SEA URCHINS, ABALONE, AND KELP

Their Biology, Enhancement and Management

Summary of a California Sea Grant Workshop

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A Publication of the California Sea Grant College

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Published by the California Sea Grant College, University of California, La Jolla, California, 1992. Additional single copies are available for $4 (check payable to "UC Regents") from: California Sea Grant College, University of California, 9500 Gilman Drive, La Jolla, CA 92093-0232. (619) 534-4444.

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This publication is funded by a grant from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, under grant number NA89AA-D-SG138, Project #R/NP-1-21K. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its sub-agencies. The U.S. Government is authorized to reproduce and distribute for governmental purposes.

SEA URCHINS, ABALONE, AND KELP: THEIR BIOLOGY, ENHANCEMENT, AND MANAGEMENT

Summary of an International Conference
Sponsored by the California Sea Grant College

and the

Director's Sea Urchin Advisory Committee,
California Department of Fish and Game

March 19-21, 1992
Bodega Bay, California

Editors

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1992

Report No. T-CSGCP-029
California Sea Grant College
University of California
La Jolla, California 92093-0232

TABLE OF CONTENTS

MANAGEMENT: FISHERY CASE STUDIES

ACKNOWLEDGEMENTS

Numerous individuals helped make this unique conference a success. The planning committee, made up of Jeff Baldwin, Louis Botsford, Andy Cameron, Tom Ebert, Pete Kalvass, Ron McPeak, Dave Rudie, Bruce Steele, and Mia Tegner helped design the conference format and identified speakers. Sue Clayholt, Debbie Datz, and Vicki Milam arranged housing, excellent meals, and meeting facilities. Jill Frommelt typed the proceedings and helped the meeting run smoothly.

We especially want to thank the group leaders who steered the diverse groups through three days of productive discussions and summarized the results of those discussions. They are Jim Waldvogel, Fred Jurick, Bruce Wyatt, Connie Ryan, John Richards, Leigh Johnson, Leon Davies, Alex Bradbury, and Bob Carpenter.

This work is funded, in part, by a grant from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Additional funding was provided by the California Department of Fish and Game Director's Sea Urchin Advisory Committee. These funds, which come from sea urchin fishery landing fees to support resource enhancement, helped cover the cost of key speakers from overseas.

Finally, we would like to thank the conference attendees for their enthusiastic participation in a highly interactive conference. The quality of papers and group discussions was uniformly high.

Christopher M. Dewees
Wallis H. Clark, Jr.
University of California, Davis
Conference Co-organizers

INTRODUCTION

Valuable sea urchin, kelp, and abalone resources occur throughout the world. In California these resources are especially important. The nearshore kelp beds are also important habitat for many other marine organisms. In recent years, utilization of kelp bed resources has intensified, with the rapid expansion of the sea urchin fishery to 40 to 50 million pounds annually (worth over $30 million to fishermen) serving as a prime example. Urgent kelp bed resource management and research issues need to be addressed in California.

Fishery managers, researchers, the fishing industry, and others are aware of wide gaps in our knowledge about the biology, population dynamics, enhancement potential, and management of these resources. Similar resources and fisheries exist in all Pacific Coast states, Maine, Canada, Chile, Japan, and other nations. The California Sea Grant College, in cooperation with the California Department of Fish and Game Director's Sea Urchin Advisory Committee, funded this Sea Urchin, Kelp, Abalone Conference to bring together academics, agency personnel, and resource users from throughout the world to identify research needs, management alternatives, and enhancement potential. The conference took place March 19-21, 1992, at Bodega Bay, California. It was organized by Professor Wallis Clark of the University of California, Davis, and myself, with the assistance of the individuals named in the acknowledgments. The 148 participants came from the Pacific and Atlantic coasts, Canada, Mexico, Japan, Australia, and New Zealand.

Sea urchins were the primary focus because of the explosive growth in the fishery and urgency of management issues. Kelp and abalone discussions tended to focus on the interactions between these resources and sea urchins. In addition, abalone had been discussed thoroughly at the recent World Conference on Abalone held in Mexico.

With the help of a multidisciplinary planning committee, we designed the conference to be highly interactive by integrating discussion sessions into the program. The conference covered three primary topics: biology, enhancement, and management. We started with a series of papers on the status of biological knowledge about these organisms. Participants from industry, agencies, and academia were assigned to discussion groups to identify research issues and needs. The trained discussion leaders then

concisely summarized the discussion results for the entire conference audience. The process was repeated for the enhancement and management topics. This approach greatly facilitated the sharing of diverse viewpoints and full participation by attendees.

These proceedings are organized into the three main topics of biology, enhancement, and management. In each section, abstracts of the presented papers are followed by a summary of the group discussions and a list of recommendations. We have noted on the presentation abstracts when a full copy of the paper is available. A set of these papers can be obtained for $5 (checks payable to "UC Regents") from: Communications Department, California Sea Grant College, University of California, 9500 Gilman Drive, La Jolla, CA 92093-0232, Phone 619-534-4444. Please request publication T-CSGCP-028, The Manag*ement and Enhancement of Sea Urchins and Other Kelp Bed Resources: A Pacific Rim Perspective*.

The conference results will be used by 1) the California Sea Grant College to help guide future research and extension activities; 2) the Department of Fish and Game for resource management; 3) the fishing industry in its enhancement research and fishery management discussions; and 4) by researchers, fishermen and fishery managers in other states and nations who are interested in these and similar organisms.

Three days of papers and discussions identified many knowledge gaps and complex management issues surrounding sea urchin, kelp, and abalone resources. These are summarized in this publication. In addition, a need for a worldwide communication network for sharing research, enhancement, and management information was identified as highly desirable to transform the momentum of this conference into action and progress. The desire for cooperative agency/university/industry research was expressed by many participants. Fishermen were especially eager to share their underwater experience and skills. The first step would be the development of and training in data collection methods to assure unbiased data. Finally, and most importantly, the format of this conference seemed to open new communication channels among agencies, fishing industry, and academics that will facilitate creative approaches to sea urchin, kelp, and abalone issues.

Christopher M. Dewees
Marine Fisheries Specialist
California Sea Grant
Extension Program

BIOLOGY

ABSTRACTS

URCHIN SETTLEMENT PATTERNS IN CALIFORNIA

S. SCHROETER, J. DIXON, T. EBERT, AND J. RICHARDS

Temporal and spatial patterns of the settlement of red and purple sea urchins, *Strongylocentrotus franciscanus* and *S. purpuratus*, have been monitored weekly at sites along the mainland in the Southern California Bight and in Mendocino County, from February 1990 to the present. Locations in the Southern California Bight ranged from San Diego to Gaviota, near Point Conception. In northern California, sites were located near Point Arena, Ft. Bragg, and Westport, about 25 miles north of Ft. Bragg.

Settlement is strongly seasonal for both red and purple urchins. There have been two major settlement events in the Southern California Bight, one in Spring 1990 and the other in Spring 1991. In general, the event in the Spring of 1991 was of longer duration and began earlier in the year than the one in Spring of 1990. Settlement has recently been detected in the Southern California Bight during January/February of 1992, and may signal the beginning of another Bight-wide settlement event.

During the course of this study, purple urchins generally settled in greater numbers and for longer periods than red urchins. For both species, there was greater settlement in southern than northern California.

The implications of these settlement patterns with regard to differences in population dynamics between species and geographical areas are discussed.

RED URCHIN RECRUITMENT PATTERNS IN SOUTHERN CALIFORNIA

MIA J. TEGNER

Red sea urchins (*Strongylocentrotus franciscanus*) exhibit a very unusual behavior pattern: juveniles are frequently found sheltered under or near the spine canopy of adult conspecifics. As larvae do not appear to settle in response to adults, the spine canopy association is a result of juveniles choosing this habitat, which offers protection from predators and a share of food snared

by the adult. We demonstrated significantly reduced recruitment and survival of previously settled individuals on experimentally fished (all animals larger than 95 mm were removed) reefs in the Point Loma kelp forest near San Diego in the 1970s. Subsequently the minimum size limit for red urchins in southern California was set at 76 mm. Studies of the number and sizes of juveniles sheltered by larger urchins as a function of the adults' size class further suggest that the fishery impacts survival of juveniles as well as brood stock potential. Unprotected small animals and intermediate size red urchins too large to derive shelter from adults are highly susceptible to predation by spiny lobsters and sheephead; adults achieve a partial refuge in size from these predators at about 90 mm.

The Department of Fish and Game provided us the opportunity to sample the size-frequency distributions of Channel Island populations on an irregular basis from 1976-1984. These data illustrate spatial trends in recruitment of young-of-the-year individuals and survival of mid-size animals which were relatively stable in time. Recruitment rates were highest on the southeastern islands and declined to the northwest. Survival of mid-sized animals increased from the southeast to the northwest, paralleling decreases in the abundances of spiny lobsters and sheephead. A major deviation from normal oceanographic conditions, the El Niño of 1982-84, led to increases in recruitment of both urchins and their predators in the northwestern islands, strong support for the role of oceanographic transport processes on red urchin recruitment rates and population structure.

We compared recruitment of young-of-the-year individuals at three sites in the center of the Point Loma kelp forest near San Diego in the mid 1970s with the period from 1983 to the present; two additional sites at each end of the forest were added in 1983. The commercial fishery was very intense at Point Loma from 1976-1983. Recruitment rates were very low during and after the El Niño, recovered in 1986, and, with the exception of the south end of the forest, were very low 1989-1991. In both decades, recruitment rates were higher along the outer edge of the kelp forest. While recruitment rates along the outer edge of the forest are again comparable to the 1970s, despite a significant decline in adult red urchin densities, recruitment rates at sites within the forest have been very low and sometimes zero. Thus with the elimination of unfished stocks throughout the forest, only the edge of the forest sites appears to be recruiting at rates sufficient to support the fishery.

NORTHERN CALIFORNIA RED SEA URCHIN FISHERY STUDIES

LOUIS W. BOTSFORD, BARRY D. SMITH, JAMES F. QUINN, STEPHEN R. WING

Management decisions for urchin fisheries require information on growth and mortality rates. A reliable method of estimating these from size distributions and other data is therefore needed. We describe how growth, mortality, recruitment, and random variability in growth rate shape size distributions, then use that information to evaluate several explanations of bimodality in red sea urchin size distributions. We then present a new method for estimating growth and mortality rates from size distributions and size increment data. Estimates of parameter values for the Northern California red sea urchin are then used to compute yield-per-recruit, egg-per-recruit, and refuge-per-recruit for various combinations of fishing mortality rate and lower and upper size limits. We briefly describe our ongoing monitoring of recruitment and settlement.

VARIATION IN RED URCHIN MORPHOLOGY WITH DEPTH

LAURA ROGERS-BENNETT

The rapid expansion of the red sea urchin fishery and subsequent decline in catch from northern California has prompted investigations exploring alternative management strategies. At present, minimum size limits are in effect statewide. While small red urchins (test diameter < 75 mm) are sexually mature, they presumably produce few larvae. Management efforts would be aided if biologists could identify habitats occupied by urchins that enhance recruitment, either by spawning large numbers of larvae or by sheltering juveniles, thereby increasing their survival. Preliminary observations of red urchins in Bodega Bay, California during 1988 suggest that shallow habitats have higher densities of juvenile urchins and adults which are morphologically distinct from conspecifics found in deeper habitats.

I investigated whether the external morphological differences observed in individuals from shallow habitats were associated with differences in reproductive potential (gonad weight). In 1989 and 1990, 13 internal and external morphological features were measured in red urchins from shallow (depth 5m, N=45), mid (depth

11m, N=42) and deep (depth 23m, N=39) subtidal habitats. I examined the density and microhabitat utilization patterns of juvenile urchins (test diameter < 50 mm), from shallow and mid depth habitats using 1.0 m^2 quadrats.

Results show that adult urchins (>75 mm) from shallow subtidal habitats have larger gonad weights than individuals of similar size (measured as either test diameter or weight) from deeper habitats. Principle component and discriminate analysis identified 4 morphometric variables that together provide a multivariate description of urchins with high gonad weights collected from shallow habitats. These variables are small lanterns, small oral diameters, thick tests and short blunt spines. These variables correctly identified 100% of the urchins into the depths from which they were collected.

Juvenile red sea urchins were more common in shallow habitats, where they utilized cryptic microhabitats, including the spine canopies of adults. Juveniles from deeper habitats were less common and utilized exposed rock surfaces. Adult canopy providers were found primarily in shallow habitats (regardless of test diameter), where they occupied rock scars. In addition, adult densities were high (6.06/ m2) in shallow habitats, perhaps increasing fertilization success. Preliminary data suggest that drift algae food availability, which could influence gonad weight, was also greater in shallow habitats.

These results suggest that external morphological features such as spine length and oral diameter can be used to identify adult urchins with heavier gonads from shallow habitats. Morphometric identification of urchins with the largest gonads (>100 g), which are usually of inferior quality and less marketable, indicates the possibility of excluding these urchins from the fishery. This would protect urchins from shallow habitats, maintaining (1) adults with large gonads at high densities and (2) juveniles under the spine canopy of adults. Further investigations are needed to determine whether these depth-related differences in gonad production and juvenile survival occur in regions other than Bodega Bay, California.

RED SEA URCHIN (*S. FRANCISCANUS*) SIZE DISTRIBUTION AND ABUNDANCE: STUDIES IN OREGON WITH EMPHASIS ON ORFORD REEF

JONATHAN GRAVES AND NEIL RICHMOND

A cooperative survey of the size distribution and abundance of the red sea urchin, *Strongylocentrotus franciscanus*, was conducted at Orford Reef, and a broad-scale survey was initiated coastwide. Commercial urchin divers volunteered boat and diver time to collect a series of random size distribution samples at Orford Reef from February to September 1990. An underwater urchin transect survey was conducted at Orford Reef from November 1990 to August 1991. The first phase of the coastwide survey was completed in the Depoe Bay area in October 1990.

The mean size of red sea urchins at Orford Reef was 92 mm (SD=26) during the ten month study period. A distinct size mode centered at 43 mm was detected from the random sample collected in February 1990, and growth of this mode was tracked through August 1991. Random and transect size distribution samples demonstrating a similar mode were collected at Depoe Bay in June of 1990 and October of 1991.

The mean density of red sea urchins at Orford Reef was .89/m^2 (SD=.81) for the 37 transects completed. The mean density increased to 1.0/m^2 (SD=.79) when transects devoid of any hard substrate were subtracted. An estimated 5.5 million pounds were harvested at Orford Reef during 1990 and 1991 combined. Overall recruitment (percent of population less than or equal to 50 mm) was 5.4 percent during the ten month transect survey. Recruitment estimates from the random samples increased from 14 percent in February 1990 to 20.4 percent in September 1990 as the dominant size mode became more detectable. During the transect survey, the recruit percentage decreased to 9.4 percent in November of 1990 and only 2.2 percent in August of 1991 as the cohort grew past the 50 mm size and few younger recruits were detected.

RED SEA URCHIN (*S. FRANCISCANUS*) STUDIES IN BRITISH COLUMBIA

ALAN CAMPBELL

The densities, size frequencies, and gonad indices of *Strongylocentrotus franciscanus* populations were monitored periodically at three study sites in Georgia Strait. At site one (Kendrick Island, rarely commercially harvested), recruitment and densities fluctuated during 1989-92. Gonad indices (gonad wt/ total wt) were lower than 20 percent during May to October and higher than 25 percent during November to March, reflecting a seasonal reproductive cycle. Growth of newly settled juvenile red sea urchins was also monitored in caged settlement collectors near site one for one year. Site two (Yaculta, closed to harvesting) and site three (Big Rock, heavily harvested), both near Campbell River, had similar densities for red urchins <50 mm test diameter (TD). Although densities of urchins ≥50 mm TD were higher at site two than for those at site three, the quality of gonads in terms of color and gonad index was lower at site two than at site three during 1991-92.

SEA URCHIN–KELP INTERACTIONS IN CHILE: A REVIEW[1]

JULIO A. VÁSQUEZ

The lack of studies in subtidal environments along the Chilean coast has introduced an erroneous idea of the abundance and distribution of subtidal kelp communities. It has been proposed that the dominant kelp along the Chilean coast is *Macrocystis pyrifera*. But *Macrocystis* is limited to areas mostly protected from wave impact, an infrequent situation on the continental Chilean littoral. The more prevalent coastal profile between 18° and 42° S is one that is frequently exposed to water movement, in which *Macrocystis* is not abundant. In this geographical region, *Lessonia trabeculata* is the dominant community component of the rocky bottom, forming extensive subtidal bottom kelp between depths of 0 and 30 m. *Macrocystis pyrifera*, on the other hand, is the dominant species south of 42° S.

[1] This paper is available as part of a set of papers from this conference for $5 (check payable to "UC Regents") from Communications Department, California Sea Grant College, University of California, 9500 Gilman Drive, La Jolla, CA 92093-0232. Request no. T-CSGCP-028.

Different species of sea urchin are associated with the kelp communities mentioned above. My paper reviews the literature on the ecological role of sea urchins associated with kelp stands along the Chilean coast. I discuss and compare the evidence obtained from northern and southern Chile kelp communities on the following topics: sea urchin diversity and distribution, sea urchin–predator interactions, and biological and physical factors in the structure of these South American kelp communities. I also contrast this evidence with the results obtained in the Northern Hemisphere kelp communities.

DISCUSSION SUMMARY AND RECOMMENDATIONS: STOCK ASSESSMENT

Three groups discussed stock assessment. All groups agreed that the top priority is the establishment of research areas that are permanently or temporarily closed to all urchin harvest. The present closed areas are far too small and too scattered. Suitable new locations need to be found. Such research reserves would serve as control areas for comparison with fished areas or they could be used for controlled fishing experiments. The other primary stock assessment issues and needs are listed below.

1. There is a need to continue the abundance indices begun by Pete Kalvass in northern California for at least another three years to assess the effect of continued fishing on density, recruitment, and size distribution.
2. There is also a need to establish the statistical power of these abundance indices. Managers must first decide on an acceptable power, such as the minimum detectable difference in urchin abundance levels from survey to survey that would be acceptable from a management standpoint, then determine the power of the present survey method and adjust it if necessary.
3. We need to do a yield-per-recruit analysis for the urchin fishery. This will require estimates of growth rates and natural mortality, which will presumably be available following tetracycline tagging. We also need to do an egg-per-recruit analysis, because it is well documented that a simple yield-per-recruit analysis overlooks frequent cases where fishing mortality affects recruitment. Such models incorporate both yield per-recruit and egg-per-recruit analyses which have been proposed for abalone and should be investigated with urchins.
4. Existing fishery-dependent stock assessment analyses could be refined with improved data collection. Industry participants suggested that the fish tickets (market receipts) could be modified to 1) record the number of divers working on a boat to improve catch per unit effort estimates; and 2) replace the current Fish and Game geographic blocks with smaller, more natural areas.
5. We need to determine the effects of large scale oceanographic events (El Niño, global warming) on kelp, urchin, and abalone abundance.

DISCUSSION SUMMARY AND RECOMMENDATIONS: SEA URCHIN, KELP, AND ABALONE INTERACTIONS

Two groups addressed sea urchin, kelp, and abalone interactions. These groups took a community ecology/ecosystem approach. Their priority issues and research needs are summarized below.

1. Research is needed to determine if fishing pressure affects succession patterns and species interactions in kelp forest communities. Studies are needed to determine how harvesting one species of a kelp community affects other members of the community. Specific areas of concern include the effects of red urchin harvesting on abalone recruitment and stock recovery, and the effects of various methods of kelp harvesting on the recruitment of benthic fauna. In addition, long-term studies are needed to determine the effects of global change and large-scale oceanographic events (e.g., El Niño) on kelp communities which are under fishing pressure.
2. Research is needed to identify the principal biotic and abiotic factors that affect recruitment of urchins, abalone and kelp. Among the biotic factors that should be investigated are the effects of the size of the kelp canopy edge on recruitment of urchins and abalone, and the effects of urchin harvesting on the recruitment of kelp and abalone. Long-term monitoring is needed to determine the relationship between oceanography and recruitment of urchins, abalone and kelp.
3. Investigations are needed to identify the source of urchins, abalone, and kelp recruited to fishing areas. Such investigations could help clarify the efficacy of using refuges as a management tool.
4. We need to understand temporal and geographic variability of spawning in urchins and abalone.
5. We need to increase our understanding of species interactions and succession patterns in kelp forest communities. We need to understand how species interactions and succession will change under various fishery management schemes and with the re-introduction of sea otters. Studies are needed which compare kelp communities in northern

and southern California. Studies are needed to identify methods for maintaining urchin, abalone, and kelp populations in the same area, and to identify the relative urchin, abalone, and kelp densities needed for optimal yield.

6. The primary environmental factors that influence kelp, urchin, and abalone populations need to be identified. These studies should include comparisons of kelp abundance, urchin population sizes, and oceanographic factors. The effects of coastal development (e.g., pollution and erosion) on kelp communities also need to be investigated.

DISCUSSION SUMMARY AND RECOMMENDATIONS: GROWTH AND SURVIVAL

One group examined issues related to growth and survival. They focused on research needs at different sea urchin life stages. Their recommendations are as follows:

1. Describe local habitat characteristics and limiting factors affecting growth and survival and describe "ideal" habitats for all life stages.
2. Understand the effects of major human-caused habitat disturbances on growth and survival.
3. Learn more about the early life stages, especially the survival of post-settlement larvae. This includes identifying post-larval microhabitats and identifying factors that induce or impede proper metamorphosis.
4. Review the role of spine canopy as drift food catchment for juveniles and compare urchin dominated areas with other habitats to examine the relative significance of spine canopy as protection from predators.
5. Improve our understanding of natural mortality in urchins at or just below the size limit to verify the proper size limit.
6. We need to know the relationship between food availability and fecundity of spawning urchins.
7. Understand the effects of harvest on recruitment.

DISCUSSION SUMMARY AND RECOMMENDATIONS: URCHIN DOMINATED AREAS (BARRENS) AND THE PURPLE URCHIN FISHERY

This discussion group focused on the biology of purple sea urchins and issues related to the development of the purple urchin fishery.

1. We need to know the importance of urchin barrens in maintaining and/or replacing healthy urchin stocks. Are barrens really nurseries?
2. Is supplemental feeding in urchins barrens worthwhile? If so, how should this be done?
3. Does selective harvesting of red urchins allow purple urchins to take over for the long term?
4. Learn more about the biology of purple urchins, such as 1) size/age of first spawning, 2) recruitment, 3) effects of food availability and type on roe quality, and 4) interactions with red urchins.
5. Understand the dynamics of the purple sea urchin market and develop other potential product forms to market.
6. When is the best time to harvest purple urchins? And how can we enhance their quality during the times of the year when quality is low?
7. Develop a fishery management plan for purple sea urchins.

ENHANCEMENT

ABSTRACTS

STRATEGIES FOR LARGE-SCALE KELP CULTIVATION TO SUPPORT THE CALIFORNIA ABALONE AND SEA URCHIN INDUSTRIES

M. NEUSHUL AND M. KARAKASHIAN

As the traditional fisheries for abalone and sea urchins decline, prices increase and markets grow for cultivated animals. At present the successful cultivation of abalone is mainly restricted by shortages of kelp in China (Zhong, pers. comm.) and Japan (Seki, pers. comm.). It is likely that producers in California will also be food-limited as the amounts of animals produced increases.

The large seaweed farms that now produce kelp in China and Japan grow an annual plant, *Laminaria japonica*, using on-land greenhouses (for seedlings) and in-the-sea long-line farms (for final growout). In China alone more than one million wet tons are harvested yearly (Tseng, pers. comm.). In contrast the giant California kelp, *Macrocystis pyrifera*, is a more tree-like perennial that can be coppiced repeatedly and maintains a high standing crop. A harvest of 50 wet metric tons, from quarterly harvests, was produced by an initial standing crop of 11 metric tons (Neushul and Harger, 1985). Nutrient irrigation was effective during the summer months. This farm, planted in 1981, survives and is productive today, without additional re-planting and/or cultivation.

The materials and labor required for seedling production, outplanting and nutrient irrigation have been estimated, using established cultivation methods and known growth rates. Methods that have been developed for isolating and cultivating gametophytes and for outplanting larger sporophytes are described. Although initially expensive, the establishment of kelp beds specifically for the production of food for grazing abalone and sea urchins is feasible, and could be achieved in a cost-effective incremental fashion. Using the methods that have been developed, cultivated kelp beds could provide feed for land- and sea-based cultivation efforts and for "feed-lot" operations where animals would be held prior to harvest and processing. The establishment of new kelp forests for the abalone and urchin industries would decrease pressures on natural forests as the industry grows.

JAPAN'S SEA URCHIN ENHANCEMENT EXPERIENCE[1]

KATSUO SAITO

The Japanese sea urchin fishery has been managed for a long time. Now the development and spread of mariculture is considered important. We are proceeding mainly in three ways: 1) seed production, 2) the creation of artificial fishery ground, and 3) revitalization of fishing villages. Seed production has showed a large improvement, owing to the development of mass production technology for biological food. Artificial fishery grounds have been vigorously created under a national plan called Equipment and Development Works of Coastal Fishing Ground. Habitat is enhanced. The revitalization of fishing villages involves educating and training the fishermen who actually administer and manage the grounds. Seed production has greatly increased since 1986. In 1989, it quadrupled to 30 million seeds, with *Strongylocentrotus intermedus* comprising 70 percent. The number of released seeds is rising. Information on growth after release, the number that remain, catch, ability to distinguish released sea urchins from natural sea urchins, the state of maturation, etc., has been obtained. However, economic effectiveness cannot yet be estimated.

EXPERIMENTAL OUTPLANT OF JUVENILE RED SEA URCHINS

JOHN DIXON, STEPHEN SCHROETER, AND TOM EBERT

There is a great deal of interest among sea urchin fishermen and processors in culturing urchins in the laboratory and outplanting them as juveniles, as a means of increasing the standing stock of harvestable animals. This strategy is based on the assumption that recruitment is limiting, which may be true for many marine populations. We conducted a field experiment to assess the feasibility of this technique for red sea urchins, Strongyloce*ntrotus franciscanus*, in California.

Using brood stock from Palos Verdes in southern California, Sea Farms of Hawaii cultured the juvenile sea urchins used in this experiment. We outplanted about 5,000 juvenile red urchins to each of four sites: Van Damme and Noyo in Mendocino County, and La Jolla and Pt. Loma in San Diego County. The outplanted urchins were approximately 5 mm, 10 mm, or 15 mm in test diameter, in a ratio of abundance of 3:2:1. Before transplanting to the field, they were incubated in calcein for 24 hours, which left a

permanent fluorescent mark on their skeletal elements. At the end of one year, the sites were searched and all small red urchins were collected. Their tests were cleaned and examined under an epifluorescent microscope to identify tagged individuals and measure their growth.

The return rate varied greatly from place to place and among size groups, and ranged from zero to about 23 percent. In general, there was better return in southern than in northern California, and better return in habitats with large boulders and little sediment than in areas with smaller boulders in a sandy gravel matrix. At all sites, the return of 15 mm urchins was much higher than that for smaller individuals. However, the return rate for small animals was many times higher in the south than in the north, where it was near zero. On average, 15 mm outplants attained a size of about 30 mm test diameter after one year in the field, with a range of about 13 mm to 50 mm. Growth was somewhat faster in northern than in southern California.

SUPPLEMENTAL FEEDING OF SEA URCHINS TO PROTECT AND ENHANCE KELP

DALE GLANTZ

During 1991, Kelco tested a new strategy to protect giant kelp (*Macrocystis pyrifera*) forests from grazing red (*Strongylocentrotus franciscanus*) and purple (*Stronglyocentrotus purpuratus*) urchins. This strategy involved supplying a superabundance of chopped kelp to sea urchins fronted on adult plants and those in a nearby sea urchin barrens. The site chosen for this work was an area of the Point Loma kelp bed where random combined sea urchin abundance samples often exceeded 100 per m^2 and kelp was being lost at a rate of up to 15 m per month. Chopped kelp was dispersed within the site on a regular basis from May to December 1991. The differences in the fed site compared to an adjacent unfed site were significant. Sea urchins in the fed site backed off the adult plants and stopped scouring the bed rock, allowing juvenile kelp to recruit along the front as well as in the barrens. Sea urchins in the unfed site continued grazing plants, advancing 50 m during the duration of the test. No juvenile kelp recruited anywhere along the front or in the barrens of the unfed site. These findings suggest the feasibility of feeding sea urchins as a means to protect and enhance kelp forests.

COENHANCEMENT OF KELP AND SEA URCHIN RESOURCES

DAVID L. LEIGHTON AND LEIGH T. JOHNSON

A decade prior to the establishment of a sea urchin fishery in California, Leighton developed a chemical method to cull sea urchins where their grazing limited algal growth, fostering the rehabilitation of kelp communities. However, this and other methods to control urchins have concentrated on removal and/or destruction. Now a new and nondestructive approach to maximize yields of both sea urchin and kelp resources is being tested. Supplemental feeding of chopped kelp fronds to urchins in situ is being accomplished by Kelco biologist divers, with results highly favorable to kelp growth and recruitment as well as to the sea urchin resource.

Following an extensive sampling plan developed by the authors of this report, divers operating in the rich kelp community off Point Loma, San Diego, are collecting samples of red (*Strongylocentrotus franciscanus*) and purple (*S. purpuratus*) urchins to support studies of the effect of supplemental feeding on urchin foraging behavior, size distribution, body growth, and rate of gonad bulk gain. These observations are being made on urchins at large in the kelp bed, at the grazing front, and in the nearby extensive barren zones. Other feeding experiments employ cages and pens to test feed lot concepts and to observe growth and gonadal development in select groups of urchins. In addition, the rate of roe development is being defined for impoverished urchins collected from barren zones and fed within pens. In all cases, experimental groups receive chopped kelp on a regular basis (at least one feeding/wk), while control groups gain food only in form of drift matter and the natural growth on the immediate substrate.

Chopped kelp is delivered to the bottom by pump and diver-directed hose and is dispersed at about 1 lb/ft^2/wk to urchins at the grazing front and in the broad barren area in the experimental zone. Changes in foraging behavior observed in urchins supplementally fed at the front are resulting in markedly reduced grazing of intact kelp plants with an accompanying increase in plant biomass. New kelp is also appearing (as are young plants of many species) in experimental areas of the barren zone as urchins cease scouring of the substrate in favor of feeding on the readily available chopped kelp.

Supplementally fed urchins at large in front and barren locations have gained gonadal mass well in excess (5 to 8 percent body

weight) of control urchins. A first commercial harvest of urchins from the experimental front zone was done on a limited scale (chiefly 1.5 tons of red urchins) in early December 1991. Juvenile red and purple urchins fed kelp in cages and pens are gaining about 2 mm/month in test diameter; young adults somewhat less. Those impoverished urchins with minimal gonadal tissue, having Gonadal Bulk Indices (GBIs) <2 percent, collected from the barren zone and fed chopped kelp in pens have gained gonadal bulk at a remarkable rate, reaching commercial levels (GBI's of 10 to 14 percent) in three to four months. This project is showing ecological feasibility of the method. An economics study is planned to follow completion of the field work.

HIGH DENSITY CULTURE OF THE LARVAE OF THE RED SEA URCHIN, *S. FRANCISCANUS*

T. J. CARROLL, S. BASHAM, D. E. CONKLIN, AND W. H. CLARK, JR.

Previous efforts to culture the red sea urchin, *Strongylocentrotus franciscanus*, have been characterized by low larval densities, lengthy periods of larval development, and variable levels of metamorphosis ranging from low to insignificant. Results of the present study have demonstrated that the above problems can be alleviated if optimum food levels are maintained and if waste products are kept at minimal levels. Larval densities of 5 per ml were maintained if the larvae were fed the unicellular algae *Rhodomonas lens*, at densities of 80,000 cells/ml, once per day and if the culture water was changed once per day. Under these conditions the percent metamorphosis was fairly stable, having a mean of 55.7 percent ± 7.3. Settlement began as soon as 24 days following fertilization by increasing the larval density from 5/ml to 25/ml; metamorphosis was inhibited completely unless the culture water was exchanged three times per day and feeding levels were increased to four per day. Under these conditions, settlement was not observed until 30 days post-fertilization; however, the percent metamorphosis was 18.7 percent providing the substrate surface was increased. While this was a 61.3 percent decrease in metamorphosis, it represented a near 50 percent increase in the total number of metamorphosed urchins.

The above results suggest that larval development and metamorphosis are only indirectly density-dependent, reflecting a lack of antagonistic interactions between larvae in contrast to such invertebrates as shrimp. Metamorphosis at high densities, how-

ever, does seem to be directly dependent on food availability and/ or frequent cleaning. Intensive culture of the red sea urchin on a large scale appears to be possible, but will undoubtedly require the engineering of a system capable of providing continual feeding and water exchange.

USES OF SEA URCHIN PROCESSING WASTE

BRUCE WYATT

Sea urchin waste is make up of approximately 1/3 water, 1/3 shell, 1/10 gonad, 1/4 digestive tract, including the kelp contained therein, and the locomotion system. Results of field trials indicate composting and land application are viable uses for waste. Aquatic feed is another possible use for sea urchin digestive tract.

DISCUSSION SUMMARY AND RECOMMENDATIONS: STOCK ENHANCEMENT

Seven groups discussed enhancement issues, research needs, and priorities. In general, enhancement includes promoting recruitment, growth, and survival. Enhancement could focus on a single species, multiple species, or the wider environment. Participants identified three primary, but not mutually exclusive, types of enhancement: 1) habitat modification, 2) seeding areas with hatchery produced or transplanted organisms, and 3) supplemental feeding to improve growth and quality of stocks. All groups identified effective fisheries management techniques as an enhancement tool, but those ideas will be covered in the management section of these proceedings.

Several important issues and recommendations came up repeatedly in discussions on all three types of enhancement.

1. Determine the cost effectiveness of enhancement techniques. This involves development and use of good methodology to measure the results of enhancement efforts.
2. Estimate the environmental effects of enhancement on other kelp bed organisms (interactions) and on the populations of the enhanced organism (genetics, disease).
3. Resolve issues about how those who fund enhancement will be able to realize the benefits of those efforts ("property rights"). We need to find ways to regulate these enhancement activities. In addition, we need to come up with methods to fund both enhancement research and enhancement projects.

Recommendations on Habitat Enhancement

1. Determine the effectiveness of artificial substrates to increase settlement and artificial habitats to reduce predation.
2. Examine the feasibility, effectiveness, and impacts of predator control to enhance urchin and abalone survival.
3. Continue kelp enhancement experiments because increased kelp biomass is vital to enhance urchins and abalone.

Recommendations on Enhancement with Seeding Programs

1. Continue and expand studies to determine the optimal sizes for outplanting and the environmental factors that influence outplanting success, and to develop methods to improve outplant survival.
2. Find out how to mark or identify seed organisms in the field.
3. Determine optimal seeding densities.
4. Determine if onboard spawning (i.e., when organisms are suspended in bags off fishing vessels) is an effective enhancement method to increase recruitment.
5. Improve techniques for cost effective hatchery production of sea urchin larvae (algae, temperature, water quality).
6. Determine if the transplant of small urchins from areas with little food to food-rich areas is feasible and cost effective.
7. Understand the recruitment process thoroughly to determine the optimal locations, timing, and methods for outplanting. This could include research on oceanographic variables, settlement, predation, microhabitats, etc.
8. Address issues of access to kelp or alternative feeds for hatchery production.
9. Devise viable methods for funding hatcheries and outplanting research and activity. Difficulties in the permit process for enhancement activities need attention.
10. Increase our understanding of urchin and abalone diseases in the wild and in hatchery situations.
11. Determine the most effective materials and methods for obtaining urchins on collectors.

Recommendations on Supplemental Feeding

1. Investigate the effects of supplemental feeding of urchins in the wild on their behavior, roe quality, survival, and growth.
2. Examine the relationship between urchin roe quality and composition of their diet.
3. Devise good marketing strategies for purple urchins because they could be the primary focus of supplemental feeding activities.

4. Address problems in obtaining adequate food for supplemental feeding programs of urchins and abalone in the wild or in containers. Alternative feeds, use of sea urchin wastes, use of drift kelp currently hauled off beaches by cities, and enhancement of existing kelp resources should also be examined.
5. Understand the effects of supplemental feeding projects on the kelp bed community.
6. Resolve the legal and institutional issues related to supplemental feeding activities.
7. Develop efficient methods to deliver food to urchins.

MANAGEMENT: FISHERY CASE STUDIES

ABSTRACTS

THE SOUTHERN CALIFORNIA RED SEA URCHIN FISHERY, 1972-19921

PETE HALMAY AND DAVE RUDIE

The El Niño events around 1958 wiped out the southern California kelp beds. Sea urchin grazing was considered the factor preventing the re-establishment of the kelp beds. The harvest of red sea urchins began in 1972 as a means of controlling sea urchin grazing.

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

The San Diego based red sea urchin fishery is described in detail. This kelp-sea urchin interaction 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 presented.

The management of the southern California red sea urchin fishery started with few regulations as a market-driven fishery harvesting a 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 of future management schemes, including enhancement programs, mitigating seeding, habitat improvement, and quality enhancement are discussed. The need for fishery independent data for management decisions is presented.

THE SOUTHERN CALIFORNIA RED SEA URCHIN: A CASE HISTORY

PETER HAAKER

A commercial fishery for the red sea urchin, Strongylocentrotus franciscanus, began in southern California during 1971 in the Avila and San Diego areas, as part of a National Marine Fisheries Service program to develop fisheries for "underutilized" marine species. Since then, sea urchin landings have increased and effort has expanded throughout the nearshore areas of southern California.

By 1973, sea urchin processing technology and connections with Japanese markets had developed sufficiently to support landings of more than 3.5 million pounds, increasing to over 25 million pounds in 1981. Landings declined to 15 million pounds in 1984, but rose to nearly 25 million in 1986 and have since averaged 23.5 million pounds through 1990. A ready pool of divers and boats involved in the similar, but declining, abalone fishery contributed to the growth of the fishery.

The majority of sea urchin landings in southern California have come from the northern Channel Islands off Santa Barbara, where large, accessible sea urchin stocks occur. During the period 1973 through 1977, 80 to 90 percent of total landings came from these islands. In more recent years, however, there has been a relative decrease in the contribution from the northern Channel Islands as harvesting effort has increased at other locations such as San Clemente Island, San Nicolas Island, the Palos Verdes Peninsula and the San Diego area.

Regulatory restrictions were put in place in 1987. They are aimed at reducing effort (limited entry, permit reductions, closed seasons) and protecting a portion of the stock (minimum size). Current proposed changes are aimed at buffering southern California from major added effort shifts from the north and at protecting more of the stock (increased minimum size).

Fishery monitoring efforts have continued since 1988, revealing needed information about this segment of the fishery. Overall mean harvested test diameters have ranged from 90 to 92 mm, with definite differences by area (e.g., 84 mm for Palos Verdes vs. 102 for Southern Islands). Minimum size regulations resulted in positive shifts in size composition (e.g., 17 percent undersize pre- vs. 8 percent undersize post-size limit). Overall mean CPUE's have declined from 340 lbs/hr during 1977-83 to 240 lbs/hr during 1988-91, with definite differences by area (e.g., 117 lbs/hr at Palos

Verdes vs. 406 lbs/hr for San Nicolas Island in 1991). The fishery now relies on recruitment and growth to sustain harvest levels. Fishery monitoring should continue and fishery independent assessments should be instituted to delineate the status of the resource.

THE NORTHERN CALIFORNIA COMMERCIAL SEA URCHIN FISHERY: A CASE STUDY[1]

PETER KALVASS

The northern California commercial sea urchin fishery could become another "boom to bust" story. Since the "gold rush" days of 1988 when over 30 million pounds of urchins were harvested from north-coast waters, the fishery has seen a 44 percent drop in landings to about 17 million pounds in 1991. Both fisheries-dependent and fisheries-independent stock indices strongly suggest that this decline represents more than just the expected "fishing down" process that occurs on almost every virgin fish stock. While conservative management strategies for similar semi-sessile macroinvertebrate fisheries suggest that harvest rates should be in the range of 4 to 6 percent, relative abundances at unfished Point Cabrillo Marine Reserve near Fort Bragg are more than three times greater than those at nearby sites which have been subject to commercial harvest since 1985, when the fishery began.

Management to date has followed a reactive "points of concern" approach by tracking various fishery indices including relative abundance, size distribution and recruitment rates for the stock, CPUE and catch by area and depth from fishery logbook data, as well as the size distribution of the catch and fishing pressure. The most significant management measures were not instituted until June 1990 and include a 3.5 inch minimum test diameter limit as well as a July closure and a reduction of the summer season fishing week to four days. Undoubtedly these measures contributed to the decline in landings to some degree by causing an effort reduction which included a marked seasonal shift of fishing effort to southern California. Based upon these indices and what is known about sea urchin ecology, there is reason to be concerned that the continuing high harvest potential in this fishery could lead to recruitment overfishing and fishery stock collapse.

OREGON SEA URCHIN FISHERY, 1986-1991

JEAN McCRAE

Red sea urchins (*Strongylocentrotus franciscanus*) were first commercially harvested in Oregon in 1986. The first five years of the fishery saw much growth and development: from 55 thousand pounds landed the first year to over 9 million pounds in 1990; from essentially no regulations to a detailed limited entry system. Data from 1990 and 1991 indicate we are beginning to see the effects of several years of intense fishing on the resource.

In 1988, a limited entry permit system went into effect for the commercial sea urchin fishery. At that time, the maximum number of permits was set at 92. The new permit system had a renewal requirement of 20,000 lb of urchin landed in the previous two years. Permits were made nontransferable and any unissued permits were issued through a lottery each spring. Other regulations adopted at the same time included a three-inch minimum size limit and a minimum harvest depth of 10 ft from mean-lower-low water (MLLW).

Since the beginning of the limited entry system, regulation changes have included reducing the maximum number of permits to 46, changing the 20,000 lb renewal requirement to an annual requirement, temporary transfers for medical reasons, creation of seasonal buffer zones to protect sea lion pupping rocks, and an increase in size limit to 3.5 inches.

Total landings and number of harvesters peaked in 1990 at 9.3 million pounds and 61 harvesters. Landings and effort dropped in 1991 to 4.7 million pounds and 57 harvesters.

Port Orford continues to be the major port of landing. However, landings into other ports have increased each year as the pressure in the Port Orford area continues.

A greater portion of the harvest has occurred during the summer months than we had anticipated. Closures in other states have created a higher demand for Oregon urchins even though the quality and price is lower during this time of year.

Logbook data show decreases in CPUE and increases in average depth in major harvest areas, indicating pressures of the fishery are beginning to show.

A HISTORY OF RED SEA URCHIN MANAGEMENT IN WASHINGTON: THE MANAGER'S PERSPECTIVE

ALEX BRADBURY

Red urchins were first landed in 1971, and harvest for the next four years remained below 100,000 pounds annually. Management was passive, requiring only a license and landing records. In 1976, harvest increased to 1.5 million pounds, prompting more active management by the Washington Department of Fisheries (WDF).

Underwater surveys began in 1976, leading eventually to the establishment of 172 permanent index stations located within commercial beds throughout the state. Performed yearly, transect counts provide a relative measure of urchin abundance over time, rather than an estimate of total biomass. Surveys show that recruitment rates are low, similar to those described for northern California, British Columbia, and Alaska, and well below those in southern California. Gonad yield peaks in late January and reaches an annual low in mid-June.

Following the 1976 surveys, WDF implemented the basic regulatory measures still in use: 1) fishing districts were rotated every three years to allow recovery; 2) upper and lower size limits were established to protect spawning stock and provide juvenile habitat beneath the "spine canopy" of larger urchins; and 3) seasons were restricted to the period of highest gonad yield.

The fleet grew little from 1977 through 1985, but roughly doubled in size each season from 1986 through 1988, growing from 12 to 197 boats by early 1989. Landings in 1988/89 reached 8.1 million pounds, prompting the first emergency closure. Divers formed an association (WHDA) and jointly authored a limited-entry law with WDF that took effect during the 1989/90 season. The law cut the fleet back 68 percent, although effort increases among the remaining 64 boats lowered catch only 35 percent (to 5.2 million pounds). An emergency closure midway through the season was still required to conserve stocks.

These effort increases, as well as court decisions which increased the fleet by 25 percent, prompted further regulations in 1990/91 limiting the fishing week and the number of divers working from a boat at a single time. Landings in 1990/91 topped 6.6 million pounds before a closure shut down one district six weeks early.

Prior to the present season (1991/92), WDF surveys concluded that neither district fished in 1988/89 had recovered to 1984 abundance levels; the decrease in urchin density over the seven-year

period averaged 35 percent. A sharply restricted season was designed to harvest at roughly half the 1988/89 level; only 70 fishing days are now allowed, compared to 182 in 1987. Catch is expected to reach 4.5 million pounds, with no early closures anticipated.

Limited entry has not been a panacea, although without it the fishery would clearly have become chaotic. Benefits include tighter enforcement, fewer diver accidents, and increased economic returns per boat. Average landed value per boat remains roughly double what it was in the three years prior to limited entry; decreases in landings due to shortened seasons have been offset by fewer boats and higher prices.

WDF's ultimate goal is a stable fishery managed for maximum sustained yield. For the moment, management is still "probing" and empirically-based; whether current regulations designed at cutting back landings to pre-1988 levels will succeed remains to be seen. Although a more scientifically-based approach is desirable, traditional yield models cannot be applied at this time. Research is currently underway to estimate growth and mortality, parameters which can be used in yield-per-recruit modeling.

A HARVESTER'S PERSPECTIVE OF WASHINGTON STATE'S URCHIN REGULATIONS[2]

RANDY KRAXBERGER

I want to say a few words from the diver's point of view. I started in 1985 when there were only two buyers and ten boats. By 1989 there were 250 licenses. Washington's regulations are complex. The upper and lower size limits are the biggest hassle, because divers need to frequently size urchins. Size limits are a very important tool of our biologists, allowing them to target the catch on the most valuable 50 to 60 percent of the population while leaving enough for future harvest. The upper size limit has been the most controversial, because some divers feel that oversized urchins will overpopulate kelp beds. However, biologists' surveys and my observations in the Strait of Juan de Fuca do not show a buildup of oversized urchins.

Another important regulation is the formation of five different harvest areas with a three-year rotation. This allows the population

[2]A manuscript (not in bound volume) of this presentation is available from Communications Department, California Sea Grant College, University of California, 9500 Gilman Drive, La Jolla, CA 92093-0232.

to reproduce and grow without disturbance. Some people complain that the system crowds the vessels and forces fisheries to operate from a different port each year. We also have seasons that occur primarily in the winter when prices are higher. Early closures have led to a three-day work week to spread picking over a long season.

The 1989 license moratorium (licenses go to vessels, not divers) set a goal of 45 vessels in the fleet. The fleet currently has 77 vessels which is more than needed to harvest the resource. A long-term outlook, improved law enforcement, good data on the resource, and good industry-biologist communication are all important to maintaining a viable industry.

RED SEA URCHINS IN S.E. ALASKA: STATUS OF RESEARCH AND MANAGEMENT[1]

DOUG WOODBY

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 percent 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.

SEA URCHIN FISHERY OF JAPAN[1]

KATSUO SAITO

The Japanese sea urchin fishery includes as many as 16 species, six of which constitute the primary species fished. *Strongylocentrotus intermedus* and *S. nudus* belong to the northern species; *Tripneustes gratilla* and *Pseudocentrotus depressus* belong to the southern species; and *S. pulcherrimus* and *Anthocidaris crassispina* are intermediate. The two northern species and *Pseudocentrotus depressus* account for 87 percent of productivity. Total national productivity decreased from 25,000 tons to 20,000 tons in this decade. In recent years, imports have

expanded and now equal our domestic catch. About 50 percent come from the United States and 32 percent from Korea. Fishery resources have been managed for a long time. Mariculture has been emphasized in the last few years, and many seed production facilities have been built. The northern species especially show rapid increase in productivity. Numerous artificial fishery grounds for sea urchins have been built. The fishermen, however, are aging rapidly as a group and there is concern with the numbers of their successors.

MANAGING ABALONE FISHERIES BY QUOTA IN AUSTRALIA, SOUTH AFRICA, AND NEW ZEALAND: A REVIEW[1]

S. A. SHEPARD

Abalone fisheries in Australia, South Africa and New Zealand developed during the 1960s and were initially managed by regulations on input (license limitation, closures, etc.). These have gradually been superseded by output controls, namely quotas which confer property rights on fishers. A revolution in management is now in progress, as the implications and advantages of property 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 (which is minor in Australia, New Zealand and South Africa, where high incomes of divers reduce 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 percent of the legal catch. Elsewhere it is contained to <20 percent by intense surveillance and severe penalties.

The commitment by 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 falls 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 to 50 percent (e.g., South Australia, Tasmania) have also been used, not to set quotas, but to reduce the risk of recruitment overfishing. Yet stock assessments of any kind have been rarely systematic, nowhere complete and always spasmodic. The reason is that costs are high and no government has committed itself to such a program.

Management of abalone fisheries by quota is now a permanent feature, but substantial improvements are possible. The transformation of property 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 development.

THE SEA URCHIN FISHERY (*LOXECHINUS ALBUS*) IN CHILE[1]

JULIO A. VÁSQUEZ AND CHITA GUISADO

Among Chilean artisanal fisheries, the most important is that of shellfish, based on molluscs, echinoderms, and crustaceans. In 1987, total landings of these benthic resources was 114,316 tons. For Chile this meant an income equivalent to $43 million U.S., of which $15.8 million resulted from exports of the edible sea urchin, *Loxechious albus*.

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

In our paper we present an updated diagnosis of the artisanal sea urchin fishery in Chile, including our basic biological information (bathymetric and geographic distribution, morphology and spawning); extraction level; fishery areas; processing of the gonads; culture; management; and repopulation of natural areas.

Because of the current level of harvest of Lox*echinus albus* along the Chilean coast, we hope to generate, in the shortest possible time, management plans allowing for the recovery of natural populations of this resource. Management plans must include (a) cultures under controlled conditions and in the natural environment and (b) management and protection of coastal areas.

SEA URCHIN FISHERIES OF BRITISH COLUMBIA, CANADA[1]

RICK HARBO AND KERRY HOBBS

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 t) for a landed value of $4 million. Licenses 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 percent 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 from 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 pending more information 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 license limitation, a minimum size limit of 55 mm, and area and seasonal restrictions. The 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.

THE GREEN SEA URCHIN INDUSTRY IN MAINE—A STATUS REPORT

BEN BAXTER

The green urchin (*S. droebachiensis*) in Maine is ubiquitous, inhabiting ledge and cobble substrates from the surface to several hundred feet of depth and subsisting on an omnivorous diet of suspended plankton, fish detritus, and a wide variety of sessile and drifting algal species. However, only a few sublittoral broadleaf algae, particularly *Laminaria* spp. and *Alaria* spp., are recognized as consistent sources of beta-Carotene responsible for the marketable bright yellow roe emanded by the Japanese consumer.

The harvest of green urchins in the Gulf of Maine (the only commercially abundant species) has been unregulated over its unsteady 15 year history, but an annual harvest increase from one million to over 15 million pounds in the last three years has spawned conservation concerns from both inside and out of the industry. Shortage of supply is apparent in several zones only halfway through the eight-month winter harvest season.

Natural and market forces have acted in the past to conserve the species and the fishery: spring spawn limits the season; market demand for larger urchins protects reproductive potential; and the market requires that urchins with poorly colored roe not be purchased for costly shipment in the round.

The Maine and Canadian maritime industries clearly moved in 1991/92 toward increased stateside extraction of roe to counteract rising air freight costs. This reduces the harvesters' requirement to take only from the best roe-coloring habitats and drops the industry size standard somewhat toward the size of initial fecundity.

In the absence of any funding for stock assessments and without license, size, or zone limits, Maine's urchin industry may exceed its recruitment capacity and strip the most productive beds to the extent that market interest will lapse.

DISCUSSION SUMMARY AND RECOMMENDATIONS: RESOURCE MANAGEMENT

Six groups discussed resource management issues and research needs. There was general agreement that it is urgent that a rational long-term management plan be developed now to protect the long-term health of the fisheries, the environment and society. In reviewing management issues, many participants felt that we could learn much from management experiences in other nations (Japan, China, and New Zealand). Some general organizational needs were identified.

1. Set up structures (e.g., regional advisory councils, urchin/abalone/kelp commission) to facilitate interaction and information exchange among harvesters, managers, researchers, and conservation groups.
2. Review and clarify the legal/governmental management framework within which we must operate. This includes within the state (Legislature, Fish and Game Commission, Department of Fish and Game) and federally (e.g., Maine Mammal Protection Act, National Marine Sanctuaries, National Parks).
3. Develop adequate funding for management and management-related research (e.g., resource users, agencies, Sea Grant).

The discussion groups came up with numerous resource management ideas and research needs. Many participants felt that future management objectives for sea otters need to be clarified. If otters expand their range significantly, then management efforts for abalone and urchins will be futile.

1. Compare the effects of different management schemes (e.g., area rotation, size limits, refugia) on recruitment, settlement, and postlarval survival. We need to examine the effectiveness of these methods in other locales.
2. Improve communication and education among those interested in managing these kelp-bed resources. This includes dissemination of research results and education about alternative management strategies.
3. Explore ways to reduce the number of participants in the urchin fishery.
4. Determine if individual transferable quotas (ITQs) are a viable management option for dive fisheries.

5. Determine if protecting "parental stocks" in permanent refugia or rotation of closed zones is an effective management method. If so, what sizes, locations, and duration closures are most effective.
6. Assess the value of the urchin, kelp, and abalone resources to the state.
7. Look at the feasibility of dividing the coast into smaller management units or zones and utilize catch per area rather than catch per unit effort as an indicator of health of the resource.
8. Develop more effective enforcement methods.
9. Consider reducing diver efficiency as a management tool (e.g., by equipment restrictions).
10. Examine the effects of urchin/abalone management and enhancement activities on other kelp-bed organisms. We need to consider ecosystem management rather than single species management.
11. Develop a management plan for purple sea urchins.
12. Improve landings data with more accurate information on harvesting locations and individual diver landings (for possible ITQ catch histories).
13. Encourage industry-government cooperation in developing management plans. Examine the feasibility of co-management which involves the sharing of management planning, implementation, and enforcement responsibility between agencies and industry.

DISCUSSION SUMMARY AND RECOMMENDATIONS: INFORMATION NEEDS

Two groups discussed information needs, and they had quite different perspectives. One group focused on research and development needed to provide information on key aquaculture and resource management issues. They concentrated on identifying major informational gaps. The other group was concerned with improved communication between people interested in kelp bed ecosystems, such as divers, processors, researchers, resource managers, and the general public. Improved communications was the primary concern expressed by both discussion groups.

Recommendations on Information Needs

1. Establish a single clearinghouse for information on sea urchins, kelp, and abalone that researchers, industry, and resource agencies can utilize. This clearinghouse would not need to house all information, but should be able to refer people to the information sources.
2. Establish a newsletter to maintain communication. (Some looked on the newsletter as localized; dealing with management, legislative issues, public relations, and communications between interest groups. Others envisioned a broad focus on urchin, kelp, and abalone research and resource management information from throughout the world. At the final session of the conference, the consensus of the attendees was to maintain the momentum of this conference with a general newsletter to allow industry, academics, and agency personnel to share information on urchins, abalone, and kelp. Fishing industry people offered to help produce the newsletter.)
3. Improve relationships and develop trust among divers, processors, legislators, managers, scientists, and the public through improved communication.
4. Develop better methods of disseminating research results, including information on alternative feeds for abalone and sea urchins and on kelp forest polyculture.
5. Streamline the process. Let people know how this can best be accomplished.

6. Develop and disseminate education programs to inform the public on the value of kelp bed resources and fisheries.
7. Hold conferences like this one as often as feasible to promote the sharing of current research, enhancement, and management information among interested people.

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