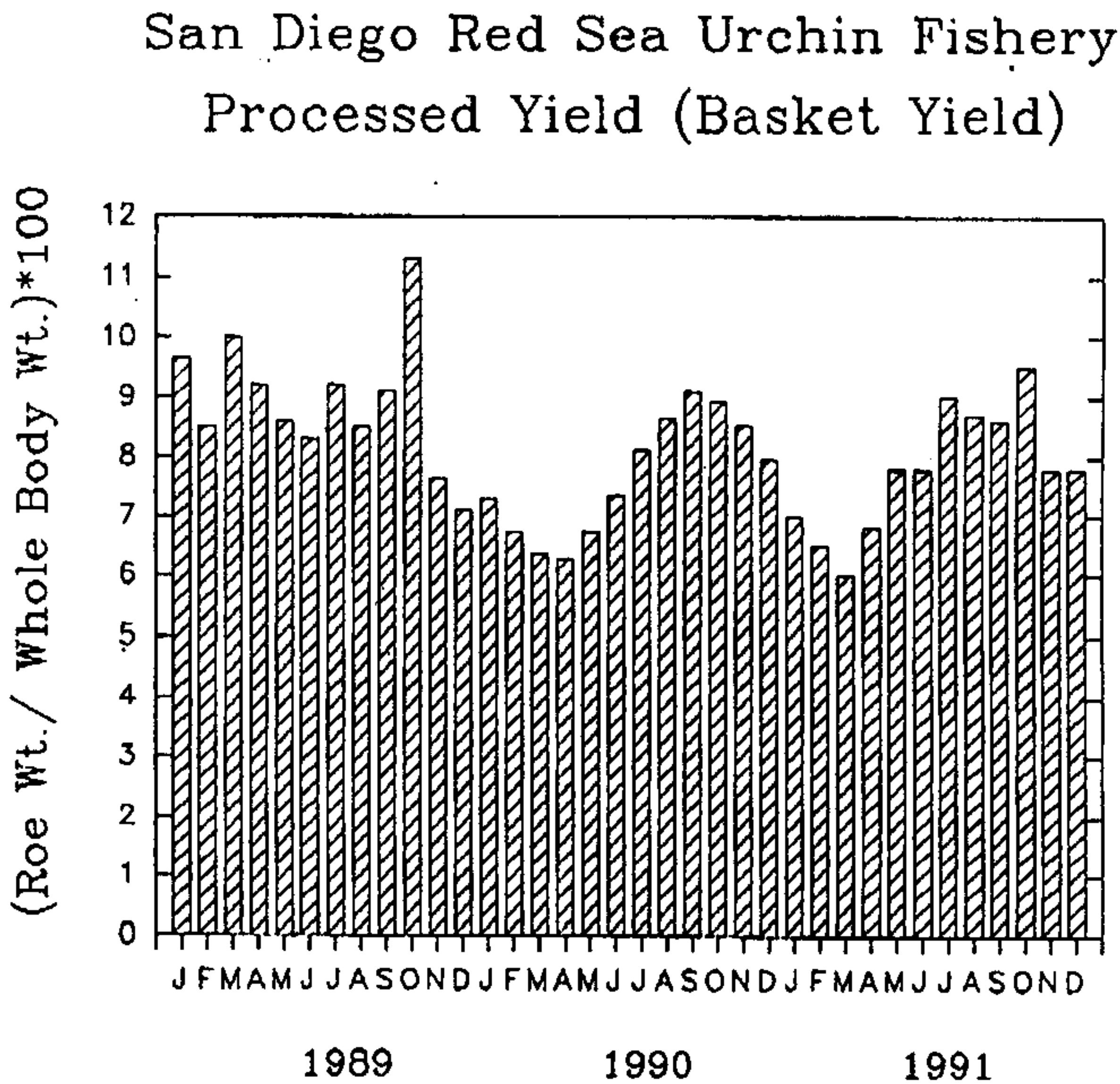
Figure 9

Point Loma



Source: Kelco
M. Tegner

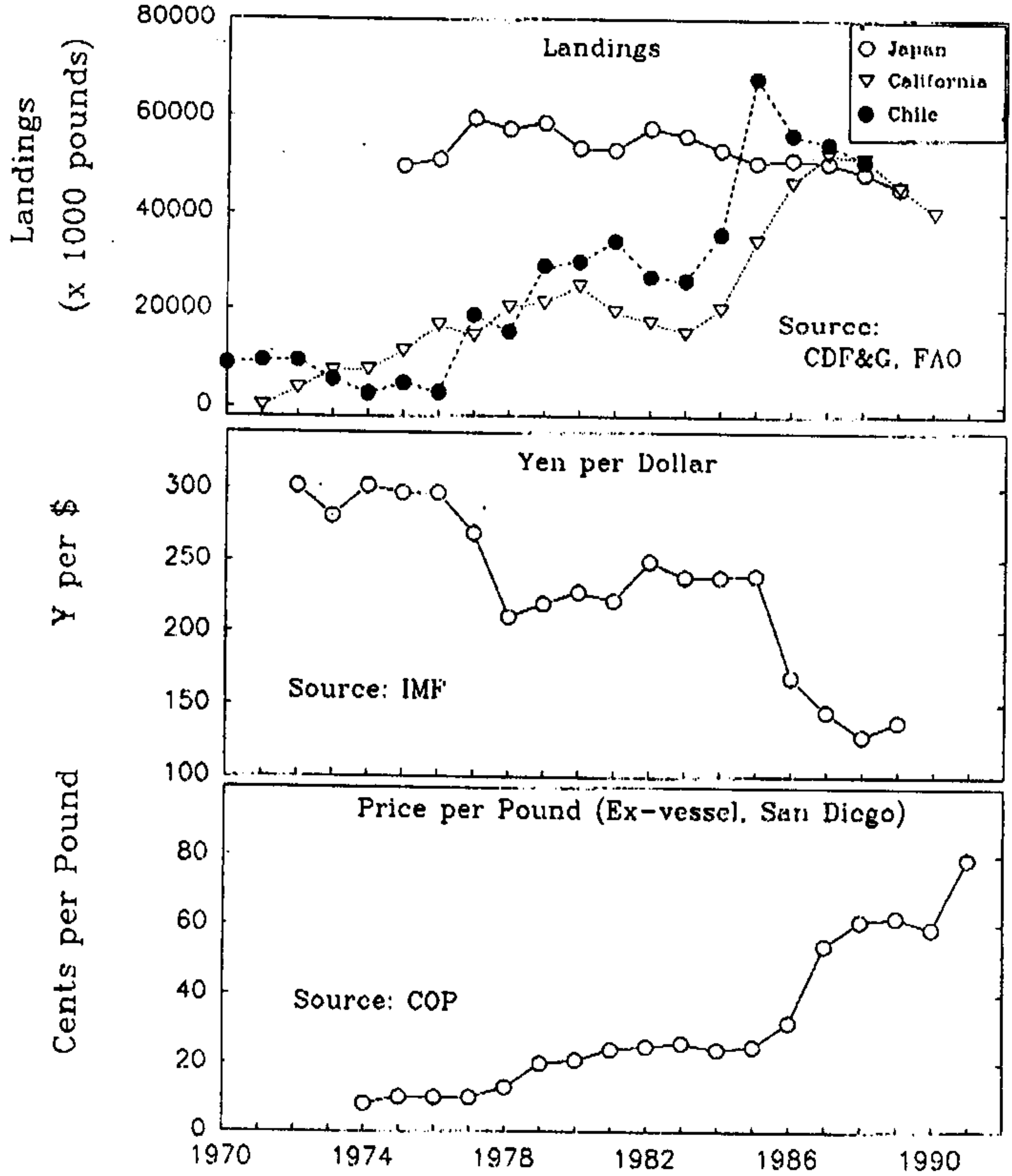
Figure 10

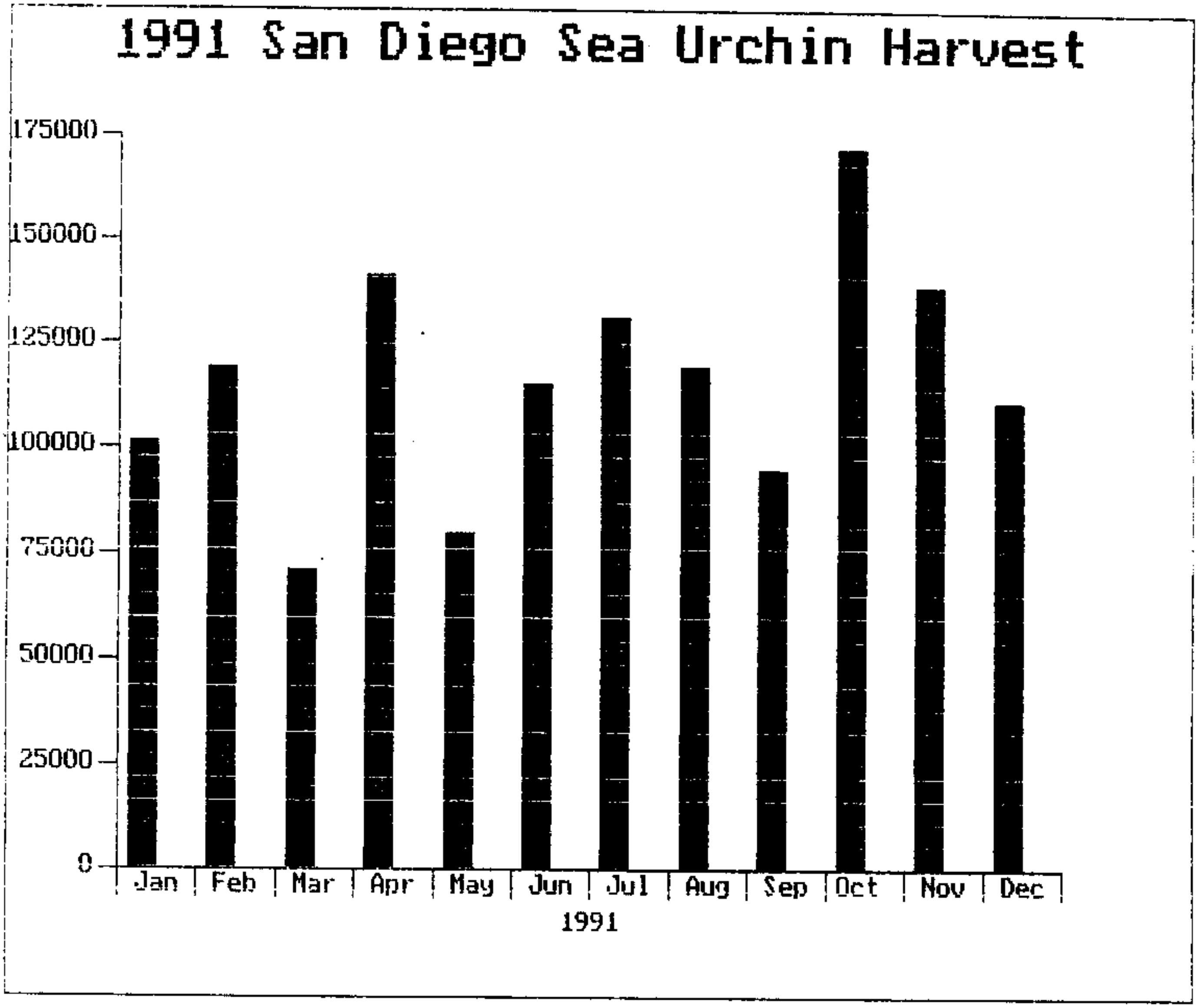


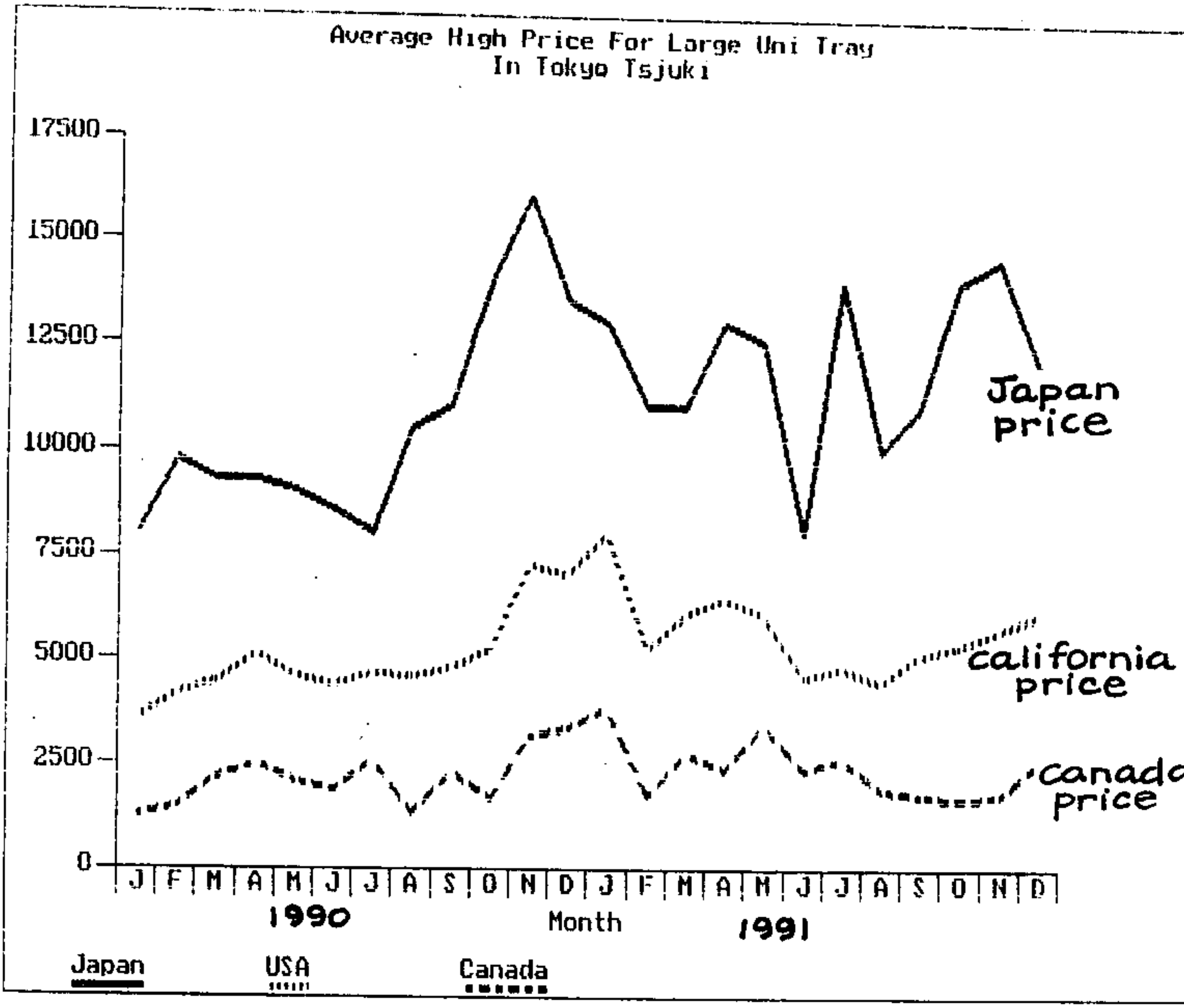
Source: COP

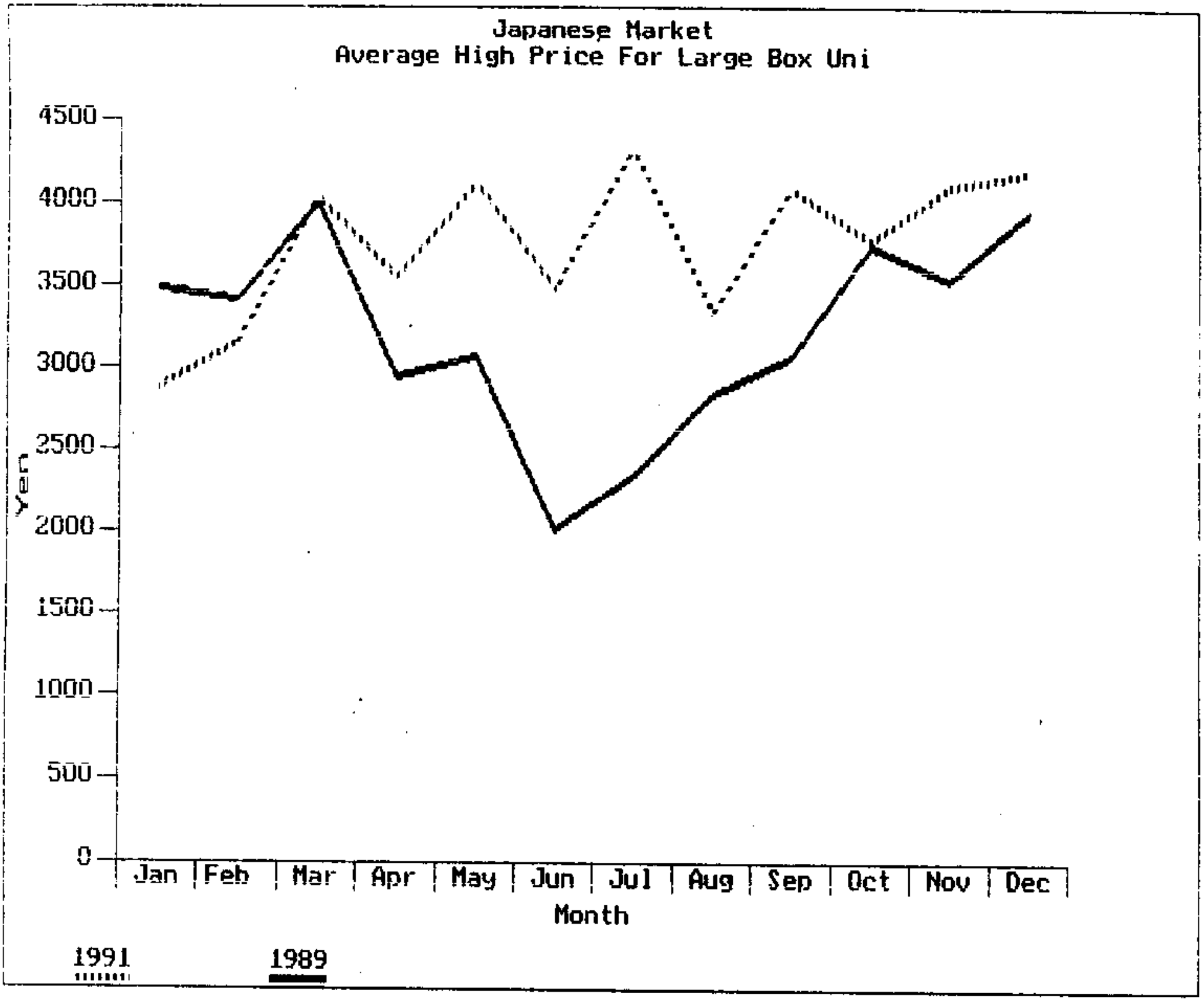
Figure 11

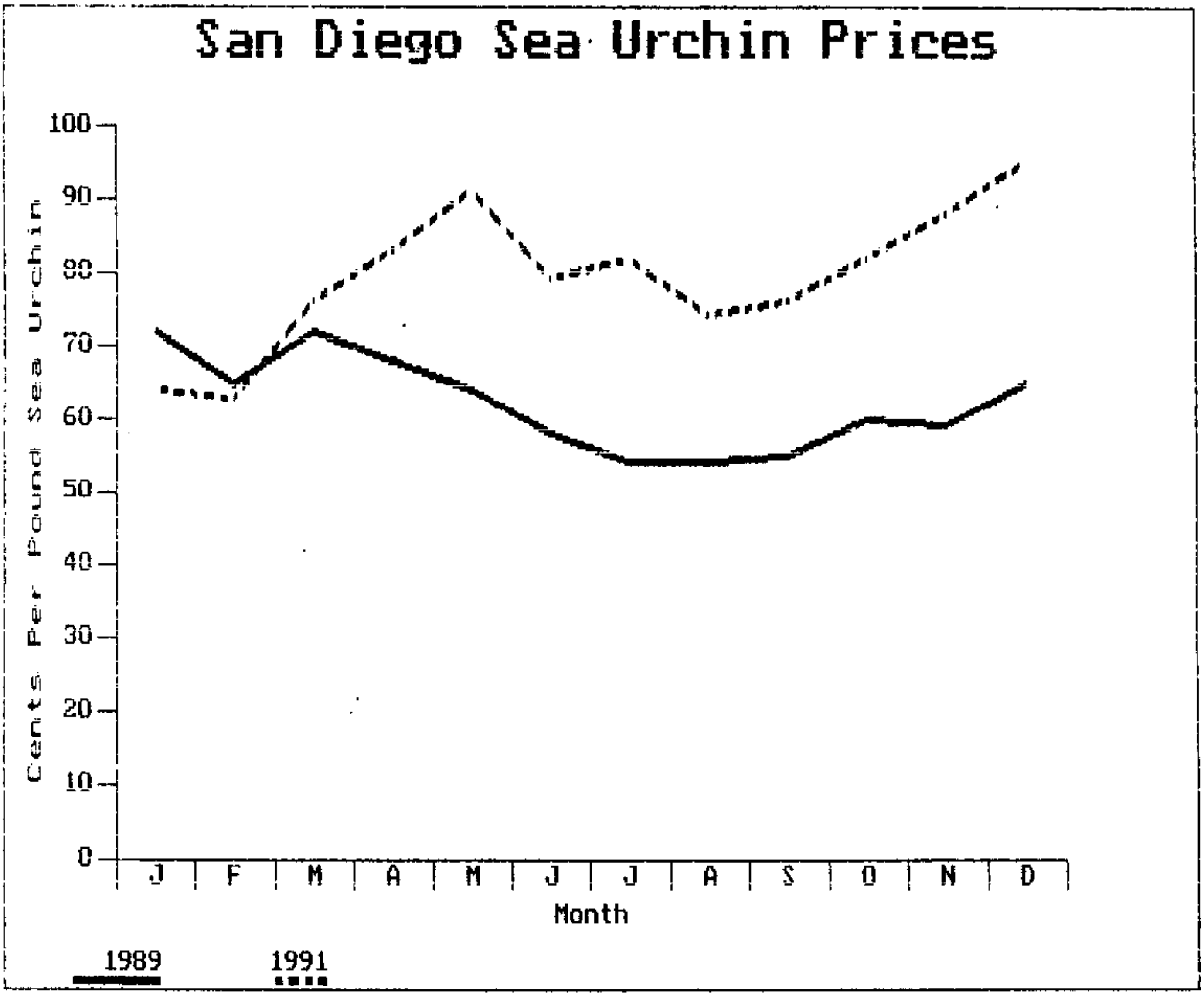
Economics of California Red Sea Urchin Fishery




1991 San Diego Sea Urchin Harvest
175000
150000
125000
100000
75000
50000
25000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1991


Average High Price For Large Uni Tray
In Tokyo Tsjuki
17500
15000
12500
10000
7500
5000
2500
0
J F M A M J J A S O N D J F M A M J J A S O N D
1990
Month
1991
Japan price
california price
canada price
Japan
USA
Canada


Japanese Market
Average High Price For Large Box Uni
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Yen
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
1991
1989


San Diego Sea Urchin Prices
Cents Per Pound Sea Urchin
100
90
80
70
60
50
40
30
20
10
0
J
F
M
A
M
J
J
A
S
O
N
D
Month
1989
1991

SEA URCHIN FISHERIES OF BRITISH COLUMBIA ,CANADA

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Sea Grant Extension Program
University of California
Bodega Bay Marine Laboratory
Bodega Bay, California
March 18-21,1992

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ABSTRACT

There have been commercial fisheries in B.C. waters for red sea urchins, *Strongylocentrotus franciscanus* since 1970, green sea urchins,*S. droebachiensis* since 1987 and an experimental fishery for purple sea urchins *S. pupuratus* since 1990.

The red sea urchin fishery has grown rapidly since 1990 with the development of the northern fishery. Landings for B.C. in 1991 were 14.8 million lb.(6714 tonnes) for a landed value of $4 million. Licences were limited in 1991 to 102. There are different management regimes in the south and north coasts. A smaller minimum size limit is being considered for red sea urchins.

In the south coast the red sea urchin fishery is managed very conservatively with 26 area quotas. Some quotas were based on surveys but most quotas are precautionary, aimed at removing 5% of the "guesstimated" stock. There is a minimum size limit of 100 mm in effect. Fishing effort is restricted to time openings, and during the period October to February, openings are four days a week to provide a longer supply to the market.

In the north coast, there have been few restrictions until more is known about the stock. Minimum and maximum size limits have been set with plans for rotational fisheries. Once the stock in an area between 100 and 140 mm has been reduced the area is closed for three or more years. The north coast fishery was year round in 1991 and landings rose to 11.8 million lb.(5375 t).

Green sea urchins are harvested for live shipments to Japan. Landings of greens peaked in 1989 at 1.3 million lb. (611 t) for a landed value of $1 million. The fishery is managed by licence limitation, a minimum size limit of 55 mm and area and seasonal restrictions. The fishing season is October 1 to February 28.

There has been an experimental fishery for purple sea urchins since 1990. In 1991, five vessels landed 29 t for $100 thousand. Management actions include limiting the number of permits to four in area, a minimum size limit of 55 mm and a restricted season, October 1 to February 28. Permit holders are required to support collection of biological data.

Logbooks are mandatory for all urchin fisheries.

SEA URCHIN FISHERIES OF BRITISH COLUMBIA

R. Harbo and K. Hobbs

There are seven commercial dive fisheries in British Columbia, each licensed separately: geoduck and horse clams (55 licences); red sea urchins (102); green sea urchins (47); sea cucumbers (78); pink and spiny scallops (81); and octopus (44). The abalone fishery (26 licences) was closed in 1990 for conservation reasons. There is currently an experimental dive fishery for purple urchins (8 permits) on the west coast of Vancouver Island.

There are six species of sea urchins in B.C. waters, but only three are common in shallow water. There have been commercial dive fisheries for the red sea urchin, *Strongylocentrotus franciscanus* since 1970, and the green urchin, *S. droebachiensis* since 1987 (Campbell and Harbo,1991). There has been interest in an experimental dive fishery for purple sea urchins, *S. pupuratus*, with permits issued since 1990.

The fisheries for marine and anadramous species are managed by the federal department of Fisheries and Oceans. The coast is divided up into several management areas, north (Fig.1) and south (Fig.2) of Cape Caution, located to the north of Vancouver Island. Management biologists deal with all shellfish fisheries and there is currently only one scientist, supported by a technician assigned to carry out field research on dive fisheries for the entire coast.

Fisheries for red sea urchins take place coastwide (Areas 2E, 4, 5, 7; Areas 12, 13, 24), while the fishery for green sea urchins has taken place in the southern inside waters (Areas 12, 13, 19) of the east coast of Vancouver Island. Purple urchins have been harvested from the west coast of Vancouver Island (Areas 20 and 24 to date).

LANDINGS AND VALUE

The red sea urchin fishery began in 1970 and grew rapidly since 1979 to about 14.8 million lb. or 6714 tonnes ($4 million Cdn.) coastwide by 1991 (Table 1; Fig.3). The north coast fishery began in 1986, but grew rapidly in 1991 with landings to 11.8 million lb. or 5375 t.

Increasing demand for roe led to green urchin fishery in 1987, peaking at 609 t ($1 million) in 1989 (Table 2; Fig.4). Landings in 1991 were 573 t for a landed value of $1.7 million.

In 1991, buyers paid average prices of $0.27/lb.(peak of $0.35/lb.) for red, $1.33/lb.(peak $3.60/lb.) for green and $1.65/lb. for purple sea urchins.

Fifteen companies purchased red sea urchins in 1991 (2 in the north and 13 in the south), nine companies purchased greens (all in the south) and three companies bought purple urchins.

FISHERIES MANAGEMENT

Annual fishing plans (calendar year) are developed by a review of biological data, management and enforcement concerns, socioeconomic concerns and consultation with industry (processors and fishermen).

Conservation and protection of stocks is foremost, balanced with the development of an optimal harvest for social and economic benefits.

Table 3 presents a historical summary of management actions for the red and green sea urchin fisheries in British Columbia.

RED SEA URCHINS

Red sea urchin are common and abundant on most current-swept, rocky habitats of British Columbia. Red sea urchins are probably the most important shallow water marine invertebrate affecting kelp abundance and distribution. *Nereocystis* is a prime habitat for red urchins in B.C. (Breen,1980).

There are few predators and the only limiting predator is the sea otter, *Enhydra lutris*. Sea otters are limited to two small populations, one in the central coast, the Goose Island Group (~100) and the other on the west coast of Vancouver Island,(~600) Quatsino Light to Estevan Point (MacAskie,1987; G. Ellis,pers. comm).

Studies are underway on the west coast of Vancouver Island to determine the impact of sea otters on invertebrate and kelp abundance and distribution.

Harvest is by divers, on surface supplied air from a variety of vessels. Only one hose is used on a vessel. In 1990 there were 184 divers coastwide.

Divers use a hand tool to put urchins in a bag. The urchins were placed into cages or totes but now large net bags are used for delivery to a processing plant.

The divers fish at depths from 5 to 60 feet, the average depth being 25 to 30 feet.

MANAGEMENT OF RED SEA URCHIN STOCKS

Several management strategies are being employed, with a variety of regulations including size limits, quotas and seasonal restrictions in the south coast. As the fishery has developed in the south coast, management has become increasingly complex with six timed openings in 1992, and 26 area quotas. Vessels are required to notify the district fishery office prior to fishing and hail landings weekly.

A minimum size limit of 100 mm was set in 1980 to protect a spawning population. Initial harvests were wasteful with all sizes being harvested and the smaller urchins discarded at the processing plants. Processors have requested that the minimum size limit be reduced to 75 mm (Breen, 1984). The market prefers the roe from smaller urchins.

Initial quotas were set in 1981 at 5% of the estimated biomass in areas surveyed (Adkins et. al 1981). Subsequent quotas were set on a relative estimate of the available stock, often based on the advice of fishermen. Surveys in 1984-1985 found relatively low recruitment overall, less than 10% juveniles (≤ 50 mm, ~2 year old) when compared to populations from lower latitudes (Sloan et. al 1987).

Landings have stabilized in the south coast at approximately 3.5 to 4 million lb. (Fig.1) North coast landings have increased from 1986 to 3.1 million lb. ,1591 t in 1990 , then jumped to 11.8 million lb. (5375 t) in 1991 (Fig.1).

In the north coast, where effort was less (fewer vessels) initially, different management strategies have been used. A minimum size limit (100 mm-4 in.) was in effect and a maximum size (140 mm) was also set with a rotation of fishing areas similar to the Washington State practice.

A maximum size limit (140 mm- 5 1/2 in.) protects the large red sea urchins that shelter newly settled and juvenile urchins to 50 mm. Sloan et. al (1987) found that in B.C., red urchins larger than 119 mm sheltered juveniles.

In 1989, approximately 66 % of reds were taken in the south and 34% in the north. This changed in 1991, where 80% of reds were landed in the north and 20% in the south. Fig. 5 shows the landings by district and month. Prior to the 1991 fishery, fishing in the north has traditionally been after the southern fisheries and in 1989 only seven of the 39 boats fished exclusively in the north. The northern fishery is now year round. There have been closures in-season (Area 7) and closures are expected to be for at least three years before the area is open to fishing again. Closures are usually based on advice from fishermen that there is no longer significant stocks available.

There have been reduced areas open in 1992 in the north coast fishery. The plan is to rotate areas within districts to maintain supply to northern processing plants at Skidegate, Queen Charlotte Islands (Q.C.I.) and at Klemtu in the central coast. Subareas of the Q.C. I. are expected to close in 1992.

Licence limitation reduced the number of licences issued from 188 in 1990 (117 reported landings) to 102 eligible in 1992.

At the request of some native bands, a number of areas have been closed to protect stock for native food harvest. In addition,there are a number of closures in provincial and national parks. There are joint biological studies being carried out in the Q.C.I. by the Haida Fisheries Committee and the department of Fisheries and Oceans.

With the rapid growth of the fishery in the north, additional limits on the fishery are under consideration. For example, seasonal restrictions may be required to maximize roe quality. Study areas and reserves are also under consideration.

GREEN SEA URCHINS

Little is known about the abundance of green sea urchins in B.C. The fishery began in 1987 and has been limited to the inside waters of Vancouver Island and the mainland (Campbell and Harbo,1991). There have only been minor landings on the west coast of Vancouver Island and in the north coast. The fishery peaked in 1989 with as many as 113 vessels and reported landings reaching 611 t .

Most of the harvest of green sea urchins is from smaller vessels and is both by surface supplied air and SCUBA. Divers fish from depths of 5 to 60 feet.

The abundance of green sea urchins appears to fluctuate greatly. Green urchins also seem to be more mobile, changing depths and locations.

MANAGEMENT OF GREEN SEA URCHIN STOCKS

To protect a remnant population and to allow for spawning a minimum size limit of 55 mm was set as a condition of the licence. The mean sizes in two market samples in 1988 were 65 mm and 58 mm.

To limit effort the season was set from October 1 to February 28, a period of strong market demand.

There have been some minor area closures at the request of fishery officers where the stocks appear to have been depleted and there are several size limit violations.

These small urchins have been shipped live to Japan. There have been some attempts at processing them but labour costs are too high. There are many more pieces of green sea urchin roe per box than for the reds and the shape of the green roe is accepted as higher quality. One of the reasons suggested for the high price for green urchins is that they are processed and marketed as Japanese products.

Fishermen are becoming more conscious of quality. Many vessels now sample the urchins on board to determine roe quality bases on volume and color; Grade A being a bright orange. Each shipment to Japan can be traced back to the vessel and the harvest time and site determined. Premium prices are paid for consistent recoveries >8% of Grade A roe.

Licence limitation was implemented in 1991, with 47 vessels qualifying. The qualifying criteria was a cumulative landing requirement of 9,072 kg (20,000 lb.) over the two year period 1988 and 1989.

The submission of sales slips and harvest logbooks are conditions of the fishing licence. This data must be submitted before the net years licence is issued.

Higher average values have been paid for green sea urchins,$0.76/lb.in 1989 compared to $0.28/lb. for reds; $0.90/lb. in 1990 and $1.33/lb. in 1991.

In 1988,white sea urchins, *S. pallidus* were observed mixed with green sea urchins at 40 to 60 feet. Many had dark brown patches and a loss of spines. Green urchins immediately adjacent did not appear to affected.

Of interest, is the fishery for green sea urchins on the east coast of Canada, in the waters of Nova Scotia and New Brunswick. Exploratory permits (39) have been issued to both divers and draggers. All product has been shipped live to Japan.

PURPLE SEA URCHINS

Purple sea urchins are harvested from the intertidal zone down to 20 feet deep on surf exposed shores. The fishery has been limited to the west coast of Vancouver Island but fishermen report significant stocks on the west coast of the Queen Charlotte Islands.

MANAGEMENT OF PURPLE SEA URCHIN STOCKS

Exploratory fishing for purple sea urchins has been allowed under Scientific Permits. Permits are limited to four per fishery management area, issued to the first applicants. The permit holder is responsible to contract and pay for the collection of biological data by a private, approved biological consultant.

A minimum size limit was set at 55 mm, a size that should protect a spawning population. Buyers (processors) advised that sea urchins below this size did not contain much roe. In the area currently being fished, the 55 mm size limit has not been restrictive. In addition, there are significant refuge populations in crevices or in holes in the rock where the urchins cannot be harvested.

Some experimental processing was carried out by at least one company. Roe recoveries to 20% were reported from Japanese processors. They commented that the shape of the roe was different from the green and not as marketable. The roe from the purple urchins is "sweeter" than from the greens. Processors comment also that the purple urchins do not remain fresh as long as the green urchins.

The mean size of purple sea urchins (n=800) harvested from Area 20 in January 1992 was 61 mm (46 to 87 mm). Purple sea urchins are landed in plastic cages, each with an average net weight of 48 lb. at the dock.

The landings by five vessels in 1991 were only 29 t. The price paid was $ 1.65 /lb. Almost all of the product was shipped live to Japan.

FISHERY MONITORING - CATCH AND EFFORT

Each sea urchin fishery is licensed separately. The submission of sales slips and harvest log data are conditions of the licences. For quota fisheries, fishermen are required to notify the district fisheries office at least 24 hours before entering the area or commencing fishing operations.

CATCH DATA:LOGBOOKS

Logbooks have been mandatory since 1982, in addition to sales slips (Fig. 6). The logs provided only daily vessel data until 1988, when individual diver data was required. Charts of fishing sites are required and harvest "beds" are coded.

Since 1991, licence holders are required to purchase their logbooks from a private company. The price includes printing costs and keypunching charges($20 in 1991; $24 in 1992/$15 keypunch fee to continue using 1991 book). The log has been standardized for all dive fisheries.

Logs provide detailed catch per unit effort data (CPUE) that is not available on sales slips. CPUE may remain high in an general area, due to the movement of the fleet between areas. There are definite declines at some sites, however, determined from logs.

DIVER SAFETY

In 1990, there were >200 divers active in the sea urchin fisheries. The number of divers has increased (184 in 1990 fished reds) with the growth of the red urchin fishery in the north.Since 1988, all divers must have a provincial Workers Compensation Board (W.C.B.) Seafood Harvesting Diving Certificate (Jim Stewart, pers. comm.). A certificate is issued for three years, but an annual medical is required.

There are >600 divers currently certified; >800 have been examined since the program began in 1988. New divers now must be trained at an approved commercial dive program; a sport diving certificate is not acceptable without commercial diving experience.

Although there was a fatality in early 1992, there have been fewer accidents and incidents of decompression sickness since the program was implemented. The level of proficiency of the divers and safety awareness has increased.

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ACKNOWLEDGEMENTS

Sue Farlinger and Greg Thomas provided information on management strategies and practices for the north coast. Jim Stewart of the B.C. Workers Compensation Board provided details on diver safety.

Table 1. Annual red sea urchin landings (tonnes), value and effort for British Columbia, 1978 to 1991, as reported on sales slips and harvest logs.

Year	Type and Number of Licences Issued	South Coast Quota[1] $(t \cdot 10^{-1})$	Number of Vessels with Landings	Total Vessel Fishing Days	Coastwide Landings (t)	Landed Value $(\$ \cdot 10^{-3})$	Whole Landed Value $(\$\ t^{-1})$	Export Value $(\$\ t^{-1})$	$\bar{X}$ CPUE[2] $(t \cdot vessel\ day^{-1})$	$\bar{X}$ CPUE[3] $(kg \cdot diver\ hr^{-1})$
1978	C		4	54	75	16	213		1.4	-
1979	C		29	298	317	76	240		1.1	-
1980	C		18	331	333	84	252		1.0	-
1981	C	136	18	127	116	34	293	11,090	0.9	-
1982	C		21	195	160	56	350	17,710	0.8	-
1983	Z 64		36	825	982	348	354	15,850	1.2[1.3][3]	311
1984	Z 85		47	1,150	1,834	740	403	19,530	1.6[1.5]	281
1985	Z 86	1803	46	1,086	1,815	762	419	N/A	1.7[1.4]	360
1986	Z 103	1500	67	1,534	2,067	895	455	19,720	1.4[1.6]	363
1987	Z 184	1633	97	1,807	2,122	1,148	541	20,460	1.2[0.6]	325
1988	Z 184	1678	84	1,249	2,115	1,241	587	11,040	1.7[1.3]	296
1989	Z 240	1644	109	1,542	2,658	1,631	614	15,440	1.7[1.6]	344
1990*	Z 188	1599	116	2,651	3,158	1,953	618	N/A	1.2[1.4]	298
1991*	Z 102	1576	86	3,744	6,714	4,030	600	N/A	1.8[–]	N/A

[1] south coast quota includes exploratory areas, north coast has size limits and no quotas. See Table 2 for south coast landings.
[2] from sales slip data
[3] CPUE [ ] from harvest log data
* preliminary data for 1990 and 1991, harvest log data not complete

Table 2. Green sea urchin landings (tonnes) and effort for British Columbia, 1987 to 1991, as reported on sales slips and harvest logs.

Year	Type and Number of Licences Issued	Number of Vessels with Landings	Fishing Days	Landings (t)	Landed Value ($10^{-3})	Whole Landed Value ($ t^{-1})	$\bar{X}$ CPUE[1] (t·vessel day^{-1})	$\bar{X}$ CPUE[3] (kg·diver hr^{-1})
1987	Permit 38[2]	19	160[3]	121[3]	152	1257	754	151
1988	Z 89	68	690	444	584	1315	643	122
1989	Z 7	113	1394	611	1020	1669	438	141
1990*	Z 155	90	1352	475	939	1977	351	N/A
1991*	Z 47	47	1268	573	1683	2937	452	N/A

[1] from sales slip data
[2] scientific permits were issued to 38 vessels for fall 1987 to spring 1988 fishery. Z licences were issued for the fall 1988 fishery.
[3] data from harvest logs
* preliminary data for 1990 and 1991.

Table 3. Historical summary of management for the Red and Green Sea Urchin fisheries in British Columbia. Size limit measurements of test diameter.

Year	Red Sea Urchin	Green Sea Urchin
1970	C licence (general) unrestricted	
1973	Min. size limit 4 in. Season closure 1 Jun.-31 Aug.	
1980	Min. size limit 100 mm	
1981	Quotas set for some areas.	
1983	Z licence (species specific) unrestricted. Log books mandatory	
1985	Additional area quotas EVI and WVI (1757 t). Season closure 16 Mar.-14 Sept.	
1986	North B.C. fishery started. South: Season closure 16 Mar. -30 Sept.	
1987	North: Season open all year, no area quotas. Min. size 100 mm.	Scientific permits, Season closure 1 Jan.-21 Jul. Min. size 40 mm, logbooks mandatory.
1988	North: max. size 140 mm added South: 4d/wk (Sun.-Wed.) fishing more detailed diver logbook mandatory	Z licence, size limit 55 mm, Season closure 1 Mar.-30 Sept. Fewer minor area closures.
1989	South: additional open season 1 Jun.-15 Aug.	Some minor area closures.
1990	North: Area rotation closures South: Open season WVI 1 Jun.-30 Aug. Total quota 1599 t divided by area (28) and time (5)	
1991	Licence limitation introduced. Cost recovery for logbooks.	Licence limitation introduced. Cost recovery for logbooks.
1992	Additional native closures in north.	No changes.

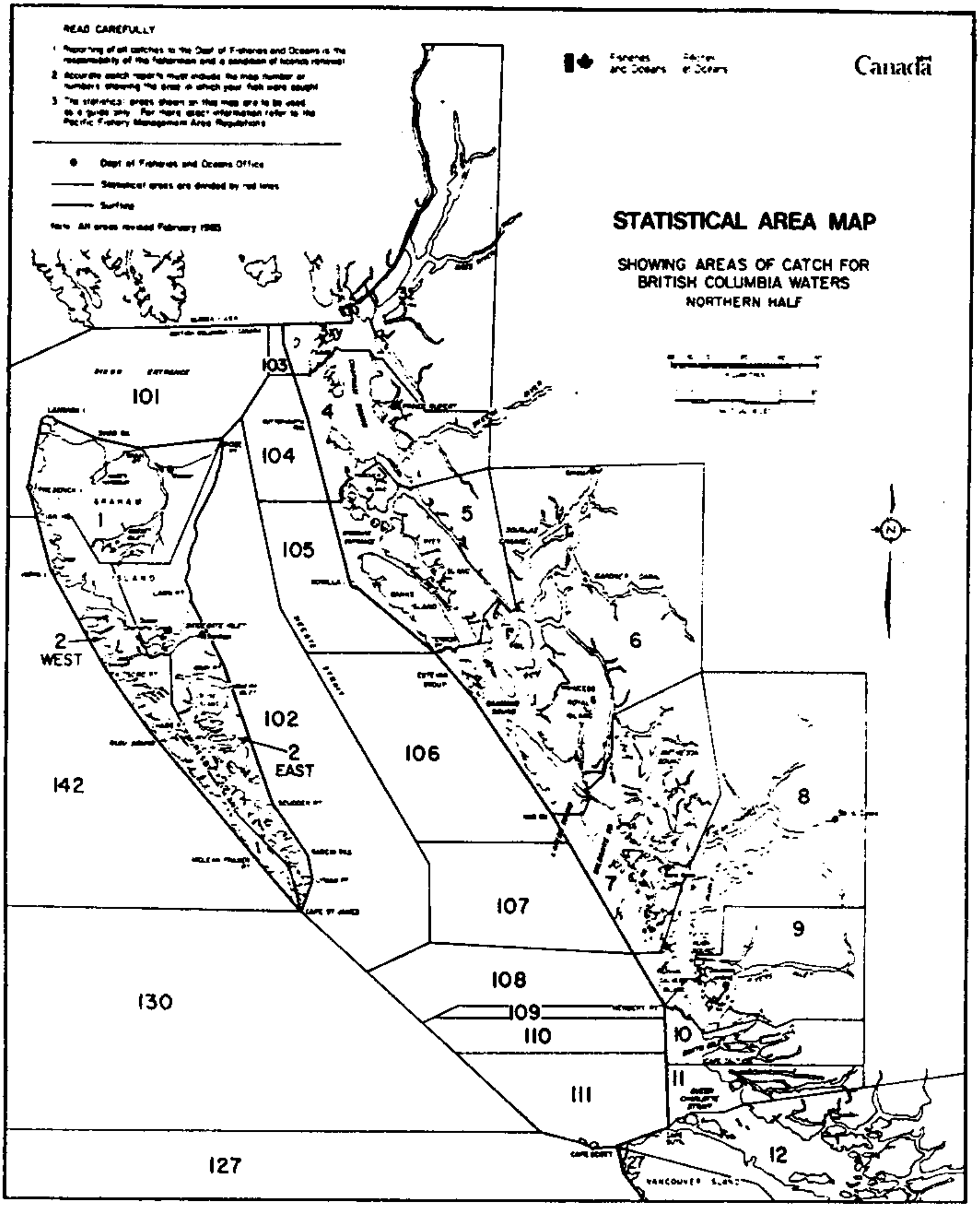

Figure 1. Pacific Fishery Management areas on the north coast of British Columbia.

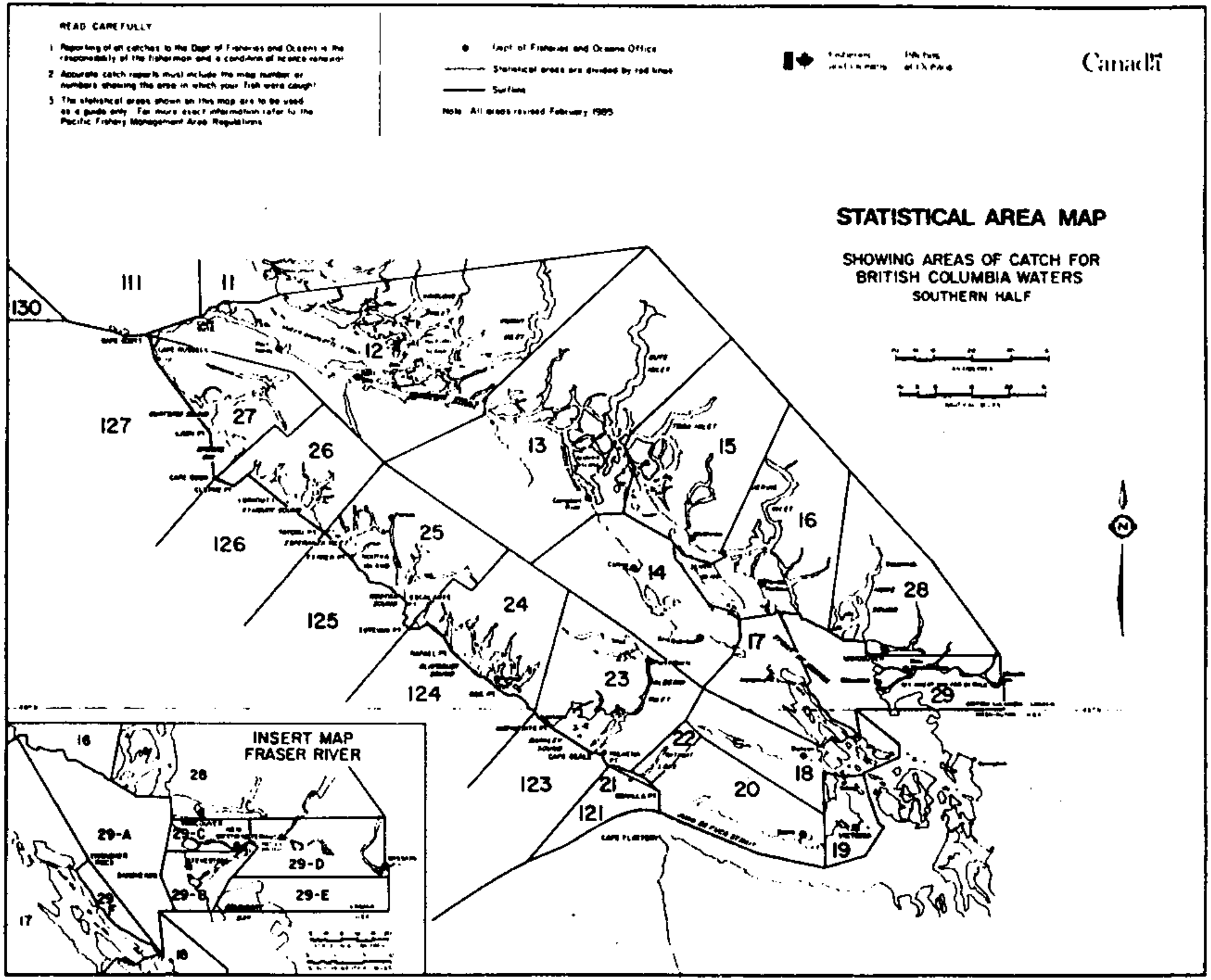

Figure 2. Pacific Fishery Management areas on the south coast of British Columbia.

Red Sea Urchin Landings in British Columbia, 1981 to 1991

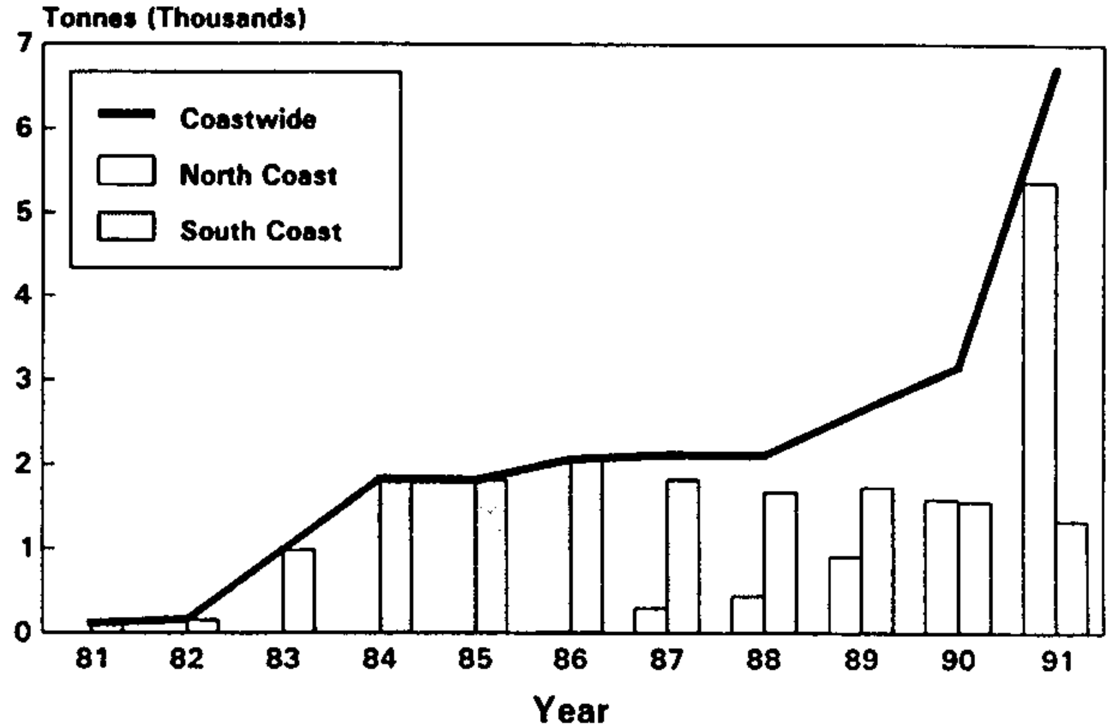

Figure 3.

Green Sea Urchin Landings in British Columbia, 1987 to 1991

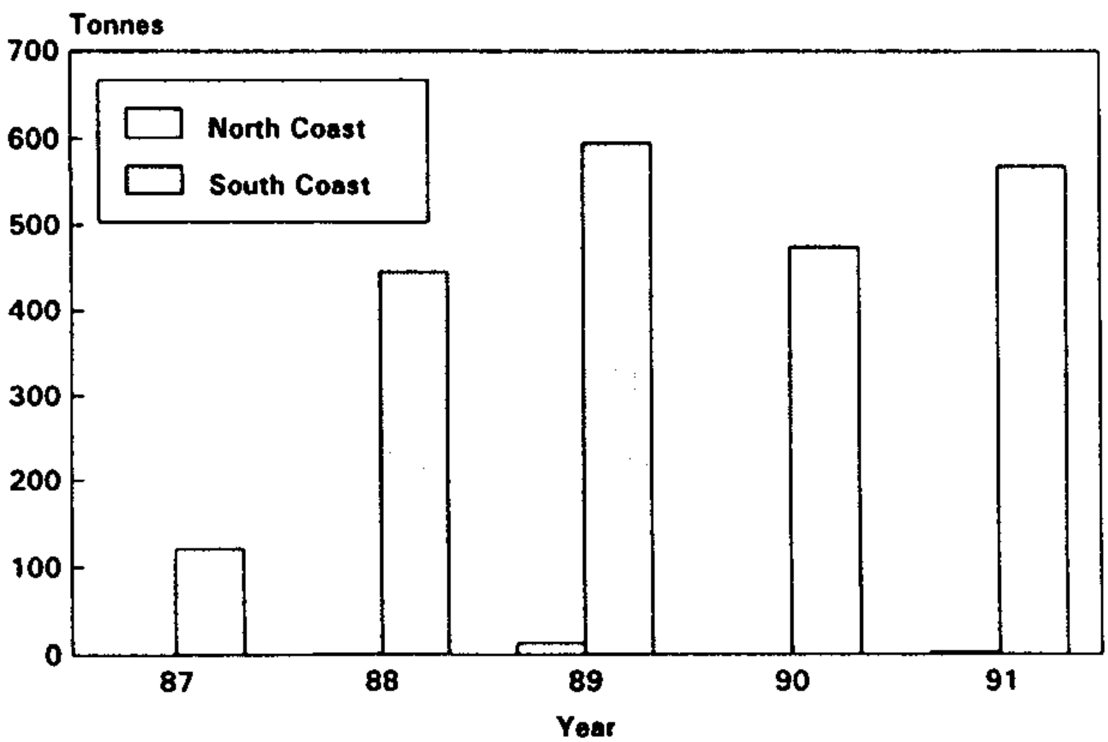

Figure 4.

Vessel Dyvalot II   Skipper B. Happy

CFV 2 9 9 9 9 (1 2 3 4 5)   Year 1 9 8 9 (6 7)

DIVING FISHERY
HARVEST LOG

☐ FOR OFFICE USE ONLY

Are weights in kilograms ☐ (54) or pounds ☒ (54)

Licence Tab # 0 0 6 0 (60 61 62 63)

Are you using cages ☒ (55) pails ☐ (55) totes ☐ (55) other ☐ (55)

Average wt/cage, pail, tote, etc 0 0 5 0 (56 57 58 59)

Check species fished: only ONE SPECIES/SHEET (51 52 53)

Abalone ☐ Green Sea Urchin ☐
Geoduck ☒ Red Sea Urchin ☐ Sea Cucumber ☐
Horse Clam ☐ Pink and Spiny Scallop ☐ Octopus ☐
Other (specify) ______

Month (10 11)	Day (12 13)	Location (attach map)	Statistical Area (14 15 16)	Sub Area (17 18)	Bed Code (19 20 21 22)	Diver Name	Diver Code (23 24 25 26)	Depth (ft) Max (27 28 29)	Depth (ft) Min (30 31 32)	Diver Minutes (33 34 35)	# cages, Pails,Totes (36 37 38)	Total Number of Pieces (39 40 41 42)	Total Landings (lb) or (kg) (43 44 45 46 47)	Company Sold To	Company Code (48 49 50)
03	02	Comox Bar	014	11		R.Miller		040	030	265	014	0203	00604	Comox	
03	02		014	11		R.Humphries		040	025	150	009	0152	00382	Cannery	
03	03		014	11		RH		035	025	250	016	0279	00702	"	
03	03		014	11		RH		040	030	270	033	0448	01446	"	

EXPLANATION OF TERMS

TERM	COLUMN NO.	EXPLANATION
weights	54	Are weights pounds or kilograms?
cages, pails, or totes	55	Are you using cages, pails or totes? Check one.
licence tab #	60-63	Record E,G, or Z licence tab #.
ave. wt. of container	56-59	Record average weight of a container full of catch.
species fished		Indicate species fished by checking one box.
month, day	10-13	Record date (month, day) of each fishing day.
location	14-18	Name location, record Fisheries Statistical Area and Sub-area, provide a map of areas fished on a separate sheet.
divers's name		At top of column record each diver's full name. Following entries on that page may be first name or initials.
depth	27-32	max = maximum depth of dive min = minimum depth of dive
diver minutes	33-35	Record minutes diving for each diver entry.
no. cages/pails	36-38	Record number containers filled.
total number of pieces	39-42	Number of shellfish (ie. sea cucumbers) harvested per diver per day.
total landings	42-47	Record total weight of catch landed per day in lbs. or kg.
company sold to		Record company name of buyer.

Figure 5. Diving Fishery Harvest Logbook sample page.

FISHERY OF SEA URCHIN (*Loxechinus albus*) IN CHILE

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ABSTRACT

Among the Chilean artisanal fisheries the most important is that of shellfish, based on the extraction of molluscs, echinoderms and crustaceans. In 1987, the total landing of benthic resources of artisanal extraction was 114,316 tons. For Chile this meant an income in foreign currency equivalent to US$ 43 million, of which 15.8 million corresponded to exports of the edible sea urchin Loxechinus albus.

During the decade of eighties, the fishery of the Chilean edible sea urchin occupied the second place in importance at the global level, with more than 30,000 tons of total extraction in 1985. Over the last years, a gradual decrease has been observed in the artisanal extraction of this resource, probably due to overfishing.

In this paper we present an update diagnosis of the artisanal sea urchin fishery in Chile concerning: basic biological information (bathimetric and geographic distribution, morphology and spawning) extraction level, fishery areas, processing of the gonads, culture, management and repopulation of natural areas.

Due to the current level of extraction of Loxechinus albus along the Chilean coast, we suggest to generate, in the shortest possible term, management plans allowing for the recovery of natural population of this resource. The management plans must include (a) cultures under controlled conditions and in the natural environment and, (b) management and protection of coastal areas.

INTRODUCTION

At world level, benthic artisanal fisheries have been considered as an important productive activity, because they employ a great number of people and provide raw material, mostly destined to direct human consumption (FAO, Rome, 1984).

Among Chilean artisanal fisheries the most important is undoubtedly that of shellfish, based on the extraction of molluscs, echinoderms and crustaceans (SERNAP, Anuarios de Pesca). In 1987, the total landing of benthic resources of artisanal extraction was 114,316 tons. For Chile, this meant an income in foreign currency equivalent to US$ 43 million, of which 15.8 million corresponded to exports of edible sea urchin (FIG. 1) (Bustos et al., 1985, 1990; SERNAP). Over the last years, a gradual decrease has been observed in the artisanal extraction of this resource, probably due to overfishing (Bustos et al., 1990). Thus, landings generated in 1988 amounted to only US$ 7.4 million.

In international markets, sea urchins are considered as species of high commercial value. Japan and Chile are the largest consumers of sea urchin gonads (Australian Fisheries, 1978; FAO, 1980). During the decade of the eighties, the fishery of the Chilean edible sea urchin *Loxechinus albus* occupied the second place in importance at the global level, with a total extraction of 30,577 tons in 1985 (Guisado & Castilla, 1987).

There are references to Loxechinus albus in the literature on: reproduction (Gutiérrez & Otsú, 1975; Bückle et al., 1978; Bay Schmith et al., 1981), diet (Bückle et al., 1977 a, 1980; Vásquez et al., 1984; González et al., 1987), ecology (Viviani, 1975; Castilla & Moreno, 1982; Vásquez & Castilla, 1984; Castilla, 1985; Vásquez, 1986; Contreras & Castilla, 1987), growth (Gutiérrez & Otsú, 1975; Bückle et al., 1977 b; Zegers et al., 1983; Gonzalez et al., 1990), larval culture (Arrau, 1958; Bückle et al., 1976; González et al., 1987; Castilla et al., 1988; Bustos et al., 1990; Guisado, 1991) and fishery (Bay Schmith 1982; Bustos et al., 1985).

It is our aim to present here an updated diagnosis of the artisanal fishery of the Chilean edible sea urchin Loxechinus albus (Molina) concerning: extraction levels, fishery areas, destination of the extractions, processing of the gonads, culture, management and repopulation of natural areas.

BATHYMETRIC AND GEOGRAPHIC DISTRIBUTION

Latitudinally, the edible sea urchin Loxechinus albus is distributed between the island Lobos de Afuera (6° 53' S) in the Peruvian littoral (Clark 1948) and the southernmost islands of South America at approximately 55° S (Vásquez et al., 1984). The eastern limit of the species is the Isla de los Estados in Tierra del Fuego (Bernasconi, 1953). Furthermore, Fenucci (1967) has reported the collection of Loxechinus individuals in the Argentinean continental platform up to 37° 35' S - 54° 33' W. Bathymetrically, Loxechinus is distributed in the intertidal zone down to 340 m deep (Larraín, 1975).

MORPHOLOGY AND SPAWNING

Loxechinus albus, whose common name is edible sea urchin or red sea urchin, has a semispherical shell, middle to big sized, of green colour with reddish or purple shades in ambulacra and interambulacra. Individuals of big size or living in depths show whitish shades (Larraín, 1975). Ambulacral plates are polypar, presenting from 6 to 11 pairs of pores each, with a primary tubercle. The ambulacral system is dicyclic with a central anus and numerous large periproctal plates. In adults, primary spines are short and conic. Secondary and miliary spines are numerous. Globiferous pedicellaria have a neck without circular musculature and big valves bearing from one to four lateral teeth on each side (Larraín, 1975).

According to the literature, the reproduction of the edible sea urchin in Chile occurs between November and April in the northern zone, around 22°S (Gutiérrez & Otzú, 1975; Zegers et al., 1983); between July and December in the central zone, at 32° S (Bückle et al., 1978; Guisado & Castilla, 1987); between November and December around parallel 42° S (Bay Schmith et al., 1981); and, in the southernmost region (c.a. 53°S) during August and September (Bay Schmith et al., 1981). Notwithstanding, viable mature gametes have been obtained beyond the normal times of gonadic maturity in experiments of spawning induction and culture (Guisado, *in litteris*). Furthermore, laboratory experiments of maturity induction in adult sea urchins indicate that it is possible to obtain gametes even six months after the normal spawning period (Guisado & Castilla, *in litteris*).

The current fishery legislation forbids the extraction of edible sea urchin between November 1st and January 15th; in this context, the restrictive measures protect only partially the sea urchin reproduction along the littoral (between 40° S and 46° S). This regulation for sea urchin extraction is in force since 1981, it restricts the capture period between 18° and 49° S, and establishes 70 mm as the minimal size of testa for catch. After spawning and the subsequent external fertilization, echinoplutei larvae remain in the plankton for periods of 28 to 34 days, during which larvae feed on phytoplankton (Arrau, 1958). In the southern zone of Chile (Huihue) *L. albus* larvae can be found in the plankton between October and April, not presenting a defined spatio-temporal distribution pattern. The maximal larval densities found in this area were 116 larvae/m^3 in the 4-arm state, and only 1.3 premetamorphic larva/m^3 (Bustos et al., 1970).

Larval settlements are often aperiodical occurring mostly in rocky intertidal areas (Castilla, 1981; Vásquez et al., 1984). In the central zone, juvenile postmetamorphic organisms up to ca. 2 cm in testa diameter are found in intertidal crevices with abundant broken shells, feeding on benthic diatoms, crustose algae and juvenile macroalgae (Contreras & Castilla, 1987). Intertidal populations of the red sea urchin between 2 and 4.5 cm in diameter of testa inhabit intertidal pools with permanent water exchange, feeding on pieces of drifting algae and consuming preferently red algae. Individuals over 4.5 cm migrate toward subtidal environments; they form the populations submitted to artisanal exploitation (Contreras & Castilla, 1987). Although gametogenic activity has been reported in intertidal populations of Loxechinus measuring between 3.8 and 4.5 cm in testa diameter (BÜckle et al., 1978), Bay Schmith et al. (1981) suggest that only spawnings of individuals from subtidal populations measuring over 4.5 cm are of significant importance in the renewal of the natural stocks populations.

In the area of highest population concentration, between 42º and 48ºS, Loxechinus presents two spawning periods. The first and most significant occurs between November and December and the second in March. According to Bay Schmith (1981) this spawning would be apparent since gamete are phagocytic, and the oocytes are cytoplasmically degradated. Although there is a latitudinal displacement of the spawning periods of Loxechinus along the

Chilean coast, the second apparent spawning seems to be of common occurrrence in the central and southern populations of the country (Bückle et al., 1978).

SEA URCHIN EXTRACTION IN CHILE

Extraction statistics show a sustained increase of edible sea urchin captures since 1975, which reach a yearly maximum of over 30,000 tons in 1985. These extraction levels have decreased over the last 5 years to reach only 15,648 tons in 1990 (FIG. 2). In a former analysis, Bay Schmith et al. (1981) reported that between 1949 and 1980 the sea urchin landings had not exceeded 2,500 tons per year. These authors suggest that the period between 1953 and 1973 was characterized by cycles of increases and sharp decreases in the landings which fluctuated between 1,500 and 4,000 tons a year. Ever since 1974 -and significantly from 1976 to 1990 (FIG. 3)- the increase in the landings of the commercial sea urchin has been essentially sustained by artisanal extraction in the zones nearing parallel 42°S. Over the last six years, this Chilean south-austral region has contributed with 92% of the sea urchin landings at the national level (FIG. 4).

According to the extraction statistics (SERNAP), sea urchin fishery developed along the whole Chilean coast; however, over the last years, the artisanal fishery of this resource has been centered south of parallel 40° S, mostly for three reasons: (1) the high capture in the northern and central regions made that the levels of this reource fell almost to zero. This meant a displacement of the artisanal fleet to the southern regions, with the consequent increase in extraction pressure; (2) "El Niño" (1982-1983) generated negative effects in numerous fisheries in the north of Chile, most of which have not yet recovered; and, (3) the close relationship between Loxechinus and Macrocystis, which determines the abundance of this resource in areas of the southern fjords.

If we accept that the edible sea urchin fishery is sustained at present by the extractive activity around parallel 42° S, the state of the resoure can be estimated only by evaluating the zone which concentrates over 90% of the overall extraction. This simulation has been recently performed by Jerez (1991), through direct determinations of size and catch and indirect evaluations of age, growth and catch per unit of effort. The simulation evaluates the stock of the resource sea urchin in 4 areas of the Region whose yields (c.p.u.e.) over the last 5 years have been different (FIG. 5), so that it may be assumed that these areas have different extraction pressures.

Jerez (1991) applied the SRA Aleatory Model, in order to estimate the stock of the resource, discarding the capture over the next 5 years in two of the zones analyzed (Zone B with high extraction and Zone C with lesser fishing pressure). This author concludes that there would be a significant increase in the abundance of the resource (approx. 100% over the period analyzed). Nonetheless, recruitment remains constant and even undergoes some decrease after 1993 (FIGs. 6 and 7).

MARKET AND GONAD ELABORATION PROCESSES

In Chile, three types of processes of industrial elaboration are associated to the exportation of sea urchin gonads: frozen, dehydrated in alcohol and canned. An analysis of the industrial process of sea urchin landings over the last 15 years shows a sustained increase of the frozen product (FIG. 8). Thus, in 1990, the production of frozen gonads amounted to 11,979 tons in contrast with 3,616 tons of the same product in 1976. However, considering the percentage of catch destined to this process as a function of the total catch, between 1976 and 1990, there has been an increase by only 10% in this processing of the raw material.

Other elaboration processes of the raw material such as : canned gonads, fresh gonads for direct consumption in Chile, and gonads preserved in alcohol, have maintained a fairly constant production, ranging between 200 and 5,000 metric tons over the period under study (FIG. 8). The estimation of fresh gonads for direct consumption in the local market has ranged from 206 to 5,300 tons, approximately. These values are independent from the overall annual capture, which makes a historical average of consumption of the sea urchin in Chile of the order ot 2,535 metric tons over the last 15 years.

The analysis of the industrial processes associated to the edible sea urchin fishery between 1985 and 1990 shows that 76% of the landings are destined to be frozen, followed by gonads dehydrated in alcohol (11.2%) and canned (6.8%). Over the same period 6.6% of the landings have been destined to direct local consumption (FIG. 9).

Japan is the main consumer of Chilean sea urchin gonads, with over 90% of the total exports over the last 10 years (SERNAP). Other countries appearing as eventual and aperiodical importers are Argentina, Peru, the United States of America, France and Italy (FIG. 9).

CULTURE

LARVAE CULTURE

The first cultures of edible sea urchin larvae in Chile were performed by Arrau in 1958. This author described the larval development of <u>Loxechinus albus</u> and furnished the basic background for the development of "echinoculture". He achieved larval metamorphosis using unfiltered sea water and natural phytoplankton for food. Later, results have been at variance and sometimes contradictory. Bückle et al. (1976) carried out massive larvae cultures without achieving their metamorphosis. González et al. (1987) carried out pilot experiments to test techniques for the culture of Loxechinus larvae, obtaining 90% of metamorphosed larvae. The differences in the results obtained by the above mentioned authors seem to relate to the experimental conditions used, such as quality of feed and density of the cultured larvae (Guisado & Castilla, 1987). Recently an experience of repopulation of Loxechinus albus in southern Chile, including the massive production of juveniles in the laboratory (Bustos et al., 1990), suggests that the optimal methodology for obtaining sea urchin seeds in the laboratory should consider a differential feeding as to the amount and quality of food by larval developmental stage. These authors also suggest an inverse relationship between larval density in the culture and the size reached by the larvae in the terminal developmental stages; they also found that survival between successive larval stages ranges from 10% to 30%.

In relation to the uptake of larvae (seeds) in the natural environment, the only experience reported using vynil chloride plates has yielded discouraging results since the densities obtained did not exceed 0.006 ind/cm^2 (Bustos et al., 1990).

CULTURE OF JUVENILES

The culture of postmetamorphic juveniles from larvae raised at laboratory conditions has been carried out only at an experimental scale, in the south of Chile (Bustos et al., 1990). Juveniles of Loxechinus cultured in the laboratory and fed on different diets showed that individuals fed with Ulva sp, Macrocystis and a mixed diet of both algae presented growth rates over 2.4 mm/month and high survival rates (FIG. 10 A-B). On the other hand, growth and survival are also related to the experimental densities in culture. Thus the higher growth and survival rates were obtained in experiments where initial densities did not exceed 0.5 individ/cm^2 (FIG. 10 C-D). Other data provided by Bustos et al. (1990) allow to determine that the optimal size for the transfer of juveniles to the sea is 3,0 mm, which is reached between 102 and 150 days, depending on the culture density.

CULTURE OF ADULTS (FATTENING).

There are several data on experiments of sea urchin cultures at controlled conditions, both in the laboratory and the natural environment. Bückle et al. (1977a, 1977b) suggest that sea urchins kept captive in the natural environment (Valparaíso and Chiloé, Chile) show mean growth rates of 1.10 mm/month when fed on a mixed macroalgal diet. In the north of Chile, Zegers et al. (1983)

reported that sea urchins cultured at similar conditions showed similar mean growth rates.

Experiments conducted in Bahía Metri, southern Chile (X Region) by González et al. (1990) showed that sea urchins maintained in suspended systems, with no other food than that provided by the organisms colonizing the culture structures, presented higher growth rates than those kept in the laboratory and fed on Ulva sp ad libitum (1.75 cm/year and 0.9 cm/year respectively).

The findings of the research on larvae and juveniles culture carried out in a controlled ambience, as well as studies on juveniles in controlled natural environment over the last 30 years have allowed to develop and adapt some culture techniques which must be optimized in the near future. In Chile, the culture of Loxechinus is still at an experimental stage, but some private organisms and Universities have started massive experimental cultures of this resource. The culture of L. albus from the obtention of gametes up to the obtention of seeds able to be cultured in a natural environment involves several stages which are outlined in FIG. 11. Basically, three stages may be distinguished: (1) laboratory stage, from the conditioning of the breeders till the obtention of postmetamorphic larvae; (2) hatchery stage, to generate juveniles of 3 mm; and (3) a stage in the natural environment -or intermediate culture- in which juveniles are maintained in suspended culture. A fourth stage should involve the repopulation of rocky intertidal and shallow subtidal environments.

REPOPULATION

In Chile, the repopulation of marine organisms of importance (algae and invertebrates) has been performed by means of: (1) direct repopulation with adults and juveniles obtained in the laboratory or collected in the natural environment; (2) management of coastal areas, basically through human exclusion.

MANAGEMENT OF COASTAL AREAS

Castilla (1990) suggests that the management of coastal areas for repopulation can be done using at least two strategies, not necessarily excluding one another. A first approach is the maintenance of large coastal zones as marine reservations for a long period of time. A second alernative is the sequential rotatory extraction along the Chilean littoral.

Over the last 20 years, two important experiments of human exclusion have been conducted in the Chilean coast: one in Valdivia at 40°S (Moreno & Vega, 1988) and the second in the central coast at 32°S (Durán et al., 1987). These areas have been typified as marine reservations and their protection to commercial extraction has allowed an increase in the stocks of most of the intertidal macroalgae and invertebrates. In the case of sea urchins in the reservation of the central zone, Castilla (1990) reports that 2 years after the exclusion of man, the population of intertidal sea urchins had increased by 25-fold. Similar results have been reported by Moreno and Vega (1988) for the marine reservation in Valdivia.

Several authors have reported that *Loxechinus albus* uses rocky intertidal areas for larval recruitment (Vasquez et al., 1984; Contreras & Castilla, 1987; Guisado & Castilla, 1987; Zamora, 1989). Recent results in coastal reserves of northern and southern Chile (Castilla, 1986; Guisado & Castilla, 1987; Moreno & Vega, 1988) show that these littoral zones are apt for sustaining important adult populations of this species. In this sense, natural repopulation as a function of the management of intertidal coastal areas, appears at present as one of the most promisory methods to increase the stock of adult sea urchins and the availability of larvae. Chile has optimal geographical characteristics which allow to naturally generate "buffer zones". These natural buffer areas have been postulated as being crucial for the maintenance of populations of economic importance (Castilla, 1986). Chile has 6,000 km of coast, with only one longitudinal highway which connects it from 18° S to 46° S. In many sites along this connecting way, the access to the coast is almost impossible for the natural barrier opposed by the Coastal Range. Thus, the highway passes at more than 100 km from the littoral in most of the northern region. There are not either coastal roads and when they do exist they are destroyed during summertime by the thawings from the Bolivian altiplano. South of 42° S the access is hampered by the numerous islands that form the austral-southern and south-Patagonian fjords. These characteristics of the Chilean coastal environments favour the formation of "buffer areas". The exclusion of man, as main predator, maximizes the generation and propagation of reproductive bodies of economically important resources.

There are no data concerning the rotation of extraction areas in Chile.

SEA URCHIN REPOPULATION

Many experiences on repopulation of intertidal areas have been carried in the north and south of Chile. The first investigations allow to point out that the most adequate size for the transfer of juveniles into the sea is approximately 3 mm in diameter. This size is reached after 102 to 150 days in a controlled environment. The main drawback is the control of predators. Coastal fish of the genera Semycossiphus, Cheilodactylus and Graus and asteroidea like Heliaster helianthus, Meyenaster gelatinosus and Stichaster *striatus* are the main predators present in the littoral marine communities (Vásquez, 1989). However, the major predator of adult populations is man. The increase of unemployment in seaside dwellers has induced a sector of the population to collect intertidal edible organisms. This occurrence has damaged a number of experimental repopulation programmes along the Chilean littoral.

Summarizing, we may state that in view of the current levels of extraction of the edible sea urchin along the Chilean coast, it is indispensable to generate, in the shortest possible term, management plans allowing for the recovery of the natural populations of this resource. The management plans must include: (a) Cultures under controlled conditions and in the natural environment; in this context, it is necessary to conduct massive experiences which may provide the larval and juvenile density needed for a successful repopulation. (b) Management and protection of coastal areas; this management should include repopulation activities, protection against anthropic intervention and rotation of the extraction zones, directed to a temporal recovery of the fishing areas.

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FIGURE CAPTIONS

FIG. 1 Total income in US dollars for the exports of the red sea urchin (Loxechinus albus) in the last decade in Chile. (Source: SERNAP - Chile).

FIG. 2 Total landing of red sea urchin (Loxechinus albus) in Chile between 1965 and 1990. (Source SERNAP - Chile).

FIG. 3 Total landing of sea urchin in Chile between 1965 and 1990. The landing of catch of the X Region of Chile (around 42° S) is showed in comparison with the landing of the rest of the country. (Source: SERNAP - Chile).

FIG. 4 Graphical comparison between the landing of the X Region of Chile and the rest of the country between 1965 and 1990. (Source: SERNAP - Chile).

FIG. 5 Indirect evaluation of the natural stocks in four areas of the X Region of Chile throught the use of cath per unit of effort (c.p.u.e.). (After Jerez, 1991).

FIG. 6 Simulation of the evolution of the natural stocks in areas of high cath effort (X Region of Chile). (After Jerez, 1991).

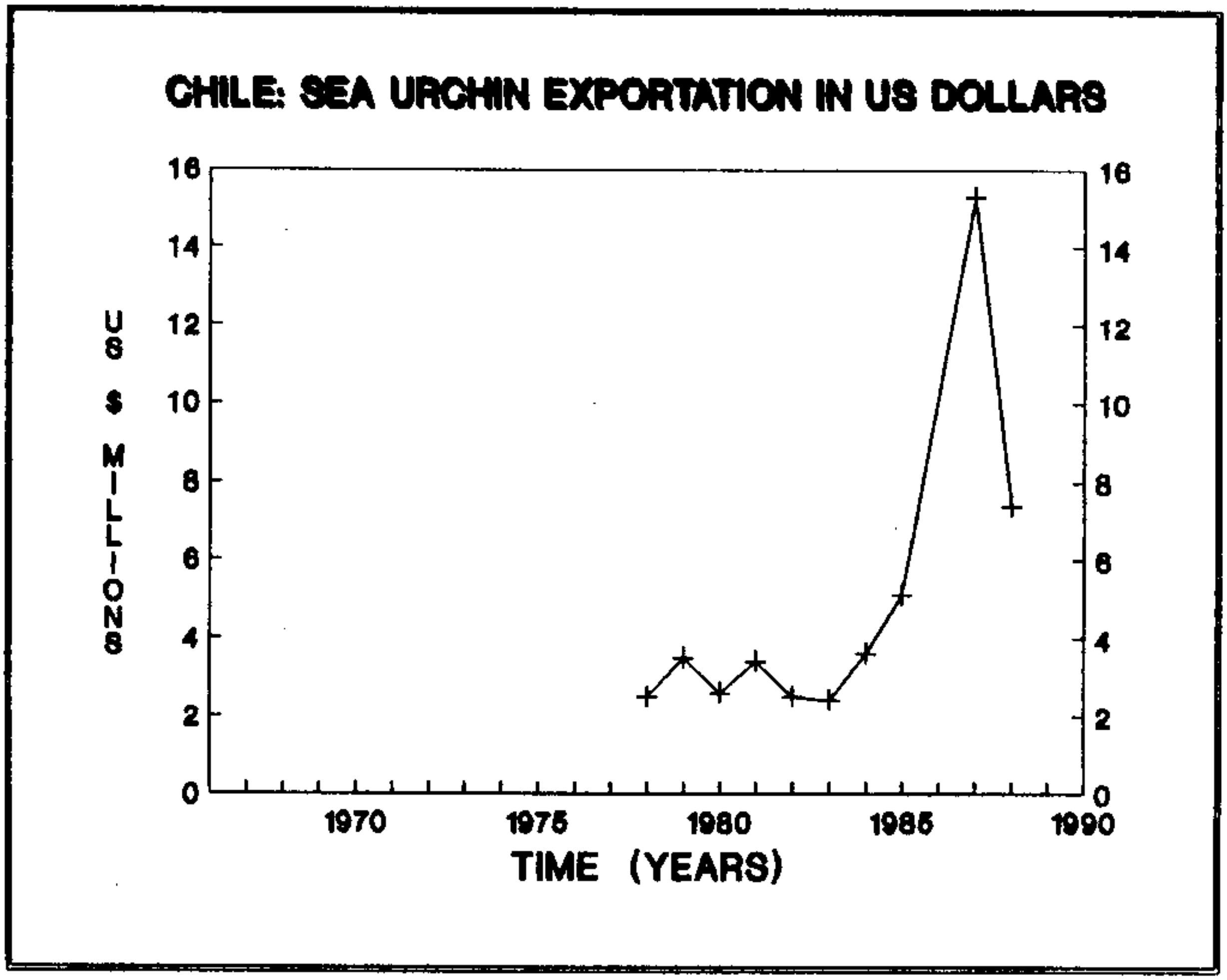
FIG. 7 Simulation of the evolution of the natural stocks in areas of low cath effort (X Region of Chile). (Source Jerez, 1991).

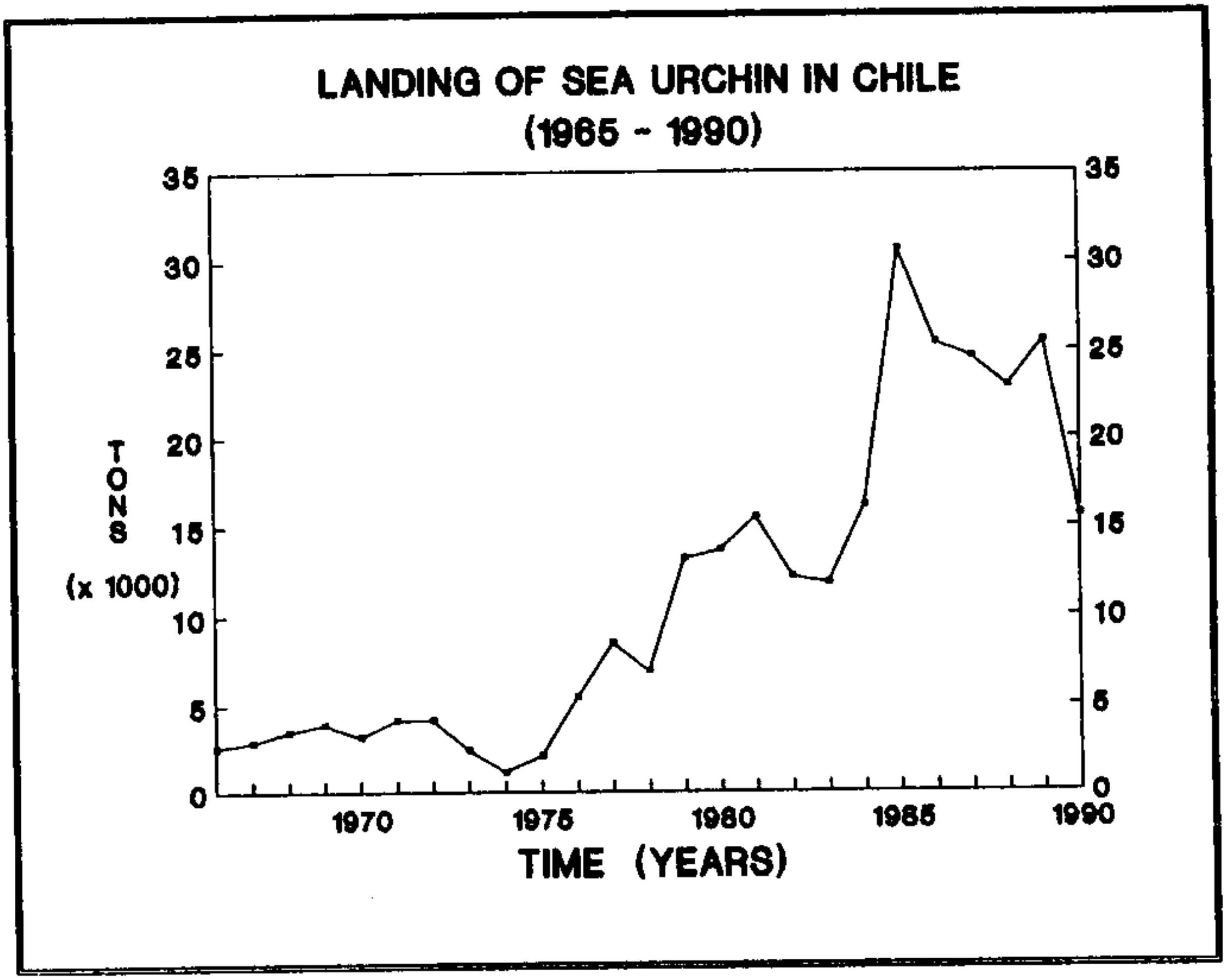
FIG. 8 Temporal variation of the main industrial processing and landings destinated to direct local consumption of Loxechinus albus in Chile (1976 - 1990). (Source: SERNAP - Chile).

FIG. 9 Graphical representation of main industrial processing (and destination of exports) of the red sea urchin in Chile (1985 - 1990). (Source: SERNAP - Chile).

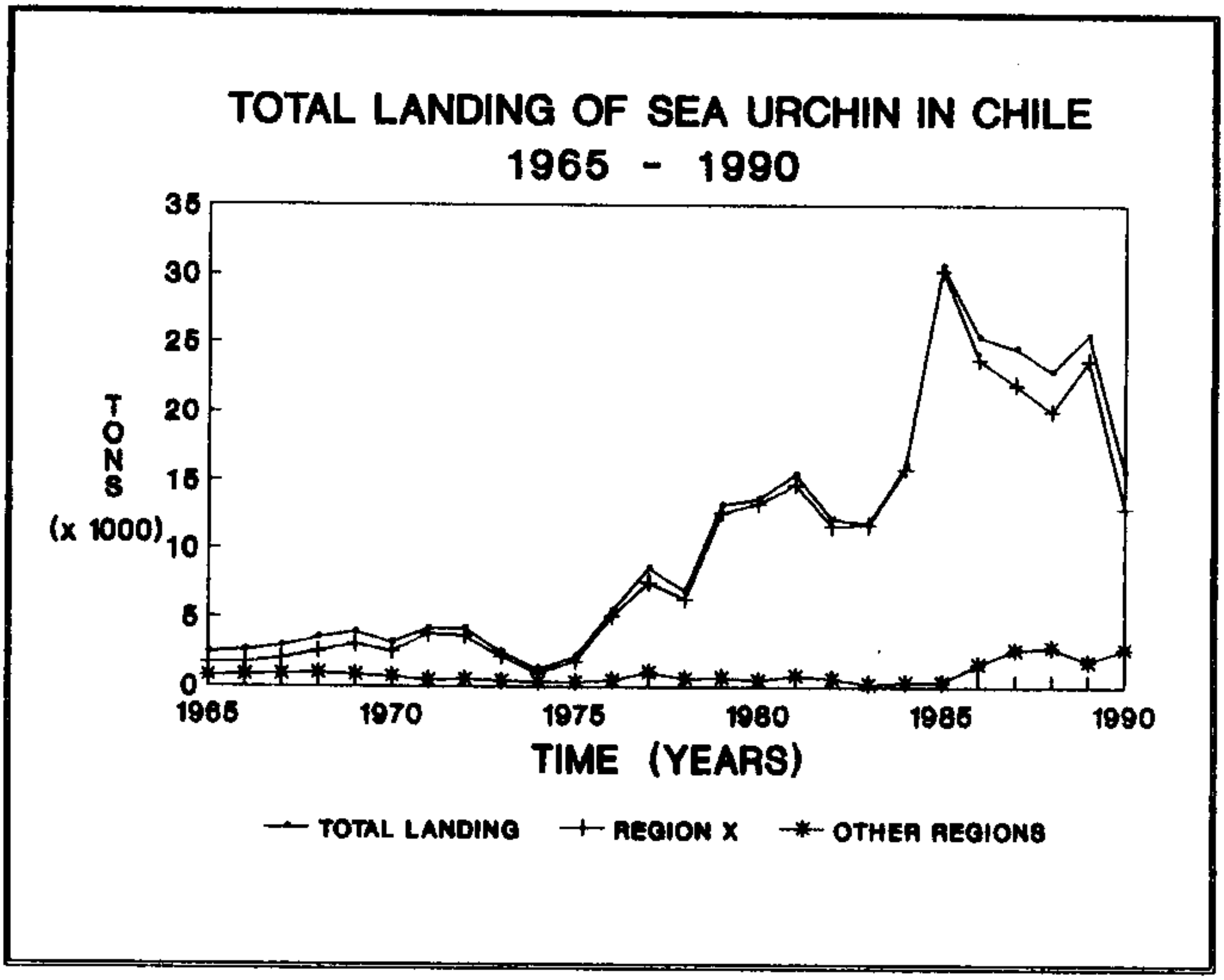
FIG. 10 Growth and survival of Loxechinus albus under different diets and density experimental conditions. (After Bustos et al., 1991).

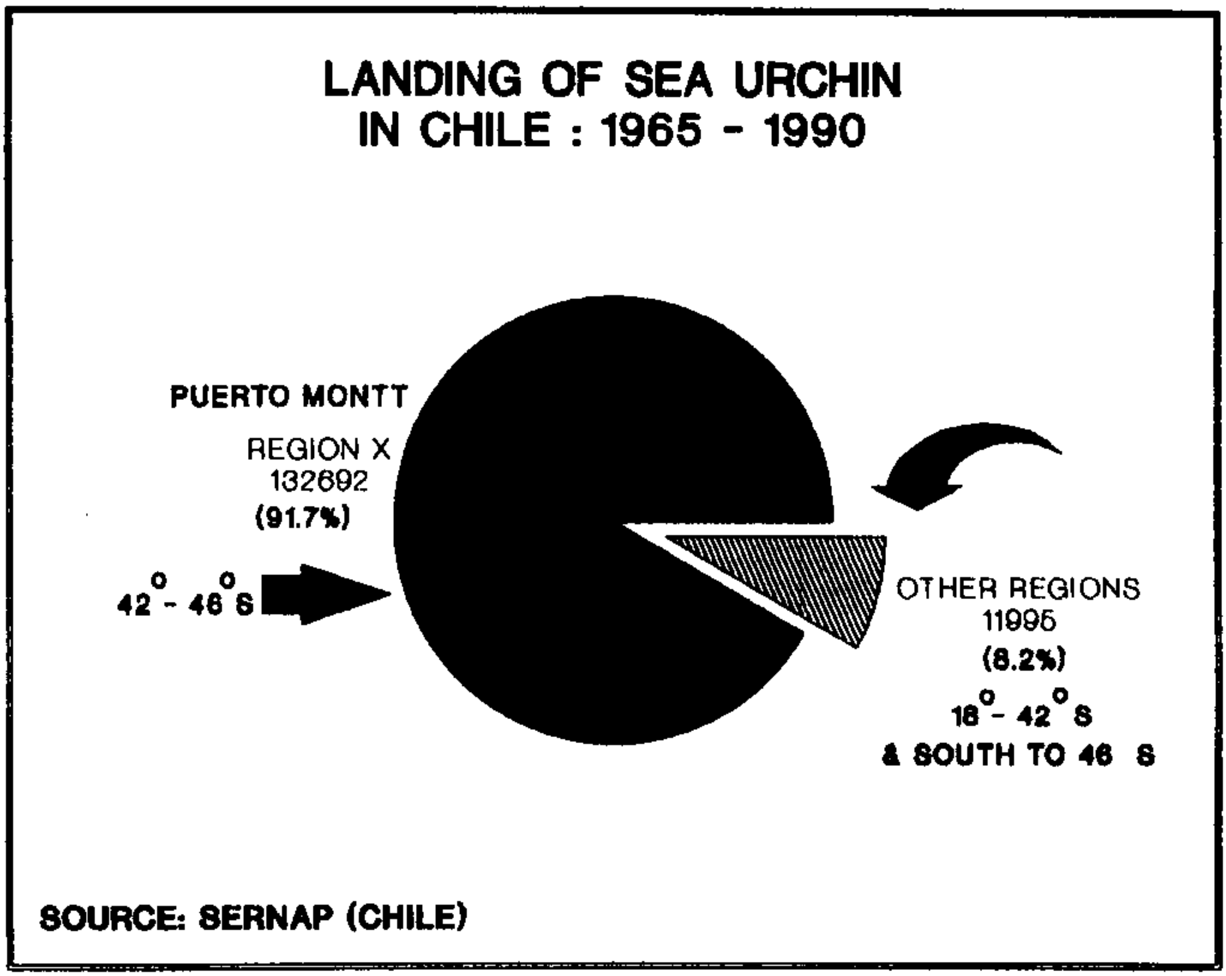
FIG. 11 Different stages involved in the culture of Loxechinus albus in Chile. (After Bustos et al., 1990).

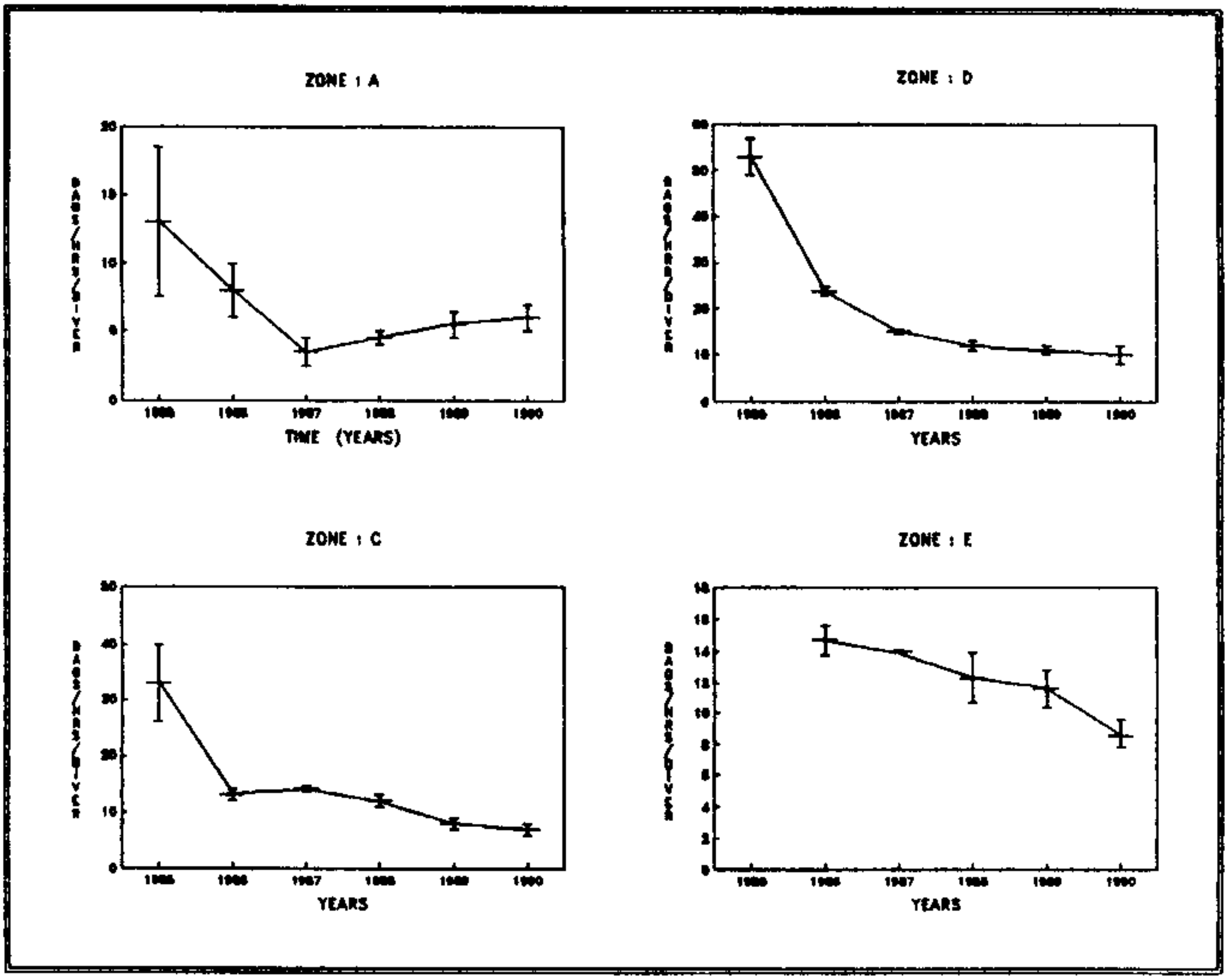

CHILE: SEA URCHIN EXPORTATION IN US DOLLARS
US $ MILLIONS
0
2
4
6
8
10
12
14
16
1970
1975
1980
1985
1990
TIME (YEARS)



LANDING OF SEA URCHIN IN CHILE
(1965 - 1990)
T
O
N
S
(x 1000)
35
30
25
20
15
10
5
0
1970
1975
1980
1985
1990
TIME (YEARS)

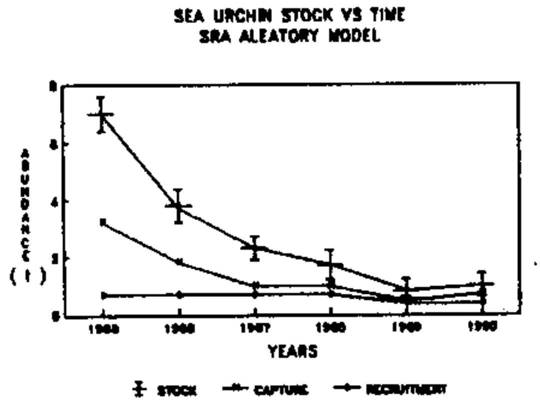

TOTAL LANDING OF SEA URCHIN IN CHILE
1965 - 1990
TONS
(x 1000)
0
5
10
15
20
25
30
35
1965
1970
1975
1980
1985
1990
TIME (YEARS)
TOTAL LANDING
REGION X
OTHER REGIONS

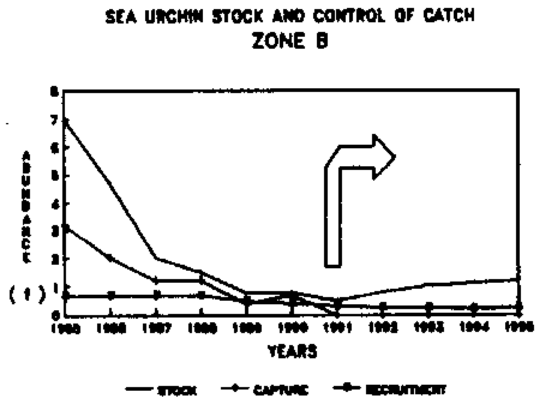

LANDING OF SEA URCHIN
IN CHILE : 1965 - 1990
PUERTO MONTT
REGION X
132692
(91.7%)
42° - 46° S
OTHER REGIONS
11995
(8.2%)
18° - 42° S
& SOUTH TO 46 S
SOURCE: SERNAP (CHILE)



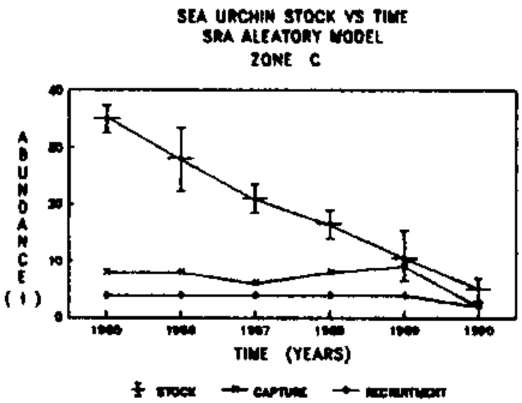
ZONE : A
BAGS/HRS/DIVER
TIME (YEARS)
ZONE : D
BAGS/HRS/DIVER
YEARS
ZONE : C
BAGS/HRS/DIVER
YEARS
ZONE : E
BAGS/HRS/DIVER
YEARS

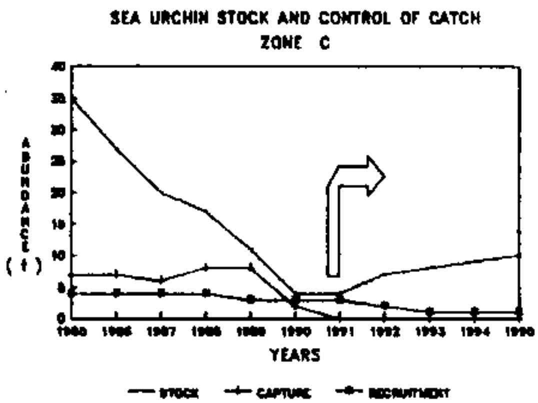
ZONE OF HIGH CATCH EFFORT

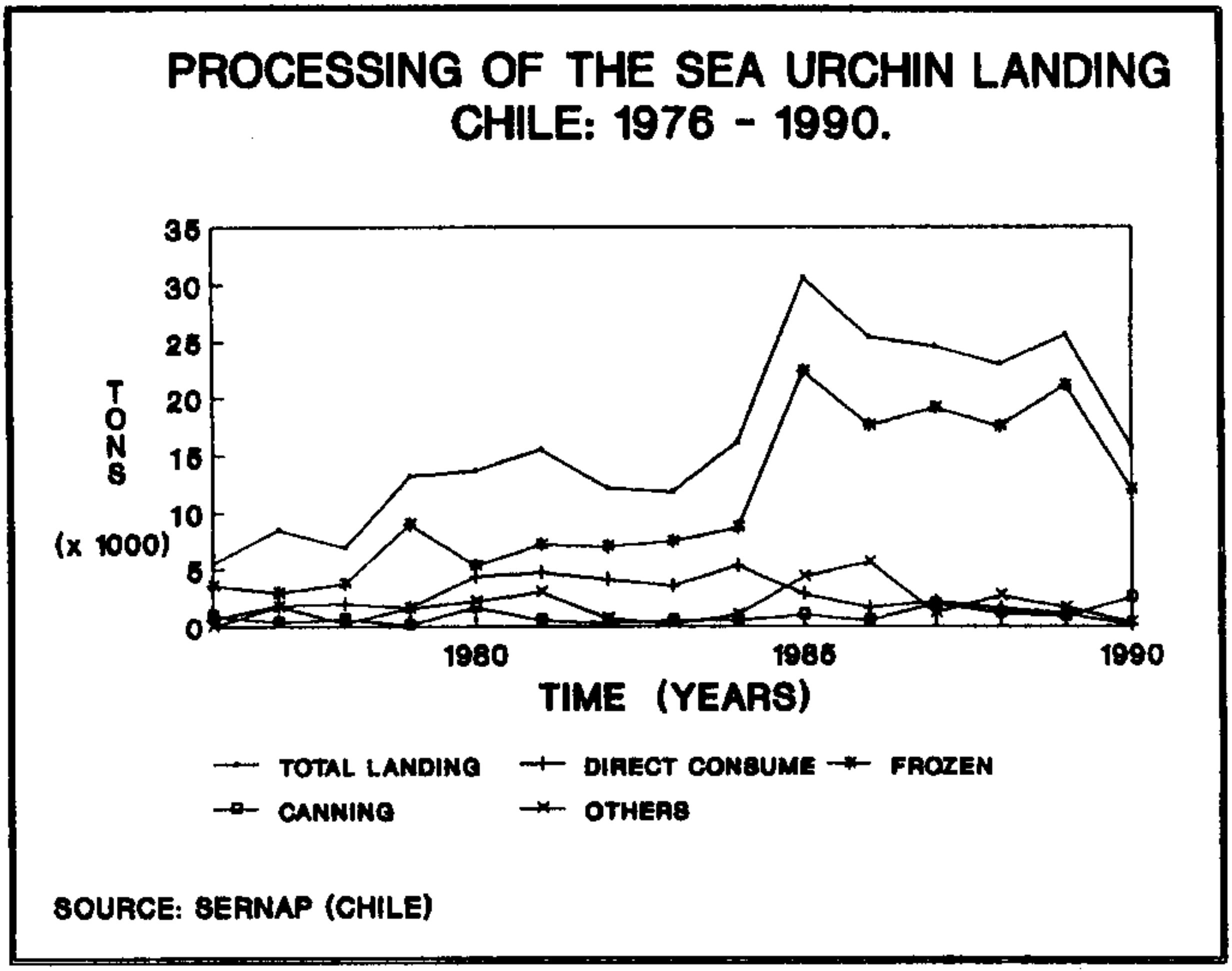


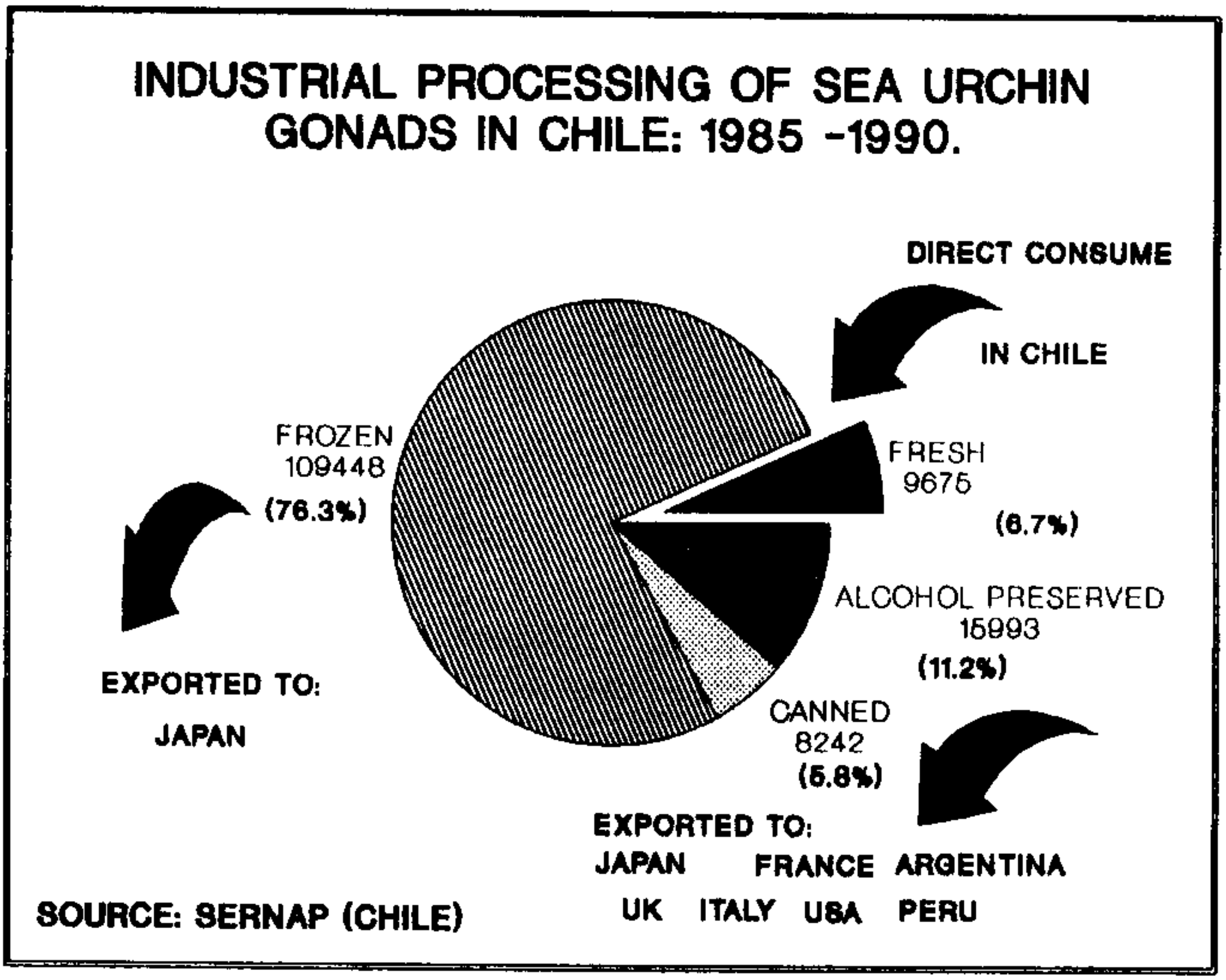


ZONE OF LOW CATCH EFFORT

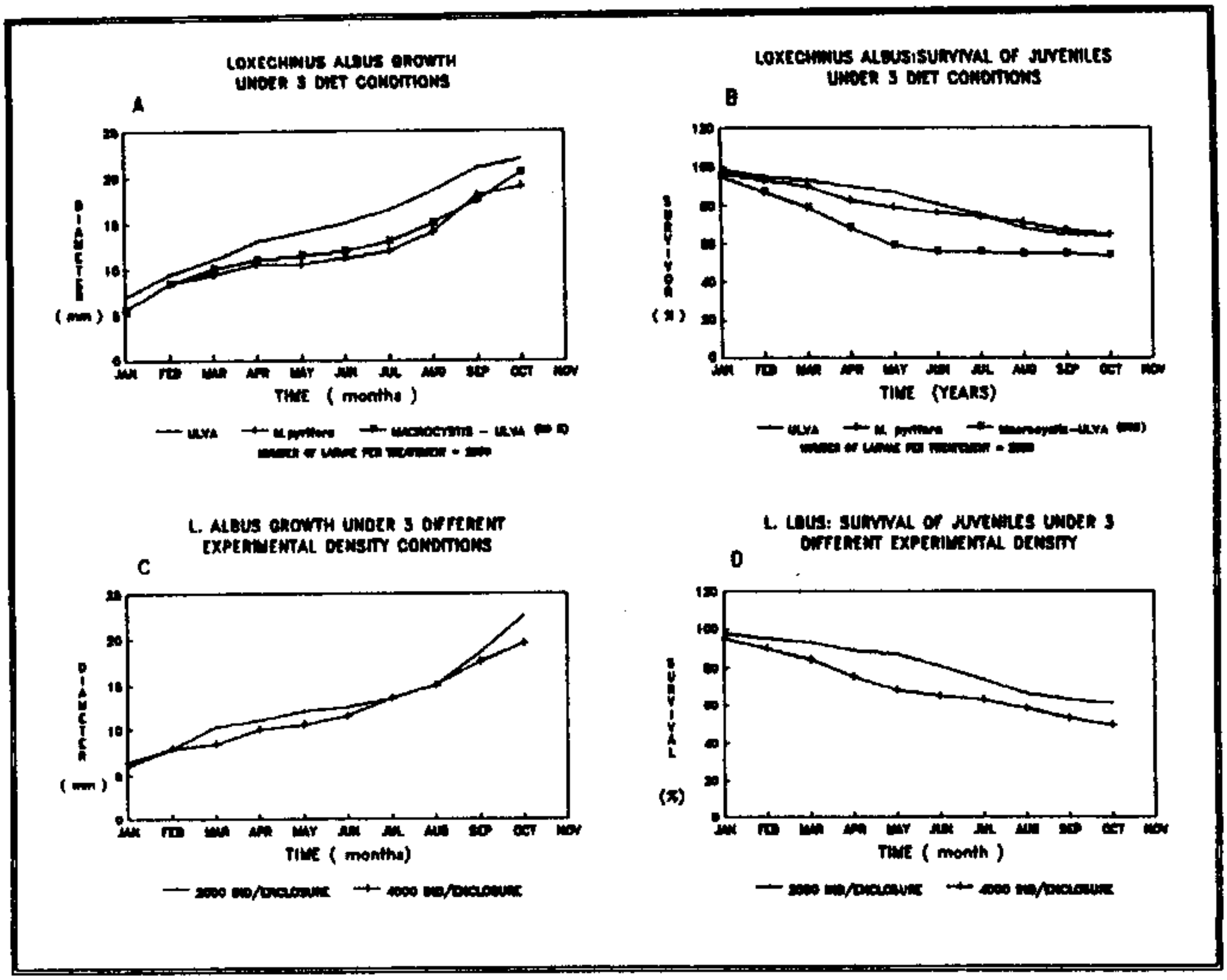


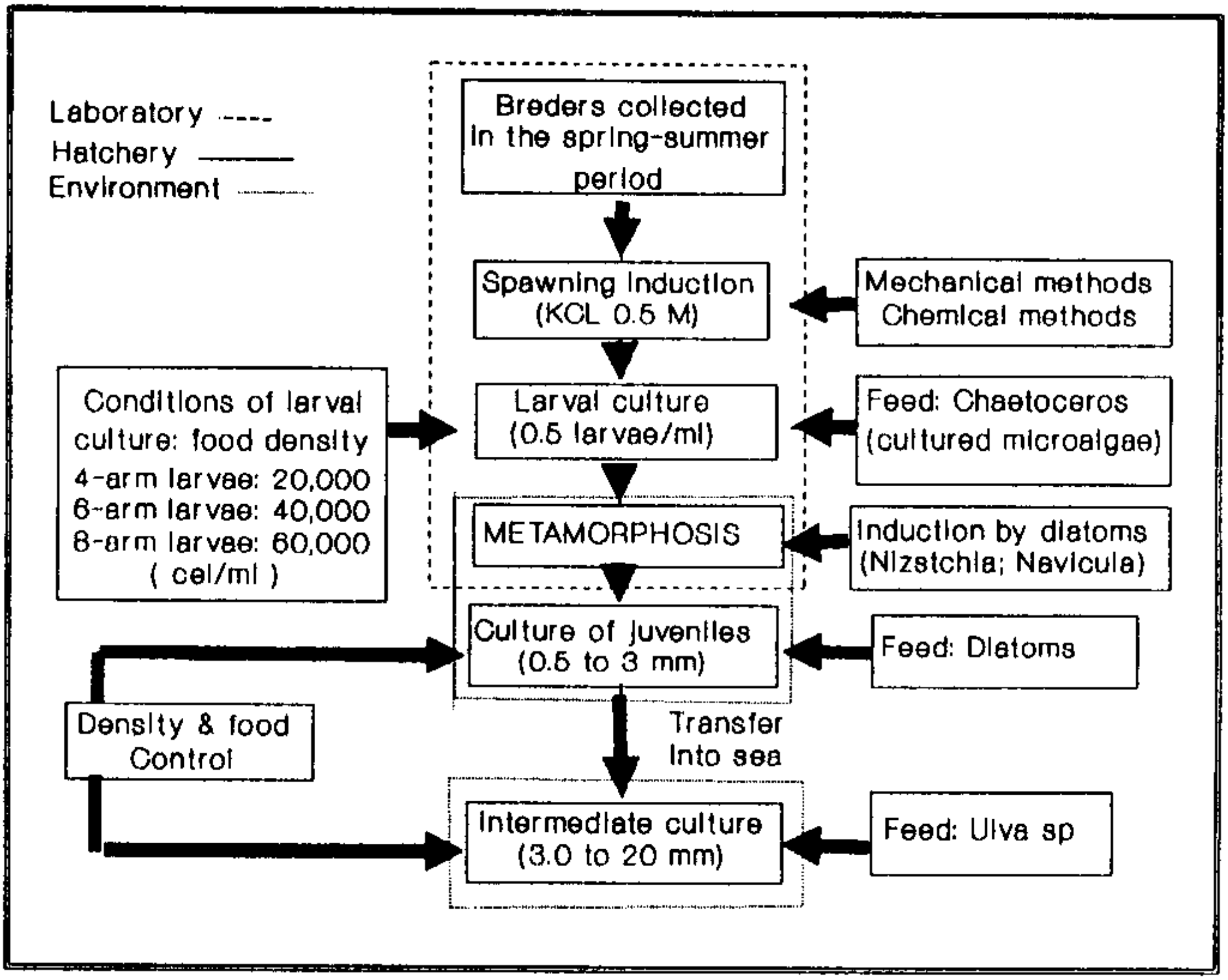



PROCESSING OF THE SEA URCHIN LANDING
CHILE: 1976 - 1990.
TONS
(x 1000)
35
30
25
20
15
10
5
0
1980
1985
1990
TIME (YEARS)
TOTAL LANDING
DIRECT CONSUME
FROZEN
CANNING
OTHERS
SOURCE: SERNAP (CHILE)



INDUSTRIAL PROCESSING OF SEA URCHIN GONADS IN CHILE: 1985 -1990.
DIRECT CONSUME
IN CHILE
FROZEN
109448
(76.3%)
FRESH
9675
(6.7%)
ALCOHOL PRESERVED
15993
(11.2%)
CANNED
8242
(5.8%)
EXPORTED TO:
JAPAN
EXPORTED TO:
JAPAN FRANCE ARGENTINA
UK ITALY USA PERU
SOURCE: SERNAP (CHILE)


LOXECHINUS ALBUS GROWTH
UNDER 3 DIET CONDITIONS
A
DIAMETER
(mm)
TIME (months)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV
ULVA
M.pyrifera
MACROCYSTIS - ULVA
LOXECHINUS ALBUS:SURVIVAL OF JUVENILES
UNDER 3 DIET CONDITIONS
B
SURVIVOR
(%)
TIME (YEARS)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV
ULVA
M. pyrifera
Macrocystis-ULVA
L. ALBUS GROWTH UNDER 3 DIFFERENT
EXPERIMENTAL DENSITY CONDITIONS
C
DIAMETER
(mm)
TIME (months)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV
2000 IND/ENCLOSURE
4000 IND/ENCLOSURE
L. LBUS: SURVIVAL OF JUVENILES UNDER 3
DIFFERENT EXPERIMENTAL DENSITY
D
SURVIVAL
(%)
TIME (month)
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV
2000 IND/ENCLOSURE
4000 IND/ENCLOSURE



Laboratory ----
Hatchery ———
Environment ....
Breders collected in the spring-summer period
Spawning induction (KCL 0.5 M)
Mechanical methods Chemical methods
Conditions of larval culture: food density
4-arm larvae: 20,000
6-arm larvae: 40,000
8-arm larvae: 60,000
(cel/ml)
Larval culture (0.5 larvae/ml)
Feed: Chaetoceros (cultured microalgae)
METAMORPHOSIS
Induction by diatoms (Nizstchia; Navicula)
Culture of juveniles (0.5 to 3 mm)
Feed: Diatoms
Density & food Control
Transfer into sea
Intermediate culture (3.0 to 20 mm)
Feed: Ulva sp

SEA URCHIN - KELP INTERACTIONS IN CHILE: A REVIEW

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CASILLA 117 COQUIMBO - CHILE

INTRODUCTION

Shallow, subtidal rocky-bottom areas in warm and cold temperate seas are dominated by large brown algal associations . Algae of the orders Laminariales and Fucales, forming extensive kelp forests, dominate cover and biomass to a depth of 25-30 m in the Northern and Southern Hemispheres. These kelp forest provide the habitat for many invertebrates and fishes, and is one of the major factors in their distribution and abundance. Large brown algae also provide areas for spawning and larval settlement where exposure to water movement and predation is reduced.

Comparatively with the evidence emerged from the Northern Hemisphere, the Southwestern Pacific and specifically subtidal communities of Chile have received less attention. Some studies have been concentrated in the southern part of Chile, generally contemplating accurate descriptions of the structure of subtidal communities dominated by Macrocystis pyrifera. Exceptions to the above constitute the experimental manipulations of sea urchin densities in southern Chile, and the exclusion of the canopy of dominate algae in Valdivia, and in the Beagle Channel. On the other hand, experimental studies has been conducted in central and northern Chile in subtidal rocky bottom dominated by Lessonia trabeculata.

Kelp communities appear unique among the world's macro plant communities because almost all the plant can be heavily grazed by one type of herbivore: sea urchin. Not all species of sea urchin have this potencial but in most temperate areas at least one specie does.

This paper review the evidences of the literature on the sea urchins - kelp interactions along the Chilean coast. I discuss and compare the evidence emerged from northern and southern Chile kelp communities on the following topics: sea urchin diversity and distribution, predator-sea urchin interactions and relevant biological and physical factors in the structure of these South American kelp communities. I also contrast these results with the evidence emerged from the northern Hemisphere kelp communities.

DIVERSITY AND DISTRIBUTION OF THE SEA URCHIN ASSOCIATED WITH KELP FORESTS ALONG THE CHILEAN COAST

Seven genera with fiftheen sea urchin species has been described habiting the Chilean coast. Five of these sea urchin species are associated with kelp communities. Tetrapygus niger (Molina) and Loxechinus albus (Molina), two simpatric species, are associated to Lessonia spp and Macrocystis intergrifolia kelp forest in subtidal and intertidal areas between 18° and 42° S. Loxechinus albus is the most conspicuous sea urchin in the fjord zone (south to 42° S), where Macrocystis pyrifera is the dominant kelp specie. Beside, in coastal kelp forest at Isla Navarino in the

Beagle Channel *Loxechinus albus*, *Arbacia dufresnei* (Blainville), *Pseudechinus magellanicus* (Philippi), *Austrocidaris canaliculata* (Agassiz) coexist in areas dominated by *M. pyrifera*.

NORTHERN AND CENTAL CHILE KELP COMMUNITIES

In northern and central Chile (18° - 42° S) *Lessonia trabeculata* Villouta & Santelices forms extensive subtidal kelp beds on rocky bottoms in areas exposed and semiexposed to heavy surge. This is the type of subtidal habitat most commonly found along this portion of the chilean coast and therefore, this species is the most important kelp in this area.

In the communities dominated by *Lessonia trabeculata* the abundance, distributional patterns and diets of the most conspicuous organisms associated with *L. trabeculata* were studied. The organisms included were selected due to their direct (benthic herbivores) or indirect (benthic predators and carnivorous fishes) relationships with the stability of the *L. trabeculata* kelp forest in northern Chile. The black sea urchin *Tetrapygus niger* and the gastropd snail *Tegula tridentata* were the benthic herbivores considered. The sea star *Meyenaster gelatinosus* and three carnivorous fishes (*Cheilodactylus variegatus*, *Mugiloides chilensis* and *Semicossiphus maculatus*) were evaluated as the most abundant predators.

The benthic herbivores, Tetrapygus niger and Tegula tridentata are most the abundant and frequently found in Lessonia trabeculata kelp beds at Playa El Francés, northern Chile. Tetrapygus niger is discontinuously distributed throughout the kelp bed forming patchess on stable rocky bottom. The distributional patterns of this sea urchin are correlated with the abundance and distributional fluctuations of Meyenaster gelatinosus. Adult specimens of T. niger comprise 43.3% of the diet of this sea star. The registered average sizes of T. niger indicated that the population at Playa El Francés is mainly formed by adults. During the study period, sea urchin recruitment was not recorded. The analysis of gut contents of T. niger, shows that crustose calcareous algae are the most frequent and abundant food item in the diet of this herbivore.

Tetrapygus niger forms high density groups ("fronts") in areas with strong water movement (bottom and coastal currents). The causes behind sea urchin fronts formation have been seldom studied in subtidal macroalgae communities. The front formed mainly by strongylocentroid individuals, has been postulated as the principal factor generating the destruction of kelp beds, stated that the sea urchin fronts are the result of defense mechanism again predators. Nevertheless, Vadas et al. (1986), have demonstrated those results are product of their experimental design and that the sea urchin grouping is produced by food concentration. Is was proposed that drifting algae constitute an important food resource and its abundance and predictability release the benthic macroalgae from grazing pressure. Apparently the sea urchins of the Northern Hemisphere have morphological adaptations that allow them to capture and incorporate this resource in its diet. However, in the Southern Hemisphere Tetrapygus niger, the most abundant sea urchin in rocky subtidal communities in northern and central Chile, is unable to use drifting algae as a significant food item. Analyzing the morphology of the podiums we have been demonstrated that these structures are not efficient to capture drifting algae. In this context, this morphological deficiency can be supplemented in part by the grouping of these organisms. Consequently the formation of high density groups of T. niger in zones with strong bottom currents should increase the probability of retaining drifting algae material among the sea urchin spines. Therefore the results of this study support the results obtained by Vadas et al. (1986), in the explanation of the formation of sea urchin groups. However, even though groups of sea urchins appear to respond in a certain degree to trophic necessities in both hemispheres, these evidence suggest that the principal inductor of T. niger grouping in subtidal kelp beds of Lessonia trabeculata are the bottom coastal currents.

On the other hand, the sea urchin aggregations in northern Chilean waters are in opposition to the results obtained in shallow coastal areas in the Northern Hemisphere. In these environments, strong water movement produces high sea urchin mortalities. Is was demonstrated that the exposure to intense water movement diminishes the abundance and modifies the sea urchin trophic behavior. Besides, the wave impact and coastal currents can limit the pasturing activity and significantly affect the annual rate of survival and the body size of many sea urchin species.

In subtidal kelp beds of L. trabeculata, the grouping of sea urchins in areas with high water movement intensity contribute to reduce the grazing pressure in areas with less water movement, favoring the settlement propagation. Consequently, where high black urchin concentrations are produced the vegetation coverage is drastically reduced generating patches dominated exclusively by crustose calcareous algae.

Even though the intensity of water movement promotes the grouping of T. niger, in contrast to the documented proof for other types of sea urchins in the Northern Hemisphere the cumulative effect of the phenomena appears to have similar ecological consequences. Therefore, the reduction of benthic grazers (due to migration or mortality) in subtidal areas, or the decreasing of sea urchin grazing abilities due to water movement, have significant effects in hard bottom benthic communities. In this way, the effect of water movement (waves and currents) can generate temporal and spatial grazing refuges, allowing the settlement and growth of macroalgal propagules.

The effect of predators upon populations herbivores associated with subtidal kelp communities of macroalgae has been profusely documented. Sea otters , fishes , sea stars and lobsters have received special attention as natural controllers of population densities and diets of Strongylocentroides in Northern Hemisphere.

In northern Chile, one star fish Meyenaster gelatinosus, and three carnivorous fish Mugiloides chilensis, Cheilodactylus variegatus and Semicossyphus maculatus, are the most important predators in the community dominated by L. trabeculata. All the carnivores mentionated above include T. niger and T. tridentata in their diets. In this way, these species would have an additive effect in the regulation of the main herbivorous associated with L. trabeculata. M. gelatinosus preys on adult T. niger, whereas, the dimensions of the oral structures of carnivorous fishes restrict them to ingest small size preys. This is evident for M. chilensis and Ch. variegatus, where the maximum sizes of T. niger in their gut contents do not exceed 20 mm of test diameter. Considering the abundance of carnivorous fish the selective predation of these organisms on small size preys could explain the absence of juveniles of T. niger in the studied area.

A number of factors have been reported to be determinant on the abundance, distribution, physiology and reproduction of benthic marine algae . Among physical factors, water motion is of particular importance in the morphological expression and distribution of benthic macroalgae. On the other hand, herbivory is the main biological factor affecting their abundance and distribution.

Despite possible interrelations between physical and biological factors, the general trends of the experimental ecological studies with few exception, has been to consider them as two independent forces. In this context, herbivory, water motion and spacing between plants, have been analized as independent structural factors that act on intertidal macroalgal populations.

Experimental studies conducted in northern Chile show that benthic herbivores, sea urchins and gastropods snails, modify algal morphology, producing two morph: plants that grow in the absence of herbivores with numerous flexible stipes ("bushy form"), and plants in the presence of grazers, with one or few stipes of little flexibility ("arborescent form"). Water motion (bottom surges) generates selective mortality which affects significatively the arborescent form.

In land environment, high densities of plants have low rates of growth, reproduction and survivorship as compared to plants growing in similar environments but with low population density. In this context, the evidences for marine macroalgae are divergent. Ecklonia radiata and Sargassum sinclairii reach a larger size when they are part of dense population in semi-exposed environments. Is was suggested that plant gregariousness decreases the mortality produced by water movement. As has been found that mortality and growth rates of juveniles of Egregia laevigata are density-dependent, at least during the first three months of age of these plants. Is was suggested that distance between adult plants of Lessonia nigrescens is a critical factor in the recruitment of juveniles at intertidal habitats of central Chile. In subtidal bottom kelp forest of Lessonia trabeculata in northern Chile, the distance between plants (high densities) is a mechanism that favor the persistence of the Lessonia stand, primarely reducing herbivory (increasing the whiplash effect of the fronds) and secondarely reducing the dredging effect of the bottom surges.

Another seasonal but very important factor in the structure of bottom kelp forest in northern Chile is the use of L. trabeculata as the substrate for the settlement of elasmobranch fish egg capsules. This events generates high rates of mortality in adult plants during summer months. Notwithstanding, this reproductive behavior facilitates the settlement of propagules and the growth of juveniles of L. trabeculata, through the reduction of intraspecific interaction with parental plants.

SOUTHERN CHILE KELP COMMUNITIES

The most conspicuous kelp association are those formed by the giant kelp Macrocystis pyrifera, whose geographical distribution in the Pacific Ocean includes the west coast of North America and southern Chile. In contrast with the situation in the north Pacific, few ecological works have been done in giant kelp forest from southern South America. These works has been focused in: 1) The influence of the sea urchins on the distribution and abundance of M. pyrifera 2) Population dynamics and community structure of M. pyrifera and 3) Regulation patterns of sea urchin populations.

In the kelp forests of Isla Navarino, were tested the effects of three sets of ecological factors in the distribution and organization of the M. pyrifera populations: 1) the possibility of competitive exclusion of Macrocystis by Lessonia vadosa by removing specimens of L. vadosa at the upper side of the giant kelp forest. 2) by transplanting plant they examined whether plants could survive and grow in deeper water and adequate substratum. 3) By removal of the floating canopy of adult Macrocystis they investigated the interspecific interference on density and distributional patterns of M. pyrifera.

Field observation and experimental work carried out at Isla Navarino indicate that different factors are important at different part of the bed in the determination of population structure and distributional patterns of Macrocystis. These authors pointed out that the nearshore edge of the belt appears to be set by interspecific competition with Lessonia vadosa. Experimental results indicate than even though M. pyrifera could recruit under L. vadosa canopy, densities as well as growth rates are more reduced than in absence of L. vadosa. If L. vadosa is removed, the Macrocystis belt could extent 1 to 2 m further into shallower water. However, these experimental data provide no information to evaluate the factors restricting L. vadosa to shallower waters.

The deeper end of the Macrocystis pyrifera bed in the Puerto Toro area appears primarily set by substratum availability. However, during winter, decreased ligth intensities and temperatures are perhaps limiting for apical elongation, while increased storminess resulted in increased thallus detachment in transplanting experiments. Field observation further indicated that under extended substratum availability interspecific competition between M. pyrifera and Lessonia flavicans, could be expected. In the few areas with solid substratum extending into deeper waters, seemingly monospecific stands of L. flavicans often seems to limit the seaward extent of M. pyrifera sharply.

In the coastal kelp forest of Macrocystis pyrifera at Puerto Toro, in the Beagle Channal there are four species of sea urchins: Loxechinus albus (Molina), Arbacia dufresnei (Blainville), Pseudechinus magellanicus (Philippi), Austrocidaris canaliculata

(Agassiz). We studied the distributional patterns and diets of all four species, suggesting coexistence of these 4 sea urchin species with clear separation of the microhabitat used and the diet consumed by them. The localization of the sea urchin species was noted in relation to 4 types of microhabitat defined as: on boulders, in holdfasts of Macrocystis plants, under boulders and crevises. The gut content analysis provided the diets of all four species. The number of observation and the probavility of ocurrence of each species of sea urchin in each of the four microhabitat categories showed that Pseudechinus and Austrocidaris were found in the 4 microhabitat categories but with diferent probabilities. Pseudechinus occurs more frequently inside the holdfast of Macrocystis pyrifera, while Austrocidaris is more frequently found under boulders. Loxechinus was commonly found on boulders, less frequently found in rock crevasses or under boulders and never found inside the holdfast of Macrocystis pyrifera.

The abundance of the different food item found in the gut content analysis of the four species of sea urchin indicated that Loxechinus had the most diversified diet of benthic algae, Macrocystis being the most frequent item. Pseudechinus consumed mainly Macrocystis, whereas Austrocidaris and Arbacia contained others frondose benthic algae and sessile invertebrates; Arbacia was particularly notable with over 50% of the gut content being serpulid and barnacles.

If the gut contents obtained in the four sea urchin species are grouped according to their nature, it is possible to distinguish 4 group of food: (a) Macrocystis pyrifera fronds, wich are the commonest food; (b) other frondose algae (mainly Gigartina skottosbergii, Halopteris hordacea, Lessonia spp., Epymenia falklandica); (c) calcareous algae (crustose coralline); and (d) invertebrates (barnacles, serpulids, sponges). These four categories together with the 4 microhabitat considered was used as axes to characterize the utilization of these items by the 4 species of sea urchin graphically. Not a single pair of species of sea urchin has a complete overlap. The greatest overall similarity is shown by Pseudechinus magellanicus and Austrocidaris canaliculata. However, both species have a significantly different utilization of holdfast of Macrocystis.

The results of measurements of microhabitat used by these species of sea urchin indicate that with the exception of Pseudechinus and Austrocidaris there is low overlap in microhabitat used by them. Pseudechinus and Austrocidaris share a diversity of rather cryptic microhabitat such as crevices, under boulders and holdfasts of Macrocystis pyrifera. Nevertheless, even though they have a high overlap, they show some segregation, thus Austrocidaris was more frequently found in crevices and under boulders while Pseudechinus ocurred mostly in holdfast of Macrocystis.

The results on the gut contents indicate that the four species include fronds of Macrocystis in their diets, showing a high degree of overlap among several pairs of species. Nevertheless. 3 species: Loxechinus, Arbacia and Austrocidaris consumed other species of algae (frondose and calcareous) and one of them, Arbacia, consumed mainly invertebrates. Furthermore, according to a related experimental study performed in this Macrocystis bed, the fronds of M. pyrifera, the main food item in 3 of the sea urchin species, do not appear as a limiting resource. Is was showed Loxechinus albus , one of the most conspicuous sea urchin in the belt, to be consuming mainly pieces of drifting fronds and having no significant effect on the recruitment or survival of juvenile Macrocystis. In addition, is was showed that the pattern of recruitment of M. pyrifera is determinated mainly by the presence of adult canopy rather than by grazers.

Througth a broad geographical survey between 44° and 52° S along southern Chile and Argentina coast, Dayton (1985) pointed out that the distribution and abundance of Macrocystis is determined by: availability of suitable rocky substratum; the interspecific competition with Lessonia vadosa (shallow waters) and with L. flavicans (deeper waters); the entanglement with drift algae and the heavy settlement of bivalves on the kelp fronds; the degree of exposure to waves; the grazing of the echinoid Loxechinus albus and indirectly, the effects of human fishing of Loxechinus. These author documented that in many areas between 44° - 52° S, Macrocystis is overgrazing by Loxechinus albus. In other areas Loxechinus exist in lower densities or is absent altogether and does not affect the Macrocystis population.

The Loxechinus foraging behaviour is influenced mainly by the degree of wave surge and by hunger, as is seen for Strongylocentrotus spp. As Dayton (1985) indicated Loxechinus was often observed to restrict its ambit in areas exposed to severe wave action. The importance of hunger is also well know to influence the behaviour of sea urchin and eventually the formation of the sea urchin grazing fronts irrespective of density. With regard to hunger, there was a considerable amount of drift algae in all the areas where there large kelp forests In these areas Loxechinus was commonly seen but usually was not very abundant, and it was clear that they did not farage far for food . In most of the protected areas, there was a great deal of drift, and Loxechinus often was rare . In most other areas where the Loxechinus were abundant, they forage activaly.

There are very few evidence related with the regulation of the sea urchin population density in southern Soudamerica. Dayton (1985) hypothesized that low larval availability is an important factor related to the relative low Tierra del Fuego Loxechinus population. These habitats are influenced by the circumpolar Westwind Drift current, and the only source of Loxechinus larvae is from the Cape Horn Archipielago. Assuming that Loxechinus larvae are similar to other echinoids in spending four or more weeks in the plankton, the Westwind Drift would carry most of the larvae away, and the only recruitment into these habitats would come from eddies or areas where larvae are trapped.

There is no single, efficient sea urchin predator in the Macrocystis pyrifera kelp communities of southern Chile. Apparently the most conspicuous predators of sea urchin are two species of asteroids: Meyenaster gelatinosus which occurred in abundance only north of Golfo de Penas and Cosmasterias lurida which is the main top predator found in coastal belts of Macrocystis at Puerto Toro in southern Chile.

As has been documented by Dayton et al. (1977), Loxechinus has effective defense behaviors, and Meyenaster only reduces Loxechinus densities on isolated boulders from which the urchins can be stampeded without inmmediate immigration. When the boulders are sufficiently isolated and large, this stampeding phenomenon can result in Macrocystis being released from Loxechinus predation long enough to recruit and survive to reproduce.

The diet of Cosmasterias lurida, include 25 prey items being Balanus sp. (28 %) and Crepipatella dilatata (20 %) the most frequent food items in their everted stomach. Loxechinus and the other sea urchin species were very rare and were detected twice in the 246 in situ analized individuals. In summary, as has been pointed out by many authors, these South Amarican kelp communities do not seem to have predators capable of controlling sea urchin populations.

CONCLUSION

The result of several investigation in Southern South America suggest that the sea urchin herbivory is not an important structuring factor of kelp communities. Is was documented the absence of large and abundant grazing echinoid population along the Chubut coast of Argentina. Three species of echinoids occurred in this area but individuals were too small an not in sufficient number to intensively graze. Likewise, Dayton (1985) found kelp forest where sea urchins do not actively graze at southern Isla de Los Estados and Tierra del Fuego in southern Argentina, and we found similar situation in the kelp forests of Isla Navarino, southern Chile where algal species were apparently regulated by interspecific competition and substrate availability. This was comfirmed experimentally by Castilla & Moreno (1982), who artificially enhanced the densities of four species of echinoids in artificial enclosures in the same kelp forest.

The situation described above would be rather different north to 42° S where Macrocystis is not the dominant kelp species. In this subtidal shallow rocky communities, Tetrapygus niger is the most abundant sea urchin. Dense population of this specie impede the settling of macroalgae propagules and maintain extensive barren grounds. As has been discussed previously, in areas dominated by the subsurface Lessonia trabeculata kelp forest the ecological impact of T. niger seems not to be all or none, as has been reported for Northern Hemisphere kelp communities. Tetrapygus modifies algal morphology and produce two morphotipes that are different affected by bottom surges. These morphological modification have relevant consequences for the persistence of L. trabeculata populations.

Although the carnivores gut content analysis does not allow inference regarding the regulation of their prey population, the results suggest that the herbivores abundance conspicuously associated with kelp forests along the chilean coast are affected by the predation of a carnivorous guild. This differs from that proposed for subtidal kelp beds of Northern Hemisphere, where one key predator regulates the population density of its prey items. Nevertheless, the evidence presented by Foster & Schiel (1988) strongly indicates that the concept of sea otter as a keystone species is applicable only a relative small number of sites thus does not constitute a general explanation of kelp community structure in California.

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Sea Urchin Fishery of Japan

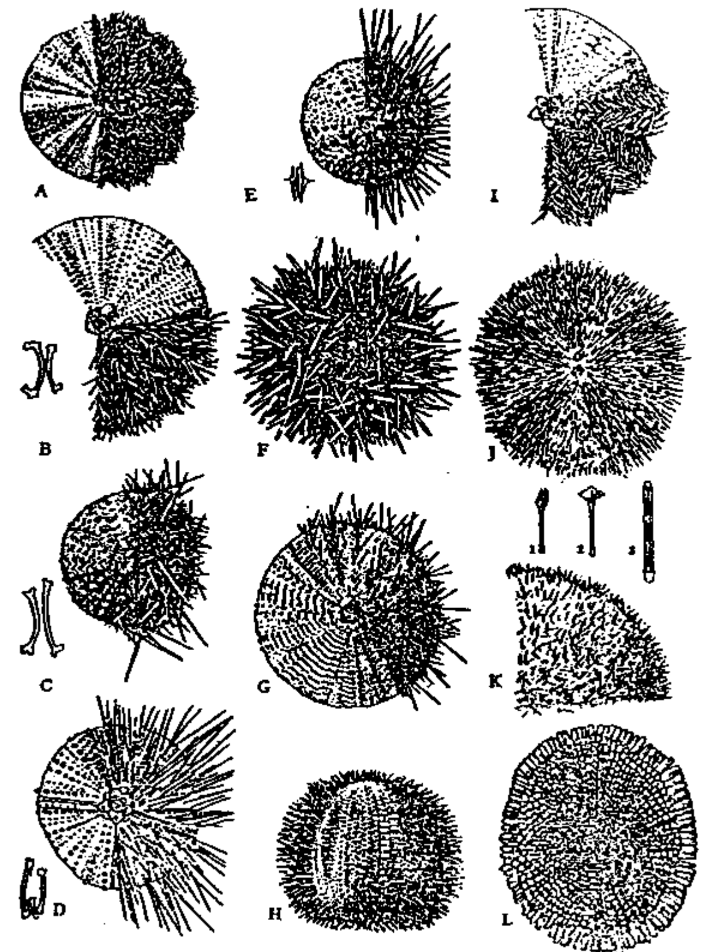
Katsuo Saito

(Hokkaido Hakodate Fisheries Experimental Station)

It is known that the Japanese have been eating sea urchin ever since the prehistoricera.(ruins, shell mounds) The written records can go back to 718 A.C., which is described in "Yourou Ritsurei". Sea urchin in English implies "Sea Hedgehog". Sea urchin in Japanese is written as "Sea Chestnut". Both manifest its figure.

Estable sea urchin is widely distributed all around Japan. *Strongylocentrotus intermedus* and *St. nudus* represent the northern species. *Tripneustes gratilla* and *Psudocentrotus depressus* represent the southern species. *St. pulcherriumus* and *Anthocidaris crassispina* come in-between. Aside from then, there are 10 other catable species which amount to a small quantity (Figure 1). The 6 species described before are industrially important.

The catch in weight (weight with shell) for 10 years from 1980 to 1989 is shown in Table 1. In this past 10 years, the maximum fishing catch is about 26,000 tons in 1982. The minimum is about 20,400 tons in 1989. The catch in recent years tends to decline. As shown in Figure 2, the coast line of Japan is diveded into 8 zones. Hokkaido zone holds 44.2 % supplying 10,351.5 tons on average. Next comes Eart China Sea zone which holds 22.4 % supplying 5,235.9 tons. Northern Pacific Ocean zone holds 21 % supplying 4,929.9 tons. These 3 zones take up 87.6 %. The average value of the former 5 years and the latter 5 years is taken and compared (Table 2). In nation wide, there is 10 % decrease. In zonal respect, only southern Pacific and northern Sea of Japan show increase. Hokkaido zone shows only 0.5 % increase. Other zones are decreasing. The Sea of Japan zone, especially, decreased 40 %.



A *Strongylocentrotus pulcherrimus* (A. Agassiz) バフンウニ
B *Strongylocentrotus intermedius* (A. Agassiz) エゾバフンウニ
C *Strongylocentrotus nudus* (A. Agassiz) キタムラサキウニ
D *Strongylocentrotus franciscanus* (A. Agassiz) ハリナガオオバフンウニ
E *Anthocidaris crassispina* (A. Agassiz) ムラサキウニ
F *Pseudocentrotus depressus* (A. Agassiz) アカウニ
G *Temnopleurus toreumaticus* (Leske) サンショウウニ
H *Mespilia globulus* (Linné) コシダカウニ
I *Tripneustes gratilla* (Linné) シラヒゲウニ
J *Pseudoboletia maculata* (Troschel) マダラウニ
K *Toxopneustes pileolus* (Lamarck) ラッパウニ
L *Colobocentrotus mertensii* (Brandt) ジンガサウニ

Figure 1 Distribution of Eatable Sea Urchin in Japan (Matsui 1966)

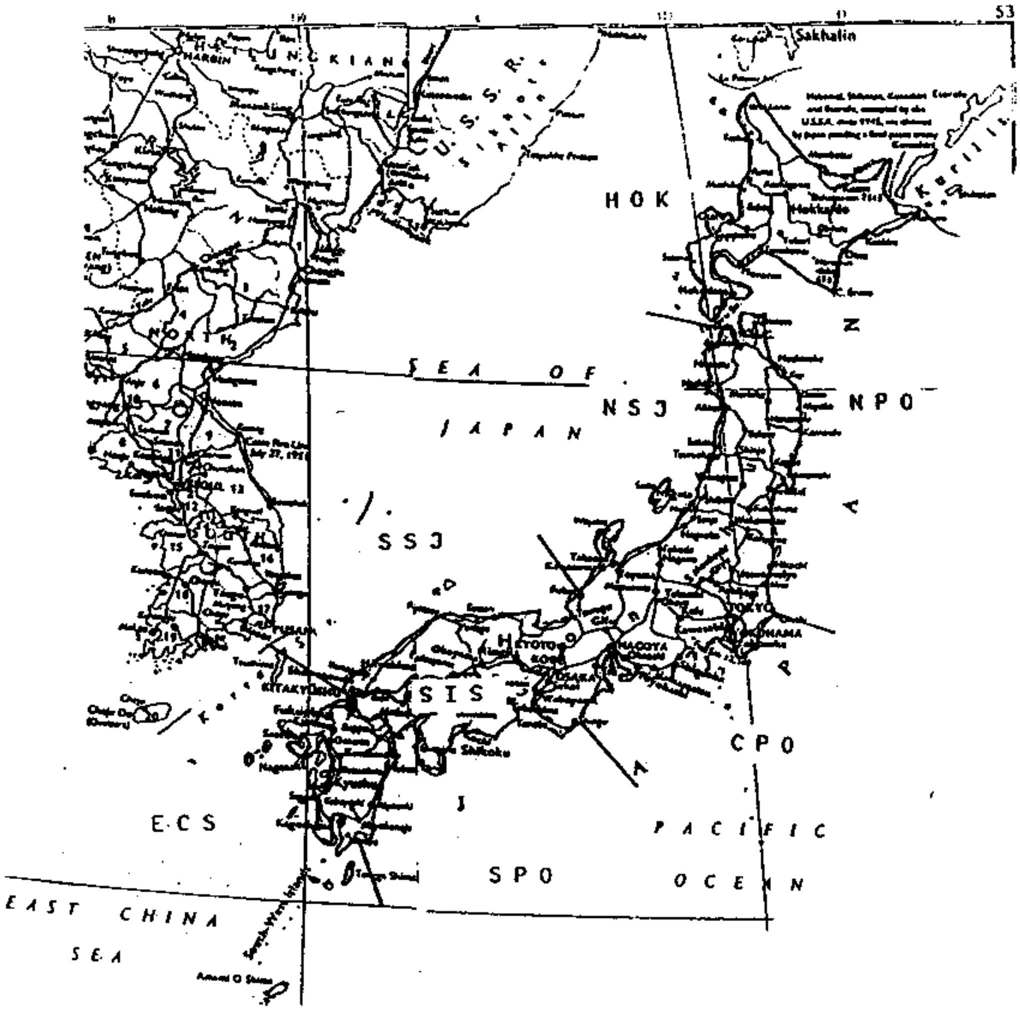


Figure 2 Map of Japan (8 zones)

HOK: Hokkaido
NPO: Northern Pacific Ocean
CPO: Central Pacific Ocean
SPO: Southern Pacific Ocean
NSJ: Northern Sea of Japan
SSJ: Southern Sea of Japan
ECS: East China Sea
SIS: Seto Inland Sea

Table 1 The Catch in Weight (weight with shell) for 10 years from 1980 t0 1989 in Japan (ton).

Year	Total	HOK	NPO	CPO	SPO	NSJ	SSJ	ECS	SIS	Ratio of Hokkaido(%)
1980	24,158	10,866	4,317	32	855	4	1,291	5,944	849	44.98
1981	23,984	9,517	5,395	39	867	17	1,420	5,993	736	39.68
1982	25,975	10,639	6,954	22	636	61	1,269	5,558	837	40.96
1983	25,254	10,589	5,668	22	900	68	1,335	5,720	952	41.93
1984	23,962	10,017	3,875	18	941	106	1,447	6,773	785	41.80
1985	22,745	10,094	4,905	19	928	148	985	5,085	581	44.38
1986	23,072	10,655	4,600	18	1,092	223	879	5,029	576	46.18
1987	22,760	10,753	5,176	21	937	225	679	4,450	519	47.25
1988	21,812	10,955	4,234	18	1,318	245	687	3,775	580	50.22
1989	20,414	9,430	4,175	8	1,193	298	806	4,032	472	46.19
$\overline{X}$	23,414	10,352	4,930	22	967	140	1,080	5,236	689	44.36

HOK: Hokkaido NPO: Northern Pacific Ocean CPO: Central Pacific Ocean
SPO: Southern Pacific Ocean NSJ: Northern Sea of Japan SSJ: Southern Sea of Japan
ECS: East China Sea SIS: Seto Inland Sea

Although the catch in weight tends to decrease, the Japanese continue to favour sea urchin strongly. Sea urchin therefore is imported fror abroad. The change in the amount of sea urchin import is shown in Table 3. In 1982, 2,400 tons had been imported. In 1987, 3,700 tons had been imported. If the amount of the imported is converted into the weight with shell, as we always measure our catch, the amount of the imported sea urchin goes over our total national productivity.

In 1988, 3,400 tons were imported. Fresh seaurchin counted 2,640 tons ; frozen, 760 tons. The expoting countries are indicated in Table 4. With respect to fresh seaurchin, U.S.A. exports 1,305 tons taking up 49.4 %. Korea comes next exporting 848 tons and taking up 32.1 %. With respect to frozen sea urchin, U.S.A. exports 432 tons, 56.8 % ; Chili, 179 tons, 23.6 %.

It is considered that in Japan approximately 45,000 to 50,000 tons of sea urchin are consumed as in fresh state like "SASHIMI," "SUSHI," "SEA URCHIN RICE" and impreserve state like "KNEADED SEA URCHIN," "BOTTLED SEA URCHIN," "SALT SEA URCHIN,". Among the "BOTTLED SEA URCHIN," sea urchin which is in the state much more close to fresh state is recently apprecieate. "OVERNIGHT SOAKED" is becoming very popular.

Sea urchin is thus favored by the Japanese. Let me touch upon the countermove of mariculture concerning sea urchin resource. The important but old technique of fishery resource management rests upon fishery adustment amonung the prefectures. Let me take Hokkaido as an example. The period of fishery prohibition is decided according to the state of apawning. The seed that can be fished is regulated according to size (*St. intermedius*, larger than 4 cm ; *St. nudus* larger than 5 cm). Aside from those, each

Table 2 Comparison of Catch in Weight of Sea Urchin from 1980 tO 1984 with from 1985 to 1989

	Total	H O K	N P O	C P O	S P O	N S J	S S J	E C S	S I S
From 1980 to 1984	24,666.6	10,325.6	5,241.8	26.6	839.8	51.2	1,352.4	5,997.6	881.8
From 1985 to 1989	22,161.0	10.377.4	4,618.0	16.8	1,093.6	227.8	807.2	4,474.2	545.6
	-10.2	+0.5	-12.0	-36.8	+30.2	+444.9	-40.3	-25.4	-34.4

Table 3 The change in the Amount of Sea Urchin Import (ton)

Year	Fresh	Frozen	Mean price(yen/Kg)
1975	1,700		1,800
1980	2,200		2,900
1982	2,400		3,400
1983	2,300		3,500
1984	2,600		3,900
1985	2,900		3,700
1986	3,600		3,400
1987	3,700		3,900
1988	2,640	760	5,200 (Fresh) 1,800 (Frozen)

Table 4 The Exporting Countries in 1988

	country	amount(ton)	ratio(%)
Fresh	U.S.A.	1,305	49.4
	Korea	848	32.1
	Canada	406	15.4
	Hong Kong	47	1.8
	Chile	17	0.6
	Other countries	17	0.6
Frozen	U.S.A.	432	56.8
	Chile	179	23.6
	Mexico	71	9.3
	Canada	37	4.9
	China	30	3.9
	Other countries	11	1.4

fishery cooperative association respects its decision concerning the limit of the catch in weight per day, the setting of marine preserve, the rule of fishing gears and others. The transplantation of natural seed is carried out in 2 way : The transplantation from other area, and the transplantation of poorly-grown seed to the good-conditioned area.

The important measure other than management technique is the propagation of mariculture, so-called the set of three : (1) seed production, (2) building of artificial fishery ground, (3) revitalization of fishing village.

(1) The seed production started on collecting the seed of *Pseudocentrotus depressus* belonging to southernspecies in 1967. The increase is observed as in Table 5 ending with 4.3 million seeds native-wide. In 1989, mass production species were *Strongylocentrotus intermedus, St. nudus* and *Pseudocentrotus depressus*. *St. intermedus* calls for attention. It had reached 23 million seeds. Aside from those, *St. pulcherriumus* and *Tripneustes gratills* were added. Nationally, the production reached 30.61 million seeds.

(2) The building of artificial fishery ground began back in 1952 under the national plan for development works of shallow fishing ground. Ever since then, many development plans were carried out. The first plan for the Equipment and Development Works of Coastal Fishing Ground (Ensei) started in 1976 all over Japan with the budget of ¥ 200 billion and lasted for 6 years. The second plan (1982 to 1987) was granted ¥ 400 billion : the third, ¥ 480 billion. The first plan achieved 82 % ; the second, 55 %. Among them, the building of artificial mariculture ground for sea urchin, abalone and kelp takes up 54 % to 57 %. Hokkaido takes up about a quarter of national frame of budget.

Table 5 Number of Seed Production and Release of Sea Urchin in Hokkaido

Year	seed production			release		
	A	B	Total	A	B	Total
1984	1,133	880	4,279	2,691	7,811	12,255
1985	978	2,268	5,762	3,343	6464	11,730
1986	4,651	1,250	7,979	6,843	5,347	13,701
1987	7,167	1,410	10,884	11,448	4,601	17,563
1988	16,758	1,667	21,134	12,067	5,591	20,047
1989	23,067	4,605	30,609	21,447	8,193	32,035

A : *Strongylocentrotus intermedus*

B : *St. nudus*

The purpose of artificial maricultural ground is to enhance the reproduction of natural marine animals and plants, and to protect and to grow artificial seed. The expenses necessary for the purpose are paid mainly by the national and prefectural goverment. Local goverment partially affords it.

(3) In order to revitalize the fishing villages, the facilities to raise the successors of fishery (Fishermen Training Institute) are built and such system is set up as to acknowlege leading (modal) fishermen (master of fishery). The number of the youth in fishing villages all over Japan decreased 20 % over the period of 5 years 1983 to 1988. Table 6 shows the numbers of the membership of the youth at fishery cooperative association in Hokkaido. The 4,221 membership of 1985 dropped to 3,816 in 1990 giving 10 % decrease. The ratio of the ones older than 65 draws an upward curve keener than that of national average (Figure 3).

Hokkaido Fisheries Experimental Station carries out experiments, research and education of techniques in order to facilitate 1) the propagation of managed fisheries, 2) the promotion of mariculture, and 3) the research to give added value to sea foods. Our station also has the abent system to introduce us to fishermen. The main work of our agents is to educate fishermen.

The above-described is the outline of sea urchin fishery of Japan. Vidio tapes are provided for feature informations in case anyone is interested. If there is any question, I am delighted to answer.

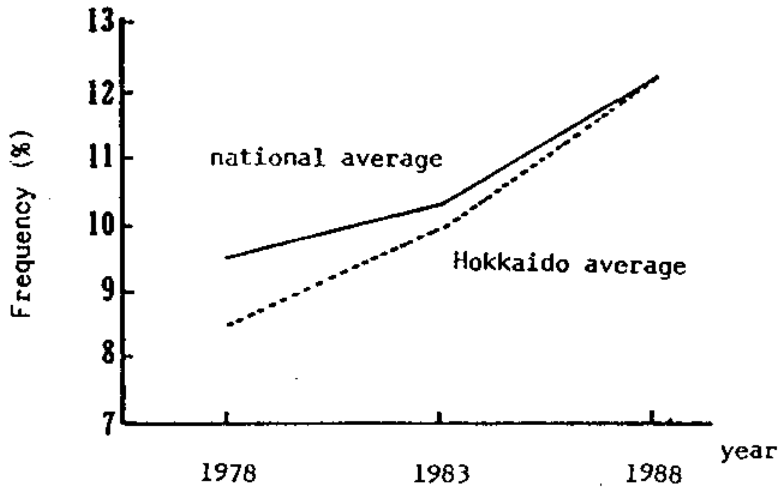


Figure 3 Ratio of the Ones Older Than 65

Japan's Sea Urchin Enhancement Experience

Katsuo Saito

(Hokkaido Hakodate Fisheries Experimental Station)

Before I report on Japan's Sea Urchin Enhancement Experience as titled, I would like to briefly touch upon why the contermove of mariculture became necessary.

It is evident from the shell mounds that the Japanese have been eating sea urchin ever since prehistoric era. In Hokkaido, up until 100 years ago, sea urchin had been regarded harmful to kelp which was the important marine product of Hokkaido. Later on, the economic value of sea urchin gradually went up. After the war (1945), it is presumable that fishery production is increasing satisfactorilly from the fact that Hokkaido now holds around 40 % of total national productivity (Figure 1). The national catch in weight, as indicated in Figure 1, the materials since 1958 show the increase in order from 12,000 tons in 1958 to 20,000 tons in 1964. The peak comes in 1968 to 1970 producing 27,000 tons. Later on, although there are minor fluctuations, the productivity tends to gradual decrease. It dropped to 20,000 tons in 1989. Under these circumstances, the propagation of mariculture was taken up as an important national policy. The establishment of the production technique of artificial seed was hastened. The result of the experiments on the artificial seed of *Pseudocentrotus depressus* was reported in 1967. On the other hand, in Hokkaido, the experiments on naturalseed began in 1974. However, although the cost of natural seed is low, the collection of seed was unstable because of the fluctuation of natural juvenile. It is described in Table 1. At the standpoint in Oshoro, Hokkaido, the annual change in the abundance of sea urchin

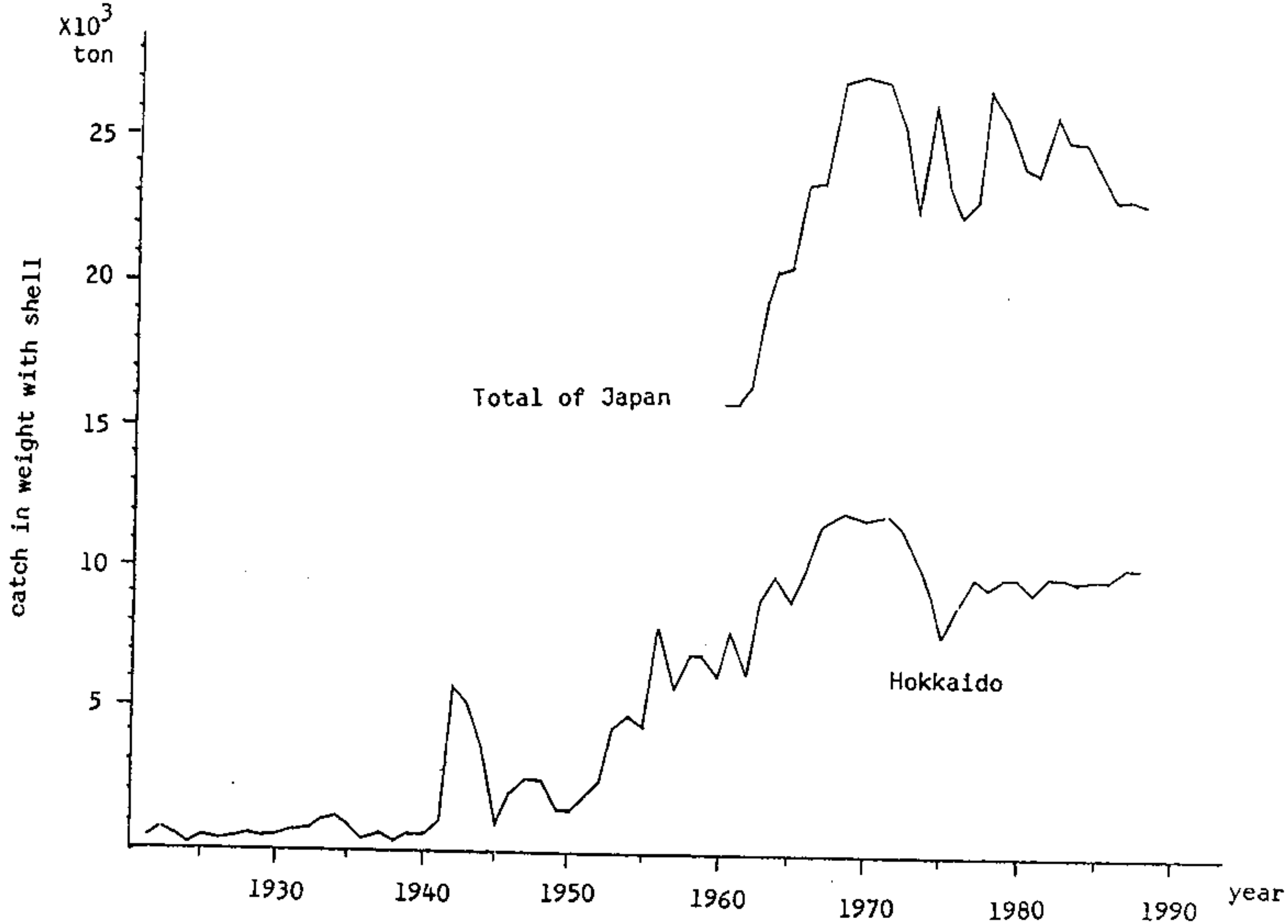


Figure 1 Annual Change of Sea Urchin Catch in Weight with Shell

Table 1 Annual Change in the Abundance of Sea Urchin Juvenile at Oshoro (HCFES 1990)*

year	A	B	C
1965	6	2.0	-
'66	10	4.3	-
'67	43	7.2	-
'68	74	9.7	-
'69	-	8.0	-
1970	-	-	-
'71	-	-	-
'72	22.9	4.4	-
'73	4.2	2.0	-
'74	3.3	1.7	22.5
1975	3.3	2.3	18.6
'76	42.9	17.2	75.3
'77	5.3	2.1	29.4
'78	15.4	9.6	33.9
'79	104.3	13.0	278.8
1980	19.5	23.9	70.5
'81	1.2	1.0	90.6
'82	8.6	8.3	43.7
'83	4.5	1.2	13.9
'84	0.3	0.5	14.9
1985	0.2	0	0.6
'86	5.0	0.7	34.0
'87	0.6	0.2	11.3
'88	0.06	0	4.8

A: 8 month-old juvenile (individual/m^2)

B: one year-old juvenile (individual/m^2)

C: 6 month-old juvenile after settlement (30X30 cm^2 waved plate)

*HCFES = Hokkaido Central Fisheries Experimental Station.

juvenile on flat reef since 1965 shows the assumption is valid. In recent years, it is especially conspicuous that abundance is little since 1981. The experiments and research on the production of artificial seed greatly developed in the mean time. Especially, the development of mass culture technique of biological food in the earyly stage of cleavage and the technique of maturation control of parents opened the way to the mass production of artificial seed. On such a background as described, various experments on countermove of mariculture, as the title of this paper,have been carried out in order to comensate the lowering of fishery production of sea urchin.

One of the countermove of mariculture, which has been taken up for a long time,is transplantation. Transplantation has a long history. Many fish and shellfish, especially shellfish, were transplanted. In Hokkaido, abalone, hen clam, short-necked clam, fresh water clam and other were at first transplanted. The transplantation of sea urchin is comparatively new. In the case of sea urchin transplantation, it is different from other shell fish because there is no effect if ganad is not matured. It is therefore necessary to get hold of precise reproductive cycle of seaurchin. The seed right before entering the Stage III of growth, when ganad develops quantatively at maximum, must be transplanted. It is possible to enhance the development of ganad in about 3 months where there is sufficient biological food (Figure 2).

The conditions for the transplantation location should be, firstly rich in algae resource, secondly appropriately deep, and thirdly not low-saline. It is also important to have proper density of transplantation and to transplant juvenile sea urchin.

Recently, algae,sea urchin's biological food, is given. When there is no algae, animal protein (fish) is given at first to facilitate the quantative development of gonad and later algae is given to enhance the taste. There is few report on the production effect of transplantation.

There are quite a few fishery cooperative associations in Hokkaido. Almost all cooperatives have carried out transplantation in some style. But, due to the decrease of the seed for transplantation and to the progress in the development of artificial seed, the release of artificial seed is more widely attempted. The collection of artificialseed of sea urchin is based on the fact that sea urchin has been used as the experimental sample of embryology for a long time. The result of experimental collection of seed was reported in 1967. As various techniques were developed, prefectural fishery experimental stations and institutes of mariculture tried other species characteristic to each locality. Table 2 shows precise data on national seed production and the number of release since 1984.

The number of national seed production rapidly increased after 1986. It was 8 million seeds in 1986, but it quadrupled to 30 million in 1989.

The increase in the number of seed production owes to *Strongylocentrotus intermedus* and *St. nudus*. *Strongylocentrotus intermedus* contributes a great deal. As the number of seed production of *Strongylocentrotus intermedus* increased, the number of release rose up. Withrespect to *St. nudus,* the number of release exceeded the number of seed production because many natural seeds were released from 1984 to 1988. The number of seed production and the number of release that the twospecies, *Strongylocentrotus intermedus* and *St. nudus,* hold in nation-wide statistics is shown in Table 3. In conjunction with the number of seed production, they held just 50 % in 1984 and 1985, 74 % in 1986, and reached 90 % in 1989. Hokkaido took up more than 70 %. The same two species were released and took up nearly 90 %. Hokkaido held more than 70 % of the number of release as in the case of the number of the seed production. Bisides the two species, *Pseudocentrotus depressus* of southern species contributed 7.1 % ; *St. pulcherriumus,* 2.5 % according to 1989 materials.

Let me go on to the enhancement experments of sea urchin resouce of Hokkaido where seed production and the number of release showed rapid increase.

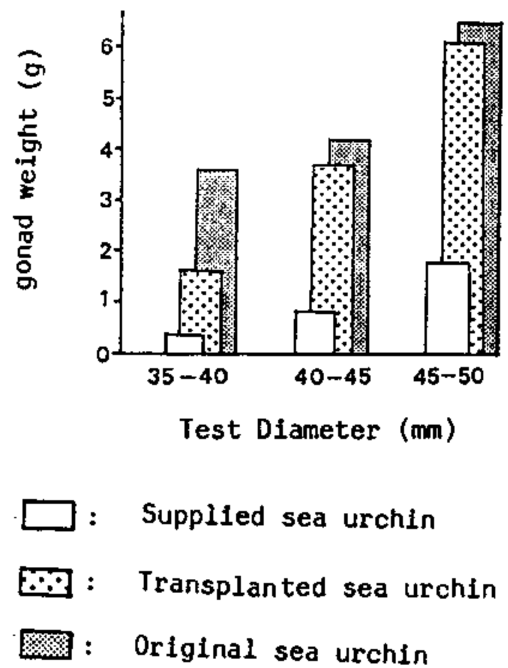


Figure 2 Effect of Transplanted Sea Urchin (Kawamura 1965)

Table 2 Number of Seed Production and Release of Sea Urchin in Hokkaido

Year	seed production			release		
	A	B	Total	A	B	Total
1984	1,133	880	4,279	2,691	7,811	12,255
1985	978	2,268	5,762	3,343	6464	11,730
1986	4,651	1,250	7,979	6,843	5,347	13,701
1987	7,167	1,410	10,884	11,448	4,601	17,563
1988	16,758	1,667	21,134	12,067	5,591	20,047
1989	23,067	4,605	30,609	21,447	8,193	32,035

A : *Strongylocentrotus intermedus*

B : *St. nudus*

Table 3 Percentage of Seed Production and Release in Hokkaido

year	seed production				release			
	A	B	Total	R	A	B	Total	R
1984	26.48 +	20.57=	47.05 %	24.84 %	21.96 +	63.74=	85.70 %	52.66 %
1985	16.97 +	39.36=	56.33 %	30.04 %	28.50 +	55.11=	83.61 %	63.50 %
1986	58.29 +	15.67=	73.96 %	58.69 %	49.95 +	39.03=	88.98 %	72.70 %
1987	65.85 +	12.95=	78.80 %	67.12 %	65.18 +	26.20=	91.38 %	84.73 %
1988	79.29 +	7.89=	87.18 %	77.76 %	60.19 +	27.89=	88.08 %	76.74 %
1989	75.36 +	15.04=	90.40 %	73.41 %	66.95 +	25.58=	92.53 %	77.17 %

A : *Strongylocentrotus intermedus*

B : *St. nudus*

R : Ratio of Hokkaido in Japan

In 1983, a project team was organized at Hokkaido Institute of Mariculture in order to develop the technique of mass seed production of *Strongylocentrotus intermedus* under 3-year plan. The themes of research were at the beginning 5 as follows :

1) to secure parent sea urchin appropriate for egg removal,

2) to cultivate biological food,

3) to grow planktonic lavae,

4) to grow juvenile,

5) to produce seed in mass.

Model Experiment

3-year experiments resulted in many achievements. According to the seed production procedure as shown in Figure 3, the technique of mass seed production was developed. If my time allows me, I would like to introduce the actual works by video tape. As the technique of artificial seed production was established, many localities in Hokkaido began suffering from the decrease of sea urchin resource. The trend to build artificial fishery ground for *Strongylocentrotus intermedus* spread out throughout Hokkaido. Many facilities started out from a small-scaled experimental outset. As receiving technical instructions, they grew up to such as to produce 3 to 5 million seeds. There are 17 institutes for artificial seed production according to 1990 statistics. They grow planktonic lavae. The density of 1.56 seed/ml ($291{,}270X10^3$) became 0.8 seed/ml ($70{,}536X10^3$) before settlement. About 1/4 of 4 armed stage lavae settled (Table 4). At the stage to cultivate settlement lavae to test diameter of 5 to 8 mm, about 225,000 waved sheets (287 seeds/sheet) with *Ulvella lens* were provided for $30{,}634X10^3$ seeds at 23 facilities (Table 5). Some were released directly to fishing ground (Pacific Ocean side). Others were grown at nursery and released after test diameter reached more than 15 mm (Sea of Japan and Tsugaru Strait) (Table 6). Nursery can be classified to 2 kinds. Under-sea

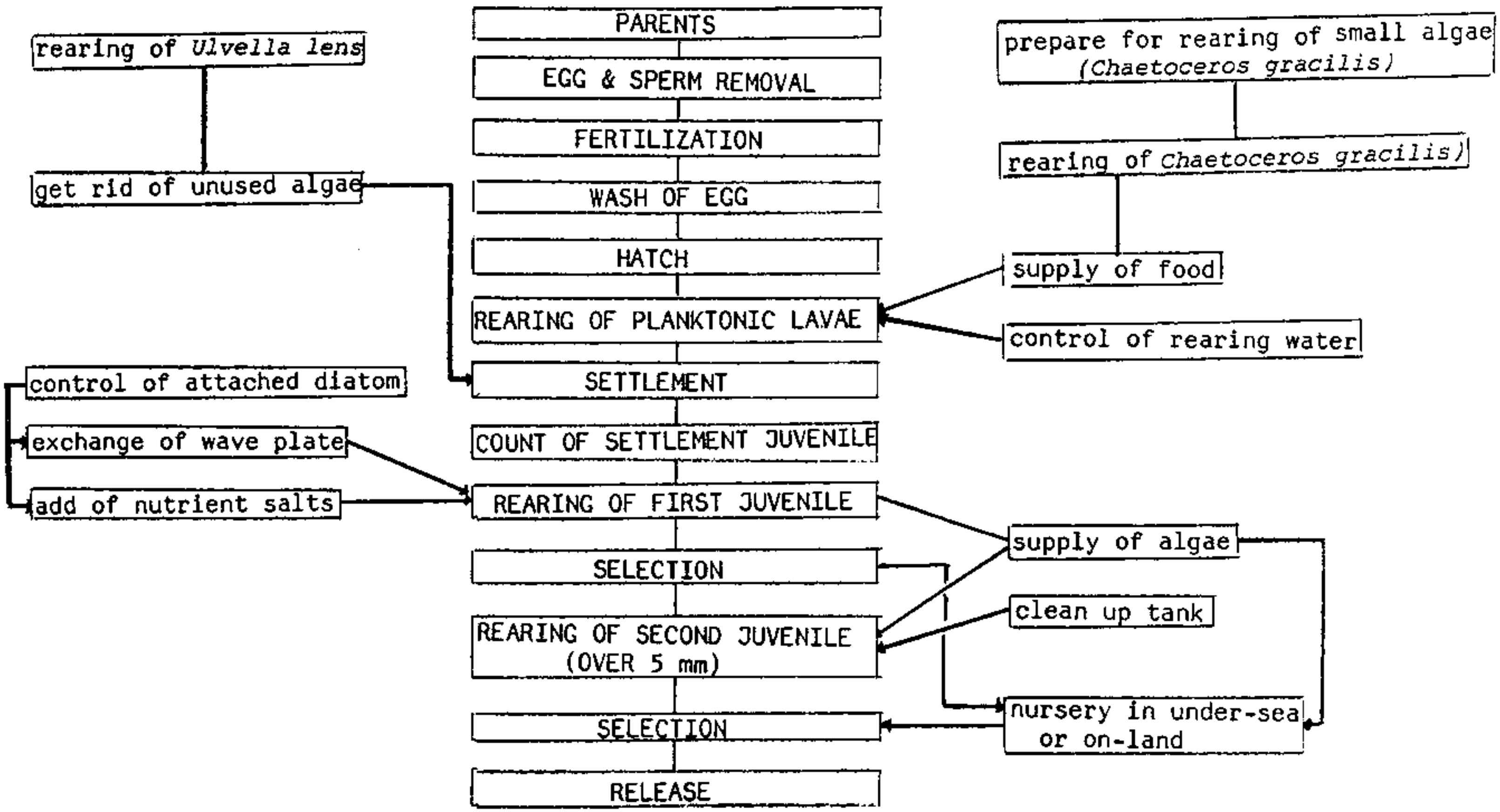


Figure 3 Flow Chaet of Seed Production

Table 4 Number of Rearing and Settlement of Lavae (1990)

Local	F	M	S	Su
Central Sea of Japan	3	20,239	9,431	3,731
Tsugaru Strait	2	53,544	21,141	4,428
Southern Hokkaido on Pacific Ocean Side.	3	26,138	4,674	
Eastern Hokkaido on Pacific Ocean Side	6	14,876	14,695	
Northern Hokkaido	2	5,520	2,289	
(KOUSHA)	1	32,961	18,306	3,000

F : Number of Facility

M : Number of Metamorphose lavae (Xthousand)

S : Number of Settlement juvenile (Xthousand)

Su : Number of supplied lavae (Xthousand)

Table 5 Number of First Rearing, Test Diameter and Ratio from Start to End in First Rearing (1990)

Local	F	J	TD	R
Central Sea of Japan	5	4,667	6.0-7.3	26.2-94.7
Tsugaru Strait	4	8,163	5.0-7.0	13.3-56.7
Southern Hokkaido on Pacific Ocean Side	4	3,476	5.8-9.1	41.0-75.1
Eastern Hokkaido on Pacific Ocean Side	6	2,382	5.6-8.9	28.7-71.2
Northern Hokkaido	3	1,477	4.0-5.3	30.0-76.5
(KOUSHA)	1	10,469	7.2-8.4	41.0-79.0

F : Number of Facility

J : Number of Juvenile (Xthousand)

TD : Test Diameter (mm)

R : Ratio from start to end in First rearing (%)

Table 6 Number of Nursery (1990)

Local	E	S	Ed	R
Central Sea of Japan	8	5,542	3,872	48-100
Tsugaru Strait	12	5,513	5,058	57-100
Southern Hokkaido on Pacific Ocean Side	16	4,447	3,591	45- 96
Eastern Hokkaido on Pacific Ocean Side	8	2,741	1,802	53-100
Northern Hokkaido	8	2,329	1,097	68- 90

E : Number of enforcement organ

S : Number of start of nursery (Xthousand)

Ed : Number of end of nursery (Xthousand)

R : Ratio from start to end of nursery (%)

Table 7 Number of Release (1990)

Local	E	R	TD
Central Sea of Japan	12	3,671	5-17
Tsugaru Strait	11	6,001	7-19
Southern Hokkaido on Pacific Ocean Side	18	4,758	7-20
Eastern Hokkaido on Pacific Ocean Side	12	5,609	6-36
Northern Hokkaido	4	561	5-16

E : Number of enforcement organ

R : Number of release (Xthousand)

TD : Test Diameter (mm)

facilities count 40 ; on-land, 12. There are 52 in total.

The seed is released at 57 places. The size varies from small seed (5 to 10 mm) to large seed (larger than 15 mm) after nursery. The number reached $20,600 \times 10^3$ seeds (Table 7). The selling price is ¥ 0.35 for the lavae before settlement ; ¥ 10.5 for 5 mm in test diameter ; ¥ 21 for 10 mm in test diameter ; ¥ 100 for a *Ulvella lens* in general.

As described, in Hokkaido, many facilities for seed production have been built. I would now like to touch upon how the facilities were built, how they are administered and managed, and how much the production costs are. As for an example, I would like to take up the seed production facility of Erimo Fishery Cooperative Association located on the Pacific Ocean side. This facility was built in 1989 with the subsides from national government, Hokkaido Prefectural government and Erimo town council. In Japan, whether individual plan gets the budget or not depends on how well the appeal is done to town council, prefectural government and national government, strictly in this order. There-fore various materials become necessary. The materials are provided by the one who is in charge of each individual plan at town council and/or each individual fishery cooperative.

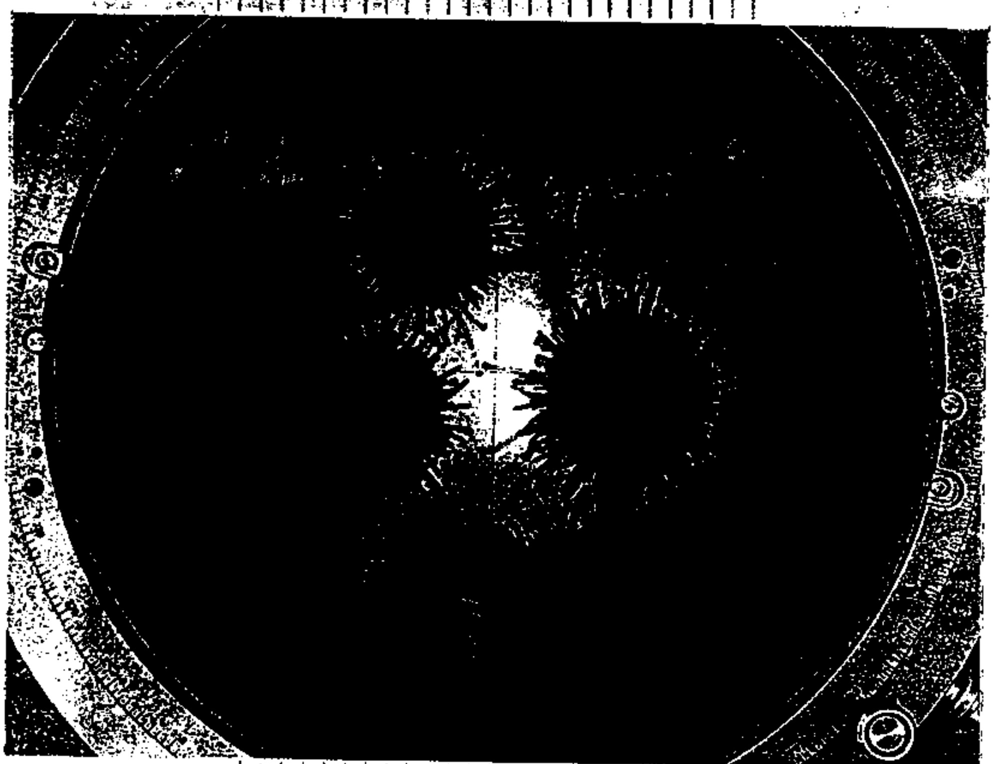
1/2 is subsidized by the national government ; 1/4, by prefectural governments ; the remaining 1/4, by town council and individual coop. The total budget was ¥ 243,422,990 (about $ 1.87 million, ¥ 130/$). The entitled to subsidy was ¥ 242,400,000 ($ 1.865 million). Erimo Fishery Cooperative Association took the burden of ¥ 42,690,990 (about $ 328 thousand). They borrowed ¥ 32 million (about $ 246 thousand). This ficility has the production capacity of 3 million seeds with the test diameter of 5 mm (Figure 4). Administration and management are done according to the administration and management rules. Administration and management committee discusses and submits a report in order to secure smooth management. Let us look at the production cost (Table 8). The income and expenditure of the primary plan were 30 million yens (about 230 thousand dollars). The income was 30 million yens to be obtained by selling

Table 8 Cost of Seed Production in 1990 (X Thousand Yen)

	Original program	1990 Program	1990 Result	1991 Program
Raw and processed materials (7.7 %)				
Food		75	0	75
Consuming material	2,300	926	494	750
Medicines				500
Total	2,300	1,001	494	1,325
Personell expenditure (38.3 %)				
Personell expenditure	11,500	10,617	10,755	10,619
Total	11,500	10,617	10,755	10,619
Expense (40.3 %)				
Power expenditure	7,200	7,196	4,728	6,000
Repairing expense		806	6	1,090
Premium	200	765	384	765
Water rates and fuel and light expense	360	675	340	480
Rent		526	828	828
Depreciation	2,758	6,160	6,160	6,160
Communication expense	100	146	121	150
Charge		232	203	232
Interest	1,472	1,393	1,393	1,393
Sundry expense		338	62	200
Total	12,090	18,237	14,225	17,298
Sundry Expense (13.7 %)				
Traveling expense	300	338		338
Social expense	3,810	280	69	280
Business expense		0	45	50
Sundry expense		0	32	50
Total	4,110	618	146	718
The sum total	30,000	30,475	25,620	29,960

種苗生産施設

Seed Production Facilities



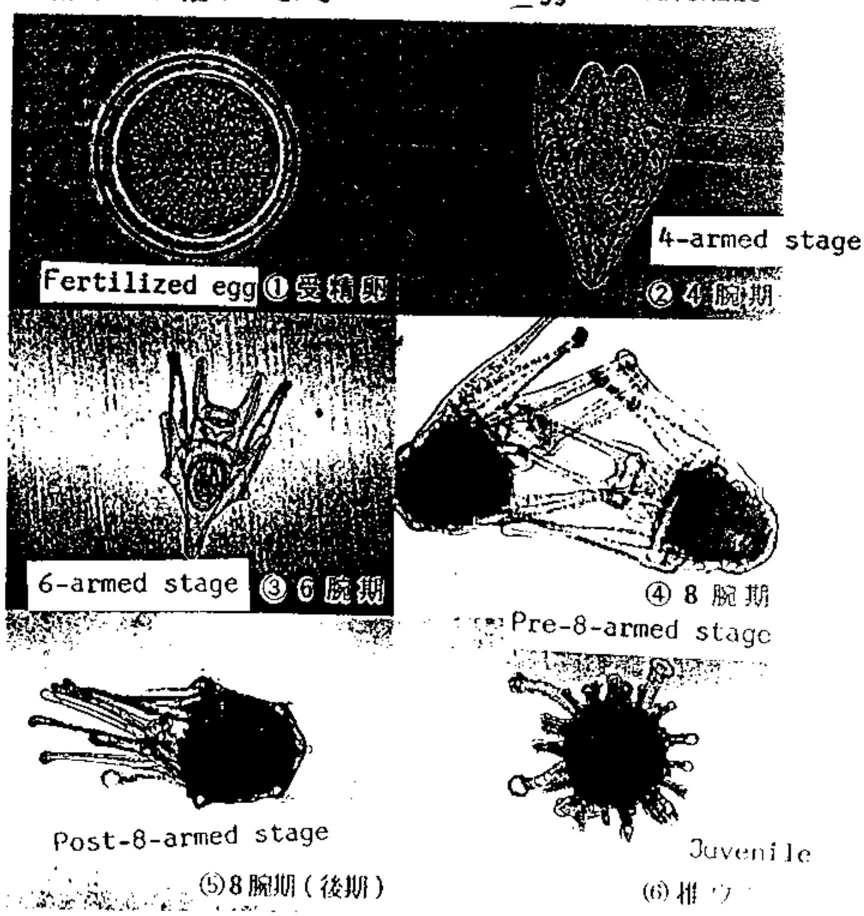
えりも町漁業協同組合

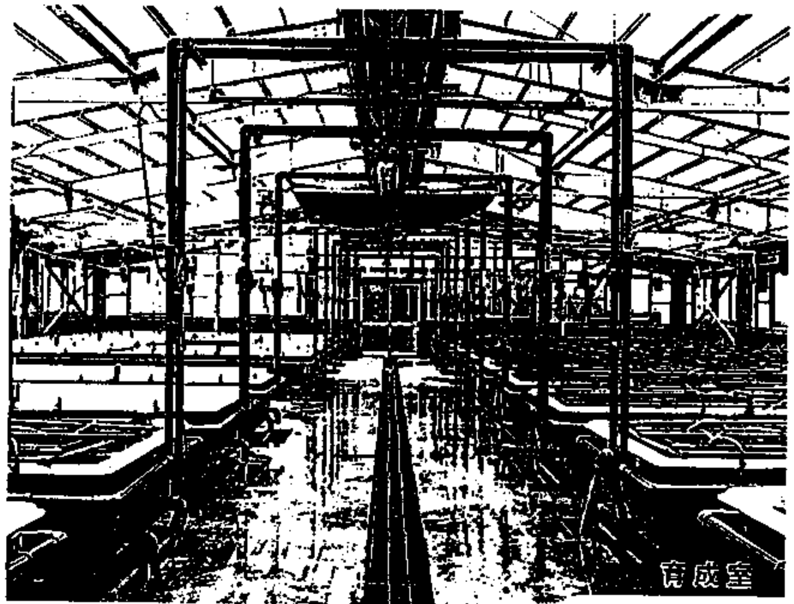
ERIMO FISHERIES COOPERATIVE

Figure 4 Seed Production Facilities of Erimo Fisheries Cooperative

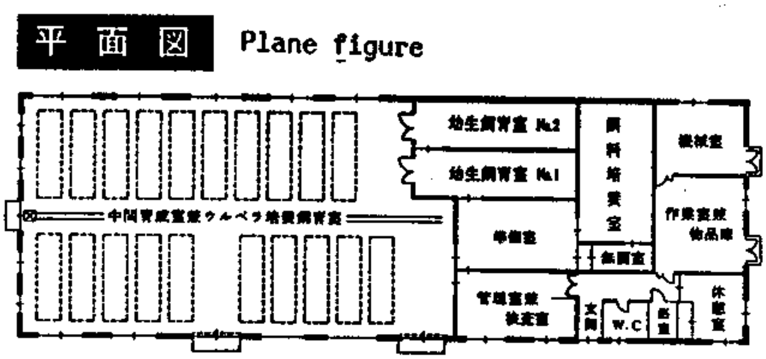
Rearing room of Larvae

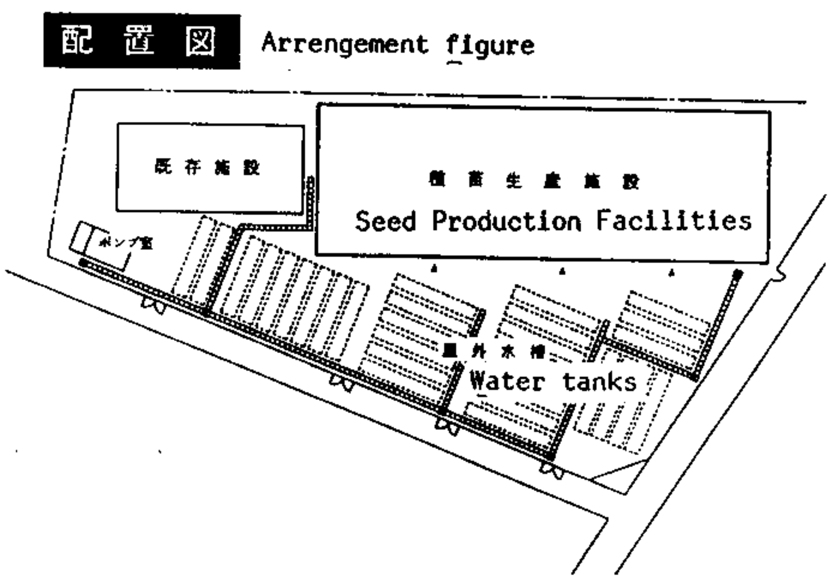
受精卵から稚ウニまで Fertilized egg --- Juvenile



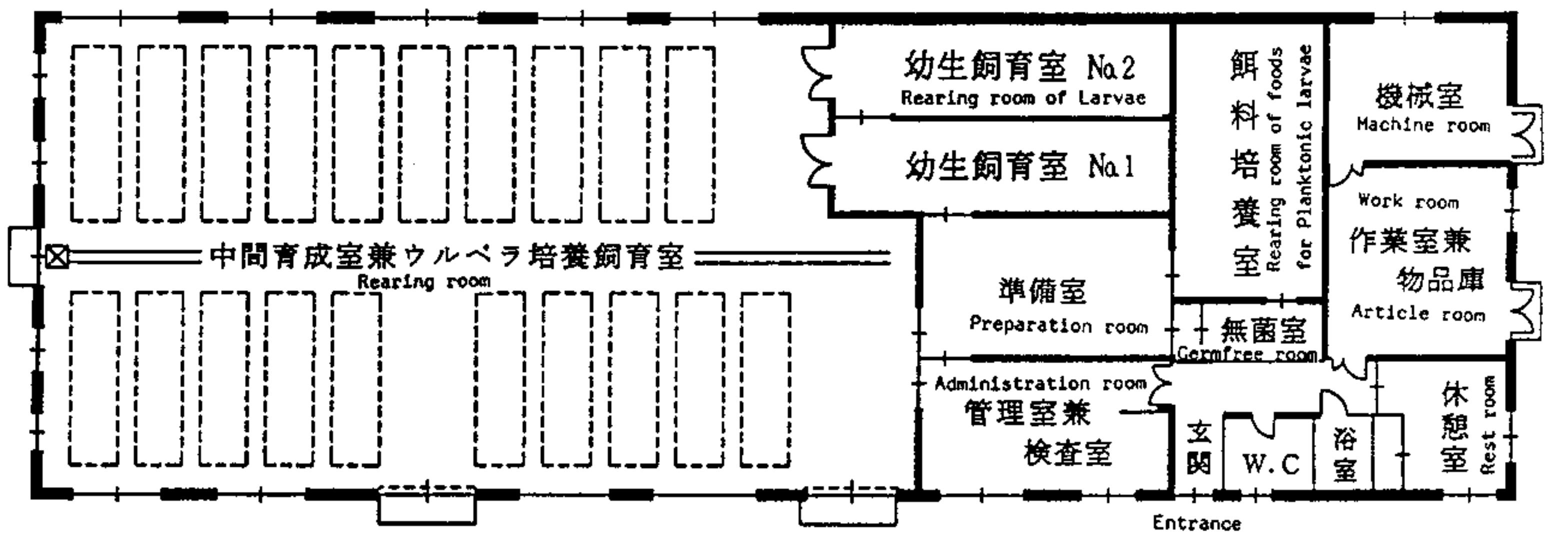


Rearing room

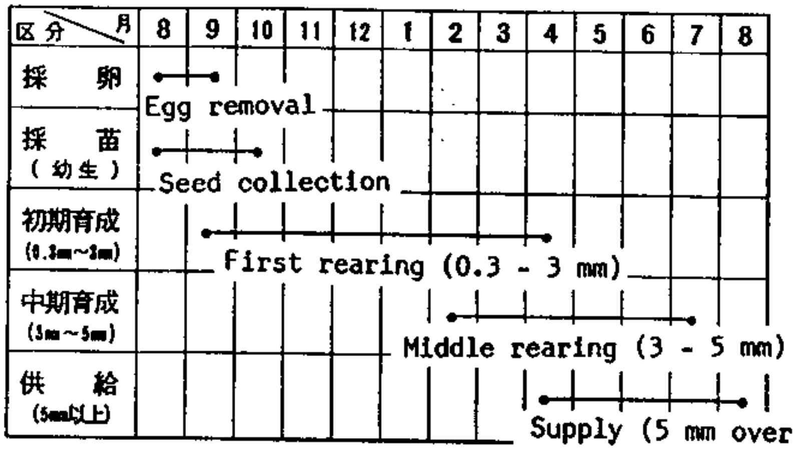




平面図 Plane figure



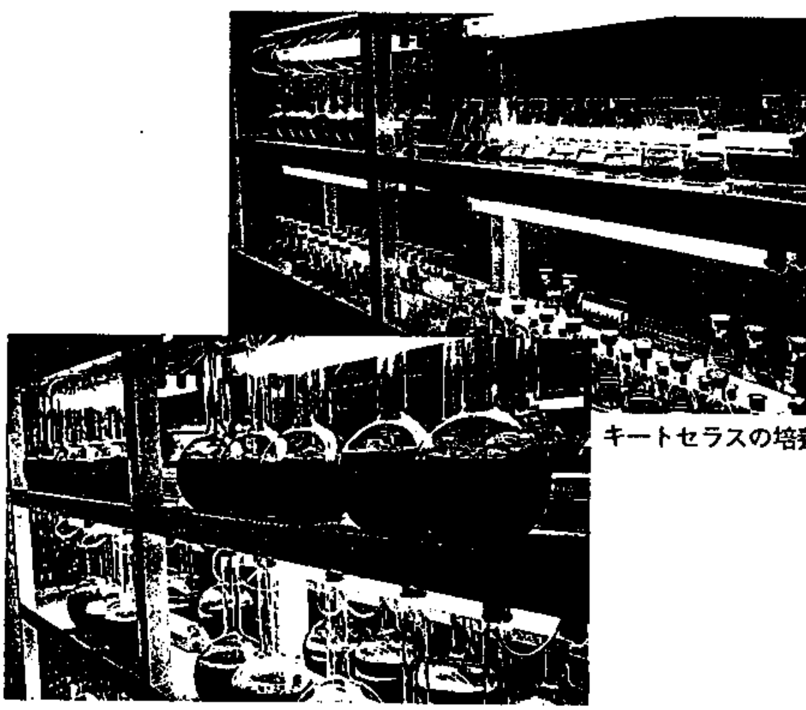
運用計画 WORKING PLAN



事業効果 BUSINESS EFFECT

	効　　果
① 放流数	3,000千粒×70%(中間育成生残率)=2,100千粒
②放流後生残量	2,100千粒×50%(生残率)=1,050千粒
③ 漁獲量	1,050千粒×80%(再捕率)×75g(1個あたり重量)=63.0t
④生産期待額	63.0t×2,143円/kg(62年平均単価)=135,009千円

Rearing of *Chaetoceros gracilis*



キートセラスの培養

BUSINESS EFFECT

(1) Numbers of released seed

3 million multiplied by 70 % (survival ratio of nurs ry)
equals 2.1 million

(2) Numbers of survival after released

2.1 million multiplied by 50 % (survival ratio after released)
equals 1.05 million

(3) Catch

1.05 million multiplied by 80 % (recapture ratio)
multiplied by 75 grams (mean weight/individual)
equals 63.0 tons

(4) Productive expectation yield

63.0 tons multiplied by 2,143 yens (1987's mean price/Kg)
equals 139,005,000 yens

種苗生産施設の概要 Outline of seed prodution facilities

事業名	全県地域沿岸漁業構造改善事業（広域種苗生産施設整備事業）	
規模 建物	育成棟	
	延べ面積	884.0㎡
	育成室	506.0㎡ Juveniles rearing room
	幼生飼育室	84.0㎡ Rearing room of Larvae
	餌料培養室	54.0㎡ Rearing room of foods for Planktonic larvae
	無菌室	10.8㎡ Germfree room
	準備室	45.0㎡ Preparation room
	管理室兼検査室	45.0㎡ Administration room
	作業室兼物品庫	46.2㎡ Work room Article room
	機械室	33.0㎡ Machine room
	休憩室	25.0㎡ Rest room
	その他	35.0㎡
	取水ポンプ室	17.5㎡
集水	取水施設	自然浸透型(海中埋設) 集水能力 615㎥/h
主施設	取送水ポンプ	5.5KW 4台 取送水能力 213㎥/h
Precision filter machine	精密濾過器	2台
Airration (air pump)	エアー設備	ブロアー5.5KW2台
Generator for emergency	非常用発電機	20KVA1台
Air conditioner	恒温室設備	空調機6台、冷凍機4台
Telethermometer	温度記録計	30チャンネル1台
Water tanks	水槽設備	幼生飼育槽 8槽、貯水槽 2槽 飼育水槽 7.5t型30槽、4.5t型20槽
Ability of seed production	種苗生産能力	エゾバフンウニ *Strongylocentrotus intermedius* 3 million (T.D. 5mm over)
Rearing of planktonic larvae	浮遊幼生飼育	1,200万粒 12 million/8 tanks
Food rearing	餌料培養	キートセラス培養能力1,200千cc Rearing of *Chaetoceros gracilis* (フラスコ846本培養) 12 million ml Rearing of *Ulvella lens* 4.5t水槽15槽、波板24,000枚 Waving plate (Poly-carbonate)
First rearing (0.3 - 3 mm)	初期育成	7.5t水槽24槽
Middle rearing (3 - 5 mm)	中期育成	7.5t水槽12槽（内6槽は初期育成槽共用） 育成篭334篭 Cage of nursary

事業主体	えりも町漁業協同組合
設計者	株式会社 中山設計事務所
施工業者	南・丸虎佐藤一般共同企業体
着工	平成元年 6月21日
竣工	平成元年11月20日
受益地域	3市町5単協（室蘭・様似・冬島・えりも町・庶野）

Waving plate (Poly-carbonete)

作業風景

ウニの採取風景
Fishing sight of sea urchin

えりも町漁業協同組合
☎01466-2-2211
種苗生産施設
☎01466-2-3573

MEMO

a seed at ¥ 10 (7.7 cents). The main expense was personell expenditure, 11.5 million yens (about 890 thousand dollars), taking up 38.3 % of the total expenditure. Power expenditure was 7.2 million yens (about 55 thousand dollars), 24 %. 2.76 million yen (about 21 thousand dollars), 9.2 %, went for depreciation. The expense for raw and processed materials was 2.3 million yens (about 18 thousand dollars), 7.7 %. Miscellaneous expenses were 3.81 million yens (about 29 thousand dollars), 13.7 %. In 1990, it was planned to be 30.48 million yens (about 23 thousand dollars), but achieved 25.62 million yens (about $ 200 thousand), ending with 84.1 % of the primary plan. By the 1991 plan, the expenditure would be 29.96 million yen (about $ 230 thousand). The income was the charges for 3.1 million seeds. The balance was in profit. Since the seed production facilities are as described quite new, it is presumable that there are few facilities where management succeeds in getting profit. However even if the facility management ends up in deficit, it is all right for the fishery cooperative so long as its fishery production of sea urchin is in profit.

Next, let me describe on the important points of the results of the numerous seeds released in Hokkaido. How many remain alive, grow, mature and contribute to fishery production. In 1984, a year after the project for seed production was set up at HIM in 1983, a project team was organized by HFES, HIM and AG to obtain the precise effect of the release of experimental seed. It started from Otaru (Sea of Japan side), gradually spread to other expermental locations, and increaced to 4 places where experimental release was conducted. Each locality took its own theme. In Otaru, where the first experiment was carried out, the seed with test diameter of 15 mm were released after nursing artificial seeds, because of the conclusion that it was best to make use of 15 mm seeds after nursery, which had been obtained froma series of experiments on naturalseed collection, nursery and release.

On the other hand, Akkeshi and Erimo looked for the effect of the release of 5 to 10 mm seeds without nursery. Toi and Shikabe searched for a method to distingush natural seed from the released and worked on maturation stages after release. The experments in Otaru were the most academic. The started with the survey of the fishing ground before release, examined the physical quality of seeds, and studied the growth, remain and catch after release. The experimented on the release for 2 years, 1983 and 1984.

1983 experiment was done by releasing 40 thousand seeds (40 seeds/m^2 on average) with 16.3 mm average test diameter into 20 m X 50 m = 1,000 m^2 release zone on September 16 as shown in Figure 5. The Figure 5 shows the depth and the bottom composition of the place around the release point. In respect to bottom composition, 40 % is stones ; 60 %, rocks ; 0 %, sand. The depth is from 0.5 m t0 3 m. The surveys were conducted after 41 days, 181 days, 272 days, 381 days and 622 days, and obtained test diameter distribution and the number of distribution (remain). Test diameter distribution is given in Figure 6. After 622 days, average test diameter is 45.3 mm (±4.3 mm). 92 % exceeded 40 mm, Hokkaido limit test diameter. Assumed number of remain is 15,474. The ratio of the remain to the released is 38.7 %. The number of sea urchin caught by fishermen is 7,771. The number of the uncaught is assumed 8,930 according to the distribution surveys conducted there-after. Therfore, the sum of the caught and the un-caught is 16,700. The assumed number according to Figure 7 by Delury method based on the materials at the time of catch is 16,586. The 3 methods give almost the same number of distribution (remain), about 16,000. Thus, 40 % is assumed to have survived(~~Figure~~ Table 9).

The 1984 release was studied in similar manner. The release was conducted at a neighboring spot of 1983 as shown in Figure 5 on October 1, 1984 and was surveyed on June 2, 1986, after 609 days. The test diameter distribution is shown in Figure 8. The seeds with the test diameter more than 40 mm hold 89 %. The number of remain is calculated as the year before. Although it varie a little depending on a survey method, the ratio is about 40 %.

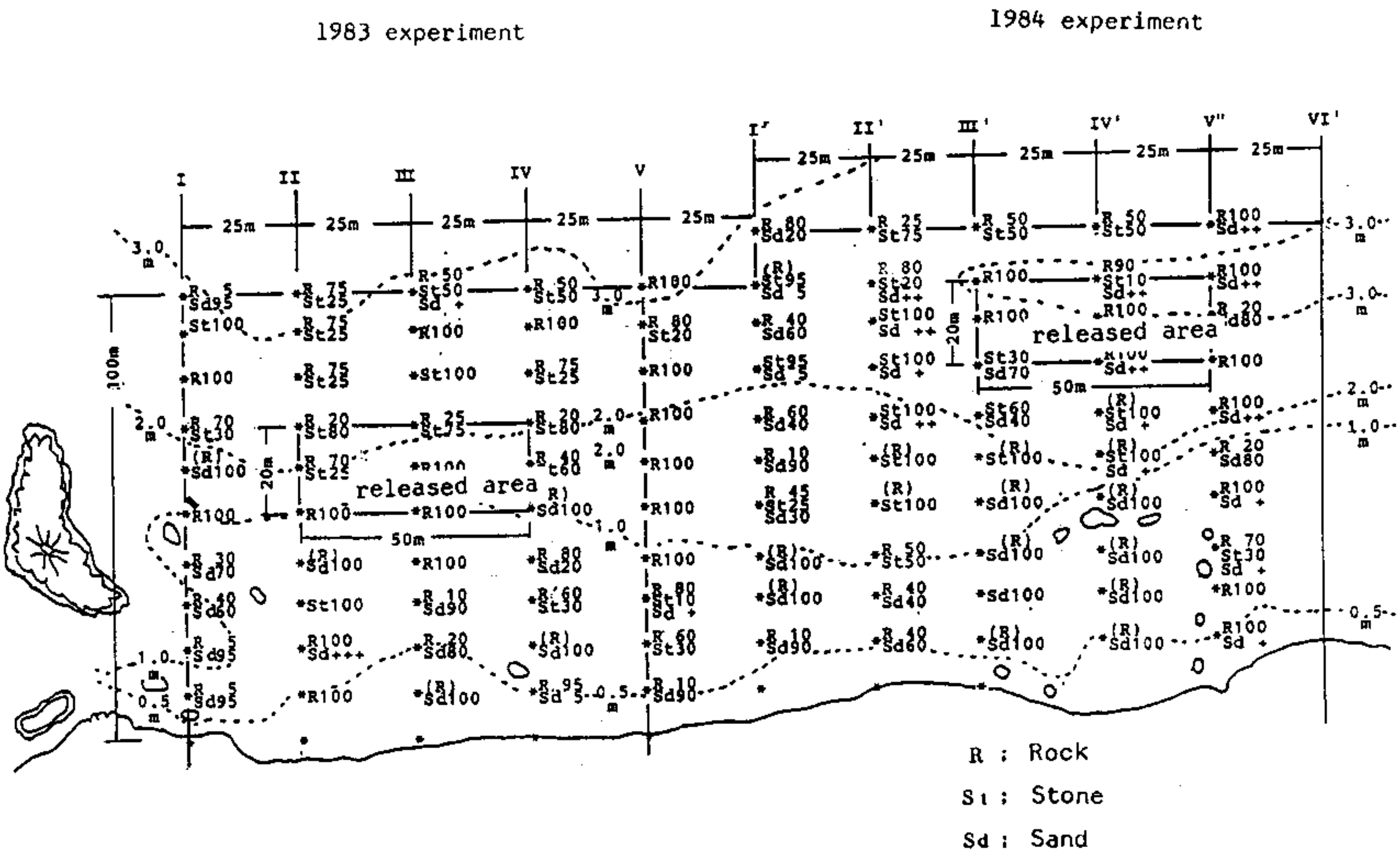


Figure 5 The Details of Experimetal Station at Oshoro in 1983 and 1984 (HCFES 1986)

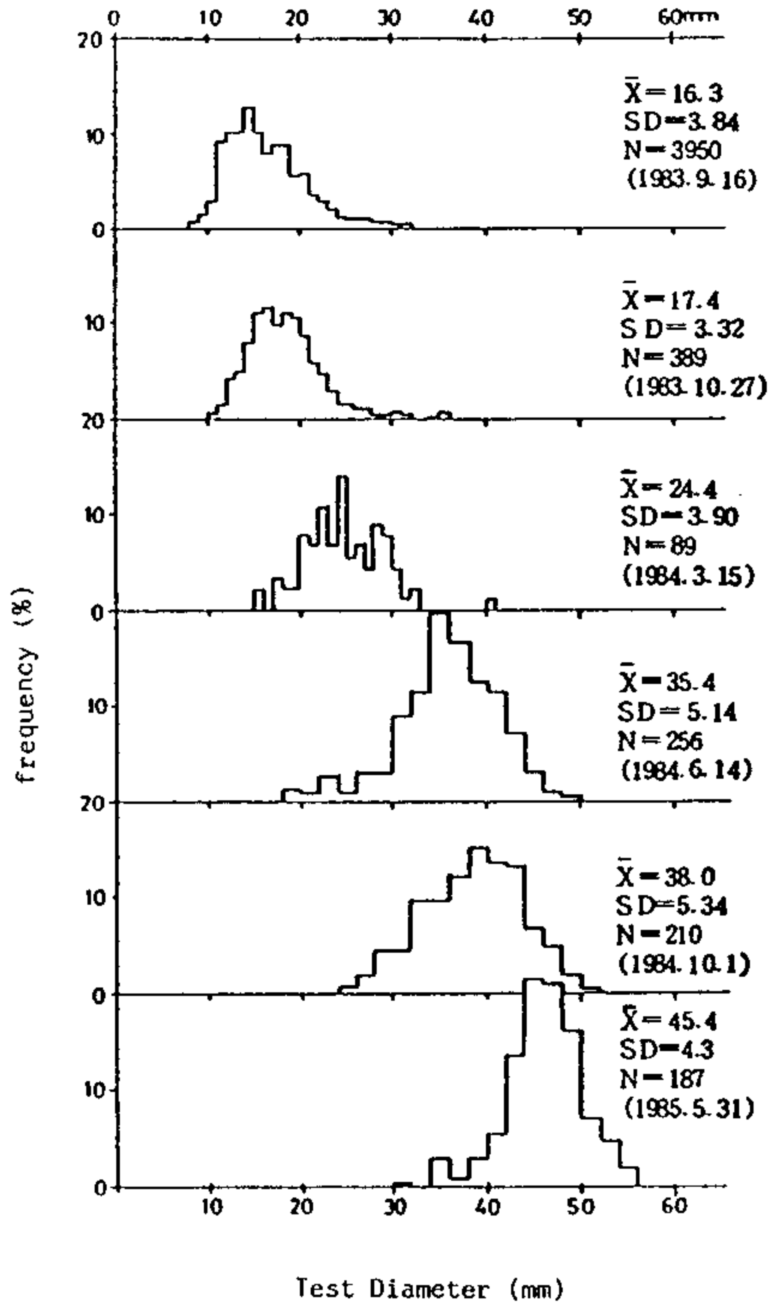


Figure 6 Test Diameter of 1983 Released Sea Urchin at Oshoro (HCFES 1986)

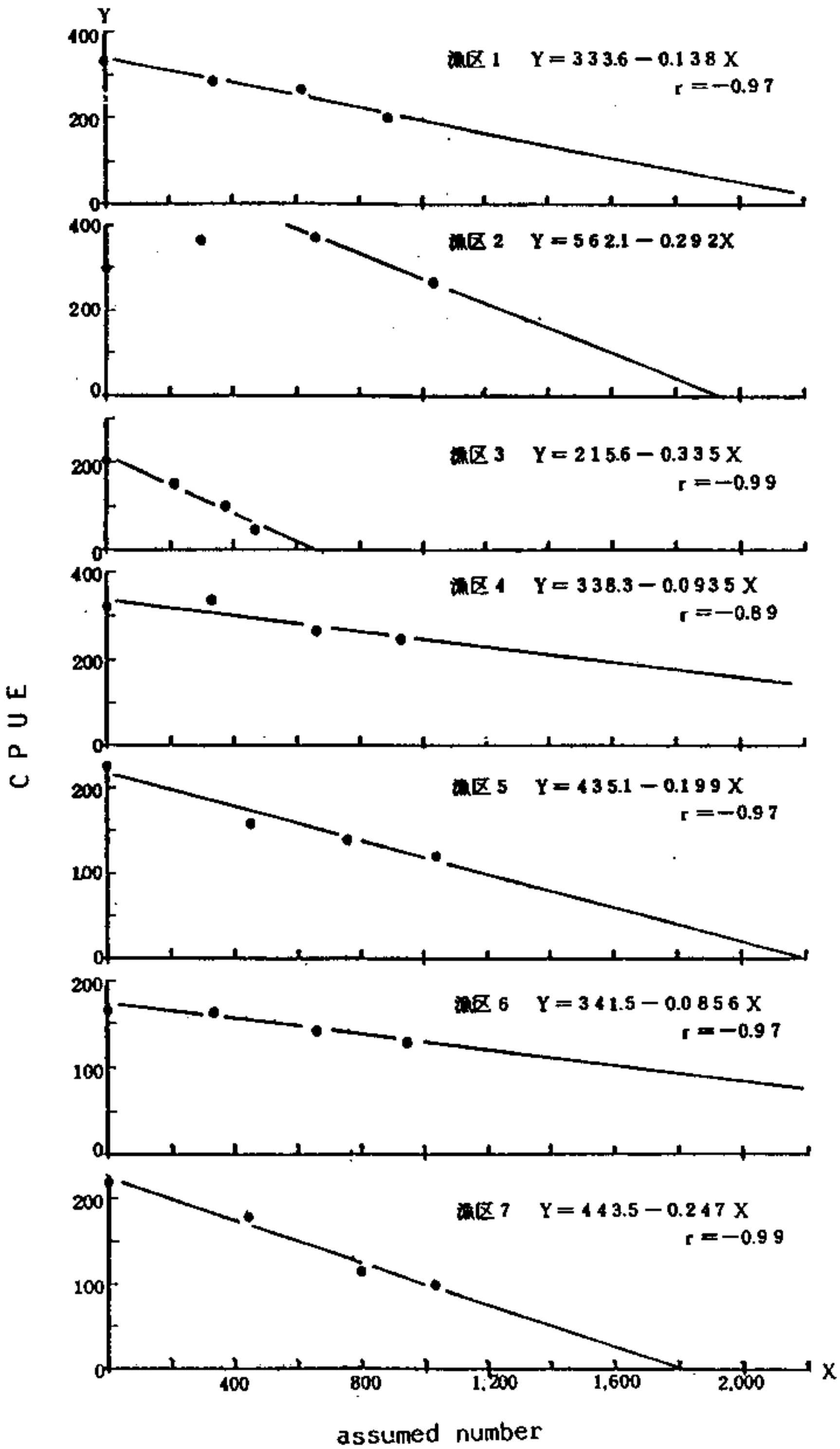


Figure 7 Relationship of CPUE and Assumed Number of 1983 Released Sea Urchin at Oshoro Caught by Fishermen (HCFES 1986)

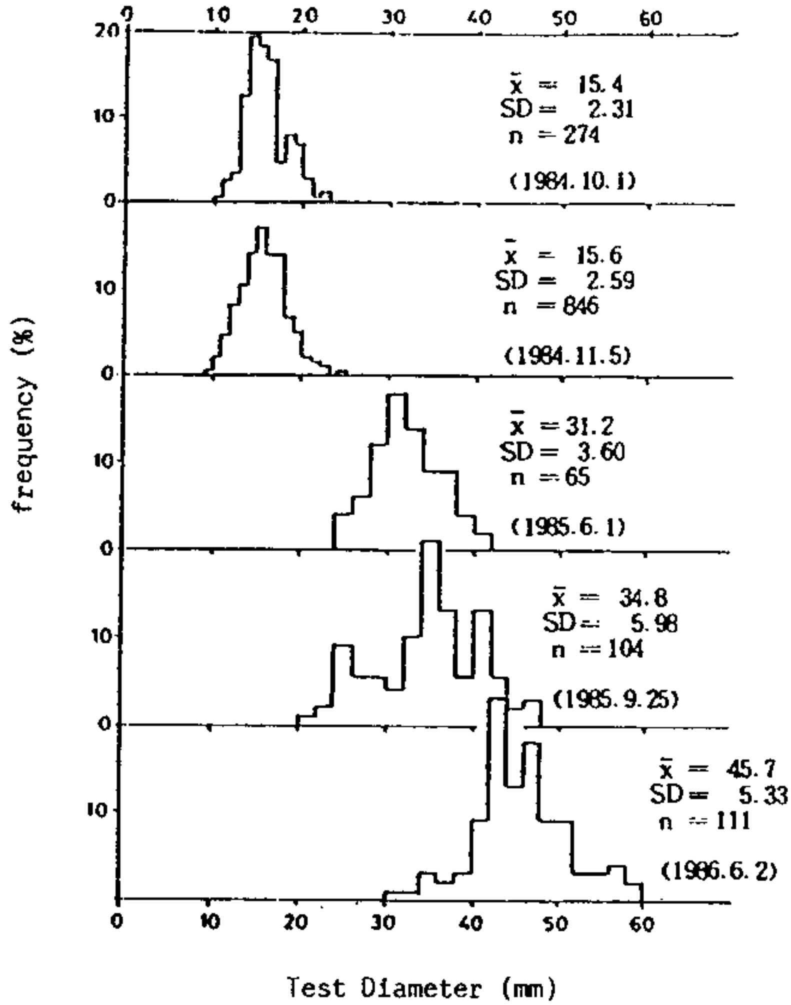


Figure 8 Test Diameter Distribution of 1984 Released Sea Urchin at Oshoro (HCFES 1987)

Table 9 Comparison of Remain of 1983 Released Sea Urchin with Different Methods

Method	Remain number(N)	Ratio of remain(%)
quad-rate	15,474	38.7
resource 1	16,701	41.8
resource 2	16,586	41.5

resource 1 : Assumed number by fishermen + remain number(sampling by SCUBA)

resource 2 : Number by DeLery

(HCFES 1986)

Table 10 Comparison of Remain of 1984 Released Sea Urchin with Different Methods

Method	Remain number(N)	Ratio of remain(%)
quad-rate	9,045	22.6
resource 1	15,534	38.8
resource 2	12,592	31.5
resource 3	16,676	41.7

resource 1 : Assumed number by fishermen + remain number(sampling by SCUBA)
resource 2 : Number by DeLery
resource 3 : Line belt sampling

Next, the development stages of ganads of the released is studied. The annual changes in the groups of the released in 1983 and 1984 at Shikabe are compared with the group of natural seed in Figure 9. Each of the released showed low ganad index in the first year. From the second year on, it showed ordinary value and followed the maturation cycle of the parents' place where the seeds were collected. On the other hand, the maturation stage of the natural seeds in Shikabe differed from that of the released. Since it is known that eggs are layed in spring from April to May (Figure 10), it is necessary to select parents as in accordance to egg-laying cycle in order to collect seeds for release. Although it becomes necessary to distinguish natural sea urchin from the released where-ever they are mixed, it is quite difficult because tagging as done in the case of abalone is not available. Dying method by the use of brilliant red is good only about 6 months. We have found a distinction method by perceiving the age of sea urchin. It can be done by measuring the size of the rings that appear on genital plate. As indicated in Figure 11, the size of the first ring is different. The size of the first ring of a released sea urchin is about 1,090 μ ; natural sea urchin, 340 μ. The second ring appears at 2,200 μ and 1,560 μ respectively.

Next, I would like to talk about the direct release of small seeds with test diameter 5 to 10 mm and without nursery. It was studied in Erimo where I have mentioned in the part of production facility of artificial seeds. On May 12,1989, 12,000 seeds with average test diameter of 6.7 mm (maximum, 9.3 mm ; minimum, 5.3 mm) were released at a point rich in algae with the depth of 3 to 4 m. According to the survey conducted on October 30, 1990, 536 days after the release, test diameter reached 44.5 mm on average. 11 % becoame larger than 50 mm (Figure 12). With respect to remain, 3,563 individuals were caught a year after the release. 2,769 individuals were caught onOctober 30, on the day survey was completed. The total number reached 6,332 individuals, giving 52.8 %. A good achievement was obtained. Concernig

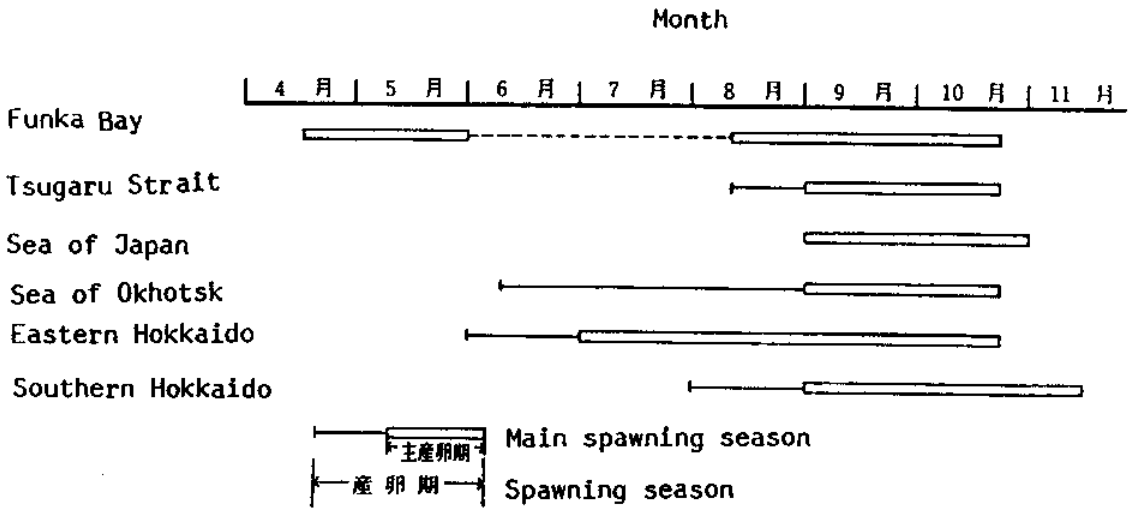


Figure 10 Spawning Season of *Strongylocentrotus intermedus* in Hokkaido Coast

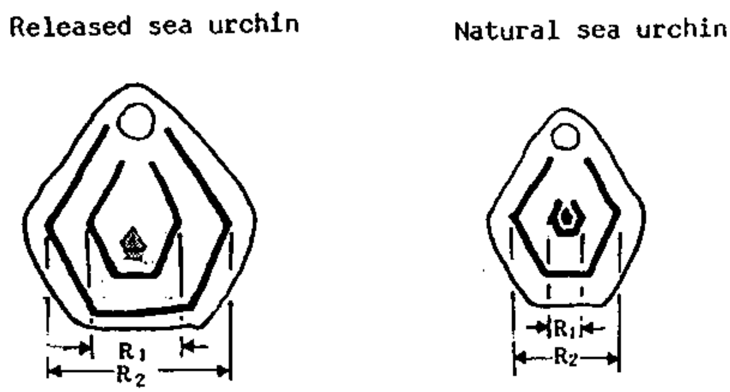


Figure 11 Compare of Released Sea Urchin with Natural Sea Urchin by Annual Ring

(HHFES 1985)

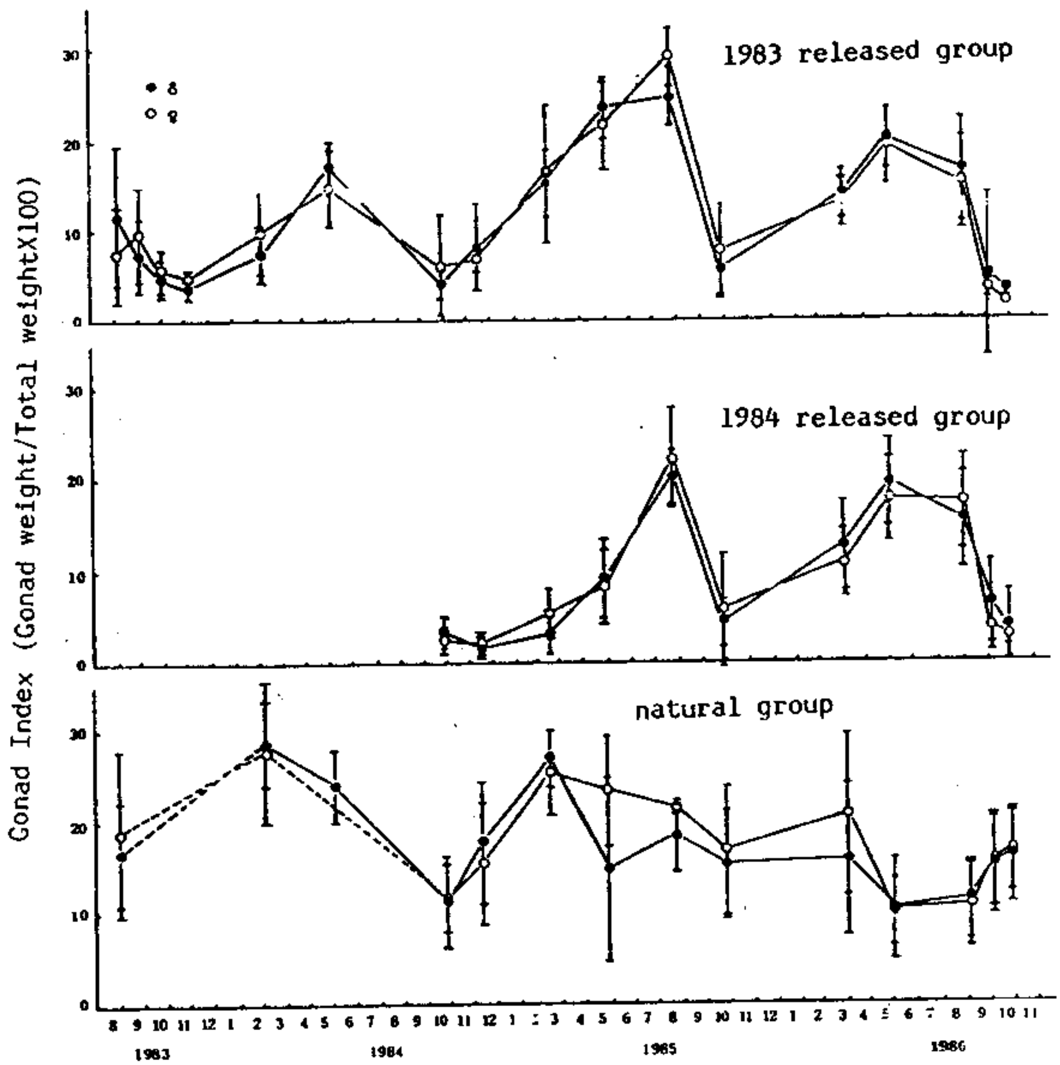


Figure 9 Seasonal Change of Gonad Index of Released and Natural Sea Sea Urchin (HCFES 1986)

the experiment in Akkeshi where small seeds were released, materials are not sufficient due to rough weather after the release.

In Japan, Equipment and Development Works of Coastal Fishing Ground (Ensei) are put into effect in purpose to build artificial ground for sea urchin and others. The policy is to help the reproduction of marine animals and plants, and to protect and grow artificial seeds on artificial maricultural ground.

In Shiriuchi near Hakodate, the structure as shown in Figure 13 was built in 1985. On August 22, 39,500 seeds with test diameter of 21.9 mm were released. The changes in test diameter after the release are shown in Figure 14. After a year and 7 months (578 days), they grew up to 58.5 mm. The amount of food algae given during this period is shown in Figure 15. The assumed remain after 578 days is obtained by multiplying average density by the area of fishing ground, getting 25,800 seeds. Among them, artificial seeds take up 82 % according to the method of distinction, as I have reported, by measuring the size of the ring that appears on genital plate. 21,200 seeds remained alive. Since 1,000 seeds were caught for study, tje ratio of remain is 55.1 %. This is higher than the value of Otaru, an ordinary fishing ground. Afterwards, catches were attempted by scuba-divers for 3 times between June and July. It is assumed that 19,067 individuals were artificial. The ratio of catch reached 89.9 % (on the hypothesis that there is no change in the surroundings).

Various examples of the release effects of artificial seeds have now been reported. Let me describe on economic effect in the cases of Otaru and Shiriuchi.

In the case of Otaru (the results of 1983 and 1984), the area of 100 m X 100 m was exlusively used for 2 years. The difference of income (remaining seeds X catch ratio X ganad weight X price) and expenditure (seed cost + release personnel fee + seed transportation fee + miscellaneous) is

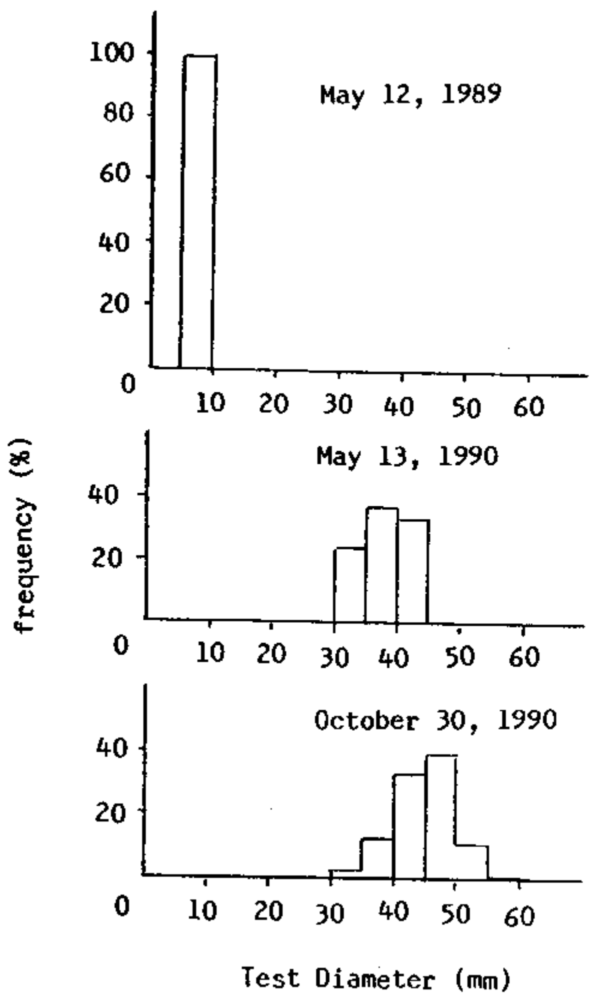


Figure 12 Test Diameter Distribution of Released Sea Urchin at Erimo

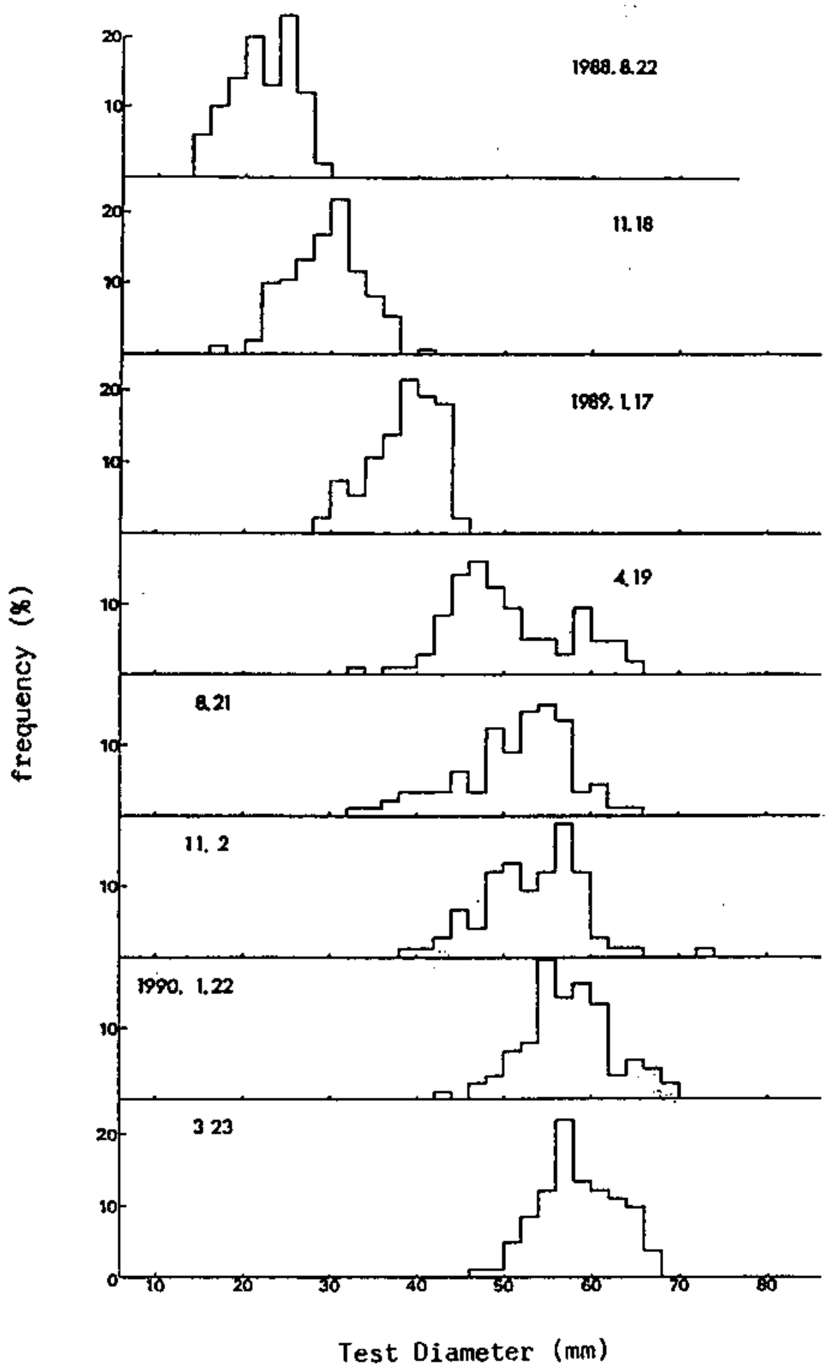


Figure 14 Test Diameter Distribution 1985 Released Sea Urchin at Shiriuchi (HHFES 1990)

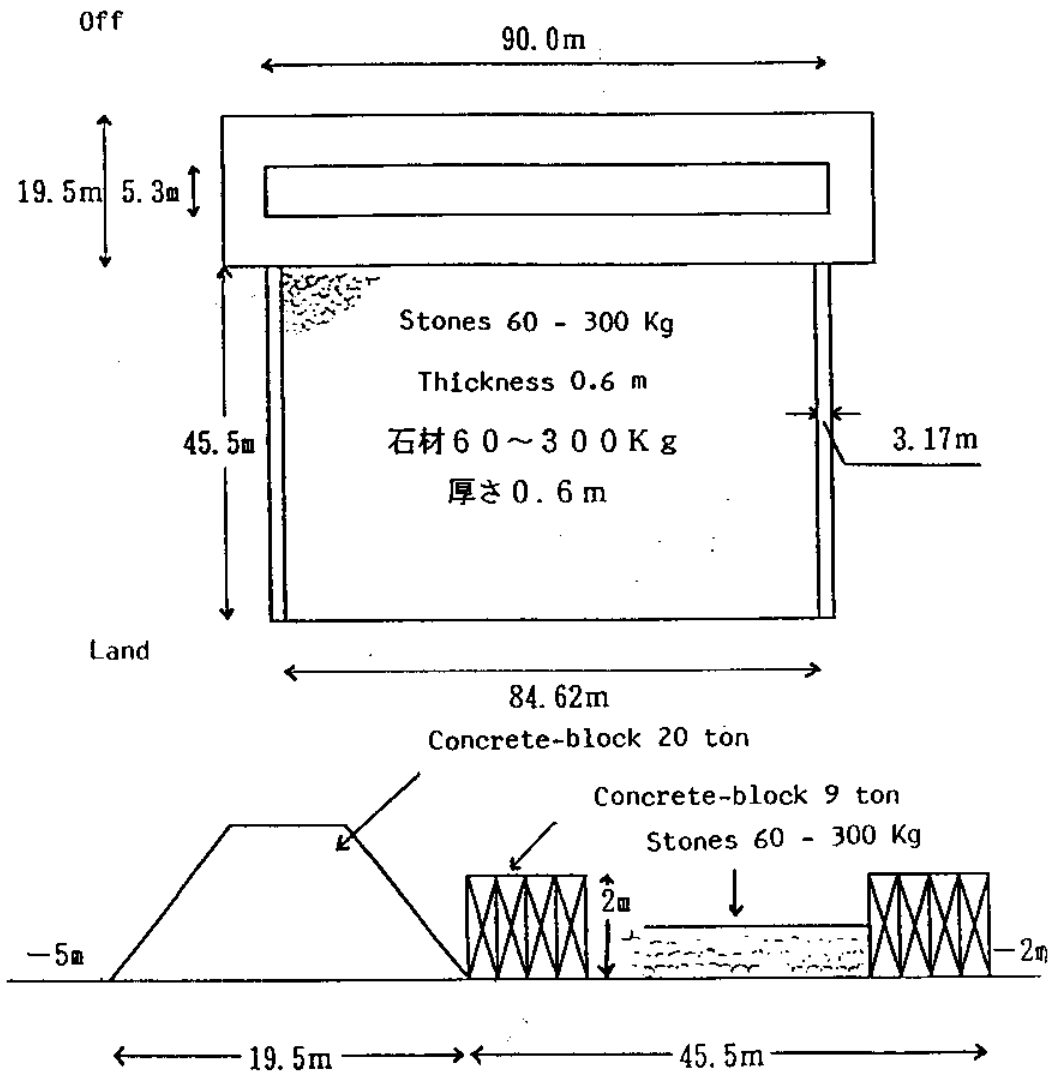


Figure 13 Facility of Artificial Fishery Ground for Sea Urchin at Shiriuchi

¥ 378,560 = (¥1,797,120 - ¥1,040,000)÷ 2. Three years later, the catch ended with ¥574,933 (¥2,764,800 - ¥1,040,000) ÷ 3.

The amount of production per boat per operation (4 hours) is in the case of 2-year catch by 24 boat-days ¥31,546 = ¥757,120 ÷ 24 ; 3-year catch, ¥71,866 = ¥1,724,800 ÷ 24.

The result of the catch in Shiriuchi is given in Table 11. By the catches for 3 times, the income was ¥3,563660. The expenses were the cost of seeds, ¥ 1 million (Y25X40 thousand seeds) ; scuba-divers' personell fee for 12 person-days (4 persons X 3 times), ¥600 thousand ; the rental fee for fishing boat, ¥25 thousand X 3 times = ¥75 thousand. In total, the expenditure was ¥1,675,000 taking up 90 % of the catch. The difference was ¥1,888,660. It was ¥157,388 per diver. If the catch is completed by diving twice and if the catch ratio is 80 %, the income will be ¥1,731,340. The cost willbe ¥1 million + ¥400 thousand + ¥50 thousand. The diving cost will become ¥216,418 per diver and about ¥60 thousand more than the catching 3 times. At first, since it was aimed to catch all what remained, the catch was conducted 3 times. But, if economy is put into consideration, the catch ratio should be assumed 80 %.

As thus the examples of the enhancement experiments on sea urchin (countermove) were studied, present main policy is 1) to build more facilities for artificial seed production (increase in the number of release). 2) to establish release technique, 3) to establish management technique and 4) to verify economic effect.

As for 1), 17 places in Hokkaido are growing planktonic lavae of *Strongylocentrotus intermedus*. More facilities are scheduled to be built in the near future. However, if the temperature keeps on being high (especially above 23 ℃) in summer like in these years, the problem of falling dead becomes important. In order to overcome this problem, the seed of *St.nudus* which is strong to high temperature will be produced. Since its intake of food is a lot more than that of *St. intermedus*, a measure to produse more food algae becomes necessary.

As for 2), the reason why the ratio of remain is low is due to the troubles right after the release. More measure are necessary to study the ecology of harmful animal (crab : *Pugettia quadridenss* and starfish *Lysastrosoma anthostictha*) and to be able to correspond to the characteristics of each individual locality with respect to release size, time and spot.

Table 11 Result of Catch at Shiriuchi

(HHFES 1990)

date of catch	Jun.28,1990	Jul.19,'90	Jul.31,'90	total
number of catch	16,902	4,153	2,199	23,254
mean test diameter (mm)	61.8	61.8	67.0	
mean weight (g)		69.6	110.1	
gonad index (%)	12.4	13.9	14.8	
number of released seed	13,859	3,405	1,803	19,067
assumed exploitation rate (%)	65.4	81.4	89.9	89.9
weight of catch (Kg)	1,590	365	198	2,153
unit cost (yen/Kg)	1,900	2,360	2,360	2,020
amount of money (yen)	3,021,000	861,400	467,280	4,349,680
weight and money of	1,303	299	162	1,764 (Kg)
released seed in catch	2,475,700	705,640	382,320	3,563,660 (yen)

Red Sea Urchins in SE Alaska: Status of Research and Management

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by

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Abstract

The red sea urchin resource of Southeast Alaska is largely undeveloped. Management is based on a conservative application of a surplus production model that allows an approximate 3% rate of harvest on an annual basis. This management approach requires an annual assessment of abundance. The state of Alaska has begun a research program to improve management and to test the possibility of sustaining larger harvests. This program includes 1) testing new assessment methods, 2) research on population biology, and 3) consideration of ecological interactions in the urchin/kelp/otter community.

I. Introduction

In this paper I describe the history and current status of commercial fisheries for sea urchins in Alaska, as well as the intention of the Alaska Department of Fish and Game for research and management over the next several years. I will describe the conservative nature of our fishery management, the reasons for this, and how our conservative approach guides our plans for research to support our management effort.

The sea urchin resources of Alaska are mostly undeveloped for commercial harvest. Red sea urchins (Strongylocentrotus franciscanus) have been harvested commercially since at least 1981, mostly in the Ketchikan area (Figure 1), with a peak harvest of over 600,000 pounds in 1987 (Figure 2). In 1991 we began a commercial fishery management program in the Sitka area, and this is currently the only location in Alaska scheduled for a red sea urchin opening this year. A green urchin (S. drobachiensis) fishery has been ongoing in the Kodiak area since 1985, where urchins are exported live to Japanese markets. Harvests in the Kodiak area have averaged 70,000 pounds in the past 7 years.

We anticipate increased interest and pressure for expanded commercial fishing opportunities for urchins in Southeast Alaska, and for that reason we are developing a management plan for red sea urchins that will provide for orderly fishery development and for sustainable harvests. Development of the management plan is funded in part by the Pacific States Marine Fisheries Commission.

II. Management Approach in the 1991 Season.

A. Methods.

Our management approach for urchins is to make a very conservative application of a modified surplus production model to estimate the sustainable yield from an unexploited stock. This approach was spawned from our sea cucumber management program. The model assumes that the maximum sustainable yield, or annual quota, can be calculated directly from the "virgin" population size, provided that an estimate of natural mortality is available:

$$\text{Quota} = CF \times GF \times M \times P_0 \qquad (1)$$

where

CF = 0.4	scaling factor relating maximum sustainable fishing mortality to unexploited population size (e.g. Caddy 1986);
GF = 0.5	correction factor due to Garcia et. al (1989) to allow for errors in assumptions upon which the surplus production model is based;
M = 0.16	estimated instantaneous mortality rate for red sea urchins using method of Van Sickle (1977) as described by Woodby (1991) for the Sitka area; and
P_0 =	virgin population size, taken as the lower bound of a one-sided 90% confidence interval.

This model is based on the assumption that the maximum sustainable yield occurs at half the virgin biomass level (Schaefer 1954), and that the maximum sustainable fishing mortality is equal to the natural mortality rate (Tiurin 1962, Alverson and Pereyra 1969). The various correction factors in equation 1 provide for a conservative harvest (about 3% per year) that is justified in developing fisheries where little is known about productivity. This approach was necessary for the sea cucumber fishery in Alaska, in which case it satisfied a legal challenge demanding a cautious and conservative approach to protect interests of subsistence users. More is known about the population biology of sea urchins than of sea cucumbers, and in part III below I describe our attempt to develop a more realistic management plan.

Management based on the model in equation 1 requires an estimate of the population biomass or size. Additionally, our original intention was to institute upper and lower size limits based on the size frequency distribution. The lower size limit was proposed to allow one or more years of reproduction prior to recruitment to the fishery. The upper size limit was proposed to ensure the viability of an adult spine canopy to protect small urchins from predation, in anticipation that the shelter-association observed between small and large urchins in southern California (Tegner and Dayton 1977) would be found to occur in Alaska.

Management in the Sitka area began with a test fishery in the fall of 1990 to assess abundance and estimate the size frequency distribution. We contracted with commercial divers, who we supervised while on board a commercial dive boat. After some trial and error, the method we devised was for commercial divers to survey 1 meter wide strip transects running perpendicular to shore across the depth contours to 12 meters depth. Transects were evenly spaced along the 110 km of shoreline to be opened to fishing. We estimated densities as the number of urchins per linear meter of shoreline length, and multiplied the density times shoreline length to estimate total population size. We used this shoreline length method as an alternative to the more usual method of estimating densities as numbers per square area, and we did so because of the relative ease of accurately measuring shorelines as opposed to estimating total area of subtidal habitat.

In sum, the assessment method may be unique in two ways: 1) we attempt to estimate the total population for the entire region open to fishing, and 2) we attempt to account for sampling error by using the lower bound of the confidence interval for our estimate of mean density.

B. Results.

Our results indicate fairly high densities of a mostly old-aged population with apparently infrequent recruitment (Figure 3). The average density of legal-sized urchins (76-127 mm) was 33.6 per linear meter of shoreline above the 12 meter depth contour (standard error = 9.8; n = 13 transects). The lower bound of the 90% confidence limit for the mean is 20.9 urchins per meter (62% of the mean), based on a ratio statistic estimate of variance (Cochran 1977; used to account for transects of several widths).

We found a clear association between the smallest and the largest urchins in a random sample of 588 individuals larger than 10mm (Figure 4). Of the 63 urchins which were less than 40 mm in diameter, 47 (75%) were underneath the spine canopy or test of large urchins 60 mm or more in diameter. In fact, all but one (97%) of the 34 urchins less than 20 mm in diameter were underneath the spine canopy or test of larger urchins. These smallest urchins were undoubtedly young of the year. Urchins that provided shelter made up only 4.6% (n = 21) of all urchins (n = 464) over 60mm width, and ranged in size from 60 to 135 mm (mean = 102 mm).

Approximately 60% of all urchins fell within the proposed legal size class range of 76 to 127 mm (Figure 3). Approximately 29% of all urchins were smaller than 76 mm, and 11% were larger. A management decision was made to remove upper and lower size limits for the fishery, because 1) most of the urchins were within the size range anyway, and 2) the harvest rate was very conservative and no major impact was anticipated on large or small urchins.

The fishery was opened in January and proceeded slowly until March and April when a handful of experienced divers harvested the quota of 220,000 urchins.

III. Current Research: More Realistic Management.

Having established a conservative approach to development of the urchin fisheries in Southeast Alaska, we are now beginning a four year research project to improve our management methods. Specifically, the objectives of this research are to:

1) develop and test new methods for population assessment,
2) estimate population parameters necessary to establish sustainable harvest levels, and

3) develop management objectives that recognize the role of urchins as grazers on kelp and the potential for sea otters to drastically reduce urchin populations.

This research is being conducted in Sitka Sound, and we will evaluate the potential for expanding our results to other areas of Southeast Alaska.

A. Assessment Methods.

Our management method is dependent on estimates of total abundance, and we have now used two methods to obtain those estimates. Last year we made estimates based on test fishing by commercial divers, and this year our own divers conducted the surveys. Despite our efforts to design survey methods this year to be similar to those used in the test fishery, we found dramatic differences in the results. In particular, density estimates by Department divers were about 4 times higher than those made in the previous year by commercial divers. This difference can be attributed in large part to survey conditions. The test fishery was conducted within a 12 day period in the fall of 1990 under poor weather conditions that often precluded visiting the more exposed, and possibly more productive sites. Even in the accessible sites, surge conditions often prevented the test fishery divers from gathering urchins in the shallower zones of each transect, so that total counts were often biased to the low side. In contrast, Department divers have been making assessments over a 5 month period, and have been able to select days with good survey conditions.

We are satisfied with the results from surveys by Department divers, but plan like to experiment with alternative methods that may be useful for large-scale assessment efforts. These methods include the use of remotely operated vehicle (ROV's) and hand-held video systems.

B. Experimental Fishery.

Our management approach allows harvests equal to the natural replacement rate in a mature, virgin stock, which we have conservatively estimated as about 3% per year. This rate may be overly conservative if, for example, urchin population growth rates are negatively density dependent. To test this possibility, we are initiating an experimental fishery program to allow harvest rates of about 20% or more in isolated areas. Our research protocol is to monitor the population densities and size frequency distributions on an annual basis in these experimental areas as well as in control areas for at least the next four years.

C. Population Parameters.

Our management is based in part on research results from more southern locations, and it is our intention to flesh out our understanding of the population biology of red sea urchins by conducting research on rates of recruitment, growth, and mortality, and to assess how these may vary in time and across habitats and geographic areas. We are also initiating monthly assessments of roe maturity, to help us select appropriate fishing seasons.

D. Ecological Relationships.

It is possible that sea urchin harvests may bring about direct and indirect effects on the distribution and abundance of kelp and various species associated with the kelp community. Although we are limited in our ability to actively monitor such changes, we plan to incorporate a monitoring program for kelp and macroinvertebrates in our experimental fishery program.

Our research and management program is directed at providing sustainable harvests without causing serious harm to other species in the nearshore environment; however, this effort may become moot if current trends in sea otter population growth continue. Otter populations have been growing at rates of about 20% per year throughout Southeast Alaska (Pitcher 1989). These populations are the result of introductions from 1965 to 1969 at 6 locations on the outer coast (Figure 5). The largest population segment, with over 2000 otters, occurs immediately north of Sitka Sound, and there is also an expanding population immediately to the south. The merging of these populations in Sitka Sound has been predicted to occur in the very near future (Pitcher 1989). There is little doubt that sea otters in Alaska have the potential to drastically reduce the population density of urchins, as suggested by our own observations north of Sitka, by research at Yakobi Island (Duggins 1980), and by observations in the western Aleutians (Estes and Palmisano 1974).

Sea otters are protected from exploitation in Alaska except for traditional use by native peoples, and are under the jurisdiction of the U.S. Fish and Wildlife Service. As a state agency without management authority for sea otters, our management approach is to simply monitor incursions of otters into the commercial fishery area, and to document changes to the urchin populations.

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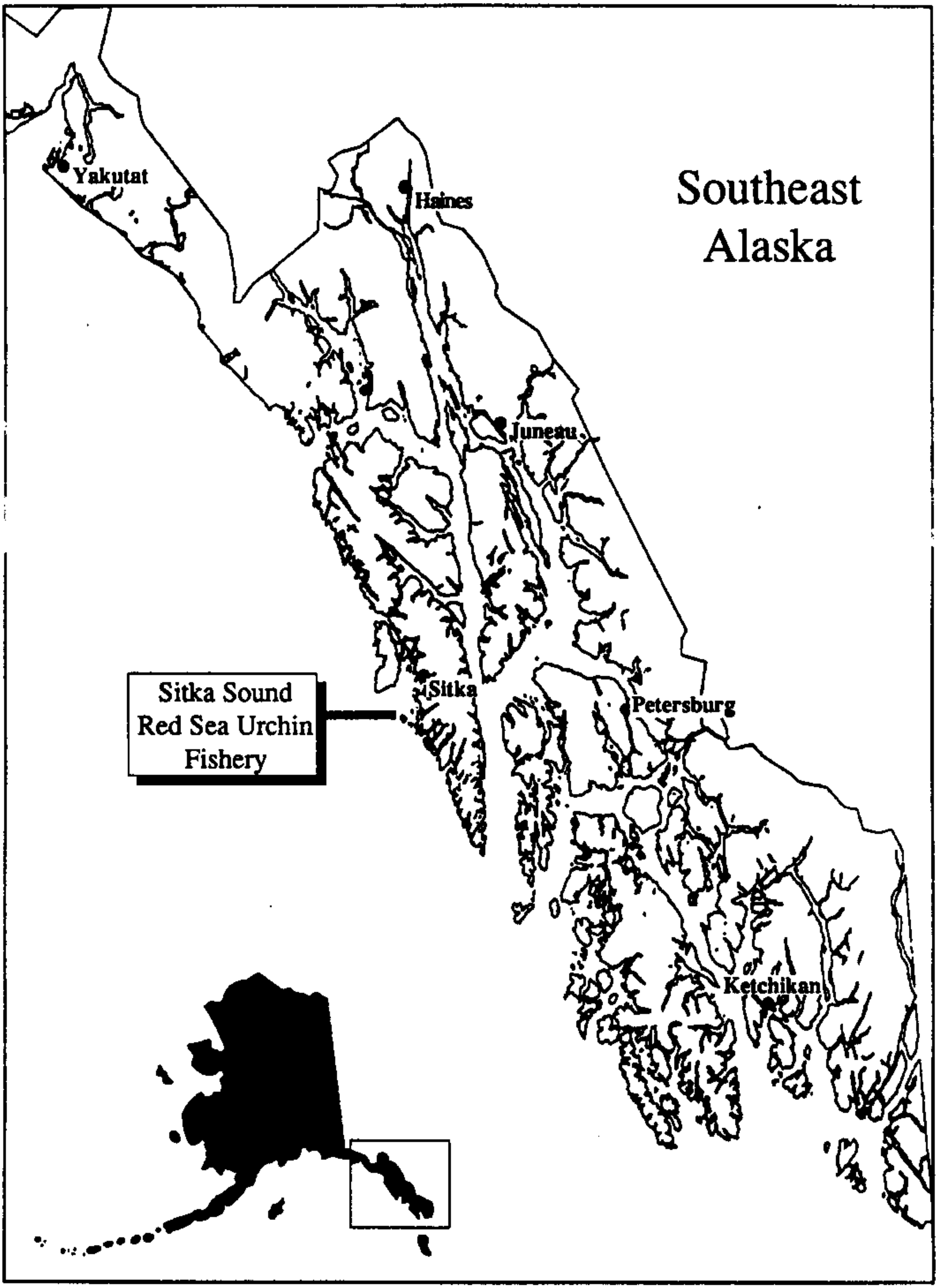

Figure 1. Location of red sea urchin fishery in Southeast Alaska, 1991-1992.

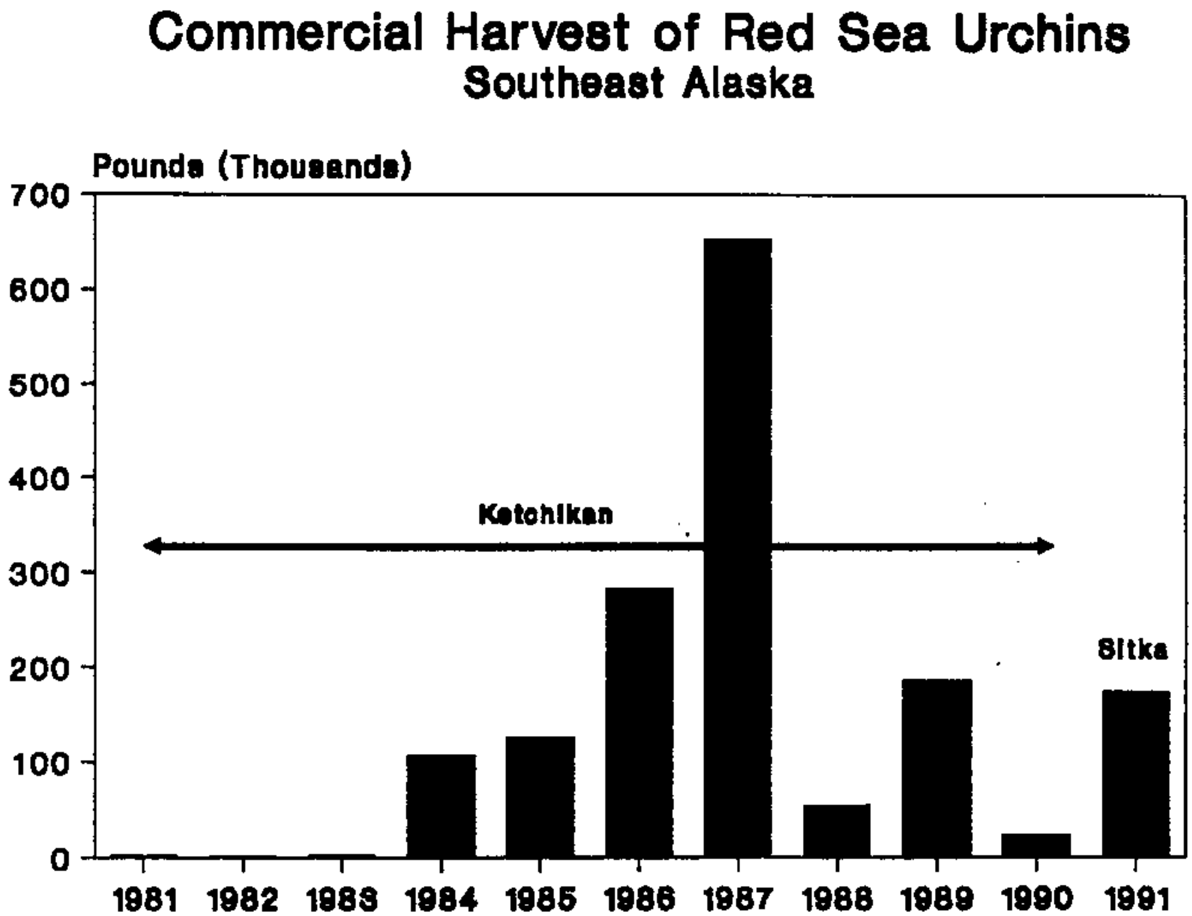

Figure 2. Commercial harvest of red sea urchins in Southeast Alaska from 1981 to 1991.

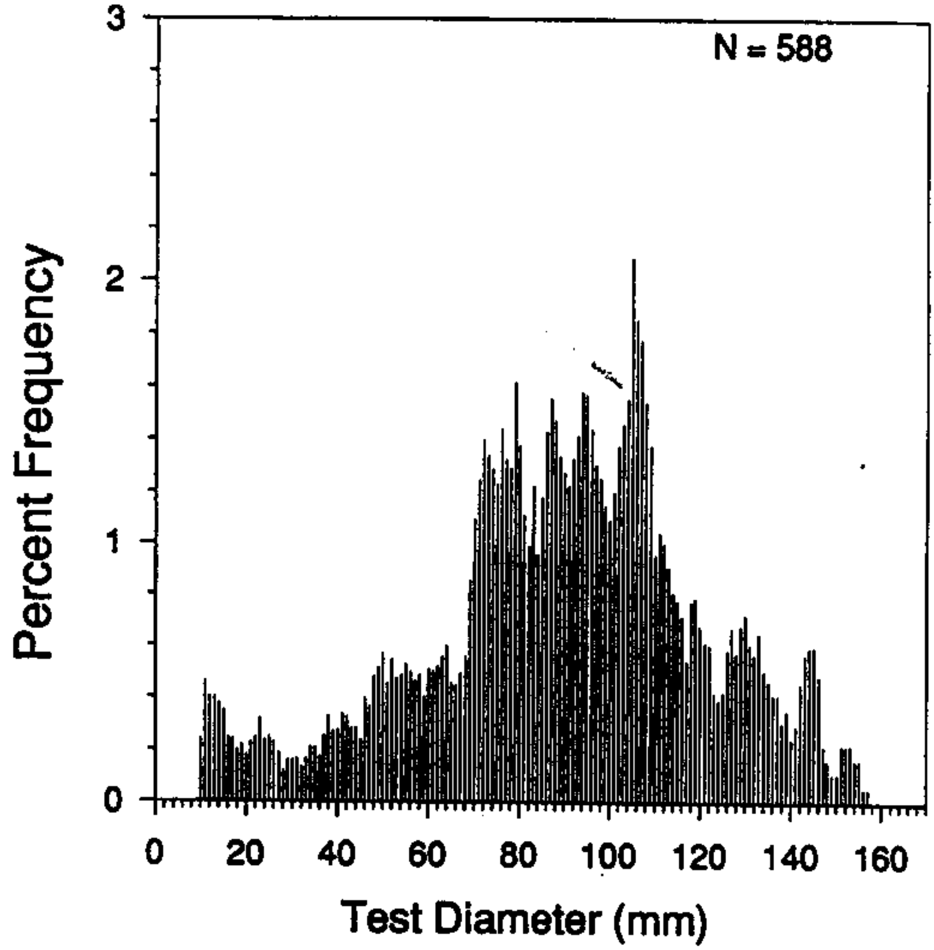

Figure 3. Size frequency distribution of 588 red sea urchins collected from 12 transect locations in southern Sitka Sound, 1990. Frequencies are weighted by the density of legal-sized urchins on each transect, and smoothed by means of 5 mm moving averages.

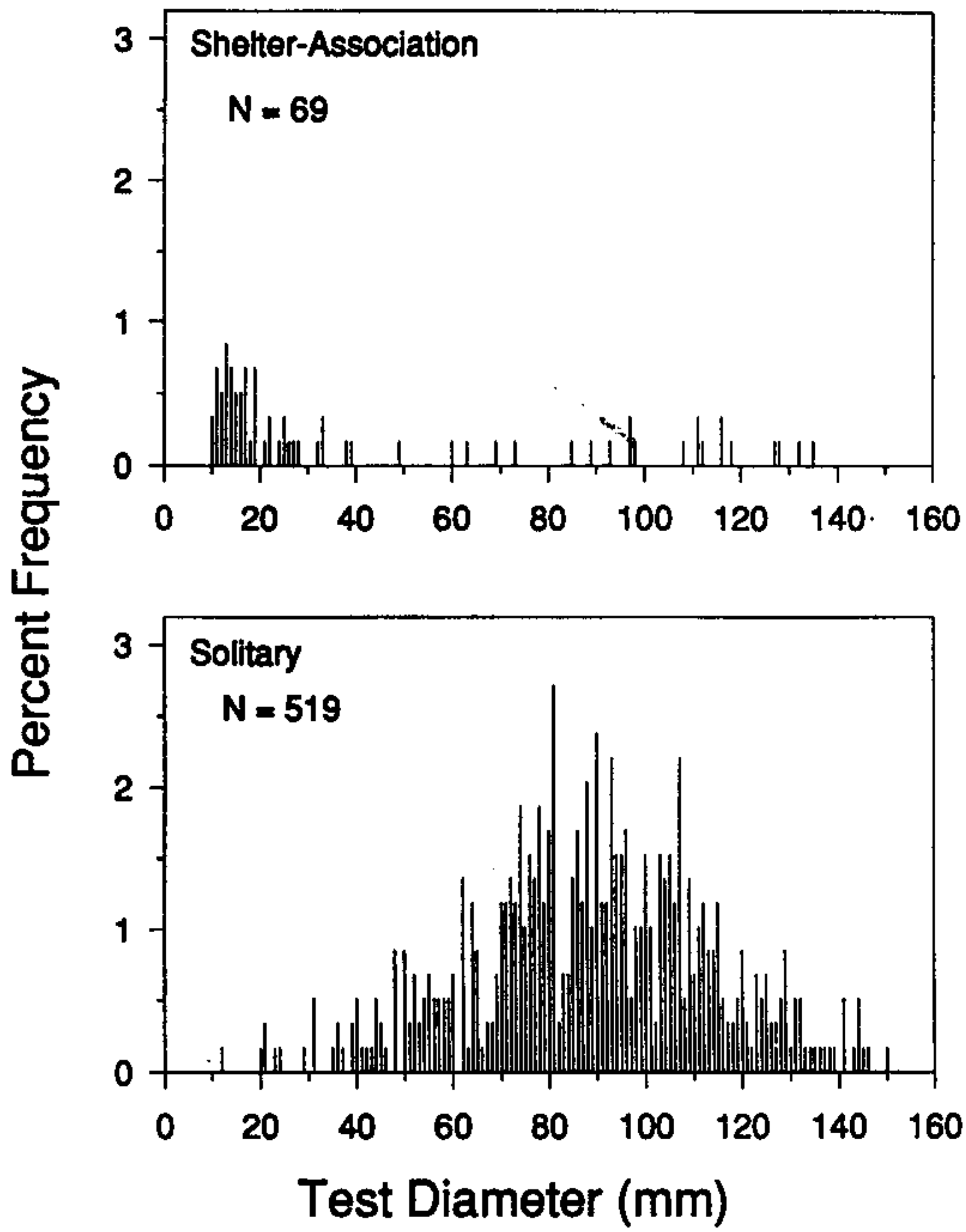

Figure 4. Size frequency distributions of shelter-associated and solitary urchins in southern Sitka Sound, 1990. Frequencies are not weighted or smoothed. Shelter-associated urchins are those underneath the spine canopy of large urchins as well as those having small urchins underneath their spines. This figure indicates that nearly all of the smallest urchins less than 20 mm diameter are underneath larger urchins.

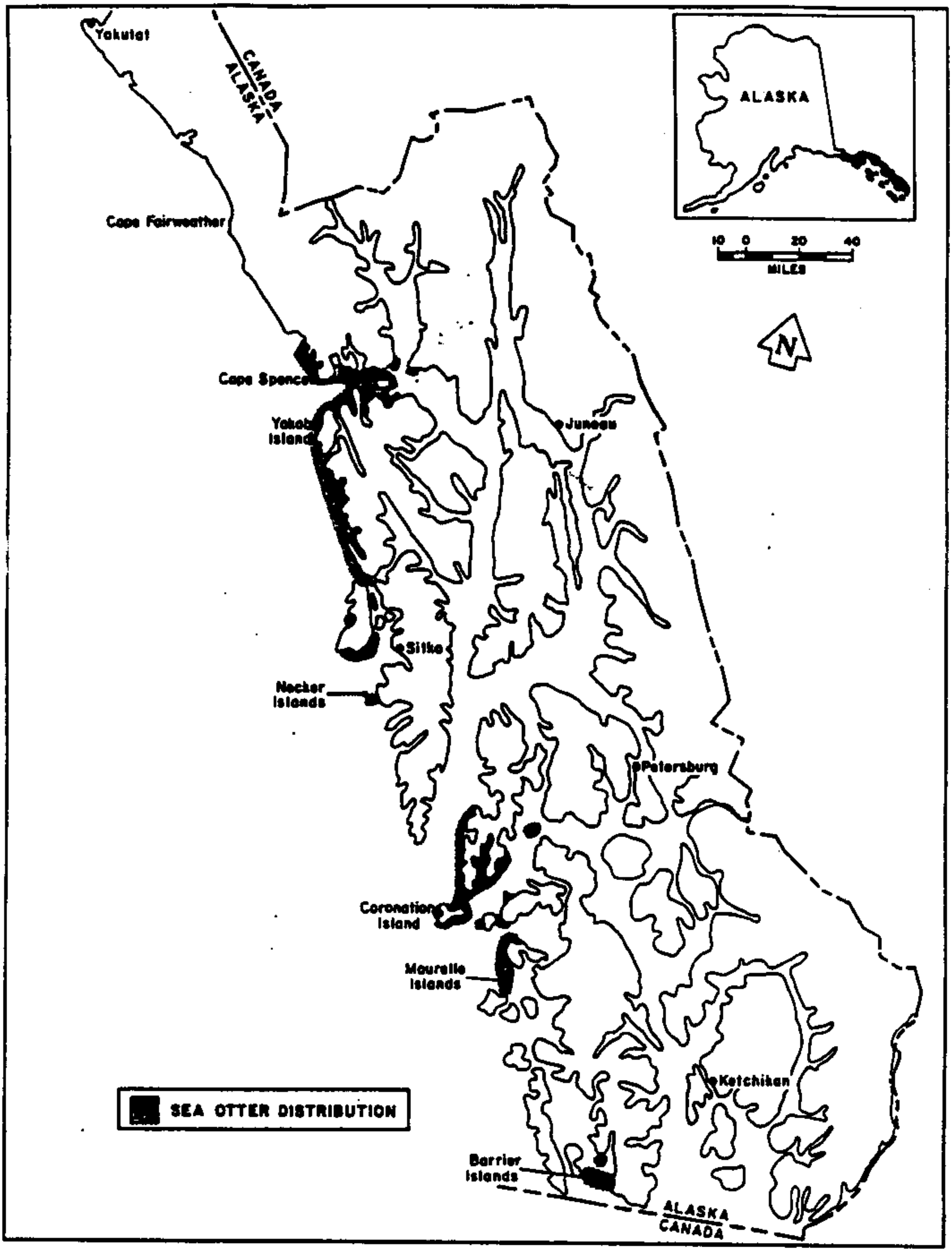

Figure 5. Range of sea otter populations in Southeast Alaska as of 1989 (from Pitcher 1989).

MANAGING ABALONE FISHERIES BY QUOTA IN AUSTRALIA, SOUTH AFRICA AND NEW ZEALAND: A REVIEW

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ABSTRACT

Abalone fisheries in Australia, South Africa and New Zealand developed during the 1960s and were initially managed by regulations on input (licence limitation, closures etc). These have gradually been superseded by output controls namely quotas which confer fishing rights on fishers. Further developments in management are now in progress, as the implications and advantages of more clearly defined fishing rights are explored.

Benefits of quotas are: more efficient use of capital and manpower through reduction in competition; better control of catch levels; reduction of conflict between divers and managers; and administrative efficiency.

Problems of quotas are: quota-busting and associated data-fouling (this is minor in Australia, New Zealand and South Africa where high incomes of divers reduces incentive to cheat); maldistribution of effort leading to uneven exploitation of reefs.

The most serious problem in managing abalone fisheries is poaching. The illegal catch is high in New Zealand and New South Wales amounting to almost 50% of the legal catch. Elsewhere it is contained to < 20% by intense surveillance and severe penalties.
The commitment of governments to principles of ecologically sustainable development explicitly requires that the total allowable catch should be based

The commitment of governments to principles of ecologically sustainable development explicitly requires that the total allowable catch should be based on rigorous stock assessments. So far management of abalone fisheries has fallen far short of this ideal. Quotas have been based on historical catch levels, assumed to be stable, and adjusted by managers in consultation with divers according to subjective perceptions of abalone abundance. The adjustment process is not completely haphazard. Divers fish to certain bio-economic expectations of catch levels and when these are not met, they perceive a decline of stocks. Those perceptions are taken to the negotiating table when quotas are decided.

Stock assessments of several kinds have been used. They include research diver surveys, and mapping of abalone habitat (in South Africa, South Australia and Victoria). Egg-per-recruit analyses and size limits set to maintain high egg production levels of 40-50% (eg. South Australia, Tasmania) have also been used, not to set quotas, but to reduce the risk of recruitment overfishing. But stock assessments of any kind have rarely been systematic, no-where complete and always spasmodic. The reason is that costs are high and neither government nor industry has committed itself to such a program. The current, imperfect methods of setting quotas are no longer a sound basis for management given the over-riding responsibility of government to conserve stocks.

Management of abalone fisheries by quota is now a permanent feature, but substantial improvements are possible. The transformation of fishing rights to area rights to give exclusive rights over defined reefs to individual divers is a logical extension. The formation of associations of quota-holders with statutory rights to levy members and manage their fishery, with the government retaining responsibility for enforcement, maintenance of stocks and environmental integrity is the ultimate long-term development.

INTRODUCTION

The major abalone fisheries in the world are those of Australia, New Zealand and South Africa. Other once significant fisheries in Canada, California, Mexico, Chine and Oman have declined or are doing so due to overfishing and other factors.

Such declines are not surprising because abalone fisheries are notoriously difficult to manage. This arises through a combination of factors. First, abalone form and reform aggregations during fishing. Divers target the largest aggregations serially according to certain expectations of catch. In consequence the usual indicators of stock abundance, such as catch-per-unit-effort (CPUE) are of dubious validity. Without this source of information it is difficult and costly to obtain stock assessments, although simulations of these complex features are now being developed (Prince *et al* 1991).

The problems associated with controlling the fisheries, mainly increasing effort, led to a shift in management, from a regulatory system based on licence limitation, to a system based on conferring fishing rights on divers. These rights give to divers either specific quotas or percentages of a total allowable catch (TAC) and have many features of property rights.

In Australia, New Zealand and South Africa divers now enjoy such rights, but they are still subject to many aspects of the former regulatory system.

It is now timely to assess management of abalone fisheries in these countries and suggest future directions for more efficient and effective management.

RECENT MANAGEMENT HISTORY

The history of management of abalone fisheries in Australia, South Africa and New Zealand is given by Prince and Shepherd (1992), Tarr (1992) and Schiel (1992). Licence limitation was introduced in each fishery early in their development to prevent expansion beyond sustainable yields. As limitations in the policy became manifest, quotas were adopted.

South Africa led the way with a TAC in 1968. The TAC was later reduced and divided among 9 distinct fishing zones. In 1985 divers were granted individual transferable quotas (ITQs) based on previous catch performance but were obliged to deliver catches to specific buyers, thus securing a high level of vertical integration in the fishery. Holders of ITQs wishing to sell were obliged to offer their quota holding to existing holders. This has resulted in the gradual accumulation of quota entitlements by the remaining divers. Few new divers have entered the fishery, and by 1990 the mean age of divers was 45 years.

New Zealand followed a similar course to South Africa. First, a kind of TAC, in the form of export control, was introduced in 1973. In 1984 individual quotas were established and became full ITQs in 1986. ITQs were allocated on the basis of previous catch history and were distributed among 10 fishing zones. A feature of this fishery is the large number of quota holders, most of whom hold only a few tonnes (Fig.1). Some 65% hold 5 t or less.

In Australia quotas were introduced independently by the 5 States with abalone fisheries, between 1985 (in Tasmania) and 1989 (in New South Wales). In each State equal shares in the TAC were allotted to licence holders. Where the number of licensed divers was thought to be excessive a two-for-one policy, in which a buyer had to acquire two licences, was used to reduce the number of licensed divers.

HOW SUCCESSFUL IS MANAGEMENT BY QUOTA?

Quotas were initially introduced to obtain a better control of the catch. But they were also seen by economists as a means of promoting economic efficiency (eg. Pearse 1982, Scott 1989) and facilitating planning. In Australia, at least, they followed licence transferability and increased capitalisation which caused an escalation of fishing effort (Prince and Shepherd 1992).

There is no doubt that the quota management system has been a successful innovation in abalone fisheries. Initially accepted reluctantly by many divers, the system soon became universally embraced by them as a better way of management. Criticism was directed only at administrative aspects that could be improved. The benefits of quotas have been well documented and recently reviewed in New Zealand (Pearse 1991) and Tasmania (Harrison 1990). In relation to abalone fisheries they are these. Competition between divers is reduced. They can spread their effort optimally throughout the year and so presumably can invest capital and employ labour in the most economical way. Harvest gluts can be avoided and income maximised in accordance with the pattern of demand. Fisheries managers also embraced the system, initially because it gave complete control over the catch, but later because conflict between managers and divers was reduced. Divers now had vested property interest in the fishery and their associations soon came to accept greater responsibility for prudent and conservative management. In Australian States divers have frequently taken the initiative in pressing for conservation measures (see below).

Perhaps the successful application of a quota system to abalone fisheries should not be surprising. The population biology of abalone lends them to quota management. The species are long-lived and relatively slow-growing. Individuals aggregate spatially to form concentrations comprising many year-classes. Populations tend to be stable over time despite fluctuations over time which may induce long-term cycles of abundance (eg. Shepherd 1990). For species with these characteristics, annual quotas can be set with reasonable certainty (Copes 1986). With high size limits the TAC is only a fraction of the total biomass and there is a lag time of at least 5 years from larval settlement to recruitment to the fishery. Hence adjustments on an annual basis can be made as required to ensure conservation of the stock.

Another reason for the success of quotas is the limited scope and incentive for cheating. A very high proportion of the catch is exported and local outlets are small and few. These can be more easily policed for illegal sales, so reducing the incentive of divers to cheat. In South Africa a proportion of the TAC is appropriated by law to the local market, thereby reducing the opportunity for illegal abalone to enter that market.

It is claimed by some (Copes 1986; Pearse 1991) that full transferability of quota entitlements is a basic and necessary characteristic of an ITQ system. Transferability facilitates rationalisation ie. the removal of excess capital and manpower from a fishery. In Australia (Tasmania excepted) quota entitlements are not permanently transferable, only within a season, so there is no scope for different levels of holdings. More efficient operators cannot buy out less efficient ones, nor is it possible for entrants to buy their way in gradually.

In Tasmania a more complex system is now operating (Harrison 1990). Divers can acquire up to 80 units of quota (1 unit ≈ 600 kg) which are fully transferable. Further, in two States (Tasmania and South Australia) the government has established financial registers so that licences or units of quota can be used as security for loans which are then registered. This facilitates trading in quotas. Improving the security of a loan by means of registration of the interest reduces the risk and therefore the interest rate. Ultimately this reduces the capital cost of quotas.

In the Australian States it often is difficult for entrants to abalone fisheries to find the capital (up to $1.5 million) to buy a licence. This has given rise to a large variety of contractual arrangements between buyers, financiers and sellers of licences (or quota). Examples are given by Harrison (1990). They include cases where a processor of abalone finances the purchase of quota units and imposes contractual obligations on the diver regarding the supply of quota to him, and cases where the financier is the beneficial owner and the diver is lessee without equity in the licence, receiving as little as 15% of the gross income. In other cases the diver becomes heavily indebted and finds himself working for very little return. The Tasmanian Working Group (Harrison 1990) considered these cases to be undesirable social outcomes of the quota system. The system now in operation there is complex (Appendix I) and it has not been working long enough to evaluate it. The optimal system would appear to be one in which quotas are fully transferable, but with an upper and lower limit to the number of quota units that may be held. The New Zealand system is closest to this model.

Quota-busting and its concomitant, data-fouling, was considered by Copes (1986) to be a serious objection to many quota systems. Although it is impossible to ascertain the true extent of cheating on quotas, divers associations and enforcement agencies consider it a minor problem. The current well-being of divers and lack of local outlets give little incentive to cheat.

On the other hand illegal fishing, or poaching is a serious problem. The problem arises, not as a consequence of the quota system *per se* but of licence limitation. In New Zealand the illegal catch has been very high and Schiel (1992) estimated that it amounted to nearly 50% of the legal catch in one year. In Australia the problem is equally serious. In New South Wales the illegal catch is thought to be 30-40% of the legal one (G. Hamer pers.comm.); in South Australia it is estimated to be 15-20% (Hutchinson 1991) and similar figures are suggested for Victoria. Poaching is likely to remain endemic in abalone fisheries. This is due to the high value of the product, the ready accessibility of abalone beds and the high densities of abalone within those beds. The problem can only be met by increased surveillance and the imposition of severe penalties.

FIXING QUOTAS

The acceptance by governments of the principle of ecologically sustainable development (ESD) has firmly established ecosystem management on centre stage with conservation of the fished species as one element, albeit an important one, of the process. Safe catch levels based on adequate data, or in their absence estimated on risk-aversive criteria become essential components of the policy. How far is management for abalone fisheries from this ideal?

In this section I describe the way in which quotas have been historically fixed, and the practical problems in fixing quotas. I argue that a much stronger commitment by government and industry needs to be made if fixing quotas is to be put on a scientific footing as required by ESD policy.

In New Zealand quotas have been based on estimates of the maximum constant yield (MCY). The annual production figures for a number of years after removal of the initial virgin population, were averaged, and 80% of this average was arbitrarily selected as an estimate of the long-term productivity (Schiel 1989). However Schiel considered that this was too high in some cases where the fishery was still dependent on accumulated biomass. In Victoria ITQs were initially set at 70% of each areas' mean annual catch over the previous 10 years (Prince and Shepherd 1992), and they have continued unchanged. In South Australia the mean annual catch for the previous 15 years was used to fix the initial quotas (unpublished data). In New South Wales, Tasmania and Western Australia quotas were simply set at the then current level of fishing and later reduced when they were thought to be excessive (Prince and Shepherd 1992). A similar pragmatic approach was followed in South Africa (Tarr 1992).

Subsequent adjustments to quotas have been no less empirical. The information relied upon to vary quotas has been mainly catch and effort data, supplemented with research data. CPUE although it has long been realised to be a dubious indicator of abalone abundance (reviewed by Breen 1992) is still used as a guide in South Africa (Tarr 1992) and some Australian States (Prince and

Shepherd 1992). Yet CPUE as an indicator of abundance is even more dubious under quota systems when divers are freed from the pressure of competition and can fish at their own more leisurely pace.

Another uncertain indicator - the mean weight of each abalone, derived from commercial catch gradings - is used in South Australia in conjunction with other information, to assess the fishery.

Research data used in setting quotas have been at best minimal and spasmodic, and in many fisheries non-existent. In South Australia, 8 out of a total of 210 abalone-bearing reefs have been monitored annually since 1980 to give data on emergent recruit (2-3 year old), and adult density. Recruit densities are used as early indicators of recruitment overfishing, and the reefs selected for monitoring are important in terms of productivity. Nevertheless the proportion of the total number of reefs monitored falls far short of an adequate monitoring program. The picture is no better in other States. In Victoria (McShane, 1988, 1991) monitored densities of newly settled abalone larvae and of adults for several years, on the most productive reefs, but the program expired in 1990. No monitoring is done in other States although Tasmania is developing monitoring techniques to establish these in 1993.

The extent and effectiveness of monitoring programs varies. Ideally monitoring should involve the identification of the principal stocks (Shepherd and Brown 1'992), measurement of their spatial extent and estimation of distribution of density in each area. Attempts have been made only in South Africa to do this. There, abalone habitat was mapped in 1986 and abalone densities estimated from diver surveys (Tarr 1992). These data were taken into account in determining later levels of quota.

Thus, of the abalone fisheries under discussion quotas have never been based on rigorous stock assessment. Only in South Africa has a stock assessment been used to validate the level of quota previously determined. The question arises why these fisheries have persisted apparently stable if exploitation rates have been set with little scientific basis. The answer is twofold. First, relatively high size limits have generally been in force, and these have conserved a substantial proportion of potential eg production, often in the range 40-50% (Sluczanowski: 1984, 1986; Nash 1992; McShane 1992). Hence, even if quotas have exceeded productivity, they have not been maintained at those levels long enough to cause recruitment overfishing.

Second, an important element in fixing quotas has been the input of divers in the decision-making process. Divers are thoroughly familiar with the reefs on which they dive and over a period of time accumulate a body of knowledge from which they can crudely assess the productivity of each reef. They fish according to specific bio-economic expectations of catch (often around 60 kg per diver hour). If abundances at one reef fall below expectation they move to another. When divers can no longer find reefs to match their expectation they quickly become concerned and transmit that concern to the negotiating table when quotas are fixed.

In 1984 South Australian divers proposed conservation measures to stem declining abundance, and in 1989-90 Tasmanian divers pressed for quota reductions of 30% for the same reason. In neither case were research data available to support or negate divers' perceptions. In all States of Australia close consultation between government and divers has characterised management by quota, and this has generally led to risk-aversive decisions.

No doubt the large investments by divers in the industry has been a factor leading to identity of interest by government and divers in conserving stocks. However even partial dependence on diver perceptions of the "state of the stocks" cannot be advocated as a sound basis of management. Divers' opinions are notoriously inconsistent and sometimes fickle; they are subject to economic imperatives and have hidden agendas. In the long term there can be no substitute for scientific data on which to base management decisions.

What is the best cost-effective information that can be obtained to provide a minimum base for sound management?

First, egg-per-recruit analyses should be carried out as a matter of priority for each major region of the fishery. The possibility of aging abalone (Prince 1989) should be examined because this, if successful, would provide better estimates of fishing and natural mortality (Shepherd and Breen 1992). If size-limits are fixed to maintain 40-50% of the potential egg production, then the fishery should be secure against decline, at least in the short term.

Second, long-term monitoring programs should be established to measure recruitment strength and adult densities. Recruitment can be monitored by collectors (W J Nash pers.comm.), at an early post-settlement stage (McShane 199?) or at later emergent stage (Shepherd 1990). The stage chosen will depend on logistics and costs.

Routine, long-term monitoring studies should be established on reefs of high, moderate and low productivities and over the geographic range of the species. At least one third of all reefs should be monitored, but this depends on the number of stocks and variability of habitat types. Monitoring should also include areas in which fishing intensity can be manipulated, because this will help elucidate, in the long term, stock-recruitment relations. Sometimes surveys which yield estimates of total biomass can be economically carried out, as in South Africa where abalone live at depths <10m. For many abalone stocks, however, such surveys are prohibitively expensive due to weather conditions, depth or remoteness of the beds.

THE WAY AHEAD

In their review of the Australian abalone fisheries, Prince and Shepherd (1992) considered that ITQs would remain the cornerstone of management. They advocated, however, the subdivision of zones into smaller units exploited by fewer divers, because this would encourage them to farm-manage the units. The optimum would be to grant exclusive rights over defined reefs to individuals, thus providing area-based rights and allowing for marine farms. Such a step is now under consideration by Canadian abalone divers. Pearse (1991), has proposed other radical changes. He argues that quota-holders collectively should be encouraged to manage their own fisheries. To enable them to do this they should have legislative authority to form associations, to make rules binding on their members, undertake projects and levy contributions from members. Recreational interests where significant should also hold quota units and should be represented. The government would retain responsibility for enforcement and overall conservation of the stocks and environmental integrity, and would provide policy and research advice to the industry.

The benefits of such a system are obvious. Divers could establish their own management schemes, with variable size limits and closures. They could conduct their own monitoring programs and set quotas on a reef by reef basis. They could carry out transplants and enhancement programs, and other research relevant to their needs. Permitting divers to assume responsibility for their own fisheries is administratively more efficient and would foster prudent management.

As divers gain experience in day-to-day management of the resource, government, as its ultimate custodian, will be able to focus attention increasingly on the broader context of ecosystem management and long-term conservation.

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APPENDIX 1

Scheme recommended by Tasmanian Working Group (Harrison 1990) and since adopted in Tasmania

Under this scheme quota could be held by divers, processors and others. Existing arrangement of beneficial ownership could be preserved or dissolved by agreement between the parties. Third party interests would be registered and financial arrangements declared thereby improving the security of the financial environment and reducing costs.

- An interim register would be established prior to the commencement of the scheme on which each of the present 125 entitlement holders would be listed.
- Legislation would be drafted requiring all contracts relating to the financial or other control of abalone licences to be declared. Contracts not declared by a specified date would be rendered invalid.
- TAC established annually by the Minister and divided by the number of quota shares.
- Each licensed diver would be assigned and registered with 28 shares in the TAC. (In 1990 one share entitles the holder to take 600kg of abalone).
- Upon payment of the registration fee and the resource rent at the commencement of each licensing year, each registered quota holder would receive a share certificate for each unit held specifying the amount of abalone that may be taken that year pursuant to that unit.
- Quota share holders may, at any time during the licensing year, negotiate with a licensed abalone diver for that diver to take any or all of the abalone permitted by their quota shares. The Division would then assign the appropriate quota shares to that diver for that year. This does not transfer the shares from the quota share holder to the diver, but is a mechanism for implementing the catching of that quota in that year.
- Assigned quota shares must be registered.
- Divers who can have assigned to them between 16 and 80 quota shares by the holders of those shares would have their licence endorsed on presentation of those quota shares to the Division. The endorsed licence will then allow the diver to take the stated quantity of abalone.
- Any dispute arising between the registered entitlement holder and a third party over the 'ownership' of quota shares currently assigned to an entitlement holder shall be determined by civil action between the parties unless a contract relating to the financial or other control of the licence has been declared.
- Quota shares could be transferred to any natural person including abalone divers, processors or other persons at the request of the entitlement holder, provided that the transfer was registered with the Division of Sea Fisheries. Such transfers would be permanent and units would not revert to the original holder at the expiry of the licence.

- It would not be necessary for the holder of quota units to be the holder of a commercial abalone diving licence.
- The present system of issuing diving rights to 125 participants would remain. It is not proposed that the Government would issue more or less than 125 diving entitlements. However it is recognised that market forces may act independently to reduce the number of divers.
- The existing diver qualifications and entry criteria would be retained.
- Diving licence fees would be structured to cover cost of administration, research and monitoring of the catching sector.
- Resource rent would be collected from the quota share holder through charges on registration, assignment and transfer of quota shares. Quota share holders would also pay administrative fees structured to cover administrative and monitoring costs associated with the quota register.

Fig. 1. Distribution of paua quota according to tonnage held.