

**The Ecological Roles of Sea Urchins:  
An Investigation of Community Structure and Stability in Kelp Forest Ecosystems  
by  
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INTRODUCTION

Kelp-forests and the community of invertebrate and vertebrate species associated with them constitute a significant ecosystem off the east and west coasts of North America. The structure of a kelp-forest may vary from one community to the next, but individual communities share many similar characteristics, including increased habitat structure and complexity within vs. without the forest, specific algal species forming the canopy and understory, and reduced wave action within the kelp-forest.

The purpose of this paper is to discuss the impact of sea urchins on kelp-forest community structure, as well as natural and human-implemented controls on urchin populations. In stable kelp ecosystems, urchins are herbivorous mesopredators with population density usually controlled by vertebrate predators. In the absence of top-down predation, urchin populations have been observed to change their feeding habits and form large and destructive feeding aggregations. Such a change often alters the dynamics of the kelp-forest community.

NORTH AMERICAN KELP FORESTS: A SOUTHERN CALIFORNIA EXAMPLE

*Community Structure, Environmental Influences, and Species Interactions*

The Point Loma kelp forest has been a site of extensive research for over 50 years and is a good representative of Southern California kelp habitat (Dayton et al. 1992). I will use a description as provided by Dayton et al. (1992) to provide a general picture of kelp forest community structure.

The upper layer of Point Loma's kelp bed is dominated by a canopy of giant kelp (*Macrocystis*) approximately 8-10 km in length and 1 km wide (Dayton et al. 1992). *Macrocystis* plants attach and grow on the wide, rocky shelves from the intertidal to a depth of about 30 m, creating a bed thick enough to minimize the effects of longshore currents away from its edges. Understory kelps of various species, including the feather boa kelp (*Egregia menziesii*), and three additional brown kelps (*Laminaria farlowii*, *Eisenia arborea*, and *Pterygophora californica*) add structure to the water column. The presence of the sea grass, *Phyllospadix*, further increases topographical complexity. This creates an environment significantly different from that found in the surrounding open ocean, where organisms lack protection from strong currents and increased wave action. Primary productivity of macroalgae is high, creating an abundance of food for marine animals. The density of planktonic food is also elevated due to the great quantities of invertebrate and fish larvae that recruit to the many niches available. Many invertebrates find shelter and food in the kelp understory, from the brittle stars and shrimps that seek refuge in holdfasts, to the lobsters and sea stars that hunt in its protected environment.

Kelp-forest density varies temporally, with much of the canopy potentially disintegrating during the winter months due to storms, in summer due to elevated water temperature, or during periodic El Nino Southern Oscillation (ENSO) events (Tegner and Dayton 1991, Dayton et al. 1992). ENSO events destroy the kelp canopy (Ebeling et al. 1985), and occasionally wipe out even the understory kelp and algae (Dayton et al. 1992). Such events significantly alter habitat structure and suitability. Variability in kelp-forest stability is also affected by community level interactions. This paper will link these natural processes together.

The ecological processes occurring in kelp-forests have long been a topic of intense study, with much research focusing on predator-prey interactions. Of particular interest are those associated with sea urchins, voracious herbivores whose appetites have been linked to massive destructions of kelp-forest habitat throughout the world (Bernstein et al. 1981, Cowen 1983, Tegner and Levin 1983, Dean et al. 1984, Harrold and Reed 1985, Miller 1985, Scheibling and Hamm 1991). ENSO events followed by intense grazing by sea urchins have been linked to a decreased ability of kelp forests to recover from regular environmental perturbations (Ebeling et al. 1985, Harrold and Reed 1985, Tegner and Dayton 1991, Dayton et al. 1992).

Many studies have identified key invertebrates within California kelp communities, including the spiny lobster, *Panulirus interruptus*, the giant sun star, *Pycnopodia* sp., and two species of sea urchin (*Strongylocentrotus purpuratus* and *S. franciscanus*) (Bernstein et al. 1981, Cowen 1983, Tegner and Levin 1983, Dean et al. 1984, Harrold and Reed 1985, Miller 1985, Scheibling and Hamm 1991). Research by Cowen (1983) indicates that predation by sheephead (*Semicossyphus pulcher*) on the red urchin (*S. franciscanus*) may be a critical interaction in maintaining community stability. Critical observations by Estes et al. (1978) and Duggins (1980) demonstrate the importance of the sea otter (*Enhydra lutris*) as a keystone predator in kelp forest community structure. As top predators in the kelp forest community, otters structure the trophic levels by feeding on various benthic invertebrates, particularly sea urchins (Duggins et al. 1980). Historic hunting of the otter for its pelts has led to a severe population decline, releasing herbivorous urchins from predatory control. The loss of entire otter populations has been shown to tip the balance of kelp ecosystems and release urchins north of Point Conception from top-down predatory control, changing the stability of kelp communities to favor dominance by urchins and increase the frequency of grazing fronts and the subsequent creation of barren grounds (those stripped by urchins of all kelp and algae) (Estes et al. 1978, Duggins 1980).

#### ECOLOGICAL ROLES OF URCHINS IN KELP FORESTS: GENERAL LIFE HISTORY AND FEEDING BEHAVIOR

The species of sea urchin addressed in this paper (*Strongylocentrotus purpuratus*, *S. franciscanus*, *S. droebachiensis*, and *Lytechinus anamesus*) share similar life histories. Urchins are dioecious (Barnes 1987). Spawning in mature adults is induced by elevated water temperature. Fertilization occurs in seawater following the shedding of gametes by adult urchins. Free-swimming larvae form within twelve hours. Larvae feed planktonically for several months before settling. Juvenile urchins are very small, and their growth rates depend on food availability. Urchins may live anywhere from a few to 30 years (as in *S. purpuratus*) (Barnes 1987). Urchins live on both hard and soft substrate, with juveniles seeking shelter under an adult's "spine canopy" (Breen et al. 1985). Mid-size individuals shelter in crevices and under rocks (Breen et al. 1985). Adults are observed either scattered across the substrate or clustered in

two-dimensional (a single layer) or three-dimensional (urchins piled on top of one another and clinging to stipes) feeding aggregations (Breen et al. 1985).

Urchins possess particular physical characteristics that are well-adapted for the formation of feeding aggregations. An urchin's mouth is surrounded by a flexible peristomial membrane; inside is found the Aristotle's Lantern, which is formed by five interlocking "teeth" and can be used to scrape algae off of rocks or opened and closed to pull and tear pieces of kelp into the mouth (Barnes 1987). Urchins' internal organs are surrounded with a calcareous skeleton, or test, which in turn is covered with layers of epidermal tissue. An urchin's spines are attached through many sockets, or holes, in the test. Spines consist of two lengths; primary spines are long, while secondary spines are short. Hundreds of tube feet are interspersed with spines and are particularly dense on an urchin's oral surface (Barnes 1987).

Sea urchin locomotion results from the interaction of its many spines and tube feet, and they can move in any direction. Movement and feeding activity are highly correlated, with some urchins remaining stationary and consuming primarily drift kelp, while others are actively foraging for attached macroalgae (Mattison et al. 1977, Dean et al. 1984). Both feeding behaviors may be observed simultaneously in a population, occurring within 100 meters of each other (Dean et al. 1984).

Large aggregations, or fronts, of urchins have been observed to form where drift algae is scarce (Mattison et al. 1977, Harrold and Reed 1985), when predators are near (Cowen 1983, Tegner and Levin 1983, Scheibling and Hamm 1991), and occasionally in response to storm activity and excessive wave action (Cowen et al. 1982). As mentioned previously, urchins may also form dense populations in the absence of predators, particularly otters (Estes et al. 1978, Duggins 1980). High levels of urchin feeding (i.e., urchins actively climbing stipes and consuming entire kelp plants) devastate kelp beds and set off a domino effect down trophic levels. Much speculation exists about why grazing fronts form.

An important study by Harrold and Reed (1985) performed at San Nicolas Island off the coast of Santa Barbara, CA revealed that barren grounds exist adjacent to complete stands of mature kelp. Sea urchins were typically abundant in areas covered with kelp, but they tended to collect in smaller, protected pockets and feed on drift algae. Urchins in barren areas were undernourished, smaller, and unprotected. New kelp sporophytes that settled in barren areas during the course of the study were quickly consumed and drift algae were virtually non-existent. Lack of drift algae encouraged foraging behavior; this was demonstrated by experimental removal of *Macrocystis* plants from a 40 x 40 meter plot. Removal of standing *Macrocystis* was followed by a rapid increase in urchin emergence from crevices to forage for algae (Harrold and Reed 1985).

Harrold and Reed (1985) proposed a model to explain the function of kelp communities and their transition between barren grounds and standing kelp beds. When drift algae are less-available due to a depletion of standing kelp-beds (i.e. as a result of a severe storm), then urchins are forced to leave cryptic habitat in search of food. This increase in grazing activity inhibits the settling and growth of new kelp, and available resources remain low. Thus, a certain threshold level of low kelp density is reached to initiate foraging behavior, and barren sites are maintained until the cycle is broken, either by landscape changes due to severe storms, the decimation of an urchin population by disease, or intensive harvest by local fisheries. This study is supported by

preliminary data obtained by Mattison et al. (1977) that indicate movement by sea urchins occurs as a response to a decreased food supply.

Overgrazing is not necessarily preliminary to a population crash for several reasons (Duggins 1980): (1) Urchins have an incredible ability to utilize alternative, although less desirable and nutritious, food sources such as benthic diatoms, less preferred foliose and encrusting coralline algae, and detritus; (2) Detached drift algae from a proximal patch of standing kelp may be plentiful; (3) Urchins can subsist for long periods of reduced availability by lowering their metabolism, reabsorbing portions of their bodies, and assimilating dissolved organic nutrients directly from the surrounding water. *Ex situ* experiments performed by Vadas (1977) indicate that feeding by sea urchins in nature is a compromise between urchin algal preferences and food availability.

Mann (1977) provides evidence that the formation of barren grounds may not be purely cyclic, that urchins in this intensive grazing pattern actually achieve a stable state that can exist over extended periods of time with decreased levels of primary productivity. His data is supported by an observational study performed by Dean et al. (1984) near San Onofre, CA. Urchins in this locality existed in both barren states and stationary clumps in cryptic habitat. Those urchins that were less mobile subsisted primarily on drift algae, while those in barrens formed highly mobile 3-D aggregations following two years of declining kelp abundance. Dean et al. (1984) identified these separate groups as subpopulations and implied that the latter had a destabilizing influence on kelp abundance and exacerbated declines in abundance initiated by other causes. They concluded that different species of urchins affect kelp abundance and distribution in different ways, and that an increase in kelp recruitment can decrease front formation. These conclusions imply that barren grounds are somewhat unstable and that, although they may persist for years, they are subject to “disturbance” by increases in kelp recruitment or storms that wipe out unprotected urchins.

#### LARGE SCALE ENVIRONMENTAL DISTURBANCES: EFFECTS ON URCHIN POPULATION DYNAMICS

Two papers published by Tegner and Dayton (1991, 1992) provide an example of one lengthy study on the kelp communities off Point Loma, CA. Information dating from the late 1950s to the late 1980s provides detail that elucidates the cumulative effects of sea urchins and weather patterns on community stability. Tegner and Dayton (1991,1992) provide conclusive evidence that El Ninos are part of a regular disturbance pattern in the northwestern Pacific Ocean that lead to the succession of stripped rocks by either kelp or urchins, depending on the intensity of the clearing, the availability of drift kelp, and the ability of kelps to disperse spores to settle on disturbed areas. They state “episodic events definitely overcame equilibrium mechanisms in the short term, but... biological mechanisms recovered quickly but with rate differences among the various areas within the kelp forest.” In other words, recovery occurred at rates specific to the degree of local perturbation. Like any other system, kelp forests must respond to large-scale events such as weather patterns, and to smaller-scale occurrences like local food availability and recruitment levels.

A critical study by Ebeling et al. (1985) revealed not only the detrimental effects storms and large-scale oceanographic events can have on kelp forest communities, but also how subsequent

storms can reverse these negative effects and enable the system to revert to its' previously undisturbed state. For a period of five years, Ebeling et al. (1985) recorded observations in four transects of southern California kelp beds in the following categories: plant, fish, and urchin density, and urchin locomotion and foraging behavior. In general, small storms and increased wave activity serve to check the movement of urchins by preventing them from making stable attachments on kelp stipes and attached blades. Urchin feeding is restricted to cryptic habitat or the base of kelp holdfasts with nearby drift algae.

In 1980, two violent winter storms decimated the top layers of the kelp canopy and removed existing drift kelp. *S. franciscanus* and *S. purpuratus* responded by emerging from their shelters in search of nourishment. Ebeling et al. (1985) suggest that a lack of predation pressure or disease were important factors in the formation of destructive grazing fronts. They hypothesize that a reduction in new kelp growth likely led to a decrease in secondary production and a reduction in fish subpopulations (i.e. those fish that previously foraged in the kelp beds were forced to seek new suitable habitat, and juvenile recruitment declined). How long this new state would have remained is not clear, for just three years later, a second severe storm impacted the same system and reversed the effects of the 1980 storms. All of the urchins previously exposed in the barren areas were swept away or killed as a result of heavy wave action and surge. Rocky areas freed from urchins were colonized by rapidly growing kelp sporophytes.

Although urchin fronts and barren grounds have demonstrated an ability to persist for multiple years, I have reservations about delineating these conditions as constituting a stable ecosystem. Anthropogenic interactions have affected kelp systems through the hunting of otters, lobster fishing, and pollution (Bernstein 1981, Duggins 1980, Estes et al. 1978, Miller 1985, Scheibling and Hamm 1991, Tegner and Dayton 1991, Tegner and Levin 1983). Other local and large-scale catastrophes outside our control such as El Ninos, hurricanes, and disease also influence ecosystem dynamics. Urchin fronts may not be the primary cause of disturbance in a kelp forest, but they destabilize community structure and intensify declines in kelp abundance initiated by other perturbations (Dean et al. 1984). We may never achieve the same "state" in kelp communities that previously existed; such is the nature of temporal variability in ecosystems. Long-term studies are infrequent in marine ecology and it is difficult to obtain data for periods longer than twenty years. In order to obtain a realistic perspective on the dynamics affecting kelp forest ecosystems, it is vital that data be recorded for multiple decades rather than over 1-2 year periods.

If urchin barrens can persist on extended temporal and spatial scales, it would be of interest to know the extent of their long-term effects on kelp-forest community structure, as well as potential mechanisms, other than weather patterns, for predicting or controlling their persistence. The removal of urchins through natural or experimental means generally results in an increase in macroalgal abundance and biomass (Duggins 1980, Cowen et al. 1982). Commercial divers in San Onofre, CA reported the removal of 75, 000+ lbs. of *S. franciscanus* in 1981 (Dean et al. 1984). Intensive harvesting has a dramatic effect on the ability of local urchin populations to devour kelp at rates exceeding those of recolonization, especially if harvest rates are higher than recruitment. An increase in the harvesting of urchins for human consumption is one possible control of urchin population explosion. Such an act of adaptive management would require the cooperation of scientists, fisheries, and government agencies to ensure the maintenance of biodiversity and community stability (Tegner and Dayton 1977).

## URCHIN DISEASES

A naturally occurring means of controlling urchin populations has been the widespread incidence of disease (Johnson 1970-71, Miller and Colodey 1983, Lessios et al. 1984, Scheibling and Stephenson 1984, Scheibling and Hennigar 1997, Scheibling et al. 1999). The virtual disappearance of *S. droebachiensis* from over 400 km of coastline in Nova Scotia, Canada has been well documented ( Miller and Colodey 1983, Scheibling and Hennigar 1997, Scheibling et al. 1999, Scheibling and Stephenson 1984). Similar cases have been recorded for *S. franciscanus* in Santa Cruz, CA (Pearse and Hines 1979), and for both *S. franciscanus* and *S. purpuratus* off Point Loma, CA (Johnson 1970-71).

The southern coast of Nova Scotia is irregular, with many coves and protected bays (Scheibling and Stephenson 1984). Urchins existed in barrens in apparently stable states in several locations prior to 1982 and again in the 1990s ( Scheibling et al. 1999). Scheibling et al. (1999) describe these community shifts as being stable. Localized outbreaks of disease that occurred between 1980-83, in 1993, and in 1995 in *S. droebachiensis* reduced grazing fronts temporarily. Timing of the outbreaks corresponded with an increase in sea-surface temperature from 12°C up to 20°C during the late summer and early fall of unusually warm years. Outbreaks declined and then ceased during winter with the onset of colder water temperatures (Scheibling and Hennigar 1997). Symptoms of disease included “loss of attachment to substratum, inability to extend tube feet, drooping and disheveled spines, and gaping peristome and jaws. This is followed by progressive spine loss and epidermal necrosis” (Scheibling and Stephenson 1984). Individuals of *S. droebachiensis* infected with the disease usually died within 2 weeks. Surviving urchins demonstrated recovery over the winter (Scheibling and Hennigar 1997).

Johnson (1970-71) reported the incidence of epidermal lesions in *S. franciscanus* during the early part of 1970 in a kelp forest off Point Loma. She described the lesions as follows: “The first evidence of abnormality was a green appearance of epithelial tissues surrounding scattered spine bases...Test and spine bases later lost both epithelium and superficial connective tissue. Denuded surfaces ranged from very small circular zones to elongate areas involving an entire ambulacrum.” Such lesions did not necessarily preclude fatality, although some die-off was observed. Urchins recovered slowly by regeneration of epidermal tissue and spines. It is unclear how initial infection took place or whether such lesions are common in southern California populations.

Perhaps the best documented incidence of widespread disease and its potential to knock out local subpopulations and even entire populations of urchins connected by ocean currents occurred in a coral reef ecosystem. Lessios et al. (1984) reported massive die-offs of the black sea urchin, *Diadema antillarum*, over a temporal scale of more than a year and a spatial scale covering the entire Caribbean Sea. The causative agent of the disease has not been positively identified, but a waterborne pathogen is suspected (Lessios et al. 1984). *Diadema antillarum* populations are specific to coral reef communities rather than to kelp forest communities, but the pattern of mortality in local populations along warm surface currents independent of point-source pollution, with equal intensity in all localities, and with great specificity to a single species of urchin, may provide insight into the type and mode of infection suspected in disease outbreaks in populations of urchins in kelp-forests.

A series of experiments was performed by scientists at a Japanese fishery in Hokkaido in an attempt to isolate the cause of periodic outbreaks detrimental to their yearly harvest. These

studies identified the epizootic responsible for infection of the urchin, *S. intermedius*, an important commodity in the Japanese fishery (Tajima et al. 1997, 1998a, 1998b, Takeuchi et al. 1999). In 1993, a gliding bacterium, *Flexibacter sp.*, was isolated from the coelomic fluid of diseased *S. intermedius* (Tajima et al. 1997). Additional ecological experimentation revealed that *Flexibacter sp.* was undetectable in seawater at temperatures less than 20°C (Tajima et al. 1998a). Infection was shown through further studies to occur simultaneously with annual increases in water temperature and always resulted in death (Tajima et al. 1998b). A final study by Takeuchi et al. (1999) led to the isolation of a second genus of bacteria responsible for infection, *Vibrio sp.*. Despite the discovery of specific bacteria responsible for infection and death in *S. intermedius*, no suggestions for controlling or limiting the spread of infection were provided.

Attempts to isolate specific pathogens include an experiment performed by Bauer and Young (2000), in which deep-sea urchins, *Paleopneustes cristatus*, were collected, and the bacteria of infected individuals isolated through dissection and culture of epidermal tissue. Healthy individuals were infected experimentally and all but one died after nine days. In short, a shallow-water bacterium infected *P. cristatus* through contact with contaminated water following retrieval from the deep sea. No single bacterium or virus was identified. It was evident that healthy urchins with minor physical abrasions suffered mortality at a higher rate than undamaged urchins. Bauer and Young (2000) referenced experimental studies performed by Maes and Jangoux (1984, 1985) in which bacterial lesions were the determined cause of illness/death in echinoids.

In order to investigate and verify the suspected cause (a waterborne amoebic pathogen) of the mass mortality observed in *S. droebachiensis* in 1982 in Nova Scotia, Scheibling and Stephenson (1984) devised an *ex situ* experiment. They collected both healthy and apparently infected individuals from selected sites. Healthy individuals in laboratory tanks were then exposed to diseased individuals placed in up-current tanks in various densities and at various temperatures. A control of healthy individuals was placed down current from healthy individuals in the same densities and at the same temperatures. Healthy individuals that succumbed to infection were removed and observed until death, a period lasting from 5-29 days, depending on exposure density and temperature. The time required for infection and death was inversely related to temperature; the higher the temperature an urchin was exposed to, the more quickly it succumbed to disease. No incidence of disease or infection was detected in the control group at any temperature, suggesting that temperature is not the only factor in disease outbreaks. High temperatures might act as threshold activators of disease, but the disease does not appear to be present at a constant low level or else the individuals in the healthy control would have demonstrated signs of infection at elevated temperatures. Scheibling and Stephenson (1984) conclude that the causative agent of infection in *S. droebachiensis* appears to be a waterborne pathogen.

A similar study was conducted by Miller and Colodey (1983) to determine the existence of a “biological agent” after observing extensive urchin mortality at separate field sites from those of Scheibling and Stephenson (1984) in Nova Scotia. Mortality observed in the field was not site-specific; it occurred in open areas, areas with macroalgal cover, areas with heavy wave action, areas with minimal wave action, and areas with and without stream run-off. Laboratory tanks were maintained at a relatively constant temperature of 17°C and both healthy and infected urchins were collected. Urchins downstream of infected urchins sickened within approximately two weeks. Symptoms included, but were not limited to: “inability to hold onto the vertical sides

of the tank, inability to right themselves, few if any tube feet extending past the spines, and lantern teeth gaping” (Miller and Colodey 1983). Both studies implicate some type of water-born pathogen that acts independently of pollution or habitat quality and appears related to water temperature (Scheibling et al. 1999). All urchins reaching this stage were unable to recover (Miller and Colodey 1983). Jones et al. (1985) positively identified *Paramoeba invadens* as the pathogenic agent. *P. invadens* is water-born and healthy urchins can be infected through contact with tainted water at elevated temperatures.

In view of the critical role sea urchins play in the ecological stability of kelp-forest communities, it is of interest to consider disease as a means to control population explosions and limit the creation of grazing fronts. I therefore pose the question, could disease outbreak control urchin populations in a predictable fashion? The use of species-specific biological agents to control invasive species and enhance agricultural productivity is a hot topic of study in terrestrial systems, but remains relatively unexplored in marine systems (Lafferty and Kuris 1996). Marine systems are usually open and understanding of their dynamics is minimal. Although it is obvious from the studies, observations, and experiments cited in this paper that disease plays an important role in altering urchin-dominated systems, I would not suggest the use of disease as a means of human-managed population control. Although *ex situ* experimentation has implicated certain waterborne pathogens as causative agents, their mechanisms are poorly understood and the ramifications of disease are largely unknown. Following the mass-mortality of *Diadema antillarum* in the Caribbean in 1983, populations have not recovered (Lessios et al. 1984). It is impossible to predict the severity (i.e. temporal and spatial extent) of natural outbreaks. It would be more useful to dedicate time to increasing our understanding of these mechanisms through experimentation than to attempt to apply our current knowledge to adaptive management. The susceptibility of local populations to disease is documented, but it requires long-term investigation to gain increased understanding of the various ecological processes at work (Dayton et al. 1992).

## FUTURE RESEARCH AND CONCLUSIONS

My interest in writing this paper was sparked by an observation of epidermal lesions on *S. purpuratus* while diving in Mission Bay during September, 2001. The lesions are characterized by a loss of primary spines and abnormal epidermal patches with mottled coloration. I was intrigued that urchins in close proximity to one another did not all suffer from the epidermal disease. I questioned whether the lesions were ultimately fatal, and whether they were spread by currents carrying pathogens from sewage spills or storm water run-off or caused by physical damage to an urchin’s exterior. I have not observed such lesions on urchins (either *S. purpuratus* or *S. franciscanus*) while diving outside the bay off Point Loma, Scripp’s Pier, or La Jolla Cove.

It would be intriguing to collect data on the incidence of this epidermal disease within Mission Bay. What percentage of the population is infected? Is infection ultimately fatal, or is recovery possible? How does transmission occur and are undamaged urchins susceptible to infection? Does infection occur outside of Mission Bay? If so, what is the cause? If not, is risk of infection increased due to generally warmer temperatures and increased pollution levels within Mission Bay?

Infected individuals could be collected with the intent of isolating the mechanism responsible for disease. One could attempt to infect healthy individuals by “painting” on infected material, or

by exposing healthy urchins to contaminated water. It would also be useful to experiment by changing water temperature and relative levels of pollution as factors that might alter urchins' susceptibility to infection.

I wonder whether an increase in grazing intensity and urchin density increases the risk of disease. Data collected by Miller and Colodey (1983) suggest that this is not the case for diseased urchins in Nova Scotia, but their conclusions were based on field observations without a null-hypothesis or any type of control. I do not recall whether the urchins I observed with lesions were located in large clumps, or only random individuals amongst healthy urchins. Such data would be beneficial in determining how grazing strategies and population densities influence the incidence and transference of disease in local populations. Urchins in Mission Bay feed primarily on drift algae in the absence of kelp canopy (personal observation). Data on the incidence of epidermal lesions as related to the abundance or lack of food availability would provide further insight. If disease is a key factor in controlling the formation of grazing fronts, or at least in limiting their expansion and temporal stability, then information accrued through observational studies and experimentation in Mission Bay could prove useful in helping us better understand the processes at work in local kelp forests of Point Loma and La Jolla.

Other natural means of control exist in the natural structuring of kelp forest communities. As mentioned previously, urchins are susceptible to predation by otters, sheephead, and spiny lobster (Bernstein et al. 1981, Cowen 1983, Tegner and Levin 1983, Dean et al. 1984, Miller 1985, Scheibling and Hamm 1991). Attempts to simulate the effects of otter foraging have identified the importance of keystone predators to ecosystem stability (Cowen et al. 1982). It may be impossible to restore the otter to its former habitat in full. Controlling the catch limits of local lobster and sheephead fisheries is a more promising possibility to stabilizing local community structure and population dynamics.

Sea urchins play a critical role in their relative communities, and increases in the formation of grazing fronts can lead to a transformation of the biological community. I would not go so far as to suggest this is a new state of equilibrium, as natural processes rarely reach such a state. It has been demonstrated that barren grounds can persist over several years. However, they are susceptible to local and large-scale perturbations and reversals just as the original kelp community. A key to understanding the ecological processes involved is to obtain more information on urchin disease and its potential to regulate populations or destroy lucrative fisheries. It is doubtful that any system can ever be returned to the state it existed in prior to anthropogenic contact, but information on ecological processes is key to ecological conservation and management.

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