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The Effects of Waste Disposal on Kelp Communities

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Research Project

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The objective of this symposium was to develop a consensus of scientific opinion about the effects of waste disposal on kelp (Macrocystis pyrifera) communities in southern California as of January 1983 and to propose additional measurements that will round out our knowledge of the subject.

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PERSPECTIVE

Willard Bascom*

What to do with man's wastes is an important national problem. The choices that were available to a thinly-populated largely agrarian country no longer exist. Large increases in our population and industry now create wastes that exceed the capacities of sites that were considered to be adequate for waste disposal only a few decades ago. A choice must be made between land, air (incineration), and ocean disposal, but there are laws and regulations that prohibit the use of each of those under some circumstances.

Much of the world is now contaminated, which means the concentration of certain objectionable materials is higher than exisited before man arrived. Pollution exists only if the contamination level is sufficiently great to cause damage to man or other biota.

Contamination is relatively easy to identify and measure with modern chemical techniques. It is much more difficult to decide the best action each community should take to minimize overall environmental contamination; that requires consideration of numerous other factors. These include such items as air pollution caused by incineration, contamination of ground water by land disposal, and secondary environmental

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costs arising from mining, manufacturing, and transporting materials used in waste treatment. It is also necessary to consider the priorities on water, land and energy usage. All the above are real environmental costs that often have been ignored.

The Clean Water Act required all parts of our country to take the same action with respect to sewage waste treatment. Although even-handedness has much political appeal, the difficulties are evident. Persons living in the high mountains of Colorado find it unreasonable to deal with wastes in the same way as those who live along the shallow bayous of Louisiana. Hawaii, with much rainfall and land that slopes steeply into deep water, should not be expected to take the same action as flat, dry, mid-continent Kansas.

As each area searches for an optimum solution it becomes increasingly evident that different kinds of answers make sense in different places.

The national problem just described is <u>not</u> the subject of this meeting. Here we are concerned only with one specific aspect of one option. Ocean disposal may be a sensible solution for as much as one fourth of our population. It is certainly a valuable resource for southern California and it would be unfortunate to reject it without sound reasons. We all know that there have been abuses in the past; these have been acknowledged and substantial corrective efforts made. Generally speaking, the coastal waters of California are now in excellent condition and the damage of a decade ago has disappeared or been greatly reduced. However, it is always

necessary to be on the alert for new or previously unnoticed problems.

The object of this symposium is to direct attention to a problem that is partly scientific and partly operational. We are asking ourselves: What are the effects of municipal waste disposal on kelp communities? The kelp forests of Palos Verdes (Los Angeles) and Point Loma (San Diego) are especially worthy of our attention because they are proximate to large outfalls and they are known to have waxed and waned over the last few decades. It is our job to try to understand the relationship between the kelp and the outfalls and give guidance to those who are responsible for seeing that these kelp communities stay in good condition.

If this group of distinguished kelp scientists believes that present waste disposal practices are causing substantial damage to our kelp forests, the authorities should take action.

If it is uncertain that present waste disposal practices damage kelp forests or if causes cannot be assigned to any changes observed, then more research will be needed.

POST-SYMPOSIUM REFLECTIONS

The major objectives of this symposium were to encourage a review of what is thought to be known about the interactions between man's inputs to the sea and the kelp beds which lie close to the southern California shoreline, and to provide a forum in which the validity and implications of this knowledge could be debated.

The problem is complicated by the fact that sewage discharges, one of the easiest inputs to monitor, are not the only factors affecting the health of the kelp forests. Carefully planned activities such as harvesting compete with natural phenomena — for example the severe storms which decimated large stands of kelp during the past winter— to produce an interacting set of factors influencing kelp survival.

In spite of these difficulties, leaders of regulatory agencies, sewage plant operators, commercial users of the kelp resources and scientists who have worked for many years on the characteristics of these plants and the nature of their environments all gathered to help one another develop better overall insight into the questions they all face. While differences of opinion still remain it appears that no disastrous effects of sewage on the kelp and the ecosystems it supports were identified. Nevertheless, the group's uneasiness as to the existence of possible effects not yet well defined led to a feeling of need for continued attention going beyond routine monitoring.

We are grateful to all those who contributed to the discussion during the 2 days of this meeting and to those who produced and reviewed the resulting papers. It is our hope that this publication will provide a useful step along the road toward intelligent utilization of our coasts.

F. N. Spiess
Director, Institute of
Marine Resources

After listening to the papers and the opinions expressed during this symposium it seems to me that nearly everyone participating was of the opinion that present ocean waste disposal practices do not cause substantial damage to kelp communities. Some were uncertain that any measureable effects are caused by the occasional dilute plumes of waste water that do reach parts of some kelp beds. Others seemed to be a little uneasy about the presence of an outfall close to a kelp forest that might possibly be damaging in some unspecified way in the future.

Virtually everyone believed that much more remains to be known about the complex ecology of kelp communities and that specific studies will be needed to answer specific questions.

Willard Bascom
Director, Coastal Water
Research Project

THE PHYSICAL AND CHEMICAL ENVIRONMENT OF A KELP COMMUNITY

George A. Jackson*

The coastal environment off Southern California is a significantly different extension of the deeper waters offshore. The coast is an area where cold, nutrient-rich water comes nearer to the surface, where higher phytoplankton concentrations decrease light penetration depths. It is a region where bottom friction regulates currents, where the shoreline constrains cross-shore flow, and where bathymetric irregularities and longshore winds create patches of cold water at the surface. Within a kelp stand, these coastal influences are augmented by those of the kelp itself.

In this paper I describe light, temperature, nutrient concentrations, and currents within a kelp stand and I note processes over a range of spatial and temporal scales that affect them.

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Light

Oceanic light distribution is determined by the complementary processes of absorption and scattering (Jerlov 1968). Plant pigments are major absorbers of light in oceanic surface waters; clay particles can be major light scatterers in shallow coastal areas near river mouths. Given the vertical distribution of absorption and scattering coefficients as a function

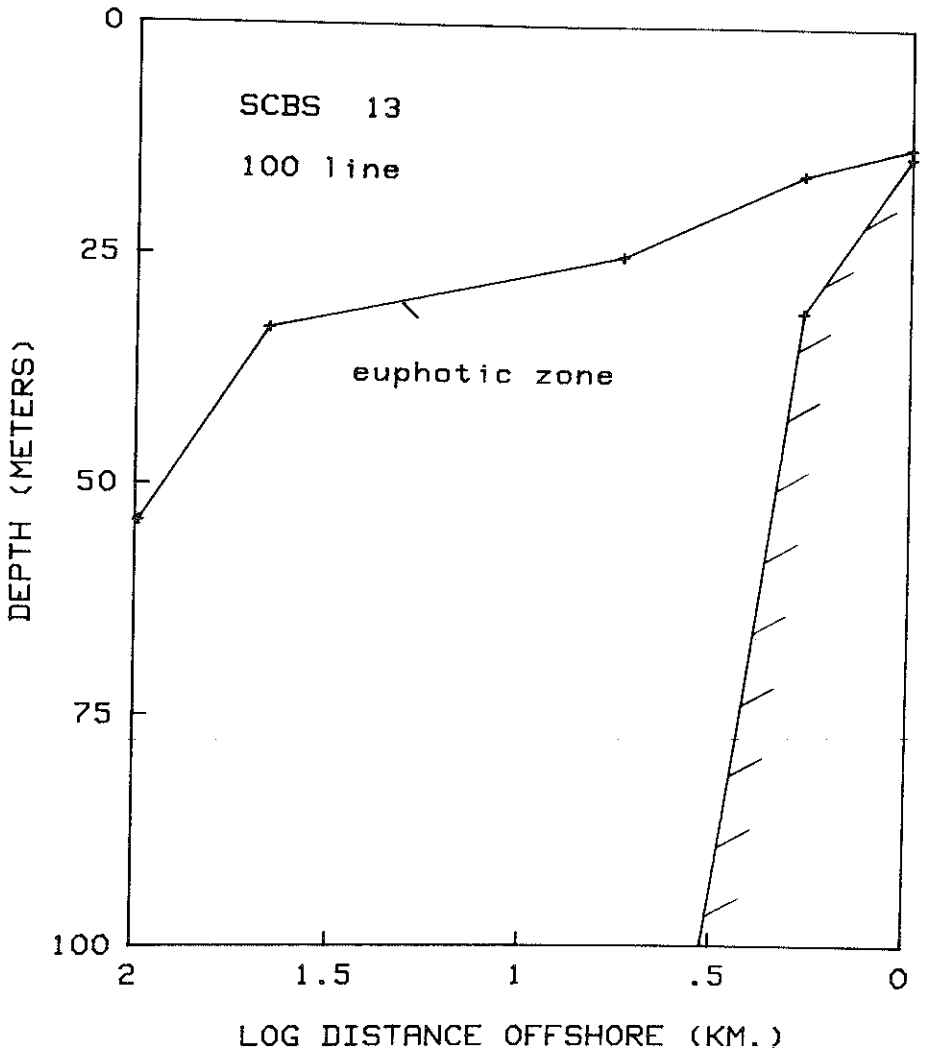

Figure 1. Euphotic depth on a line west from Del Mar, California. The euphotic depth is the depth at which light level is 1% of that at the surface. Data were taken on the Food Chain Research Group (S.I.O.) line 100, Cruise 13, August 1978..

of light wavelength one can calculate the vertical distribution of the various light descriptors. However, measuring and predicting these absorption and scattering coefficients has proven to be difficult.

Biological oceanographers have taken a pragmatic approach to the problem of predicting light fields. They commonly accept that plant respiration just balances photosynthesis when the downward light irradiance is about 1% of that at the ocean's surface. The depth of this 1% light level is known as the euphotic depth, z_{eu}; waters above it constitute the euphotic zone. Light levels decrease approximately exponentially with depth. A constant absorption coefficient, known as the diffuse irradiance attenuance, k_w, can be related to the euphotic depth: $k_w = \frac{-1}{z_{eu}} \ln(0.01)$. This approach does not adequately describe the light field in such important details as its directional or spectral nature but it does provide useful predictions and it is simple.

Station	Distance from Outer Edge (M)	Chlorophyll (µg/l)
O	-70	0.48
M	120	0.52
L	310	0.58
K	530	0.90

Table 1. Surface chlorophyll concentrations across the Pt. Loma kelp bed, 21 Oct. 1982. The four stations sampled were the sites of current meters discussed in Table 1. These sites are arranged on a line perpendicular to shore near the middle (in the longshore direction). Station "O" was outside the bed.

Phytoplankton concentrations in surface waters increase closer to shore. As a result, the euphotic depth decreases closer to shore (Fig. 1). Not only is light penetration in kelp stands decreased by these higher coastal phytoplankton concentrations but also by increased turbidity within a bed. Diving inside and out of the Pt. Loma kelp bed, my colleagues and I have observed that visibility is invariably worse inside than out. We suspect that it is caused by degraded kelp tissue which is only slowly flushed out. We have found higher chlorophyll concentrations inside than out (Table 1).

Light penetration in a kelp bed is determined by kelp absorption as well as by the absorption and scattering of suspended matter. Absorption by the kelp is by tissue predominantly in either an intertwined column of fronds rising from the bottom to the surface, or in the canopy, spread across the surface.

I have developed a simple model that calculates light penetration assuming that light is absorbed by the surface canopy, by the kelp columns, and by the suspended matter. I have assumed that light travels downward at a constant angle to the vertical that is determined using Snell's law:

$$\theta = \sin^{-1}[\frac{1}{n} \sin (\alpha)] \qquad (1)$$

where n = refractive index of seawater

$= 1.33$

α = angle of sun from zenith

θ = angle of light rays from vertical in seawater

The amount of light transmitted through the canopy depends on the area of blade surface per unit surface area (the blade area index). To estimate the light absorbance of a kelp blade I used North's (1971) observation that an

opaque cardboard cutout blocks as much light as a blade of 40% greater area. This implies that one blade absorbs 71% of the light passing across it and transmits the rest. This is a value which can change with the nutritional state of a plant. For this discussion, I will use F_T to denote the fraction of light transmitted through the canopy.

The absorption by plant columns depends on plant densities, plant widths, and the horizontal distance a light ray travels:

$$\frac{dI}{dz} = -\sigma\, d \sin(\theta)\, I$$
$$\equiv -k_c\, I$$

The absorption by suspended matter is the same as used by biological oceanographers:

$$\frac{dI}{dz} = -k_w I \qquad \text{for water column absorption.}$$

Under the canopy, then the total light change is given by

$$\frac{dI}{dz} = -(k_w + k_c) I \tag{2}$$

where I = downward irradiance as function of depth

σ = plant density, No/m^2

d = diameter of plant column, m

k_c = apparent absorption coefficient of kelp column, m^{-1}

$= \sigma\, d \sin(\theta)$

k_w = apparent absorption coefficient of water, m^{-1}.

The light intensity at a given depth, z, below the canopy is then

$$I = I_o\, F_T\, e^{-(k_w + k_c) z}. \tag{c}$$

where

I_o = light intensity at the surface

How big are the various numbers?

The value of F_T depends on plant density, frond length, water depth, and plant nutritional state. Neushul (1971) has reported values as low as 0.1 for a bed with plant density of about 0.25 plant m^{-2} in about 20 m of water. Values of F_T can range, therefore, between 1 in the absence of a bed to at least 0.1 in a dense bed.

The value of k_c depends on the sun angle, plant density, and column diameter. The angle, θ, ranges from 0° when the sun is overhead to 49° when the sun is on the horizon. The plant density, σ, ranges from 0 to an extremely high value of 0.4 plants m^{-2}. The plant diameter, d, ranges from 0.2 to 0.5 m $plant^{-1}$. Thus k_c ranges from 0 to 0.15 m^{-1}. For more typical Pt. Loma conditions where $\theta = 30^o$ and $\sigma = 0.1$ plants m^{-2}, $k_c = 0.025$.

Values for the euphotic depth, measured by the Food Chain Research Group of Scripps at a station of 20 m depth off Del Mar, California, range from 3 to 57 m, averaging 23 m for 20 cruises. The equivalent values of k_w range from 1.54 to 0.08 m^{-1}. The k_w for the average euphotic depth is 0.20 m^{-1}. Thus, k_w is usually a larger and more important determinant of sub-canopy light penetration than k_c, although high plant densities and clear water can reverse the situation.

Neushul (1971) has noted that young Macrocystis macrophytes need light levels of at least 0.8% of surface light to grow. To the extent that successful juvenile recruitment demands that this light reach the bottom, plant density and canopy coverage is determined by $k_w b$, where b is the bottom

depth. In areas with a large $k_w b$ (i.e., high water absorbence, deep bottom, or both), kelp plants can increase the light reaching the bottom by decreasing canopy and, less importantly, column absorbence. Decreased canopy absorbence can result from a decreased plant density or from less tissue at the surface, as would happen in deeper water where more of the tissue is submerged. The outer edge of a kelp stand is defined by depths too deep to have the necessary light, even in the absence of canopy absorption. For the 0.8% level, this happens for $k_w b = -\ln(0.008) = +4.83$. Thus, we expect the light-limited outer edge to be at 24 m for a k_w equal to 0.20 m^{-1}. An increase in k_w by only 10% would decrease this value by almost 10%, to 22 m.

A sewage field can be expected to affect light transmission in a kelp bed but the size of the effect depends on the concentration and vertical distribution of the sewage particles as well as how often they reach the kelp. Peterson (1974) measured light fields in various natural and sewage-affected areas near Los Angeles. After comparing downward irradiance between the two sets of samples, he concluded that sewage field could decrease the euphotic depth by 60% at high particle concentrations. The size of the decrease is suspect because he used several deep water stations as his controls when calculating sewage-caused changes in light penetration. If he had used comparable coastal stations, the euphotic zones of his control stations would have been shallower and the differences between these controls and the sewage-impacted areas would have been smaller. His results do show changes of light attenuance within a sewage plume but we cannot state the expected change in euphotic zone size.

It has been suggested that sewage discharge from the Pt. Loma outfall has reduced the outer depth of the kelp bed there by 10% from about 21 m (C.

Barilotti pers. comm.). Such a reduction could be caused by increased light absorbance of 10%. Such a small change in the average k_w in the presence of large variability is practically undetectable from light measurements. Some other measurement would be needed to show the effect of the waste field.

Nutrients

Concentrations of major nutrients (CO_2 [total], NO_3^-, PO_4^{3-}, silicate) and several trace metals are linearly related to each other (e.g. Redfield et

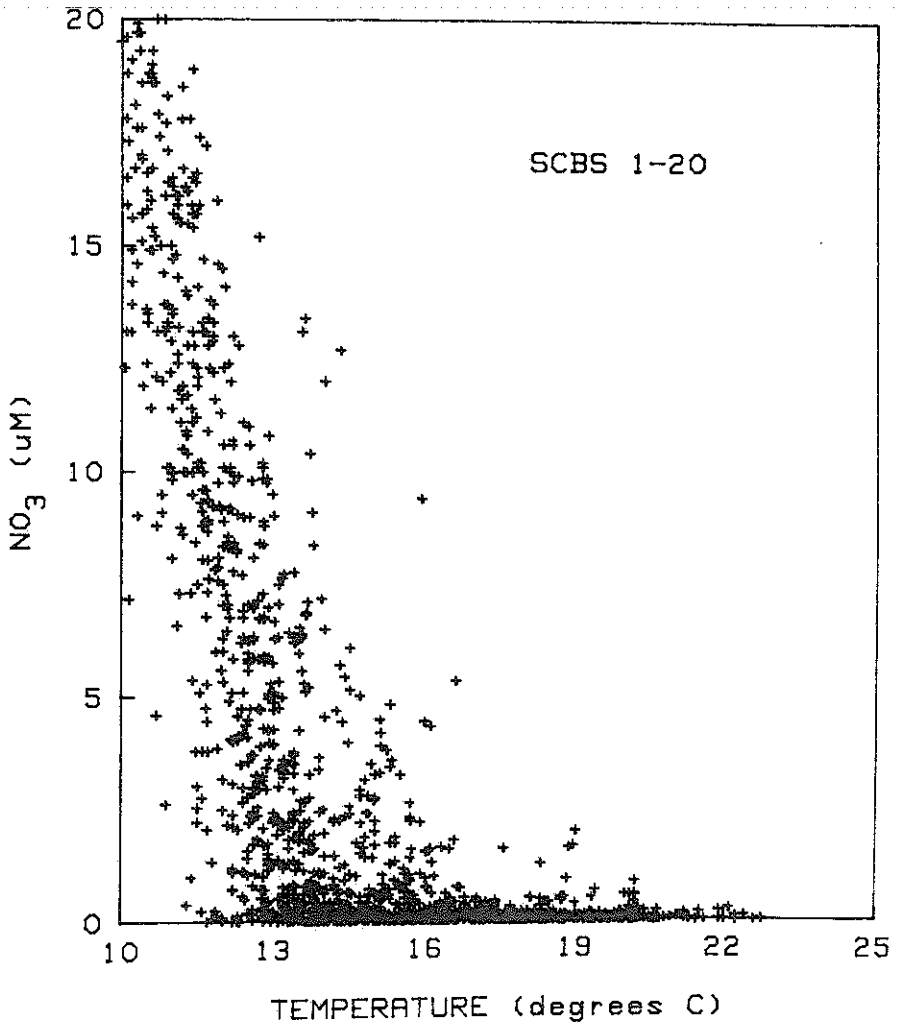

Figure 2. Temperature/nitrate relationship in Southern California Bight. Data were collected on Food Chain Research Group cruises SCBS 1-20.

al. 1963). I will refer to NO_3^- for the rest of this paper but the patterns are similar for the other nutrients because of this interrelationship. Oceanic nutrient distributions are affected by density stratification and by planktonic uptake and release of nutrients. Not unexpectedly, there is a clear relationship between nutrient concentration and temperature (T), the dominant factor controlling seawater density off Southern California (Fig. 2). For high temperatures, greater than 16°C, there is no measurable NO_3^-; for lower temperatures, a decrease in T matches with an increase in NO_3^- concentration. Because of this T-NO_3^- relationship, those processes which affect density and temperature distributions also affect nutrient distribution.

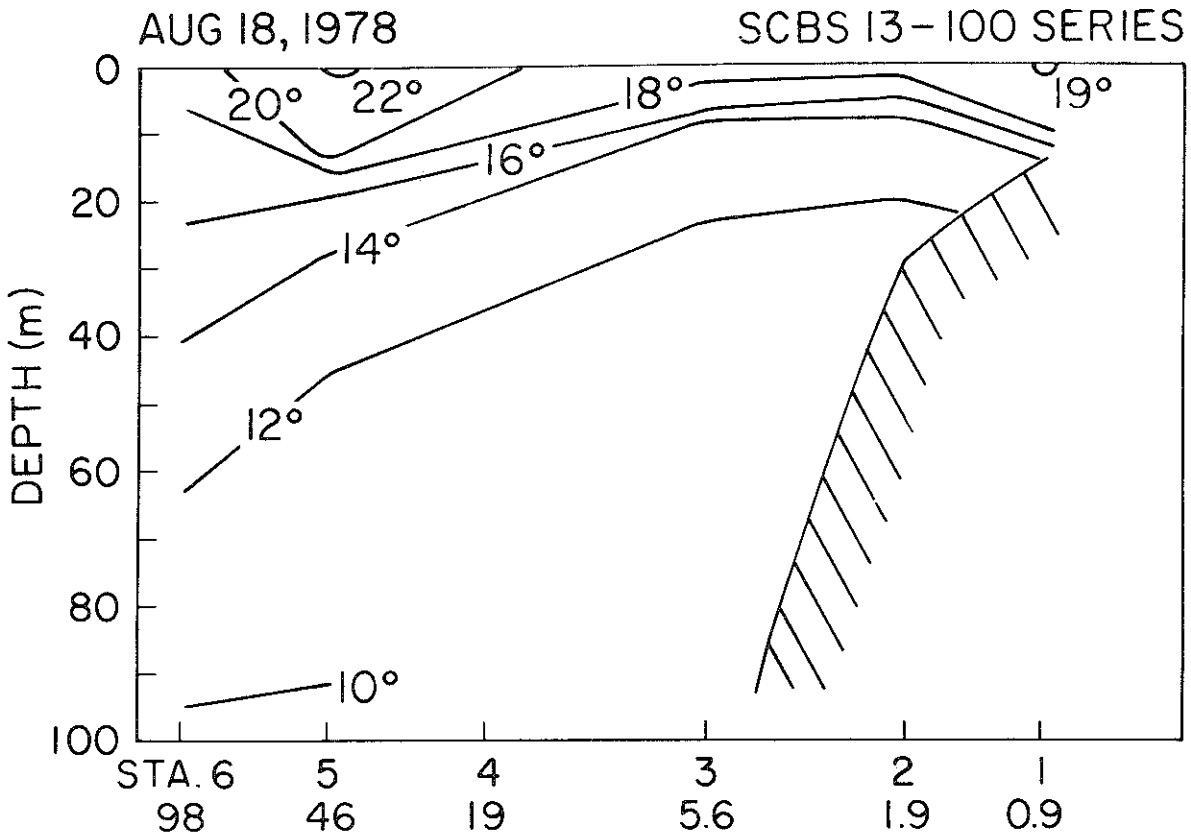

Figure 3. Temperature as a function of distance offshore. Data were from same stations as in Figure 1. Notice the shoaling of isotherms near the coast.

Changes in the T/density field relevant to kelp bed occur at many length and time scales. Recent work has shown trans-Pacific changes in temperature fields are very large spatial scale phenomena that effect coastal kelp beds. Anomalously warm water has been associated with decreased transport by the California Current (Bernal 1981; Chelton 1981), decreased phytoplankton production (Smith and Eppley 1982), and high kelp mortality (Clendenning 1968). Predictors for this warm water condition suggest that in 1983 we will be in for a very warm, and hence low nutrient, situation.

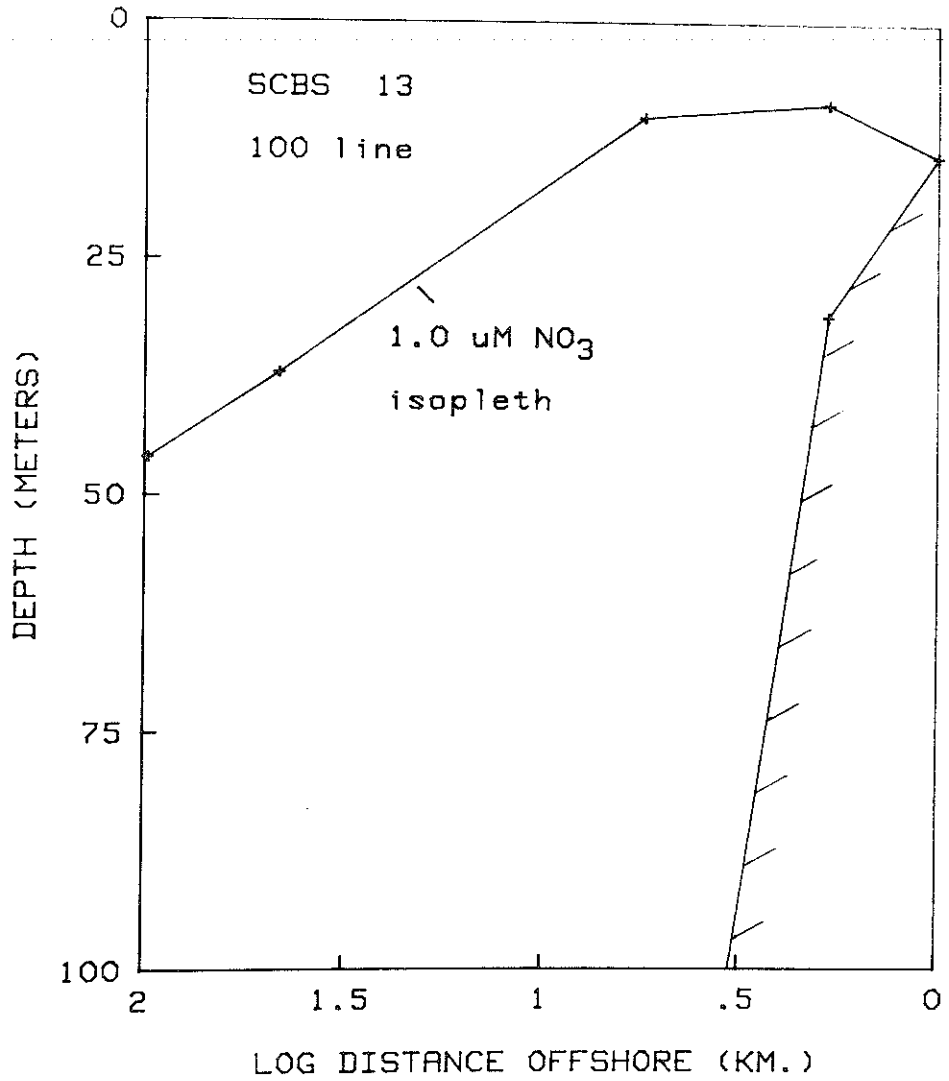

Figure 4. Depth of 1.0 nitrate isopleth as a function of distance offshore. Data were from same stations as in Figure 1.

On a scale large compared to kelp beds, there is a shoaling of isotherms near the coast that raises isotherms and nitrate isoclines from 30-50 m depth offshore to 10-15 m depth in kelp beds (Fig. 3,4). Without this shoaling, there would be no nutrients in kelp beds. On long time scales there are seasonal changes.

On medium time/length scales there are wind-driven upwelling and downwelling which can move isotherms and nutrient isoclines up or down tens of meters. Upwelling is particularly intense around points and capes. I have sampled the temperature and nutrient concentrations just offshore of the Pt. Loma kelp bed during one such upwelling event. This upwelling did not affect the bed uniformly but brought only high nitrate water to the surface in the southern half of the bed (Fig. 5). Thermal images from satellites show that the most intense upwelling in Southern California south of Santa Barbara occurs at Palos Verdes Peninsula and at Pt. Loma. Both have been sites of major kelp beds and are presently sites of major sewage outfalls.

On short time scales there are internal waves, ranging in frequency from almost daily to minutes. Internal waves propagate along density gradients, such as exist at the thermocline, and can cause vertical excursions as large as 15 meters (Cairns and LaFond 1966). By this means high nutrient bottom water can move, temporarily, near the surface. The most prominent of these motions in temperature records from the Point Loma kelp bed are those caused by a semi-diurnal internal tide.

Within the kelp bed, temperature fluctuations are coherent over the kelp bed for frequencies less than about 10 d^{-1} (Fig. 6). Internal wave motions diminish that coherence for higher frequencies.

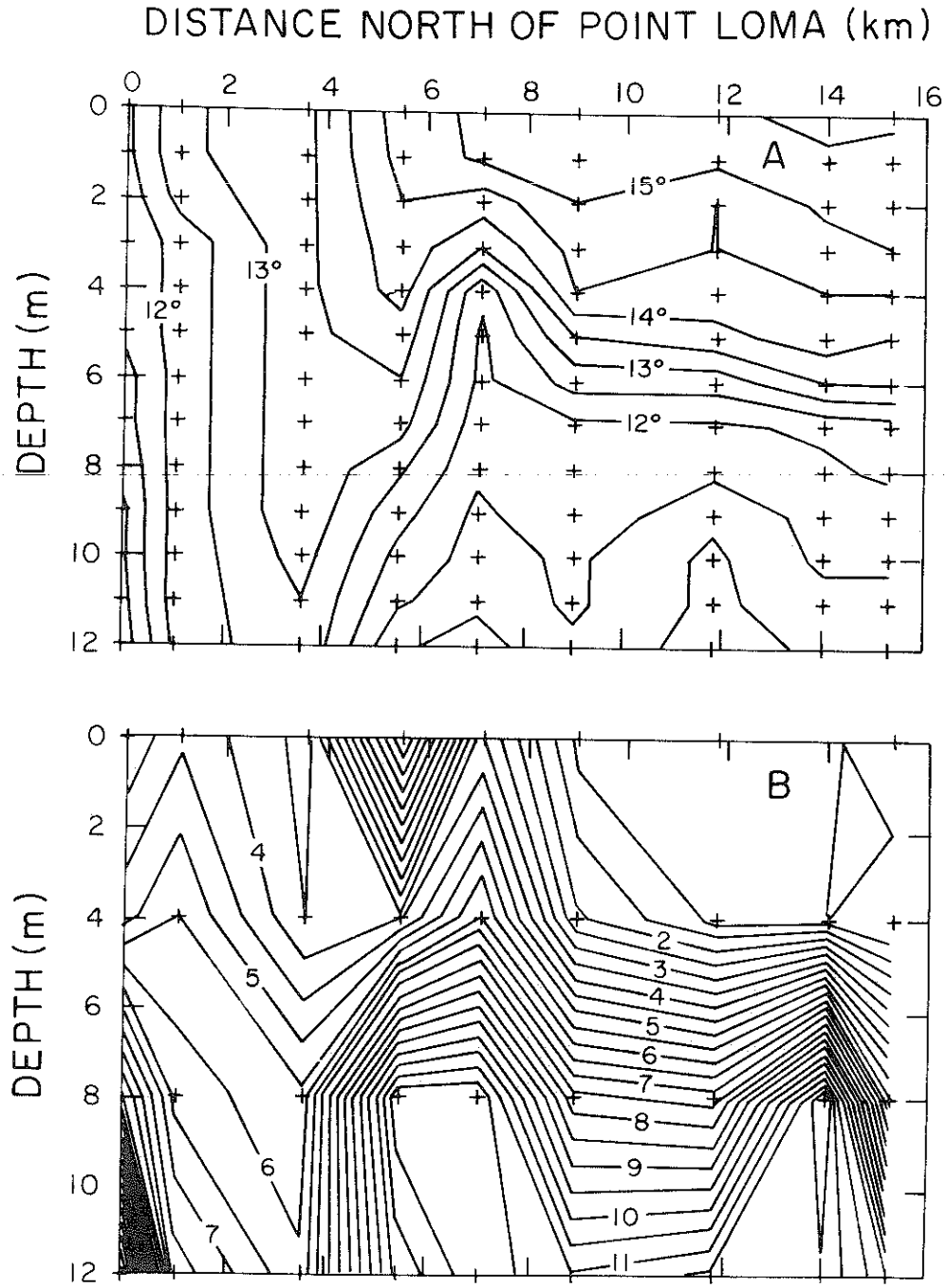

Figure 5. Temperature (A) and nitrate concentration (B) along the 20 m isobath going north from the tip of Pt. Loma. Temperatures are in degrees C and concentrations in . Note that the most intense upwelling is within the lower half of the bed.

The most systematic published set of kelp bed nutrient measurements was made by North et al. (1982) off Corona del Mar. Nitrate + nitrite concentrations (the sum of both is hereafter referred to simply as nitrate) are low for most of the year at the surface and near the bottom at 10 m.

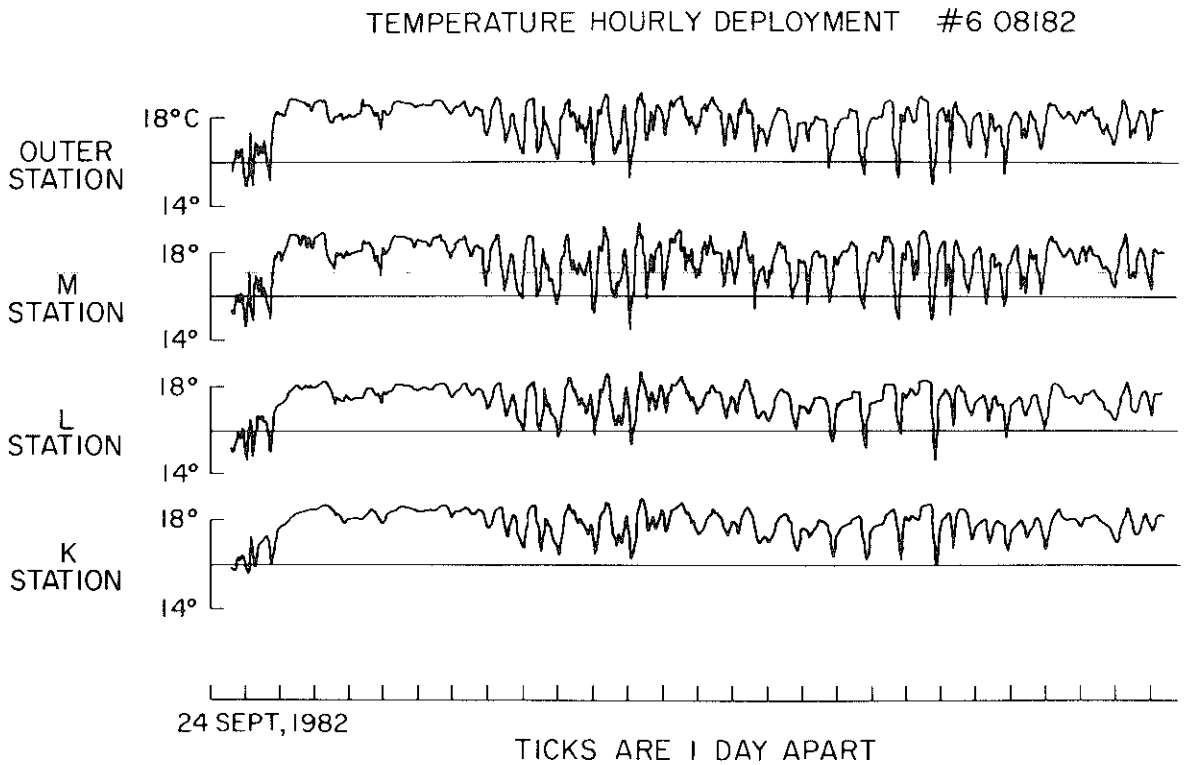

Figure 6. Near-surface temperature records at Pt. Loma. Records were taken on a line perpendicular to shore almost in the middle of the 7 km long Pt. Loma kelp bed. Station positions are in Table 1. Values plotted are hourly averages. Records start on 24 September 1982.

During the upwelling season, May-July of 1979, subsurface nutrient concentrations became quite high, 10 μM or more, but remained relatively low at the surface. Surface nitrate concentrations were high only during a period of heavy rains and surface runoff through nearby Newport Harbor. NO_3^- concentrations during February-March 1983 reached as high as 31 μM in the

surface but not near the bottom, the result of nutrient-rich fresh water runoff floating near the surface. Thus, different seasonally-driven nutrient inputs have different characteristics.

I analyzed nutrient concentrations in the bed at Pt. Loma, which is larger, deeper, more upwelling affected, and nearer to a sewage outfall

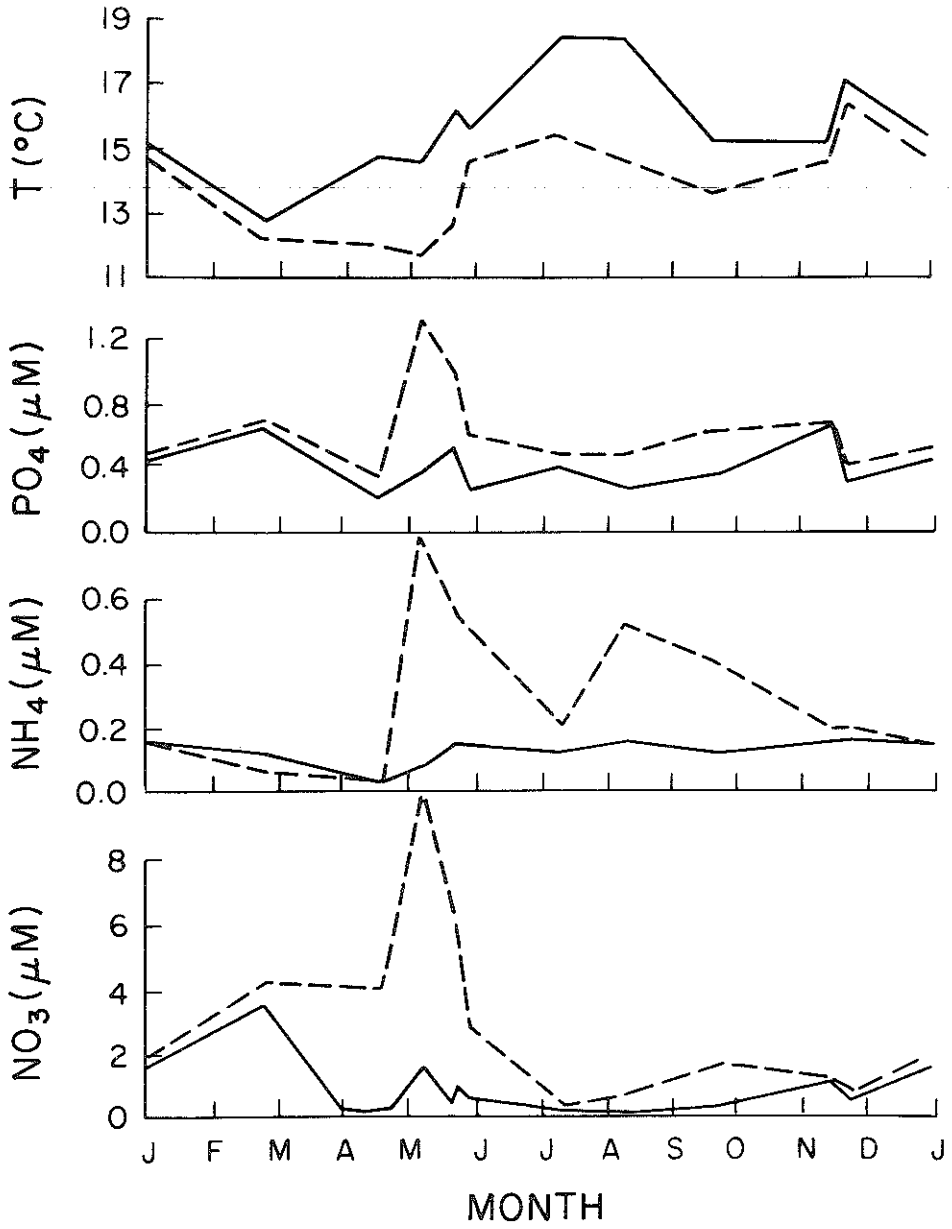

Figure 7. Temperature and nutrient distributions at Pt. Loma. Solid lines are the average for the upper 4.5 m, dashed lines are the average values for 4.5-9 m.

(Jackson 1977). My sampling was less frequent than that of North et al. (1982) and was done over several years but was more intensive spatially. My results show that Pt. Loma kelp bed, which is deeper than the bed studied by North et al., is usually vertically stratified except during winter months (Fig. 7). During the winter temperature and nutrient concentrations are nearly vertically uniform. Nitrate concentrations are on the order of 2 µM. With spring comes upwelling, which is usually reflected in especially cold and nitrate-rich water below the thermocline. Surface waters are usually, but not always, nitrate-depleted. With summer there comes low nutrient concentrations and higher temperatures through most of the water column. It is difficult to detect nutrient depletion by the kelp because the surface waters, where much of the kelp biomass resides, usually have undetectable nitrate concentrations both inside and outside of the bed. High sub-surface concentrations make it difficult to discern small changes caused by kelp uptake.

J. Kremer and R. Zimmerman (pers. comm.) have recently shown that internal wave-caused fluctuations in the vertical nutrient distributions can cause descriptions of the kelp's nutrient environment to be in error if not compensated for. They found that frequent temperature measurements used in conjunction with temperature-nutrient relationships were an effective way to describe the environment.

Sewage effluent contains high concentrations of the nitrogen form, ammonia. The average ammonia concentration in the Pt. Loma effluent is 1.7 mM (Schafer 1977). This effluent mixes with seawater to form a 200:1 seawater:effluent mixture right after discharge. Further mixing creates a mass of 800:1 within 3 km (Hendricks 1977a). The resulting ammonia concentrations are 8.6 µM and 2.1 µM. If sewage effluent is reaching the Pt.

Loma kelp bed, there should be high ammonia concentrations there, although the presence of ammonia does not necessarily prove sewage effluent because there are natural sources of ammonia as well. The highest ammonia concentrations that I have measured within the Pt. Loma kelp bed were little more than 1 μM and occurred near the bottom; concentrations were usually much less. Nutrient concentration measurements thus provide little evidence for much sewage effluent entering the kelp bed.

Currents

Water motions are determined by the interaction of wind-forcing, friction, pressure gradients, advection, and the earth's rotation. As with the other physical properties, important processes occur on a range of spatial and temporal scales. For this section I will concentrate on kelp-bed sized processes.

Winant and his collaborators have written extensively about currents and temperatures on the shallow Southern California shelf. They have described currents in 18 m of water at the NOSC tower off San Diego (Winant and Olson 1976), in a line running offshore of Del Mar with stations in 60, 30, and 15 m of water (Winant and Bratkovich 1981; Winant 1979) and in a line running longshore from Del Mar to Oceanside along a 30 m bottom contour (Winant 1983). The following background comes from these papers.

It is useful to describe coastal currents in terms of their cross- and along-shore components. The longshore and cross-shore components are coherent with each other at 60 m but not at 30 m bottom depth. As a result the two components are not correlated in regions 30 m or shallower; they assume different characteristics. Here we distinguish between a current which moves

in the same direction through the water column - a barotropic current - and one where flow reverses direction between the surface and the bottom - a baroclinic current. Longshore currents in shallow water tend to be barotropic and cross-shore to be baroclinic. Cross-shore currents have this vertical current shear partly because the coastal boundary will not allow any shoreward flow at one depth that is not balanced by a seaward flow at another depth. Otherwise water would accumulate on the shore. A shoreward surface flow can be balanced by a seaward bottom flow which, when there is a strong thermocline, causes the thermocline depth to fall. This happens when an internal wave propagates shoreward or winds cause coastal downwelling. Longshore flow is not constrained in the same way by the coastal boundary so that uniform movement through the water column is possible, although not necessary.

The coast zone is also a region where bottom drag has a greater impact because of the shallow water. The result is that current velocities and, hence, energies decrease in shallower water. Drag in a kelp bed is larger than bottom drag and drastically reduces currents.

Winant divided the currents records into 3 frequency bands which he expected to be driven by different processes. There was a low frequency band with an upper cutoff of 0.6 cpd (i.e., those currents reversing direction more slowly than every 0.83 days), an intermediate band with cutoffs of 0.6 and 6 cpd, and a high frequency band with cutoffs of 6 and 180 cpd. Low frequency events could be driven by such things as wind changes, medium frequency by diurnal (1.04 cpd) semi-diurnal (2.08 cpd) and their harmonics, and high frequency by internal waves. There is an overlap here in the forcing frequency bands because internal wave energy extends from the inertial frequency (1.12 cpd) and because local winds have a strong day-night component

(1 cpd). However, this has proven to be a useful way to divide the frequency spectra. I will focus the discussion currents in areas 30 m shallower unless otherwise noted because these are the depth range of giant kelp.

Longshore mean currents for records of 6-weeks to three months duration were to the south at the Del Mar line. Highest values near the surface were 11.6 cm s^{-1} at the 30 m station and 3.2 cm s^{-1} at the 15 m station. Cross-shore mean currents were zero. Hendricks (1977) reported that currents off of Pt. Loma also move south at the surface but move north at a depth of 41 m in 56 m of water.

Low frequency cross-shore currents are effectively zero but longshore currents are very energetic. Longshore currents are predominantly barotropic at 30 and 15 m bottom depth.

At intermediate frequencies, energies are comparable in cross- and longshore directions. There are strong motions at the tidal diurnal and semi-diurnal frequencies but they are not directly linked to the surface tide. Tidal components are linked to internal tides which are generated offshore and then propagate to shore. Cross-shelf currents at the surface in this band are out of phase with those on the bottom and both are correlated with temperature changes. Energy associated with cross-shelf currents at 15 m in this band decrease to one-tenth the energy at 60 m. Seasonally, cross-shore current energy is higher in spring than in winter by about a factor of three. The cross-shore currents in this band are the most energetic of all the bands, are baroclinic, vary seasonally, and have strong periodicities that are close to tidal. Longshore motions in this frequency band are predominantly barotropic, less seasonally variable, and have strong tidal frequency overtones with some surface tide linkage.

Higher frequency motions are mostly generated by internal waves. Energetically, they are the least important of the frequency bands

Clint Winant and I have been studying the effect of the Pt. Loma kelp bed on the currents. By comparing with a comparable kelp-free site, we found that cross-shore and longshore currents are less energetic than those outside by an order of magnitude (Jackson and Winant 1983). This difference in current strengths is explained by the high drag of a kelp bed, which is a factor of 10 larger than that of a sand bottom.

The effect of the kelp is evident in current records taken at various distances into the bed (Table 1). The cross-shore currents have no significant mean velocity at any of the four sites ranging from outside to 530 m inside (Table 2, Fig. 8); they did show a factor of 4 decrease in the RMS

Station	Bottom Depth (M)	Distance From Outside Edge (m)	Longshore Current (cm/sec)		Cross-shore Current (cm/sec)	
			Mean	RMS	Mean	RMS
O	28	-70	2.1	10.0	-0.1*	4.0
M	17	120	1.5	5.5	0.2*	1.8
L	14	310	-0.1*	2.0	-0.3*	1.2
K	14	530	-0.2*	2.0	0.3*	1.0

Table 2. Statistics of currents through the Pt. Loma kelp bed, 19 Sept.-21 Oct., 1982. Longshore currents are positive to the north, cross-shore positive to the south. * - not different from 0.0.

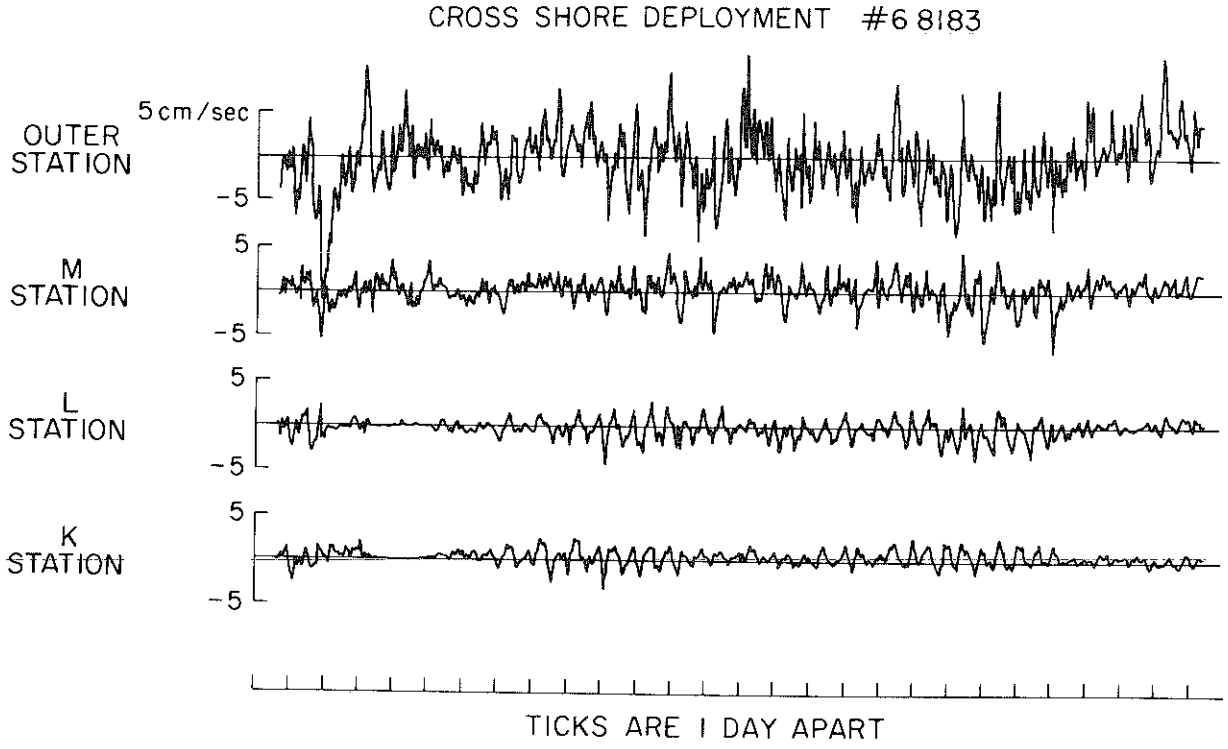

Figure 8. Cross-shore currents on a line perpendicular to shore at Pt. Loma. Records were taken in conjunction with those of Figure B. Gaps in records at stations K and L for days 4-6 were caused by kelp fouling of meters.

velocity over this distance. RMS velocities were almost the same for stations 310 and 530 m into the bed. Spectral analysis shows that the largest most important motions occur at semi-diurnal and diurnal frequencies. The semi-diurnal motions correspond to an internal tide.

Longshore currents show a slightly different pattern, with net northerly currents at sites outside and 120 m inside but none at the 310 and 530 m sites (Table 2, Fig. 9). RMS velocities decrease by a factor of 5 over this distance, almost the same as the decrease for cross-shore RMS velocity. Longshore velocity at the two inner stations (K and L) are virtually identical both visually (Fig. 9) and statistically (as determined by cross-spectral

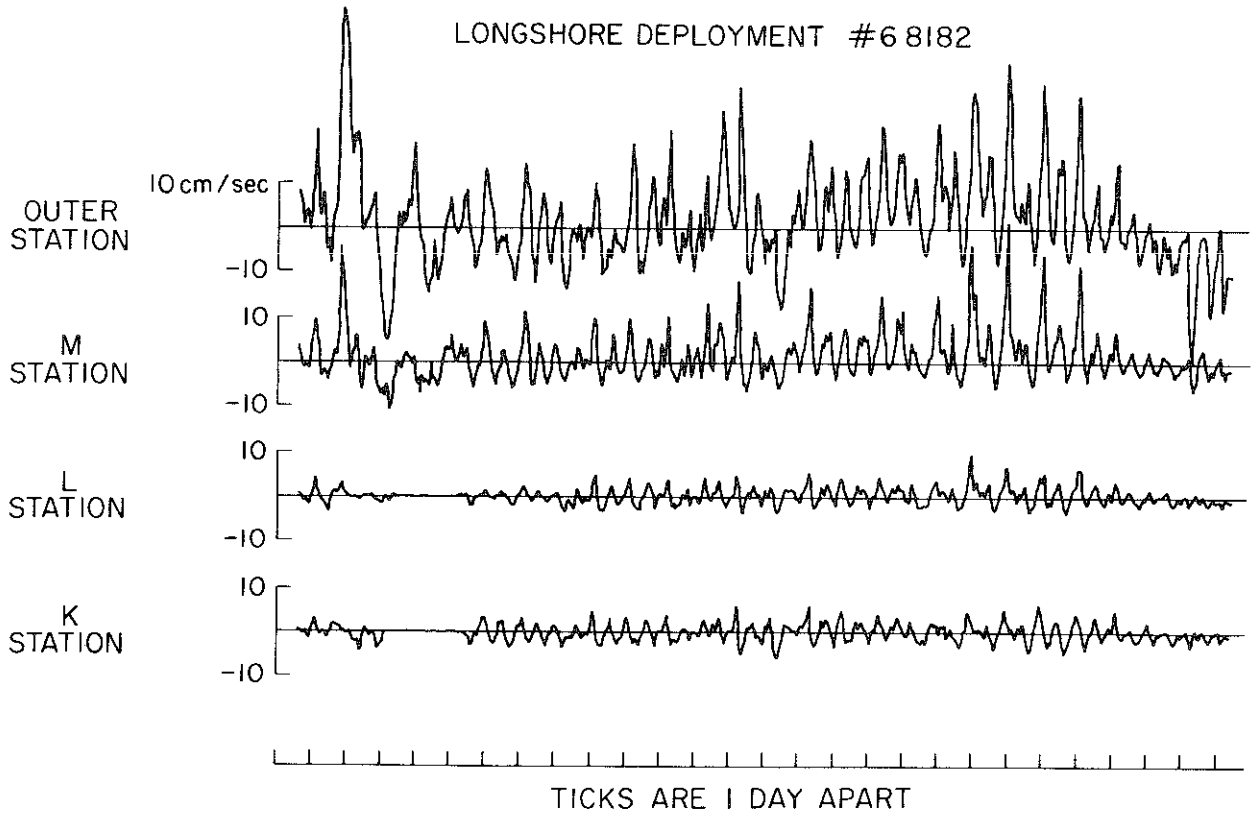

Figure 9. Longshore currents on a line perpendicular to shore at Pt. Loma. Records were taken in conjunction with those of Figures B and G. The high currents during days 2 and 3 of the record at Stations O and M are caused by a local storm. Notice that there is no large current in the kelp bed at Stations K and L.

analysis). Diurnal and semi-diurnal motions dominate the energy spectra of all longshore currents, as with cross-shore currents, but low frequency currents (sub-tidal) are important energetically for the longshore.

A comparison of the strength of currents in different frequency bands shows similar patterns to currents at Del Mar. The largest difference is that in the kelp bed low-frequency components of long-shore currents appear to be more heavily damped than those of tidal-frequency.

Given this short description of kelp bed currents, what are the implications for kelp exchange processes? Among the things we want to know are: how far into a kelp bed do the currents become typical of the kelp; how far and how frequently does water travel into the kelp, and what is the residence time of water in the bed. We can now start to estimate some of these quantities.

Calculations made using the high drag values for the kelp suggest that the transition from outside to inside current regimes occur over distances of 100 m at the longshore edge for a simple coastline. For a complicated area, such as the south end of Pt. Loma, this would not be true. For the cross-

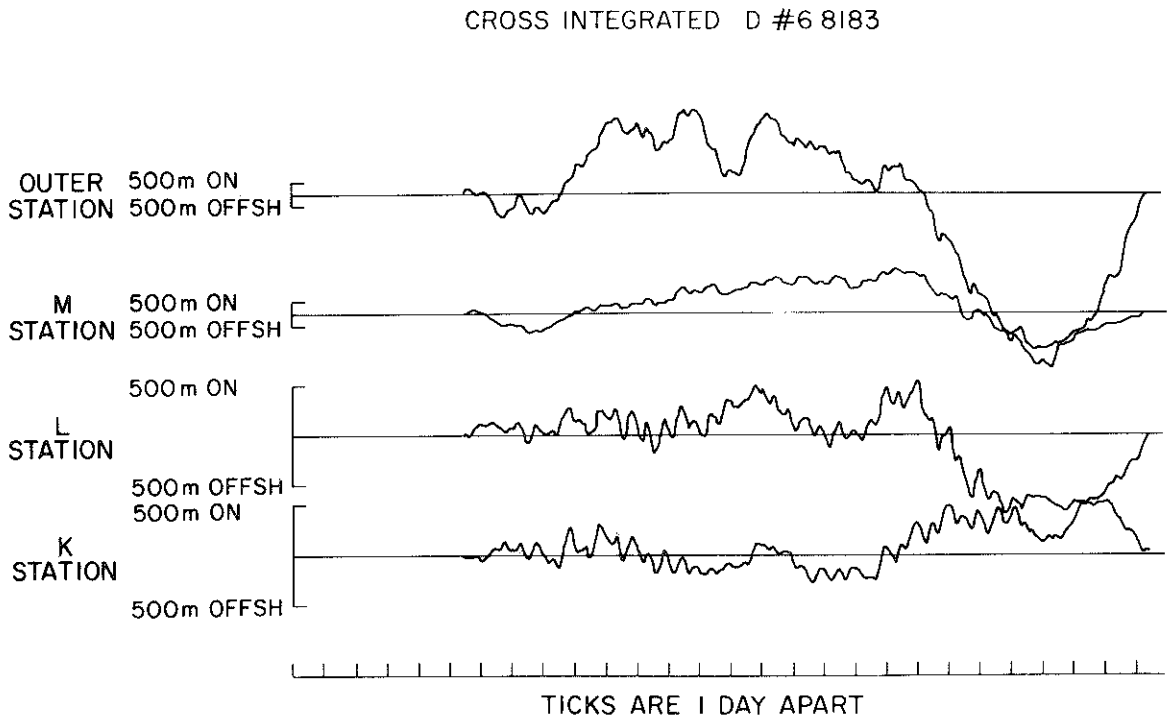

Figure 10. Integrated cross-shore currents. Cross-shore current records shown in Figure G had the mean current subtracted and were then integrated with respect to time starting on 29 September 1982. This time was picked to start after fouled meters were cleaned. Notice the scales are different for meters O and M than for K and L.

shore edge, the results shown in Table 2 show that the transition occurs between 120 and 310 m from the offshore edge. The general agreement between these two different techniques suggests that perhaps a good value for the transition zone at either the cross-shore or longshore edge is 200 m.

It is not possible to answer question of travel paths of water parcels in the kelp bed without a complete understanding of the flow field, which we do not have. It is possible to try, cautiously, to do so by using the current record at a particular site. If a water parcel, moving through the bed, has the same velocity as a current meter measures at one spot, then the parcel's path can be determined by integrating the meter's record. If the currents vary spatially, as they do at the four sites previously discussed, the assumption does not hold (Figs. 8 and 9). For example, the integrated cross-shore current record for station O would imply 3 km onshore excursions over two days, but the shoreline is less than 2 km away (Fig. 10).

The integrated currents for the stations inshore do not show such large excursions. They do show, however, a strong similarity in semi-diurnal fluctuations for the two inner stations, K and L. This coherence over more than 200 m implies that within this history the current meter record well describes the region of a water parcel. The integrated K record shows excursions of up to 200 m cross-shore twice a day. Thus, we can estimate a cross-shore excursion distance of water in the Pt. Loma kelp bed of about 200 m. The similar distance in the longshore direction would be about 300 m (Fig.11).

These results suggest that the water in a large kelp stand is relatively stagnant. Most of the water in a longshore current moving over a sandy area will flow around a kelp bed upon encountering it because the high drag within slows the water down (Fig. 12). The transition from the fast,

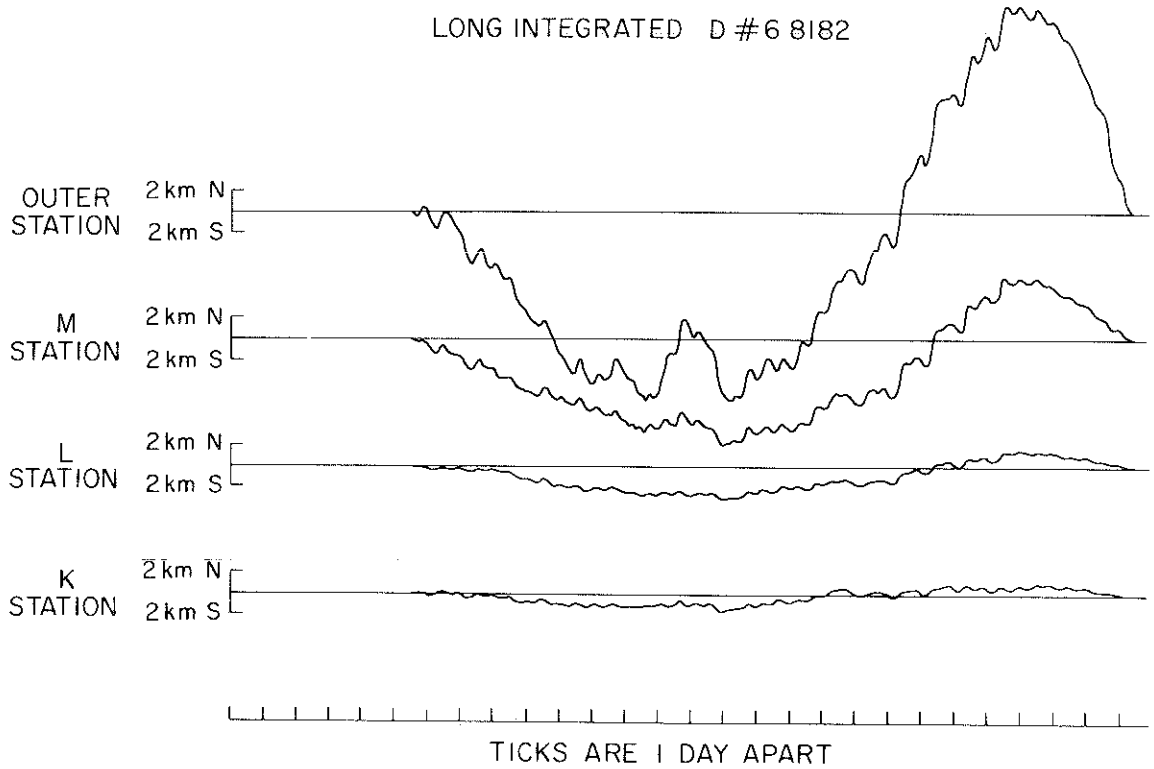

Figure 11. Integrated longshore currents. Processing was the same as for Figure 10.

sandy-bottom longshore current to a slow kelp bed current should take place over a distance of about 100 m for Pt. Loma plant densities (Jackson and Winant 1983). Mean longshore currents within the bed are slow, typically 1 km d^{-1} or less; oscillations are weak, moving water up and down coast a few hundred meters per tidal cycle. Longshore exchange of the kelp bed with the surrounding water is slow. Cross-shore water motion is slower because there is no mean flow and cross-shore tidal excursions are smaller than longshore. Even so, cross-shore exchange is more important for the interior of the bed because the distances that must be transversed are smaller, 1 km vs 7 km. Exchange with the outside is the result of mixing processes rather than simple advection. Residence time of water in the bed should be at least several tidal cycles, or several days (Table 3).

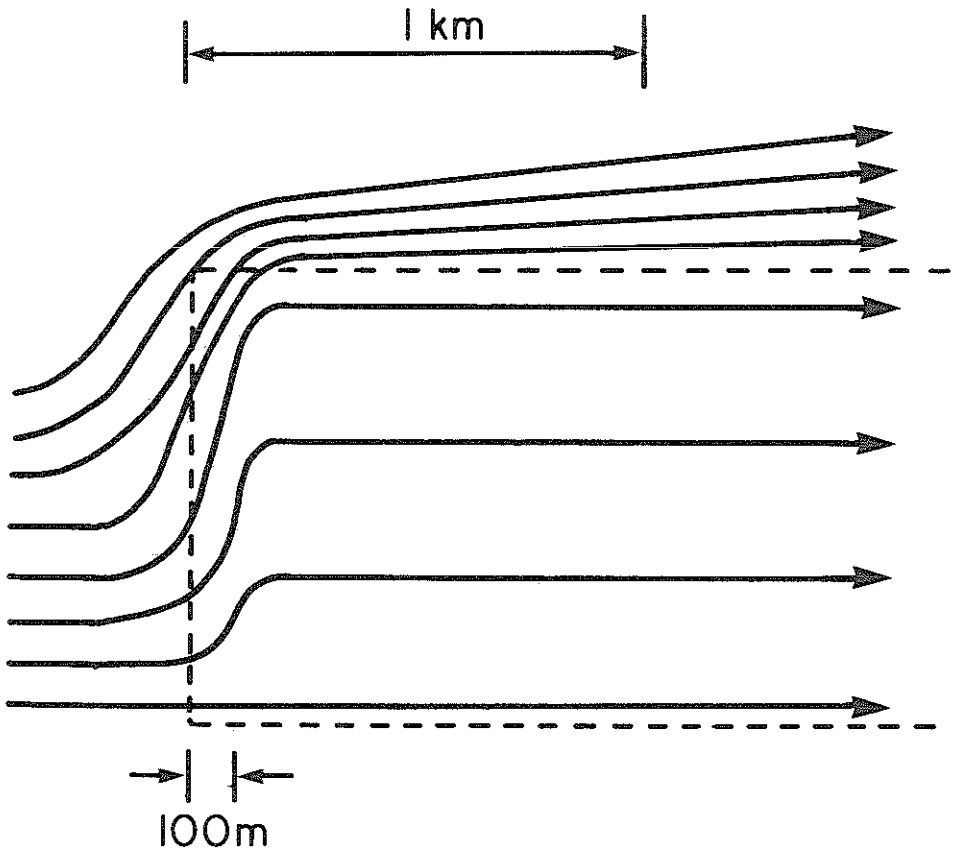

Figure 12. Hypothetical flow of a longshore current around and through a kelp bed. Notice the transition occurs with 100 m.

This residence time is long relative to several kelp ecosystem processes (Table 4). Planktonic larvae coming into the kelp stand from the open ocean respond quickly to the presence of the appropriate habitat by settling out of the water column onto the bottom. Because of the long transit

Characteristic Distances for Currents	
Transition zone for longshore current	~100 m
Daily longshore excursion distance	~300 m
Daily cross-shore excursion distance	~200 m

Table 3. Scales for flow in the Pt. Loma bed interior.

Relevant Timescales for Kelp Bed

Water residence	- 1 week	
Phytoplankton doubling	- 2 days	(a)
Larval development	- ~5 days	(b)
Larval settlement	- ~ hours	(c)
Nitrate uptake by canopy	- 4 hours	(d)

Table 4. Relevant time scales for biological processes. (a) R.W. Eppley (pers. comm.); (b) Jackson and Strathmann (1981); (c) Morse *et al*. (1980); (d) Jackson (1980).

times from the outside to the interior of the bed, there should be few larvae left by the time they would have arrived there. As a result, the interior should have less recruitment than the outer edge, a phenomenon observed by Bernstein and Jung (1979). Similarly, any nutrients present at the surface outside the bed would be taken up by the time they could reach the kelp bed interior. Nutrients should therefore come from the deeper waters or from recycling. The long residence time should allow recycling of nutrients within a kelp bed to be reasonably efficient. This recycling property, where a substance does not leave the kelp bed, could also apply to animals having planktonic larvae with short development times. Such animals could spend their whole lives in one bed if the bed were large enough. Thus, the weak currents in a large kelp bed to significantly change the distribution and fate of ecologically important material.

Conclusion

The coastal kelp community is a product of the larger marine environment. It does, however, customize this physical and chemical environment. The result of all of these processes is a very variable environment which makes predicting and even measuring the effects of sewage discharge very difficult.

Acknowledgments

I would like to thank Dwight Wahlberg, Betsy Stewart, and Mary Anne Ogle for their continued help. This result was sponsored in part by NOAA, National Sea Grant College Program, Dept. of Commerce, under Grant #NA80AA-D-00120, Project #R/CZ-59, and by the California State Resources Agency through the California Sea Grant College Program. The U.S. Government is authorized to produce and distribute reprints for governmental purposes not withstanding any copyright notation that may appear hereon.

PHYSIOLOGICAL BASIS OF KELP GROWTH

Steven L. Manley*

The purpose of this discussion is to present an overview of the basic physiological processes of kelp with emphasis on the adult sporophyte of the species Macrocystis pyrifera. Excellent reviews are available which give a more complete and detailed description of kelp and other marine algal physiologies and growth (Darley 1982; Lobban and Wynne 1981; Srivastava 1982; Stewart 1974).

The term "kelp" has evolved to refer to those large marine brown algae (Phaeophyta) comprising the order Laminariales. The most conspicuous member in southern California is the giant kelp M. pyrifera of the family Lessoniaceae. Other prominent members include Laminaria farlowii (Laminariacea), Egregia menziesii (Alariaceae), Eisenia arboria (Alariaceae), Pterygophora californica (Alariaceae), and Pelagophycus porra (Lessoniaceae). The Laminariales display an alternation of generations between a microscopic haploid gametophyte and a macroscopic diploid sporophyte stage. Although the gametophytic stages are similar for kelps, the sporophytes differ in morphology and size. The morphology of these species is differentiated into a holdfast which anchors the plant, a stipe to

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which is attached the blade (laminae), which is the primary site for photosynthesis and nutrient absorption. Other morphological distinct "organs" may be present (in Macrocystis for example) such as pneumatocysts for buoyancy and bladelike sporophyll which contain the spore-producing sporangia.

The tissue is differentiated into three distinct regions. The outer one to five cell layers contain the chloroplasts and comprise the photosynthetic meristoderm. The cortex includes many cell layers and contains few plastids. The innermost layer, the medulla, contains a zone of sieve tube cells and medullary filaments. The sieve tube cells constitute the translocation pathway which distinguishes these algae from all others.

Kelps, as marine photoautotrophs, use sunlight for energy to synthesize organic compounds from nutrients (CO_2 and other inorganic precursors). Growth is, therefore, a complex integration of photo- and biochemical reactions and in this context refers to the increase in biomass without accounting for nonphysiological losses such as predation or breakage. Those physical and chemical environmental factors which influence the growth and development of kelps are light, temperature, water motion, and solute (nutrients and toxicant) concentration. Potential harmful effects of waste disposal on the growth and development of Macrocystis would be caused by increasing water temperature, turbidity and/or solute concentration. Although the gametophyte and juvenile sporophyte may be more susceptible to

these changes, the following discussion will concentrate on the physiology of the adult Macrocystis pyrifera sporophyte. The reproductive physiology and growth of the gametophyte, although of equal importance, will not be discussed (see Luning 1980; Luning and Neushul 1978).

SOLUTE AVAILABILITY AND TOXICITY

An examination of the elemental composition of kelps reveals numerous elements (North 1980). Those which are considered essential for growth must satisfy certain criteria (O'Kelley 1974). Essential elements are divided into macro- and micronutrients historically based on their tissue concentration in higher plants.[a] This classification generally holds true for kelps. The macronutrients C, H, O, N, P, S, K, Ca, and Mg are present in concentrations greater than 1000 ppm. The micronutrients Mn, Zn, Co, Cu, Mo, and Fe are present in concentrations less than 100 ppm. The major exceptions for kelp are Cl (>1000 ppm) and I (600 ppm). Boron (270 ppm), Br (250 ppm), and As (1.4 ppm) may be micronutrients, but this has yet to be shown.

Nutrients (and toxicants) enter cells through the plasmalemma by diffusion (passive or facilitated), in which the driving force is an electrochemical potential or by active transport which directly requires metabolic energy. The chemical form of

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[a]Chemical oceanographers have used the term micronutrient in reference to inorganic P, N, and Si to denote their low concentration in seawater. This is not the definition used by algal physiologists.

the nutrient will determine its availability. Nitrogen is available to Macrocystis as NO_3^{1-} and NH_4^{1+} but not in organic form (Wheeler 1979). Phosphorus is available as orthophosphate (P_i). Carbon is available to Macrocystis as CO_2 and not HCO_3^{1-} (Blinks 1963). A change in the total inorganic carbon, C_T, concentration or pH results in a change in uptake due to the nature of the seawater carbonate system. The trace metals are available as the free ion (Kuwabara 1981; Kuwabara and North 1980) although organically bound Fe is probably also available (Manley 1981). Iodine is available as I^{1-} and Mo as MoO_4^{1-} (Kuwabara and North 1980).

The uptake of solutes by kelps is influenced by the external concentration of the solute, water temperature and motion, and the physiological state of the alga. The rate of diffusion is directly proportional to the concentration gradient. The uptake of most nutrients is facilitated (carrier mediated) and thus displays saturation kinetics. The rate of uptake at low concentrations is directly proportional to the external nutrient concentration. With increasing concentration, the proportional increase in rate diminishes until after a certain concentration the rate is unchanged. The mathematical description of enzyme kinetics is applicable to uptake kinetics (Epstein 1976). Kinetic parameters for the uptake of NO_3^{1-}, NH_4^{1+}, C_T, PO_4^{3-} (P_i), and Fe by Macrocystis have been determined (Gerard 1982b; Haines and Wheeler 1978; Wheeler 1980; Manley 1981). After saturation has been achieved, a further increase in uptake can occur at concentrations far greater than usually encountered

(biphasic or multiphasic uptake). This has been observed for NH_4^{1+} uptake by Macrocystis (Haines and Wheeler, 1978).

Water motion affects the uptake rate of solutes by increasing the number of solute molecules at the thallus (cell) surface per time interval. As the alga absorbs nutrients, a depletion occurs at the plant surface and a concentration gradient from the plant surface to the outer water (diffusion boundary layer) is created. The diffusion of nutrient molecules (a slow process) from the outer water to the plant surface is required. The slower the water motion, the thicker the boundary layer and the slower the uptake. Water motion saturation of macronutrient uptake occurs between 3-5 cm sec^{-1} (Wheeler 1980 and 1978). Gerard (1982c) has shown that water motion is almost always saturating for nitrate uptake by blade tissue in situ due to wave surge and relative movement of the plant.

Temperature also affects the uptake rate of nutrients. The uptake rate increases with increasing temperature, reaching an optimum and then rapidly decreases due to denaturation of the carrier. Temperature optima for P_i uptake by Macrocystis is 24^oC (Manley unpublished).

Light stimulates the uptake of nitrate and P_i but not the uptake of ammonia by Macrocystis (Gerard 1982b; Schmitz and Srivastava 1979a). This stimulation is likely via photosynthesis supplying energy for the active uptake of P_i and nitrate and the reducing power for the reduction of nitrate. The uptake of micronutrients was not significantly stimulated by light (Manley and North 1980).

Haines and Wheeler (1978) demonstrated that the nutritional history, presumably the tissue nitrogen content, influenced the kinetics of nitrogen uptake: Macrocystis grown in a low nitrate environment absorbed nitrate at a greater rate than those grown in a high nitrate environment. Recently, it has been shown that P_i uptake is inversely proportional to the P_i tissue content (Manley unpublished). It, therefore, appears that the uptake of nitrate and P_i is regulated. The uptake of CO_2, NH_4^{1+}, and nitrate is tightly coupled to assimilation, the actual incorporation of a nutrient into an organic compound. Internal pools of these compounds are small to nonexistent. Pool sizes of P_i, on the other hand, can vary from 10-85% of the total P in Macrocystis tissue (Manley unpublished).

The uptake of micronutrients does not appear to be tightly coupled to assimilation, nor does it appear to be regulated. In Laminaria digitata, trace metal content shows a slow net accumulation with tissue age with probable storage in cell vacuoles (Bryan and Hummerstone 1973).

At times Macrocystis growth may be limited by the availability of certain nutrients. The concentration of N and P in the water can fluctuate dramatically and may be limiting to growth at certain times (Gerard 1982a; Jackson 1977; Wheeler and North, 1980). The plant does have the ability to store excess nutrients (N as amino acids and P as P_i and organic P) and, for a period of time, this

can buffer the effects of a low nutrient seawater concentration. Gerard (1982a) has shown a moderate correlation between growth of a large adult sporophyte and tissue N. Juvenile sporophytes are growth saturated at 15 µM external nitrate at a tissue N content of 3% dry wt (North and Manley unpublished; Wheeler and North 1980). Growth was saturated at 1 µM P_i, which corresponds to 0.2% P dry wt (North and Manley unpublished). Analysis based on uptake and assimilation rates of micronutrients indicates that Mn and Co could be limiting to the growth of adult sporophytes when N and P are optimal for growth (Manley unpublished).

Most nutrient and nonnutrient elements are toxic at high concentrations. The toxic level is dependent on the element in question and the length of exposure. Nitrate and P_i concentrations as high as 30 µM (5 wks) and 2 µM (3 wks), respectively, were not harmful to the growth of juvenile sporophytes. Necrotic lesions appeared on juvenile sporophytes held at 30 µM and 10 µM NH_4^{1+} (North personal communication). Lesions appeared sooner and were more severe at the higher concentration. Growth inhibition and tissue deterioration occurred at 400 nM Cu in seawater, but such a concentration is extremely high compared to ambient, 1.6 nM (Anderson et al. 1983). Gametophytes are far more sensitive (see Kuwabara in this publication).

Little is known about the toxic effects of organic compounds. Certain higher plant herbicides (i.e., Diuron) are toxic to marine algae, but their effective concentration and half-life

in seawater is probably very small. Plastisizers which leach out of plastic materials are also known to inhibit the growth of juvenile sporophytes (North personal communication).

Gametophytes and juvenile sporophytes may be more sensitive to the direct physiological effects of certain toxicants, including elevated levels of nutrients. Adult sporophytes may be indirectly affected by becoming more susceptible to disease. Little is known about the pathology of kelps, but certain pathological conditions exist (Andrews 1976; North 1976). The appearance of tumors and stipe rot has been associated with sporophytes growing near sewage outfalls. "Shot-hole" disease was found to occur on the blades of plants maintained in a high nitrate (15 μM) and P_i (1 μM) environment during elevated water temperatures of the summer months (North unpublished). Black rot was not associated with sewage discharge but with high temperatures during the summer.

Deterioration of Macrocystis beds occurs during the summer months when the water temperature is 18-20°C and accelerates above 23°C. Initially attributed to temperature (North 1971), Jackson (1977) has proposed that it is a result of a lack of nutrients (see North in this publication). Phosphate uptake and PS are optimal at 24°C and 20°C, respectively, and, therefore, temperature inhibitio of these processes cannot be the causative factor.

PHOTOSYNTHESIS AND PHOTOMORPHOGENESIS

Photosynthesis (PS), an oxidation-reduction process, is divided into two functional steps, the light (photochemical,

temperature-independent) reactions and the dark (enzymatic, temperature-dependent) reactions. Both processes occur in the chloroplasts.

All photosynthesizing plants utilize a small portion of the electromagnetic spectrum, visible light of wavelengths 400-720 nm. The photosynthetic (light harvesting) pigments of brown algae are chlorophyll a and c and the carotenoid fucoxanthin. The light reactions use the electrons from water and the energy from the absorbed light to produce reduced nicotinamide-adenine dinucleotide phosphate (high reduction potential) and adenosine-5'-triphosphate (ATP) (high free energy of hydrolysis) which are subsequently used in a large number of biochemical reactions which do not require light.

Although the reduction of nitrate and sulfur are important processes of plant growth, PS emphasizes the reduction of carbon because it requires the bulk of energy from the light reactions. Plant growth involves the accumulation of a far greater amount of C than N or S. The C/N ratios in Macrocystis tissue can range from 5 to 30, primarily due to differences in tissue N (Wheeler and North 1980). The C/S ratio is relatively constant at 118. The reduction of nitrate (assuming all of the N comes from nitrate and not ammonium) in the formation of new tissue requires up to 40% of the reducing power produced from PS while the reduction of sulfate requires 1/60.

Carbon is primarily fixed by the reaction catalyzed by the enzyme ribulose 1,5-biphosphate carboxylase (RuBP-C) and converted

into carbohydrate via the Calvin cycle (Vaughn 1955). Mannitol is the final product of kelp PS and the major storage carbohydrate. Temperature affects the rate of the dark enzymatic reactions. The temperature optimum for M. pyrifera PS is 20°C (Arnold & Manley, unpublished). The C_T (actually CO_2) concentration in seawater is relatively constant and is well below the concentration saturating for PS (Wheeler 1980). During periods of optimal light intensity and little water turnover in the canopy, CO_2 depletion in this water can occur, due to PS, which can significantly reduce the rate of PS.

The PS rate increases with increasing light intensity (or more correctly, photon flux density, PFD; Ramus 1981) until it becomes light saturated. At this point, PS is limited entirely by the rate of the dark reactions. As the PFD decreases so does the rate of net PS until it reaches zero, the compensation point. The water depth at which the compensation point is reached is called the compensation depth.

The absorption spectra of the pigment constituents indicate that the photosynthetic apparatus is less able to harvest green light than other wavelengths. Action spectra (rate of PS vs wavelength) produced with monochromatic light (Anderson 1969) for Macrocystis shows a lower rate of PS in the green window. This effect would seem to be significant because of the absorption of blue and red light by coastal seawater (green light remaining). In the ocean, light quality probably has far less effect on PS than those factors which influence absorptance (the fraction of

light absorbed by the PS apparatus). These factors include pigment concentration, chloroplast orientation, and thallus structure, which of increase absorption of light in the green window (Ramus 1981). Physiological adaptations of the adult sporophyte involving storage, transport, and metabolism of photosynthate tend to dampen the effects of short-term fluctuations in photosynthetically available light on productivity. Light quantity is of great importance in terms of recruitment of juvenile sporophytes. An increase in turbidity, causing a decrease in the compensation depth, could drastically diminish recruitment (see the article by Devinny in this publication).

Light can also affect development without acting through the photosynthetic light absorption apparatus. Developmental (photomorphogenic) responses are induced by the absorption of light by other photoreceptor systems. Such receptors do not supply the cells with the energy to manifest these changes in development. The promotion of rapid stipe elongation of the kelp Nereocystis by far red light (726 nm) and inhibition by red light (658 nm) strongly suggests the presence of a phytochrome photoreceptor system (Duncan and Foreman 1980). Other known photomorphogenic responses of kelps involve gametophytes (Luning 1980; Luning and Neushul 1978). Changes in the transmission characteristics of seawater could, therefore, potentially influence the recruitment and growth of kelp.

PHOTORESPIRATION AND DARK CARBON FIXATION

Most of our knowledge about photorespiration (PR) has come from studies of terrestrial plants and unicellular algae. The process is metabolically complex and involves the enzymatic machinery of three organelles, chloroplast, peroxisome, and mitochondria.

The enzyme (RuBP-C) has been shown to have an oxidase activity which results in the formation of P-glycolate (2-carbon) and 3-P-glycerate (3-carbon). It is the subsequent metabolism of P-glycolate via the photorespiratory carbon oxidation cycle that results in the formation of CO_2. The magnitude of the loss in photosynthetic productivity by Calvin cycle (C_3) terrestrial plants can be as high as 50% (Zelitch 1979). PR requires light and increases with increasing temperature.

Few studies of PR in marine macroalgae have been performed. Research to this date indicates that for those brown algae and kelps studied, the capacity for PR is present (Burris 1977; Hatcher et al. 1977), but whether PR is a factor in photosynthetic productivity has not been shown. The occurrence of PR is dependent on the CO_2/O_2 ratio because CO_2 and O_2 compete for the same enzyme (the affinity of RuBP-C is 11 times greater toward CO_2 than O_2; Andrew et al. 1975). The ratio is 10.4 in seawater and 0.001 in air (Burris 1977). The surface canopy of Macrocystis may photorespire due to its proximity to the air or during periods of little water exchange resulting in a depletion of CO_2 and enrichment of O_2 due to PS.

Kelps are able to fix CO_2 in the dark due to the presence of the enzyme phosphoenolpyruvate carboxykinase (PEP-CK). The rate of dark fixation (DF) is significant and can be as high as 17% of photosynthetic carbon fixation by young tissue (Willenbrink et al. 1979)

Dark fixation allows for the rapid synthesis of precursors required for biosynthesis and may limit the amount of carbon lost due to photorespiration (Kremer 1981; Willenbrink et al. 1979). Dark fixation, therefore, enables the plant to better regulate its carbon metabolism.

DARK RESPIRATION AND TRANSLOCATION

The energy stored in mannitol can be used by the plant when the immediate energy needs of the tissue cannot be met by PS. This would be the case during the night or during the day for those portions of the plant which are shaded. Catabolism of mannitol occurs via the glycolytic and respiratory pathways, producing 38 moles of ATP per mole of mannitol.

The rate of dark respiration (DR) is dependent on temperature and tissue type. Dark carbon fixation, respiration, and mannitol consumption occur at very high rates in young kelp tissue (Kremer 1981; Willenbrink *et al.* 1979; Arnold and Manley, unpublished). The catabolism of mannitol is integrated with DF and regulated through a common intermediate phosphoenolpyruvate (Kremer 1981). The integration of these processes enables

the growing regions to allocate carbon rapidly for biosynthesis. This is especially important for those growing regions which rely entirely on respiration because of a lack of light.

Macrocystis sporophytes translocate photoassimilate from mature nongrowing, actively photosynthesizing regions to apical and basal meristems and to those shaded portions of the plant which are respiring, including the sporophyll and holdfast. This source-sink translocation is typical of other Laminariales and involves the loading and unloading of solute and water (Schmitz & Srivastava 1980, 1979a,b). Members of the Laminariales contain elongated sieve cells which constitute the transport pathway.

The major constituents of the sieve tube sap from Macrocystis are mannitol (65% dry wt), amino acids (15%), and inorganic ions (including micronutrients) (20%) (Schmitz & Srivastava 1979b; Manley 1983). The total P content, organic and inorganic, is approximately 0.900 (mg/ml) (Manley 1983).

Translocation velocity has been recorded at 35-72 $cm \cdot h^{-1}$ for M. integrifolia (Schmitz Srivastava, 1979b), with a calculated specific mass transfer rate of 5.3-10.6 g $dry \cdot cm^{-2} \cdot hr^{-1}$ for M. integrifolia (Schmitz & Srivastava, 1980). Light and temperature through their action on the relative metabolic activity of the source and sink tissue, are the main environmental factors that influence the rate of translocation.

CONCLUSION

There are various interpretations of the cause of decline of certain kelp beds after introduction of sewage outfalls in their vicinity. Such discussions are usually based on analysis of the historical record and direct field observations. Our present understanding of the physiologies of both sporophytes and gametophytes enables us to speculate as to the direct effects of waste disposal on the growth and development of Macrocystis and other kelps, and allows us to design the proper experiments to quantitatively test our hypotheses. As evidenced during this symposium, there is an alarming lack of such data, especially pertaining to possible toxicants.

THE ECOLOGY OF KELP COMMUNITIES

Michael S. Foster*, John W. Carter ** and David R. Schiel*

A review of the ecology of kelp forests in California indicates that the composition of this community is highly variable in space and time. A number of factors can affect this composition, and they are also variable. An examination of Macrocystis (giant kelp) abundance, and the abundance and composition of the remainder of the algal assemblage in forests at five different sites emphasizes these natural differences. One forest with large seasonal and year-to-year changes in the cover of foliose understory algae is structured directly and indirectly by storms and substratum characteristics. Another with abundant understory kelps and articulated coralline algae is most affected by competition for light, and the other forests with low understory algal cover are structured by substratum characteristics, light and nutrient availability and, at two sites, in part by grazing. The effects of waste disposal in this context will be site-specific, varying with the characteristics of the local environment and the discharge. The obvious solution to this complex problem of determining effects is to not discharge wastes. However, given that discharge occurs and will probably continue in the near future, long-term studies that concentrate on species that are common, and that may have detectable effects on the remainder of the community, and/or well designed monitoring programs may be useful in detecting some local effects.

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recruitment and growth of young plants.

The remaining three sites, San Mateo, San Onofre and Del Mar kelp forests, occur between Dana Point and La Jolla in southern California. The San Mateo and San Onofre forests are about 10 km apart, and Del Mar is 40 km south of San Onofre. These forests, and most others along this section of the coast, occur on patches of exposed rock along a generally sandy bottom. They are on the open coast, but not as exposed to swell as the northern sites described above (Table 2). The substratum at San Mateo is composed of low relief boulders and cobbles; San Onofre is largely cobbles and sand, and Del Mar is a mudstone reef. A long historical record is available for canopy extent in the first two forests (Figure 3), and for relative kelp harvests at Del Mar (Rosenthal et al. 1974). In contrast to Macrocystis in central California, seasonal

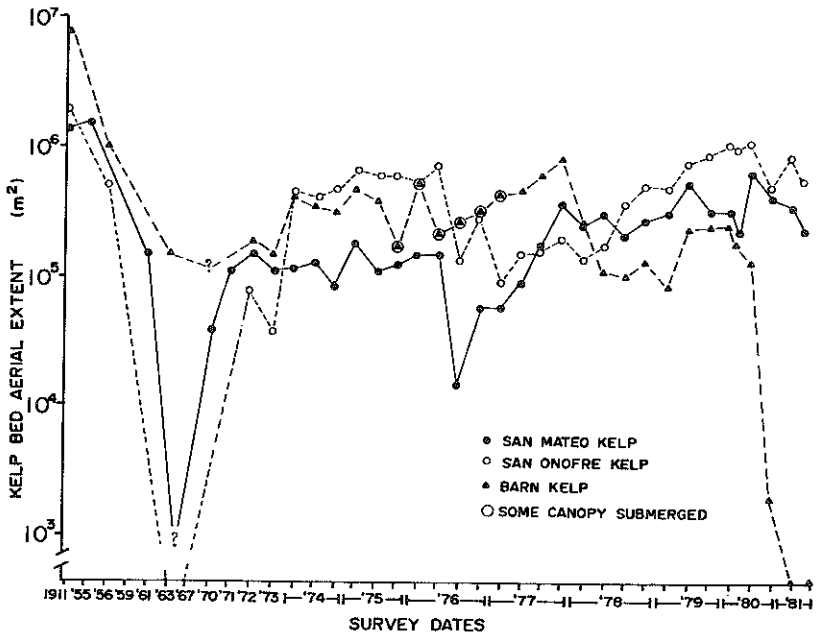

Figure 3 Estimated aerial extent of San Mateo, San Onofre and Barn kelp forest canopies from 1911 to 1981 (determined by various methods; from SCE 1982).

changes are not as evident, probably because there is relatively little seasonal difference in storm-associated swells. There is, however, considerable change between years, the most dramatic of which occurred around 1963, when the Macrocystis canopy at all three sites declined to zero. This could have resulted from widespread nitrogen deficiency, high temperature, or their combined effects (Jackson 1977). There have been other changes in canopy distribution, including the recent unexplained total loss of Macrocystis in Barn kelp forest 11 km south of San Onofre (Figure 3). This and other patterns in Figure 3 appear to result from site-specific rather than area-wide processes.

Understory kelps are rare at San Mateo and Del Mar, but moderate sized (around 50 cm tall) Pterygophora californica occur in San Onofre (Table 2). Foliose algal bottom cover is very low at all three sites relative to those in central California. Rhodymenia spp., Pterocladia/ Gelidium, and Corallina sp. are most abundant at San Mateo, Rhodymenia spp. and filamentous algal turf (Pterosiphonia spp. is probably most abundant) are most common at San Onofre, and Rhodymenia pacifica and various corallines are most common at Del Mar. The relatively low cover of foliose algae at these sites may reflect the effects of low light from the seasonally constant Macrocystis canopy cover, combined with generally turbid bottom conditions associated with large amounts of silt and sand. In addition, the non-encrusting algal bottom cover in San Onofre kelp forest is predominantly filamentous species (Southern California Edison [SCE] 1979). This is probably related to the instability of the substratum; not only do cobbles move, but sand also covers and uncovers large areas (Figure 4).

Sea urchins are uncommon at Del Mar (Table 2). They feed on drift

(Table 2), and are represented by apparent annual fleshy algae such as Demarestia ligulata, Polyneura latissima, and Plocamium cartilagineum. In addition to seasonal oscillations, there are large year-to-year differences in algal abundance. For the bottom cover algae, this is caused in part directly by differences in storm activity, and in part indirectly by variations in the surface Macrocystis canopy. The inverse relationship between surface and bottom cover is clear when data on Macrocystis canopy cover are compared with foliose algae cover on the bottom in fall, when cover of both is highest (Figure 2; the figure

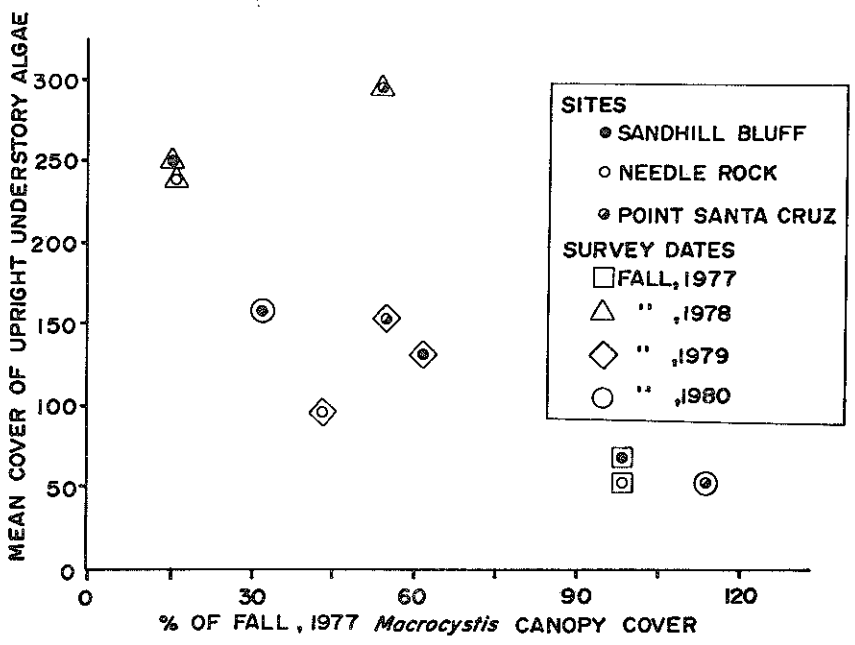

Figure 2 Relationship between Macrocystis canopy cover and upright (non-encrusting) understory algal cover in three kelp forests north of Santa Cruz. Total understory algal cover exceeds 100%, as layering was determined. Macrocystis canopy cover at each site was considered 100% in fall 1977. Cover at other times is expressed as a % of this value. Understory cover was not surveyed at Point Santa Cruz in fall 1977.

includes data from two nearby forests, Needle Rock and Point Santa Cruz, that have similar physical characteristics and algal assemblages).

Sandhill Bluff is outside the present range of the sea otter, and sea urchins (mostly Strongylocentrotus franciscanus) are common (Table 2). As the range suggests, the urchins are highly clumped. Their distribution, and perhaps abundance, may be regulated by water motion, and experimental removals have shown their effects on algal abundance are much less than those related to storms (Cowen et al. 1982).

The Stillwater Cove kelp forest is inside Carmel Bay in central California, and is protected from northwest winter swells. The substratum is hard rock relatively free of sediment, and the water is generally clear. Beneath the Macrocystis is an extensive understory canopy of large (usually greater than 1 m tall) Pterygophora californica plants (Table 2), and the bottom is covered with a dense mat of articulated coralline algae. The Macrocystis canopy varies in extent with season and year, but in contrast to Sandhill Bluff, variability in algal cover on the bottom is reduced (Table 2). In this relatively benign physical setting, the cover of P. californica results in uniformly low light on the bottom, even when the surface canopy of Macrocystis is reduced. Shading by P. californica inhibits its own recruitment as well as recruitment and growth of other species (Reed and Foster in press). In comparison with Sandhill Bluff, the number of foliose algal species is low (14 at Stillwater Cove vs 30 for Sandhill Bluff), with articulated corallines predominating. Sea otters are common at the site, and large sea urchins extremely rare. Strongylocentrotus purpuratus does occur as small (2-4 cm test dia.) individuals in the coralline mats (Table 2). They may have an as yet unknown effect on

urchin populations and grazing effects are clearly variable, and we feel that a direct link between urchins and waste discharge has yet to be established.

Like toxic substances, the list of grazers in Table 1 is probably incomplete, because the effects of numerous herbivores have not been studied, and available studies have concentrated on those that eat adult plants. Most of the grazers listed, and many others, forage on the bottom where they may have important effects on the survival of microscopic life stages and juveniles, and where waste impacts, particularly those associated with sedimentation, are likely to occur.

A list like Table 1 also obscures the interactive and synergistic effects of various factors such as nutrients and light, mentioned above. Water motion over a sediment-laden bottom may indirectly increase mortality by increasing turbidity and abrasion. Differences in light requirements could cause shifts in the relative abundance and thus competitive abilities of different seaweeds. The combined effect of reduced light and elevated copper concentrations may be greater than either alone. The possibilities are endless, and not trivial. Moreover, the community response may be rapid (a single storm removes all large Macrocystis in one day), or may take several years (a gradual loss of adult Macrocystis due to toxin-induced reduction of gametophyte fertility).

SOME REAL COMMUNITIES

To illustrate community differences among sites and the contribution of various factors to these differences, we will briefly review the ecology of five kelp forests and the factors that appear most important

TABLE 2. Characteristics of five kelp forest communities. Data are summarized from the following sources: Sandhill Bluff - Foster et al. 1979, Foster 198[illegible]; Cowen et al 1982; Stillwater Cove - Foster et al. 1979, Foster 198[illegible]; Reed and Foster in press; San Mateo and San Onofre - SCE 1979, 1982; Del Mar - Rosenthal et al. 1974.

Kelp Forest	Substratum	Water Motion[1]	Light[2]	Nutrients	Foliose Algal Cover Range in %	Density of Understory Kelps (#/m^2)	Density of Sea Urchins[3] $\bar{X}$ (range/m^2)
Sandhill Bluff	mudstone, silt and sand pockets	moderate	low	not limiting	41-250	1.1	1.0 (0-20)
Stillwater Cove	sandstone, conglomerate, sand pockets	low	high	not limiting	90-170	2.0[5]	2.0 (0- 4)[6]
San Mateo Kelp	boulders and cobble	very low	moderate	limiting	20- 40	.03	1.4 (0-14)[7]
San Onofre Kelp	cobble and sand	very low	low	limiting	25- 30	1.2	0.5 (0- 4)[7]
Del Mar	mudstone, silt and sand	very low	low	limiting	low[4]	low[4]	0.19 (moderate)

[1]Based on qualitative comparisons of the five sites.

[2]Based on diver observations; low = < 5 m visibility; moderate = 5 to 10 m; high = > 10 m.

[3]*Strongylocentrotus franciscanus* plus *S. purpuratus*.

[4]No quantitative estimate available.

[5]Large (> 1 m tall) plants of *Pterygophora californica*.

[6]Mostly small *Strongylocentrotus purpuratus* in coralline mats.

[7]Range of means from 11 (San Mateo) and 24 (San Onofre) stations (courtesy of Dixon, Schroeter and Kastendiek, pers. comm.).

to the structure of the algal assemblage. The sites are listed in Table 2 along with information on their characteristics. Sources of information are also given in the table, and will not be repeated in the text unless warranted in making a specific point.

Sandhill Bluff, located on the open coast 5 km north of Santa Cruz in central California, has substratum characteristics similar to Del Mar. However, it is only slightly protected from winter storm-associated swells and, like many other exposed kelp forests growing on soft substrate in the area, *Macrocystis* and other algae go through seasonal oscillations in abundance with a fall, pre-storm maximum and a spring, post-storm minimum. Understory kelps are moderately abundant but small (*Pterygophora californica* usually less than 50 cm tall), and don't form a significant canopy. Bottom growing plants can be extremely abundant

TABLE 1. Factors affecting kelp forest populations, with emphasis on *Macrocystis* forests in California.

Factor	Effects	Source
Substratum	Required for attachment	
	Hardness related to water motion mortality	Foster 1981
	Topograhpic heterogeneity correlated with distribution diversity	Pequegnat 1964, Quast 1971
Sedimentation	Attachment and survivorship of microscopic life stages	Devinny and Volse 1978
Light amount	Survival and growth of plants, at least 1% of surface for kelps	Luning 1981
Light quality	Gametogenesis in kelps	Luning and Neushul 1978
Water motion	Plant loss in surge and currents	Rosenthal et al. 1974, Foster 1981,[2] Cowen et al. 1982
	Distribution of food (plankton and detritus)	Pequegnat 1964
Temperature	Growth and fertility of plants	Luning and Neushul 1978
Nutrients	Growth of benthic plants (and phytoplankton)	Jackson 1977
Toxic substances		
Cu	Reduced *Macrocystis* growth, reduced fertility at 30 ppb	Smith 1979
DDT	Possible general alteration of community	Anon. 1978
Pathogens		
Plants	Occur , but population effects?	Andrews 1976
Urchins	Can cause massive mortality	Pearse et al. 1977
Sea stars	Occur , but population effects?	pers. obs.
Fish	Occur , but population effects	Mearns and Sherwood 1977
Grazing		
Sea urchins	Can create areas of varied size nearly devoid of macroalgae	North 1964, Mattison et al. 1977
Fish	Can destroy *Macrocystis* if plants at low density	McPeak et al. 1972, Bernstein and Jung 1979
Isopods	May destroy canopy in absence of fish predation	Bernstein and Jung 1979
Predation	Sea stars, sheephead, sea otters and others, including humans, may affect sea urchin distribution and abundance	Rosenthal and Chess 1972, Lowry and Pearse 1973, Tegner and Dayton 1981 Cowen 1982
	Sea stars and fish may alter plant-sessile animal competition	Foster 1975b
Competition	Canopy shading inhibits understory algal recruitment and growth	Pearse and Hines 1979, Reed and Foster in press
	Algal competition for space and light affects distribution	Kastendiek 1982

light quality sufficient for kelp gametogenesis (Luning and Neushul 1978). Waste discharge may reduce light on the bottom by introducing particulates and increasing nutrients, the latter indirectly reducing light via stimulation of phytoplankton growth.

The short list of toxic substances is misleading and is probably more a reflection of lack of information than unimportance. We know little about the effects of toxic substances on kelp forest populations. The problem is complex because various potential toxins are generally discharged together, and their chemical forms may be difficult to detect and duplicate in the laboratory.

Grazers, especially sea urchins, have been implicated in kelp forest declines in southern California and elsewhere, and North (1964) suggested that urchin populations may increase in areas where wastes are discharged. As he points out, however, urchin-dominated areas occur naturally at sites outside the influence of wastes. If urchins increase their activity when starved, as indicated by Mattison et al. (1977), then an equally likely alternative, also suggested by North (1964), is that something associated with waste discharge causes a decline in plants, and urchin activity increases due to lack of drift algal food. Urchin "fronts" and increased grazing may start naturally by similar processes (Dean, Dixon, Schroeter, Harrold, and Reed pers. comm.). These interactions are difficult to sort out after an event has occurred. Moreover, other observations show that urchins can naturally co-exist with the remainder of the community (Rosenthal et al. 1974, Cowen et al. 1982), can naturally produce "barren" areas within a kelp forest (above), and can dominate certain depth zones over wide areas in locations relatively undisturbed by man (Choat and Schiel 1982). Sea

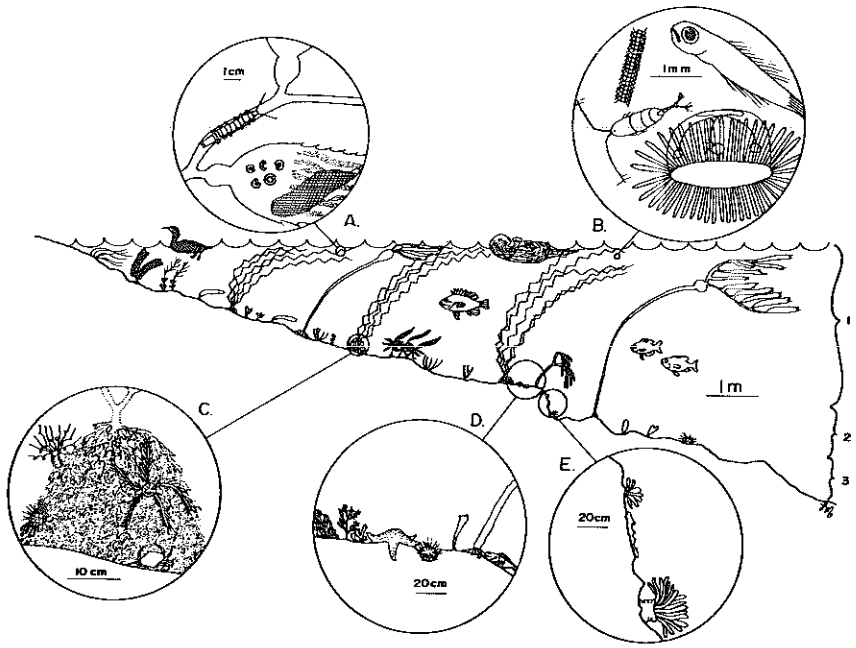

Figure 1 Cross-section showing the inhabitants of a generalized giant kelp forest. The numbers to the right indicate vegetation layers. 1. Surface canopy forming kelps (Macrocystis, Nereocystis, Pelagophycus). 2. Understory or sub-canopy kelps (Pterygophora, Laminaria, Eisenia). 3. Bottom cover algae (Rhodymenia, Gelidium , articulated and encrusting corallines). The circular diagrams indicate some common subcommunities or associations. A. Animals associated with Macrocystis and other seaweeds (polychaete worms, isopods, bryozoans). B. Plankton in the water column (various phytoplankton, zooplankton, larval fish). C. Animals associated with giant kelp holdfasts (small sea urchins, brittle stars, crustaceans, polychaete worms). Although shown on the outside, these organisms occupy the spaces between branches of the holdfast. D. Plants and animals most characteristic of horizontal surfaces (sea stars, sea urchins, benthic fish, various understory and bottom cover algae). E. Organisms most commonly found on vertical surfaces (primarily animals such as sponges, tunicates, bryozoans, sea anemones).

over 50 species of fish that commonly segregate into various sub-areas (Quast 1971), and numerous invertebrates also often found in particular sub-habitats (e.g., on plants, on vertical or horizontal surfaces, in holdfasts). The giant kelp holdfast alone may contain over 150 species (Ghelardi 1971). A variety of birds and mammals forage in the community, including cormorants, harbor seals, and sea otters. The community also contains a planktonic assemblage of generally microscopic organisms, many of which are stages in the life histories of larger members of the forest. Composition and abundance change with depth as well as with microhabitat. This is particularly obvious with plants (Neushul 1965, Neushul _et al_. 1967), but also occurs with fish (Quast 1971, Bray and Ebeling 1975), and invertebrates (McLean 1962, Pequegnat 1964, Neushul _et al_. 1967).

FACTORS AFFECTING POPULATIONS

The major factors known to affect kelp forest populations are listed in Table 1. Some of these deserve special mention, as they are more likely to be changed by a waste discharge. Sedimentation is one of these, and accumulation of sediments rich in organic matter is one of the major changes caused by waste discharge in the Palos Verdes kelp forest (Grigg and Kiwala 1970). Even if sediment does not accumulate, or accumulates in very small amounts, the effects on microscopic stages of _Macrocystis_ can be extreme (Devinny and Volse 1978). Light is obviously necessary for plant growth. _Macrocystis_ and other large algae may use light at the surface or in the water column as adults, but they all start life on the bottom, so light levels there must be sufficient for growth (around 1% of surface irradiance or more [Luning 1981]), and

Macrocystis pyrifera (giant kelp) forests are a conspicuous feature of near-shore waters in many temperate areas of the world. This location makes these forests particularly susceptible to waste discharges. These impacts are of special concern not only because a natural community may be degraded, but also because this particular community provides food in the form of drift algae and its derivitives to other near-shore and shore communities (Zobell 1971, Gerard 1976), and is an important recreational and commercial resource (North and Hubbs 1968). Our objectives are to review some of what is known about the community ecology of giant kelp forests in California, and suggest how this information can be used in determining waste impact. To accomplish this, we will examine the temporal and spatial variations in community composition and the factors that affect it, and then discuss the effects of waste disposal in this context.

This or any approach to determining the mechanism of kelp forest community change presents numerous difficulties. Very few sites have been examined for long periods, so information on natural variability in time is generally unavailable. In addition, investigators with a variety of different objectives have usually looked at different assemblages (algae, fish, etc.) in different forests, making comparisons among sites difficult. What information is available suggests that composition and the factors which affect it are highly variable (Foster 1982). Moreover, we lack quantitative information relating the magnitude of factor change to the magnitude of community response (e.g., what will happen if light is reduced by 10%?), and know even less about factor interaction (e.g., what will happen if temperature increases by x and sedimentation increases by y?). Given these limitations, we will

examine the kelp forest community and factors affecting it in general, and then discuss five sites for which some long-term data are available. The algal assemblage is emphasized because of available data and our interests.

Communities will be discussed relative to interactions among populations, and between populations and their abiotic environment, not relative to energy flow. Energy flow within kelp communities can be described, but we believe this approach to detecting discharge effects is too simplistic and commonly ignores population interactions that may be critical to community structure. Moreover, events such as kelp gametophyte survivorship, while essential to community persistence, are often too low in energy to be considered in energetic analyses. Changes in producer and consumer populations can be detected without measuring energy.

THE POSSIBLE COMMUNITY

Figure 1 illustrates assemblages and subcommunities that could be found in a giant kelp forest. We emphasize that this is a "textbook" community; any particular site may differ greatly from that illustrated. The figure also ignores patchiness within a site, or the clumping typical of most populations. This patchiness is explicitly discussed by Rosenthal _et al_. (1974), and can be inferred from the large variances associated with most abundance estimates from kelp forests. It is also typical of other communities, and adds another level of difficulty in assessing community change (Hartnoll and Hawkins 1980).

The figure does indicate the potential complexity of the community, with multiple layers of vegetation (Dawson _et al_. 1960, Foster 1975a),

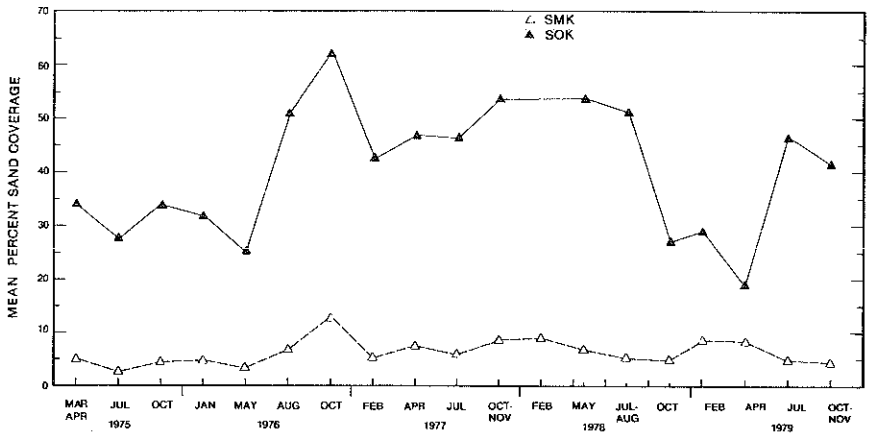

Figure 4 Sand cover in permanent 10 m² quadrats at San Mateo kelp forest (SMK) and San Onofre kelp forest (SOK).

algae, and have little apparent impact on the remainder of the community (Rosenthal et al. 1974). Urchins are more common in San Mateo than San Onofre, and are extremely patchy at both sites. These urchins also form localized grazing fronts in both areas, removing most large plants in front areas (Dean, Dixon and Schroeter, pers. comm.). Sea urchin harvesting by man is probably the most important source of urchin mortality in these areas.

Recruitment of new Macrocystis is obviously important to the long-term persistence of kelp forests. We have not made sufficient observations to establish any recruitment patterns at Sandhill Bluff, but recruitment occurs regularly in the spring in Carmel Bay forests (Kimura 1980, Reed and Foster in press). Rosenthal et al. (1974) observed recruitment only twice between 1967 and 1972 at Del Mar, in both cases associated with a reduction in adult surface canopy. High recruitment is an occasional event in San Mateo and San Onofre kelp forests. Field measurements of light and temperature, combined with gametophyte growth and fertility studies in the laboratory, suggest that

even without canopy shading or considering sedimentation, conditions at San Onofre were favorable for recruitment eight times between 1978 and 1981 (Dean and Deysher this volume).

DISCUSSION

One of the announced objectives of this symposium is to determine what additional measurements should be made to "round out" our knowledge of the effects of discharged wastes on kelp communities. Given the composition differences between kelp communities and the variety of factors producing the differences, we believe our knowledge is only an incomplete outline and are unsure if any additional measurements can be made to improve it. It is clear from our information about the forests discussed above and from experience in other areas that, other than the presence of Macrocystis (by definition), giant kelp forests each have their own unique, non-trivial characteristics. The only generalization is that community effects of waste discharge will also be site specific. These effects will also probably be unpredictable, even at a particular site, without a good understanding of the local environment based on long-term, well-designed research. Certainly, discharge of toxic substances and discharge induced changes in nutrients (as they affect light via phytoplankton growth), turbidity (from discharged particulates), sediments, and sedimentation are most likely to produce change, even if the magnitude of change is variable.

Looking from the other end of the discharge pipe, we are not convinced that engineers and oceanographers can make reasonable predictions about the kinds and extent of abiotic alterations produced by a

discharge. Thus, even with an understanding of the local ecology, predictions of discharge effects may still be impossible.

In this context, what can we do about waste effects? Dayton (1972) and more recently Christie (1980) suggest concentrating on "foundation" species in the community, those that have an influence disproportionate to their abundance, whose activities have large effects on other populations. We doubt that all communities have "foundations" in this sense; certainly, they have not yet been discovered in the sites discussed above. However, if some true understanding of waste-community interactions is the goal, perhaps the most fruitful approach will entail the study of particular species characteristic of the community and hopefully, important to its structure. Common, local organisms like Macrocystis, Pterygophora or a long-lived sessile invertebrate such as the sea fan, Muricea, could be chosen, and its population biology used as a measure of discharge effects. Study of the same organism at different sites could also provide a better understanding of variability among sites. Even this approach would be a major task, as populations will naturally vary, both between and within sites.

Another approach, and the one most widely chosen, based principally on regulatory requirements and not a thoughtful evaluation of objectives, is monitoring. This usually entails the description of a large number of species and/or taxonomic groups, along with physical/chemical variables likely to be changed by a discharge in areas within and outside its influence. This requires little knowledge of ecology or mechanisms of impact. To be useful, areas and variables to be monitored must be chosen carefully, and measurements made with adequate replication.

The last approach is to not discharge and avoid the whole problem. There is no question that waste discharges have greatly altered giant kelp communities in southern California, particularly around Palos Verdes (Grigg and Kiwala 1970, Wilson 1982).

Admittedly, this last approach is an idealistic expectation for the present and near future. However, the goal of no discharge is reasonable as well as being national policy (Clean Water Act, Public Law 92-500). While we are trying to meet this goal, waste discharge and monitoring will continue. We hope that the monitoring will be done properly, and will incorporate ecologically relevant studies of local species. At least this would give some understanding of site-specific processes in this diverse and valuable community.

A HISTORICAL OVERVIEW OF KELP IN SOUTHERN CALIFORNIA

Bruce W. Harger*

A B S T R A C T

The giant kelp, Macrocystis, forms beds off the coast of southern California. In this century these beds have decreased in size. The decreases have been attributed to kelp harvesting, sewage pollution, other human activities, sea-urchin-population outbreaks, natural warm-water periods and natural low-nutrient periods. All of these probably impact kelp populations at different times and in different localities. The present study is based on heretofore unused aerial imagery and kelp-harvesting-rate information. The focus of the work was to determine what the variation in kelp bed area and cover is and if this variation can be assigned to specific causes.

Existing aerial imagery was used to determine the kelp-bed areas and kelp-canopy areas for the kelp beds of southern California over the past sixty years. There were consistent differences through time and there are consistent differences between beds in different geographic locations. Parts of beds have been destroyed by boat traffic. Kelp beds reached a low point between 1959 and 1963. This could have been due to high temperatures, low nutrients, high numbers of sea urchins or large volumes of toxic sewage pollution. It is not possible to determine the cause. Santa Barbara beds are larger, have higher cover, and are more stable. Los Angeles and San Diego beds are smaller, have lower cover and are less stable. These differences are probably due to different exposures of these localities to winds and storms.

A statistical model was formed that can predict 46% of the variation in kelp-harvesting rate given the prior month's average surface irradiance, swell height and sea temperature. Probably over half the variation in kelp-canopy growth is determined by light, temperature (nutrients) and water motion (swell height).

I N T R O D U C T I O N

The giant kelp, Macrocystis, forms beds off the coast of southern California in water from 6 to 20 m deep. The history of these beds is poorly known. Only during this century have they been carefully studied. During the last thirty years vertical aerial photographs have been used to map the canopy area of these kelp beds and document the gradual decrease in kelp area. The present study presents some of the results of an extensive study of aerial

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photographs of the kelp beds of southern California taken over the last sixty years. Details of this study are available from the Southern California Edison Company as Research Report Series Number 81-RD-98. Since little ground truth or physical environmental information is available for the beds and their environment over this time period, interpretation of the cause for specific changes in kelp-bed area is difficult. In an attempt to link kelp canopy changes with environmental conditions, the present study compares kelp harvesting rate information for the Goleta Bay kelp bed with ground-truth environmental information for that period. A more detailed presentation of this study can be found in Harger (1979). The results of this study should be of interest to those who manage and harvest the natural kelp-bed resources of southern California.

Nautical charts from the last century indicate that the southern California kelp beds were extensive at that time. European sailors used to look for detached drifting kelp plants as an indication that they were near land (Dana 1841).

It is difficult to tell what the kelp beds were like before man settled along our coast. Sea otters used to live here and may have benefited kelp by consuming many kelp-grazing sea urchins. Stellar sea cows may have also inhabited our coastline and could have consumed large quantities of kelp (see Dayton 1975). When the local Chumash Indians settled here, they consumed sea otters (see Tompkins 1967 and Doran 1980) and may have kept their populations at low levels, allowing sea urchins to settle and graze.

The first comprehensive mapping project that dealt specifically with the kelp beds was initiated by the United States Department of Agriculture prior to World War I (Cameron 1915 and Crandall 1912) when potash supplies from Germany were restricted (Scofield 1959). This survey extended all along the continental west coast of North America from Mexico to the Aleutian Islands. Maps were drawn from bearings made from boats following the kelp bed margins. A sextant, compass, and "three point apparatus" were used to measure the areas of the kelp beds. The large sizes that were reported, compared to the present sizes of the beds (Hodder and Mel 1978), have led others to question the validity of these early studies. However, Cameron claimed that at the time of his survey the kelp beds were in relatively poor condition, compared with what had been seen in previous years. Thus, it is likely that the kelp beds of the Southern California Bight were larger in the last century than they are now.

Kelp beds have more recently been mapped and the areas projected from vertical aerial photographs. When these are properly exposed they can clearly show kelp-bed canopy. Vertical aerial photography was first used to map kelp beds by Dr. Wheeler J. North in the 1950's. Since the 1950's, commercial seaweed harvesters, particularly the Kelco Company of San Diego, have used the areal extent of kelp canopy to estimate the health and potential yield of the kelp beds. The California Department of Fish and Game regulates kelp harvesting activities and has numbered the beds for the purpose of leasing them. North has regularly mapped the Palos Verdes (1975, beds #13 and #14), La Jolla (bed #4) and Point Loma kelp beds (1974, bed #3). He has also photographed and mapped most of the beds between Palos Verdes and La Jolla (beds #5 to #10). His work is still continuing. The other beds in the Southern California Bight have not been studied in such detail.

Kenneth Wilson of the California State Department of Fish and Game has used techniques similar to North's to monitor kelp beds in the Palos Verdes region. The Department of Fish and Game is involved in an effort to restore the formerly rich kelp beds in Palos Verdes by transplanting kelp plants into this depleted area. Wilson's group is also destroying dense sea urchin populations in the transplant areas and near the borders of other kelp beds. Wilson's maps drawn from vertical aerial photographs show expanding kelp beds and confirm the efficiency of their transplanting efforts (Wilson, Haaker, and Hanan 1977).

Esca-Tech (Hodder and Mel 1978) has done the most comprehensive job of photographing and mapping the kelp beds of the Southern California Bight to date. The Bureau of Land Management, through Science Applications Incorporated, contracted with Esca-Tech to make flights on a quarterly basis for two years from 1975 to 1977, a total of eight flights. These new images were analyzed and related to the data obtained by Crandall (1912) and others in 1967 and 1972.

MATERIALS AND METHODS

Jensen, Estes, and Tinney (1980) have recently reviewed the methods used for remote sensing of kelp beds. In the present study, we collected images from several sources, converted them to a standard size, mapped the kelp beds, measured their sizes, measured their canopy cover, and studied the variation of the size and configuration of all of the kelp beds of the Southern California Bight. We found that maps we made using an optical-transfer microscope were less accurate than those we made using the photographically enlarged mosaic method. We also found that photo-enlarged imagery was very close to the quality of the original photographs. This method was also more convenient because we were able to take all the imagery to our facility to work with it and were able to convert images in several different formats to the same size.

We located several sources of existing images. These collections were evaluated and several sets were selected for processing. We found so many sets of images available that we focused on sample years spaced every four years since 1955 rather than covering all years. When photographs of specific beds were not available for the "sample" years, photographs from the prior or subsequent year were used instead. We also included photographs taken in 1977 because there were so many good photographs available.

The photographic copying was done with a copy stand and a Hasselblad El/M camera with a Carl Zeiss S-Planar 120mm f5.6 lens and a 4.5 x 6 cm format film back. H&W VTE 120 and Ilford Pan F 120 films were used. The collected images were printed with a Beseler 23CII enlarger with a 100 mm lens. All prints were scaled to a reduction of 1:24,000 by superimposing the image on a standard U. S. Geological Survey (7.5') topographic map under the enlarger. Coastline and other features in the negative image were matched with those on the map. Kodak and Agfa resin coated (RC) papers were used for printing. Prints taken as part of the same flight were assembled into mosaics. Transparent, acetate versions of the U. S. Geological Survey topographic maps were used to assure that the individual photographs in the mosaics were correctly positioned with respect to one another and land features. Maps were made for each of the numbered kelp beds, using the California State Department of Fish and Game kelp-bed numbering

system. Clear acetate was first taped over the mosaics. The configuration of the kelp beds were then drawn on these acetate sheets. Canopy cover within the configuration boundary was estimated as well as measured with an Digital Graphics CAT-100 image analysis system in a Vector Graphics System B Microcomputer.

Because individual kelp plants are irregularly spaced within a kelp bed, it is sometimes difficult to decide what to include within and what to exclude from the drawn kelp-bed boundary. Hodder and Mel (1978) used subjective criteria to define the margins of the beds. In order to be more objective we made the decisions needed to define the boundary of a kelp bed by following the guidelines listed below. The mapper would draw boundaries around any group of two plants or more and exclude single plants if they were separated by more than 2 mm (measured with a 2 mm dot) from the main body of a bed or patch (2 mm at that scale of reduction represents 48 meters at the water surface). Nearshore Egregia beds were excluded.

Area measurements were made with a Lasico L50D digital planimeter directly from the acetate maps. The measuring technique was straight forward. Care was taken by the data takers to periodically recalibrate the instrument by measuring a standard area. We found that the same observer repeatedly measuring the same area was consistent within ±1%. Different observers were consistent to within ±2.5%.

Statistics were calculated on untransformed data for kelp-bed areas and kelp cover, for each of the 33 beds over the sample time periods studied between the 1930's and 1979. The statistics that were calculated were the mean, standard deviation and coefficient of variation (100 x standard deviation / mean). Beds in the San Diego, Los Angeles, Santa Barbara, and Santa Catalina Island geographic areas were compared using means, standard errors, and t-tests. The bed length, width, area, variation in area, cover, and variation in cover were compared.

The kelp harvesting rate (catch-per-unit-effort) in the Goleta Bay kelp bed was used as an indicator of the amount of kelp canopy that was available for harvest at the surface. All harvests were done under near-calm conditions. The rates were compared with the means for the prior month's measurements of surface irradiance, wind speed, swell height, sea temperature at Platform Holly, sea temperature at Santa Barbara Harbor, surface nitrate concentration, and bottom nitrate concentration (at 12 m deep). A stepwise multiple-linear-regression model was determined for the 70 observations (of 256) for which we had information for all eight variables. Three variables were selected for the model. A second model was determined to verify the first one (as suggested by Cooley and Lohnes 1971) using the 195 observations for which we had information for the three variables that appeared in the first model. The contribution that each variable made to the regression was calculated as the product of the regression coefficient and the standard deviation of the variable (not standard deviation of the regression coefficient).

TABLE 1. MEAN KELP-BED AREAS AND KELP-CANOPY COVER OF 33 SOUTHERN CALIFORNIA BIGHT KELP BEDS FROM THE 1930'S TO 1979, INCLUDING STANDARD DEVIATIONS AND COEFFICIENTS OF VARIATION

	KELP-BED AREAS (hectares)				KELP-CANOPY COVER (%)			
BED	NUMBER OF SAMPLE PERIODS	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION (%)	NUMBER OF SAMPLE PERIODS	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION (%)
1	0	0.000	0.000	0.000	0	0.000	0.000	0.000
2	9	85.666	97.131	113.382	4	67.750	12.919	19.069
3	9	439.555	353.260	80.367	4	66.750	11.898	17.826
4	9	213.666	181.055	84.737	7	47.714	13.996	29.334
5	7	30.428	10.967	36.043	7	57.857	18.270	31.578
6	7	265.714	75.634	28.464	7	50.428	10.406	20.635
7	8	40.375	47.292	117.132	7	51.857	24.148	46.567
8	8	141.625	233.054	164.557	7	40.000	7.831	19.578
9	8	43.750	65.353	149.379	8	45.375	22.965	50.612
10	7	33.571	26.513	78.975	7	42.428	26.399	62.221
11	0	0.000	0.000	0.000	0	0.000	0.000	0.000
12	0	0.000	0.000	0.000	0	0.000	0.000	0.000
13	8	30.125	40.367	134.000	5	65.800	5.890	8.952
14	8	47.062	65.241	138.627	5	36.600	33.433	91.348
15	6	2.166	2.639	121.820	5	34.600	34.616	100.047
16	8	186.625	25.053	13.424	8	50.375	12.141	24.101
17	6	262.666	66.797	25.430	6	64.666	12.339	19.081
18	7	45.857	11.668	25.444	7	42.714	12.776	29.911
19	9	100.666	79.227	78.702	9	55.777	12.111	21.714
20	9	140.555	91.932	65.406	9	67.666	9.000	13.330
21	9	255.888	88.708	34.666	9	66.888	6.697	10.013
22	9	120.444	33.106	27.486	9	68.222	8.348	12.236
23	8	60.875	11.691	19.206	8	61.375	6.738	10.979
24	8	15.875	4.454	28.057	8	66.250	11.285	17.034
25	8	115.750	26.201	22.635	8	57.750	13.445	23.282
26	8	390.375	73.748	18.891	8	64.750	10.633	16.422
27	9	114.777	19.240	16.763	9	62.222	12.862	20.671
28	9	407.444	60.434	14.832	9	65.555	9.683	14.772
29	9	237.444	20.242	8.525	9	81.222	9.189	11.313
30	9	304.333	35.440	11.645	9	76.222	8.771	11.508
31	8	539.500	36.288	6.726	8	76.875	7.140	9.288
32	8	1,050.125	158.376	15.081	7	80.142	7.976	9.915
75	5	68.600	7.733	11.272	3	55.333	11.239	20.312
TOTAL		5,791.502						

NOTE: Numbers in this table are shown to three places, not because they are that accurate, but because we wished to not introduce "rounding error" when statistical tests are made. These numbers are accurate to one place beyond the decimal point.

R E S U L T S

In the course of this study, we examined over 15,000 aerial photographs and copied and printed more than 6,000 of these, from which we assembled 269 photomosiacs. We made approximately eight photomosaics for each of the thirty-three California Department of Fish and Game designated kelp beds that we studied. We measured the areas of the kelp beds and estimated the kelp canopy cover within each bed. Means of the kelp-bed areas and kelp-canopy cover measurements were calculated for each bed (Table 1.). Standard deviations and coefficients of variation were also calculated for the data for each kelp bed.

The areas of the kelp beds were compared between sample periods by using the measurements of each bed for the two periods as a paired sample. There was a significant decline in area from 1959 to 1963. There was a significant decline in area from 1971 to 1975 followed by a very significant expansion from 1975 to 1977. The 1955 kelp-bed areas were the highest since 1911.

The cover of kelp canopy in the kelp beds was compared between sample periods by using the measurements of each bed for the two periods as a paired sample. There was a significant increase in cover from the intermediate period to 1955 and a very significant decrease in cover from 1955 to 1959. There was a significant decrease in cover from 1967 to 1971 and a significant increase from 1971 to 1975. There was a significant decrease in cover from 1977 to 1979. The 1955 kelp cover values were the highest in the present study.

We separated the beds that we studied into four geographic areas: San Diego, Los Angeles, Santa Barbara, and Santa Catalina Island (Figure 1 and Table

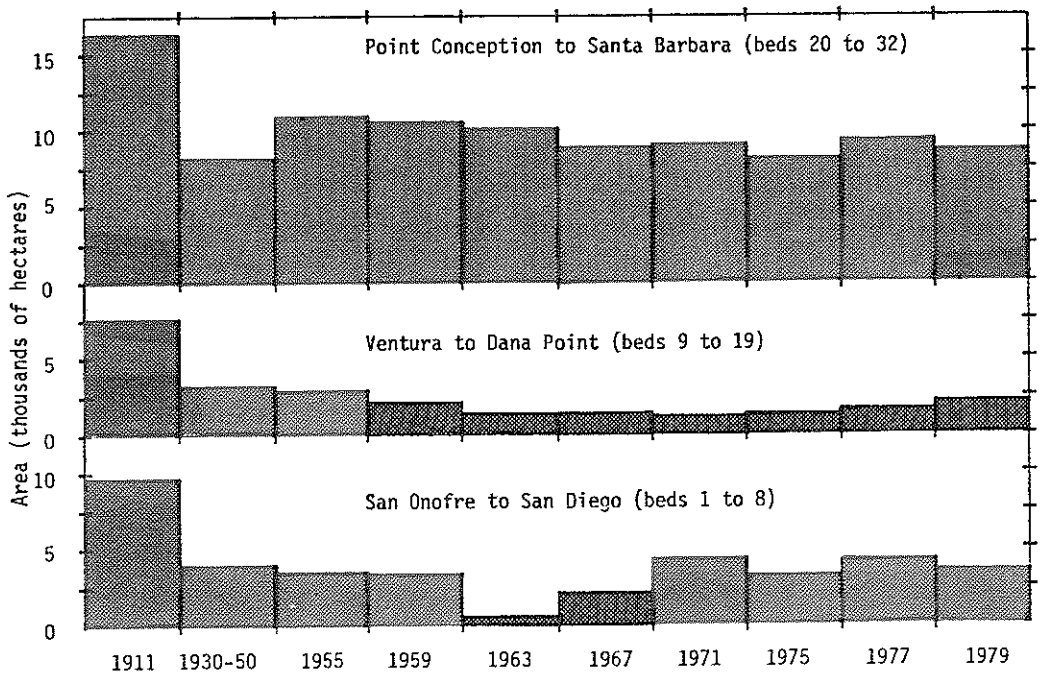

Figure 1. Changes in area of the kelp beds of three regions of the Southern California Bight. Note that the Santa Barbara area beds have covered more area and been more stable than the Los Angeles and San Diego area beds. There has been a decline and then a recovery in the Los Angeles and San Diego beds in this century.

2.). We compared the following information for kelp beds in these geographic areas: kelp bed length, kelp bed width, kelp bed area, coefficient of variation of kelp bed area, kelp canopy cover, and coefficient of variation of kelp cover canopy (Table 3.). We measured the kelp bed length as the linear distance from one California Department of Fish and Game bed boundary to the

TABLE 2. KELP-BED LENGTHS, WIDTHS, AREAS AND COVER FOR BEDS IN FOUR GEOGRAPHIC AREAS OF THE SOUTHERN CALIFORNIA BIGHT

CDF&G Bed Number	Length (km)	Width (m)	Area (Hectares)	Variation -Area (%)	Cover (%)	Variation -Cover (%)
San Diego to San Onofre						
1	9.37	0.00	0.000	0.000	0.000	0.000
2	15.29	56.03	85.666	113.382	67.750	19.069
3	10.43	421.43	439.555	80.367	66.250	17.826
4	12.95	164.99	213.666	84.737	47.714	29.334
5	11.08	27.46	30.428	36.043	57.857	31.578
6	24.32	109.26	265.714	28.464	50.428	20.635
7	28.86	13.99	40.375	117.132	51.857	46.567
8	13.88	102.04	141.625	164.557	40.000	19.578
Dana Point to Ventura						
9	17.33	25.25	43.750	149.379	45.375	50.612
10	6.66	50.41	33.571	78.975	42.428	62.221
11 & 12	38.15	0.00	0.000	0.000	0.000	0.000
13	16.34	18.44	30.125	134.000	65.800	8.952
14	12.30	38.26	47.062	138.627	36.600	91.348
15	38.06	0.57	2.166	121.820	34.600	100.047
16	12.47	149.66	186.625	13.424	50.375	24.101
17	25.68	102.28	262.666	25.430	64.666	19.081
18	35.32	12.98	45.857	25.444	42.714	29.911
19	10.14	99.28	100.666	78.702	55.777	21.714
Santa Barbara to Point Conception						
20	9.73	144.46	140.555	65.406	67.666	13.300
21	5.78	442.71	255.888	34.666	66.888	10.013
22	4.42	272.50	120.444	27.486	68.222	12.236
23	3.54	171.96	60.875	19.206	61.375	10.979
24	2.02	78.59	15.875	28.057	66.250	17.034
25	3.48	332.61	115.750	22.635	57.750	23.282
26	5.82	670.75	390.375	18.891	64.750	16.422
27	3.49	328.87	114.777	16.763	62.222	20.671
28	11.05	368.73	407.444	14.832	65.555	14.772
29	7.38	321.74	237.444	8.525	81.222	11.313
30	9.08	335.17	304.333	11.645	76.222	11.508
31	9.48	569.09	539.500	6.726	76.875	9.288
32	18.22	576.36	1,050.125	15.081	80.142	9.915
Santa Catalina Island						
75	78.72	8.71	68.600	11.272	55.333	20.312

TABLE 3. COMPARISON OF KELP BEDS IN FOUR GEOGRAPHIC AREAS OF THE SOUTHERN CALIFORNIA BIGHT

Information	Geographic Area				
	San Diego	Los Angeles	Santa Barbara	Santa Catalina Island	All
California Department of Fish and Game Bed Numbers	1-8	9-19	20-32	75	1-32&75
Linear Distance (km) along Coast (Total for Beds)	126.18	212.45	93.49	78.72	510.84
(% of Total)	24.70	41.59	18.30	15.41	
Kelp Bed Area (Hectares) (Total for Beds)	1,217.03	752.49	3,753.39	68.60	5,791.51
(% of Total)	21.01	12.99	64.81	1.19	
Kelp Bed Width (m) (Average for Linear Distance of Coast)	96.45	35.42	401.48	8.71	113.37
Linear Distance (km) along Coast (Average for Beds)	15.77	19.31	7.19	78.72	15.48
Standard Error (n)	2.49(8)	3.02(11)	1.22(13)	(1)	2.51(33)
Kelp Bed Width (m) (Average for Beds)	111.90	45.19	354.89	8.71	182.26
Standard Error (n)	48.38(8)	15.20(11)	48.45(13)	(1)	33.52(33)
Kelp Bed Area (Hectares) (Average for Beds)	152.13	68.41	288.72	68.60	175.50
Standard Error (n)	52.49(8)	25.36(11)	76.28(13)	(1)	36.95(33)
Kelp Bed Area Variation (Coefficient of Variation) (Average for Beds)	78.09	69.62	22.30	11.27	51.26
Standard Error (n)	19.19(8)	17.82(11)	4.22(13)	(1)	8.72(33)
Kelp Bed Cover (%) (Average for Beds)	47.73	39.85	68.86	55.33	53.66
Standard Error (n)	7.57(8)	6.68(11)	2.06(13)	(1)	3.66(33)
Kelp Bed Cover Variation (Coefficient of Variation) (Average for Beds)	23.07	37.09	13.90	20.31	24.05
Standard Error (n)	4.74(8)	10.46(11)	1.21(13)	(1)	3.98(33)

next. This distance was measured as straight as possible, at a distance from shore where the kelp beds grow, rather than following all of the undulations of the shoreline. We calculated the bed width as the area divided by the length.

This gives an average width across the length of the bed. If a bed only occurs along part of its California Department of Fish and Game designated length, this measure will show a narrow width compared to those sections of the coast where kelp actually occurs.

The following relationships were noted for kelp-bed lengths and kelp-bed widths. The San Diego beds were significant longer than the Santa Barbara beds ($t = 3.46$, d. f. = 19, $p = 0.033$). The Los Angeles beds were significantly longer than the Santa Barbara beds ($t = 3.95$, d. f. = 22, $p < 0.001$). The San Diego beds were significantly narrower than the Santa Barbara beds ($t = 3.34$, d. f. = 19, $p = 0.004$). The Los Angeles beds were significantly narrower than the Santa Barbara beds ($t = 5.67$, d. f. = 22, $p < 0.001$).

Kelp-bed areas and cover also differed for beds in the four geographic areas. Statistical tests of the kelp-bed area means showed that the Los Angeles beds were significantly smaller than the Santa Barbara beds ($t = 2.55$, d. f. = 22, $p = 0.020$). The San Diego bed areas varied significantly more than the Santa Barbara beds ($t = 3.55$, d. f. = 19, $p = 0.003$). The Los Angeles bed areas varied significantly more than the Santa Barbara beds ($t = 2.79$, d. f. = 22, $p = 0.011$). The San Diego beds had significantly lower cover than the Santa Barbara beds ($t = 3.29$, d. f. = 19, $p = 0.043$). The Los Angeles beds had significantly lower cover than the Santa Barbara beds ($t = 4.45$, d. f. = 22, $p < 0.001$). The kelp cover of the San Diego beds varied significantly more than the kelp cover of the Santa Barbara beds ($t = 3.46$, d. f. = 19, $p = 0.033$). The kelp cover of the Los Angeles beds varied significantly more than the kelp cover of the Santa Barbara beds ($t = 3.95$, d. f. = 22, $p < 0.001$).

The kelp harvesting rate varied seasonally as well as from year to year (Figure 2.). The lowest monthly average kelp harvesting rate was 32.9 metric tons per hour in December while the highest was 74.6 metric tons per hour in May. The lowest annual average kelp harvesting rate was 40.2 metric tons per hour in 1976 while the highest was 66.8 metric tons per hour in 1973.

The stepwise multiple-linear regression of kelp harvesting rate dependence on environmental variables was highly significant ($p = 0.001$, Table 4.). Three of the independent variables significantly increased the coefficient of determination and so were included in the final regression. Together they accounted for 59.5% of the variation of kelp harvesting rate. High surface irradiance for the prior month increased the kelp canopy available for harvest. Higher swell heights and temperatures for the prior month decreased the kelp canopy. The verification multiple-linear regression resulted in a significant model ($p = 0.001$) based on 76% of the data. The second model accounted for 46% of the variation in kelp harvesting rate, with similar contributions by the environmental variables.

The positive affect that high surface irradiance has on kelp growth is through increasing the photosynthetic rate. The negative affects that high swell heights have on kelp growth are to increase water motion around the plant and increase tissue and plant loss. High temperatures can directly damage kelp, however, since there is a negative correlation between nutrient levels and temperature, some of the negative contributions high temperatures may have on canopy growth can be attributed to low nutrient concentrations.

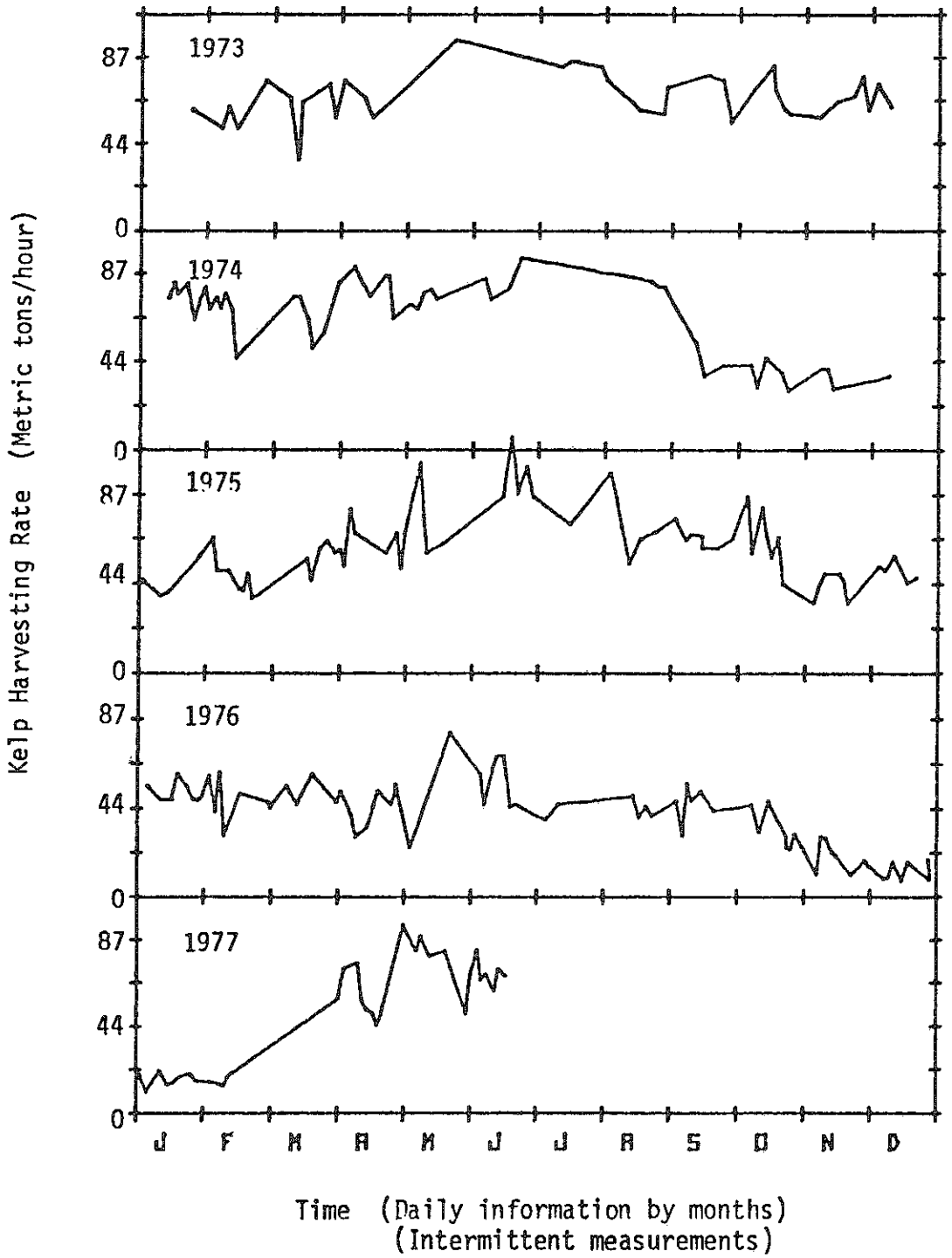

Figure 2. The rate at which kelp was harvested in the Goleta Bay kelp bed (number 26) from 1973 to 1977. The rate was higher in Spring and early Summer while it was lower in Fall and Winter (from Harger 1979).

TABLE 4. MULTIPLE LINEAR REGRESSIONS OF THE DEPENDENCE OF KELP HARVESTING RATE ON THE AVERAGE OF THE PRIOR MONTH'S PHYSICAL ENVIRONMENTAL DATA

Seven Variable Comparison # of Observations = 70

Correlation Matrix	Surface Irradian.	Wind Speed	Swell Height	Sea Temp. Platform Holly	Sea Temp. Sta. Bar. Harbor	Surface Nitrate	Bottom Nitrate
Wind Speed	0.116						
Swell Height	0.027	0.666					
Holly Temp.	0.217	-0.234	-0.483				
S. B. Temp.	0.106	-0.527	-0.829	0.654			
Sur. Nitrate	-0.132	0.485	0.491	-0.438	-0.742		
Bot. Nitrate	-0.028	0.412	0.504	-0.672	-0.808	0.706	
Kelp H. Rate	0.593	0.093	0.056	-0.305	-0.117	0.303	0.225

Analysis of Variance Table

Source	d.f.	SS	MS	F
Total	69	46,033.6		
Regression	3	27,365.5	9,121.8	32.25
Residual	66	18,668.2	282.9	

p = 0.001
Standard Error = 16.82
R Squared = 0.595
Constant = 120.54

Variables Selected	Regression Coefficient	Standard Error	Contribution
Surface Irradiance	0.313	0.089	18.75 (27.8%)
Swell Height	-39.355	8.658	6.30 (9.4%)
Sea Temp. at Holly	-6.280	0.676	15.00 (22.3%)

Three Variable Comparison # of Observations = 195

Correlation Matrix	Surface Irradiance	Swell Height	Sea Temperature at Platform Holly
Swell Height	0.061		
Sea Temperature at Platform Holly	0.297	-0.433	
Kelp Harvesting Rate	0.466	0.019	-0.273

Analysis of Variance Table

Source	d.f.	SS	MS	F
Total	194	132,504.1		
Regression	3	61,040.1	20,346.7	54.38
Residual	191	71,464.0	374.2	

p = 0.001
Standard Error = 19.34
R Squared = 0.461
Constant = 125.33

Variables Selected	Regression Coefficient	Standard Error	Contribution
Surface Irradiance	0.311	0.089	17.16 (19.9%)
Swell Height	-39.355	8.658	7.18 (8.3%)
Sea Temp. at Holly	-6.280	0.676	15.33 (17.8%)

DISCUSSION

The results of the present study, based mostly on heretofore unused imagery and kelp-harvesting-rate information, provide a detailed historical record that shows kelp variability within the Southern California Bight as a whole. There are significant differences between kelp beds in different geographic areas, presumably because of differences in exposure to currents and storms. In short term studies of the Goleta Bay kelp bed, one half the variation in the amount of kelp canopy at the surface can be predicted knowing the average solar irradiance, swell height, and water temperature over the last month.

The characteristic shapes of the southern California kelp-beds that one can see today are recognizable even in the nautical charts drawn in the 19th century. Since the depth contours are generally in the same location in these old nautical charts as they are today, so the kelp canopy configurations are probably correct. In re-measuring Crandall's (1912) maps we have found that in light of these old charts they appear in general to be accurate in spite of the contention in the literature that his maps have grossly overestimated the extent of canopy area. The smaller areas obtained by measurements from more recent maps of southern California kelp beds probably reflect both a slight increase in mapping precision over Crandall's methods, and an actual decrease in kelp-bed areas.

We have found significant differences between our measurements of Crandall's (1912) maps and those found in Hodder and Mel (1978). We also found that there are noteworthy differences in the 25-year-mean area that we calculated for each of the beds as compared to the current area values provided by the California Department of Fish and Game. The total mean area we have measured is 5,791.5 hectares while the California Department of Fish and Game cites an area of 8,547 hectares (48% higher).

We have arbitrarily divided the kelp beds of the Southern California Bight into four geographic areas: 1) San Diego, 2) Los Angeles, 3) Santa Barbara, and 4) Santa Catalina Island. The kelp beds in the San Diego area are long, small in area, and have a low cover. The variation in their area and cover is relatively high. They are made up of *Macrocystis pyrifera*. Most of these beds occur on cobble bottoms and are found far offshore. They are exposed to winter storms from the Northwest and summer storms from the Southwest. During the early 1960's their areas reached a minimum and their areas have increased since then.

The kelp beds in the Los Angeles area are long, very small in area and have a low cover. The variation in their area and cover is relatively high. They are made up of *Macrocystis pyrifera* that has been transplanted from the offshore islands. These beds were originally made up of *Macrocystis angustifolia*, as found in the Santa Barbara area, but this all died off in the late 1950's and early 1960's (M. Neushul, personal communication). The *Macrocystis pyrifera* transplantation work from the offshore islands was performed in an attempt to restore the kelp beds. These beds are mostly on high-relief rock bottoms but are rather rare along the coast. The beds are partially sheltered from the summer storms from the Southwest by the offshore islands.

The kelp beds in the Santa Barbara area are short, large in area, and have a high cover. The variation in their area and cover is low. They are made up, for the most part, of Macrocystis angustifolia (for this paper the separation of the two species presented in Neushul 1971 is used rather than calling all the populations Macrocystis pyrifera as was suggested in Abbott and Hollenberg 1976). Some of these beds are on shale and some on high-relief rock bottoms, but most are on sand. They are the most stable, being in the lee of the Santa Barbara Channel Islands. Often the beds are sheltered from the storms from the West by being to the East of prominent points of land.

The kelp bed off Santa Catalina Island is very long, small in area, and has medium cover. The variation in its area and cover is low. It is made up of a special variety of Macrocystis pyrifera that looks slightly different from the mainland variety. Some of the largest kelp beds in the Southern California Bight occur off the offshore islands, but none of these is off Santa Catalina Island. The beds face all compass directions. The south facing beds are exposed to sever winter and summer storms, while north facing beds are relatively sheltered the year round. The oceanographic conditions are different from those found near the coast of the mainland. These beds occur, for the most part, on high-relief rock bottoms.

Our maps have documented damage to kelp beds due to boat traffic near piers and harbors. However, many of the disputes about damage done to the kelp beds by kelp harvesters, by nearshore sewage pollution, and by other human activity (dredging, thermal effluents, etc.) have been prompted by the gradual disappearance of kelp beds earlier in this century. This disappearance has been attributed to the direct effects of sewage (or DDT), sewage enhanced populations of sea urchins, natural warm-water years, or natural low-nutrient years (Jackson 1977). In the present studies, it was difficult to determine which of man's activities was damaging to kelp beds and how damaging they were. Each activity is probably damaging to kelp in different places and at different times. Our short term monitoring of the Goleta kelp bed has shown that natural kelp growth is seasonal, being affected by seasonal climatic variables, and varies from year to year. Unless one monitors and determines what the natural variation is and what causes it, one cannot determine which changes are man-induced and which ones are natural. This study has provided some new insights into the natural variation of kelp beds in southern California and what causes that variation.

A C K N O W L E D G E M E N T S

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WASTE DISPOSAL IN SOUTHERN CALIFORNIA AND ITS EFFECTS ON THE ROCKY SUBTIDAL HABITAT

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This paper presents an overview of the discharge of municipal wastewater in the Southern California bight. These wastes are a principal source of solids, nutrients, trace metals and organics entering the coastal zone. Monitoring data are also presented suggesting some waste discharge effects on rocky subtidal habitat.

The Southern California bight receives dissolved and particulate materials and potentially toxic trace constituents from a wide variety of sources. Rivers contribute solids (silts), approximately 274,000 metric tons (MT) per year in 1971 (SCCWRP 1973). Harbor waters, which may be laden with industrial waste products and copper sloughed from anti-fouling paints, are constantly interchanging with the adjacent coastal waters. Some fraction of the dredge spoils resulting from maintaining or increasing the navigability of water ways are an unknown but potentially important factor (approximately 10^6 yds^3/year are removed from L.A. Harbor, some of which is dumped offshore in the San Pedro channel). Shore-line erosion in many local areas may be significant. Aerial fallout, while a bight-wide process, is probably of greater magnitude and importance near densely urbanized or heavily worked agricultural areas.

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In 1981, approximately 1100 MGD of treated wastewater were discharged directly to the ocean waters off Southern California. Of this amount, 94 percent was discharged by the five largest Publicly Owned Treatment Works (POTWs) serving together 10.4 million persons. Moving from north to south in the bight, these five discharges are located along the shoreline at Ventura County Sanitation Districts (Oxnard), City of Los Angeles (Hyperion), Los Angeles County Sanitation Districts (JWPCP), Orange County Sanitation Districts (OCSD Plants Nos. 1 and 2), and City of San Diego (Point Loma). All five agencies have at least primary sewage treatment with a variety of sludge handling systems and industrial waste source control and ocean monitoring programs mandated by State and Federal authorities. All these dischargers have modern multiport diffusers at the termini of their effluent outfalls, with up to several hundred small holes perforating the last 1-2 Km of pipe. Oxnard chlorinates continuously while Los Angeles County Sanitation Districts (LACSD) does as needed during winter months. Specific characteristics of the five POTWs are presented in Table I.

TABLE I

CHARACTERISTICS OF FIVE LARGEST POTW's[a]

	Ventura Co. (Oxnard)	City of Los Angeles (Hyperion)	L.A. Co. San. Dist. (JWPCP)	Orange Co. San. Dist. (OCSD No. 1 & 2)	City of San Diego (Point Loma)
Location	Oxnard	Santa Monica Bay	Palos Verdes Peninsula	Huntington Beach	Point Loma
Total Flow (MGD)[b]	18	374	364[c]	212	130[d]
Secondary Treatment (MGD)	18	100	0[e]	50[e]	0
Outfall Lengths (Km)	1.7	8 & 11[f]	3	8	4
Depth of Discharge (Meters)	14	57 & 98[f]	60	60	64

[a] Source: Pers. Com: G. Sienko (Ventura Co.), F. Wada (L.A. City), B. Anderson (OCSD), S. Hamilton (San Diego).

[b] MGD (millions of gallons per day.)

[c] Advanced Primary.

[d] Chemical addition for enhanced solids removal.

[e] LACSD has 200 mgd of secondary treatment under construction; OCSD has an additional 75 mgd of secondary treatment under construction.

[f] 5 MGD sludge-effluent outfall discharging into head of submarine canyon.

TABLE II

Combined Annual Mass Emission Rates of Southern California's Five Largest Municipal Wastewater Dischargers 1971-1981

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
Flow											
MGD	931	922	956	967	985	1,027	966	1,015	1,054	1,097	
Liters/day 10^6	3,524	3,490	3,615	3,360	3,728	3,889	3,658	3,840	4,000	4,160	4,160
General Constituents (metric tons/yr)											
Total Sus. Sol.	288,000	279,000	270,000	264,000	287,000	288,000	244,000	256,000	243,000	233,000	226,000
5-Day B.O.D.	283,000	250,000	217,000	222,000	237,000[b]	259,000[b]	244,000	237,000[b]	246,000[b]	260,000[b]	264,000[b]
Oil and Grease	63,500	60,600	57,400	54,700	57,420	59,100	49,000	49,000	45,000	39,000	37,000
NH_3-N	56,600	39,900	45,900	37,000	36,620	37,350[b]	41,200	39,500	41,200	42,000[b]	41,000[b]
Trace Metals (metric tons/yr)											
Silver	17.7	21.1	29.0	21.7	25.7	20.2	34.3	32.3	42.2	30.8	27.9
Arsenic	ND	ND	ND	20.9[c]	11.9[c]	10.5[c]	14.0	14.5	15.4	10.6	12.2
Cadmium	57.3	33.8	49.3	55.4	50.0	45.0	42.4	44.8	42.3	39.5	31.7
Chromium	676	673	695	690	580	593.0	366	280	237	275	187
Copper	559	485	509	575	511	507	412	417	359	336	339
Mercury	ND	ND	ND	3.1[c]	2.2[c]	2.6[c]	2.8	1.9	2.5	1.9	1.8
Nickel	339	273	318	314	234	307[b]	264	320	256	224	167
Lead	243	226	180	199	198	191	152	219	223	175	130
Selenium	ND	ND	ND	17.75[b]	16.9[d]	22.0[d]	23.0[d]	23.0[d]	7.7[d]	10.5[d]	15.3[d]
Zinc	1,880	1,210	1,360	1,320	1,142	1,064	837	905	724	730	540
Chlorinated Hydrocarbons (kg/yr)											
Discharger Values											
Total DDT	21,700	6,600	4,120	2,120	1,989	1,673	920	1,110	760	644	474
Total PCB	8,730	9,830	4,620	9,390	6,011	4,310	2,183	2,510	1,190	1,129	1,250
Project Values[e]											
Total DDT	21,600[f]	6,540	3,830	1,570	1,150	970	780	1,050	728	NM	NM
Total PCB	ND	19,490	3,390	5,420	3,070	2,820	1,560	590	1,466		

a. Oxnard included only in 1975 through 1979 data.
b. Hyperion 7-mile effluent excluded.
c. Orange County data not included.
d. Total for Hyperion and JWPCP only.
e. 1976-1979 data based on analysis of two 7-day composites; 1971-1975 data taken from final report to EPA for Grants R801153 and R803707.
f. JWPCP only.

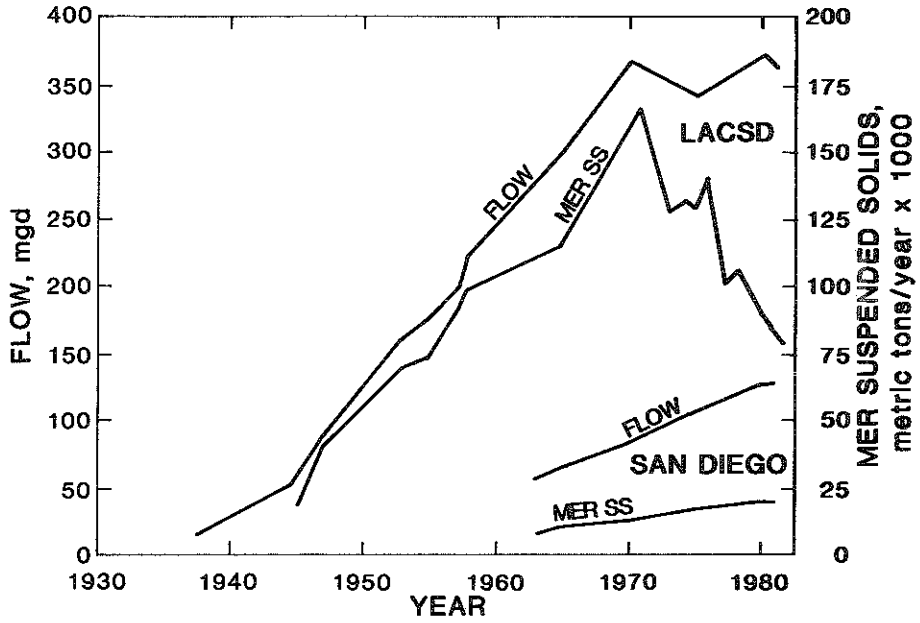
NM = not measured. ND = not detected.

Table II presents combined annual flow and mass emission rates (MER) from 1971 to 1981. Combined flow rate has increased with the expanding population of Southern California, but discharge of solids and toxic trace constituents declined between 1970 and 1981 due to source control and new treatment. Flows would have been even higher but for the increasing importance of inland reclamation and reuse. In 1981, seven of ten metals measured and DDT were at about the lowest MER reported during the ten year period. Although unchanged in the last three years, polychlorinated biphenyls are an order of magnitude lower than during the early 1970s. Biological oxygen demand (BOD) is higher in spite of the reduction in solids discharge. The discrepancy results from the relative ease at improving removal of solids versus BOD at treatment plants and industries.

Before 1970, treatment prior to ocean disposal was aimed at public health

protection and aesthetics. Upgrading treatment efficiency, i.e., greater percentage solids removal, was not emphasized. Heightened environmental awareness and resulting legislation caused a shift in resources to greater treatment efficiency after 1971 as evidenced in reduced solids emissions as shown in Figure I. LACSD and San Diego were chosen for Figure I as they discharge near kelp beds, the focus of this symposium.

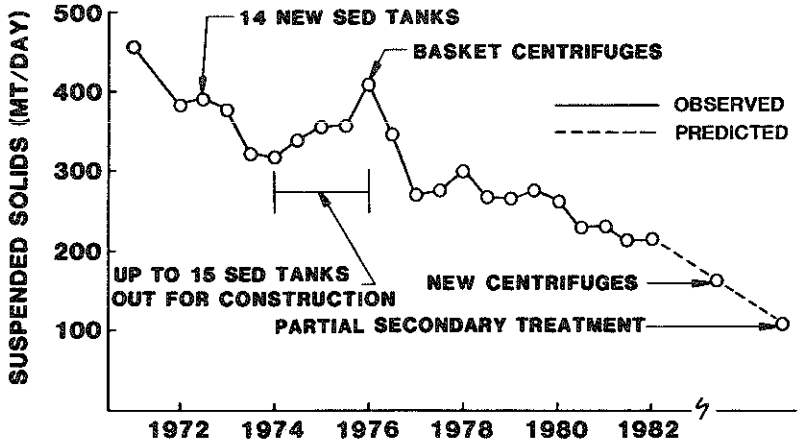
FIGURE I
FLOW AND MASS EMISSION RATE OF SUSPENDED SOLIDS
LACSD AND SAN DIEGO 1937 – 1981



As noted, when public resources were shifted to emphasize reductions in MER, a mixed strategy of industrial waste source control and increased treatment was generally adopted. Although full secondary treatment, sludge digestion, dewatering, and subsequent land-based disposal can cause a dramatic reduction in solids emissions, other intermediate and possibly more cost effective strategies also exist. These lesser modifications, shown as examples in Figure II, can significantly reduce MER without employing full secondary treatment.

Future waste disposal strategies of POTWs are also being influenced by the

FIGURE II
JWPCP MASS EMISSION RATES OF SUSPENDED SOLIDS
TO THE OCEAN OFF PALOS VERDES

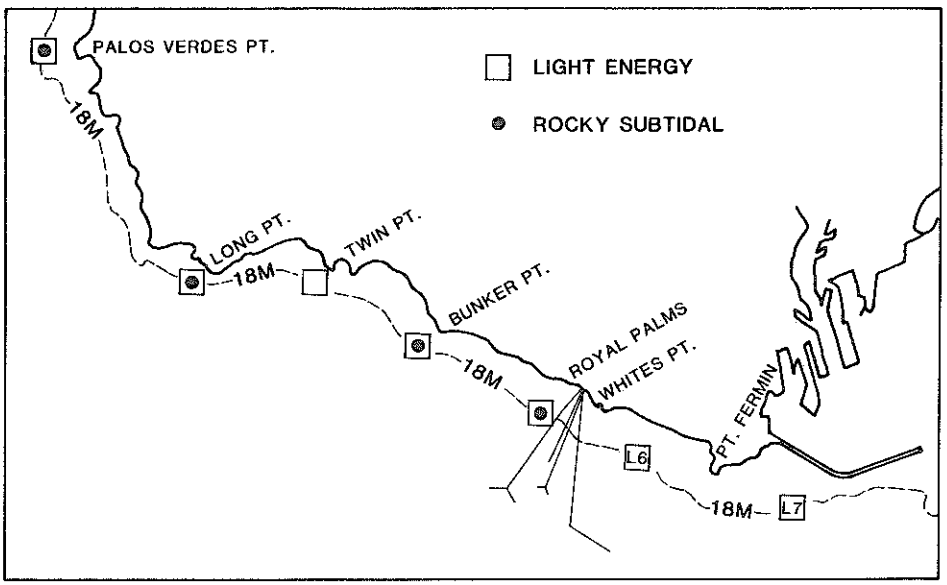


Federal 301(h) waiver process. Congress passed the Clean Water Act in 1972 (PL 92-500) calling for full secondary treatment for all POTWs. However, the 1977 amendments to the Act allowed granting a waiver wherever compliance with State and Federal Clean Water Act goals could be demonstrated short of full secondary treatment. All five Southern California agencies applied for (1979) and received (late 1981) tentative approval of waivers for five year periods. They must carry out extensive compliance monitoring and apply for renewal at that time. The alternative is construction of full secondary treatment facilities estimated to cost over $500 million for construction in Southern California alone plus annual operation and maintenance costs of $17 million. In applying for waivers, each of the agencies proposed additional treatment short of full secondary (except Oxnard which has full secondary). Proposals to upgrade industrial waste source control and marine monitoring programs were also part of the applications. Los Angeles City would add 50 MGD to their existing 100 MGD of secondary treatment at Hyperion plus providing more primary sedimentation tanks; flow at Hyperion would also be reduced by 40 MGD with construction of inland water reclamation facilities at Sepulveda. LACSD is presently constructing 200 MGD of secondary treatment at JWPCP; inland water reclamation

discharge along the 60 M depth contour some 3 Km offshore, and outside of the rocky subtidal habitat that fringes most of the Palos Verdes Peninsula inside the 20 M contour. Discharge monitoring directed at this inshore environment as well as studies by others (Grigg & Kiwala 1970, Grigg 1978) have demonstrated that ecological alterations are distributed along gradients relative to the outfall terminus, decreasing in intensity upcoast and inshore. As in any complex, open system, it is difficult to define the role of any single variable or subset of variables affecting the inshore environment. The outfall impacts hypothesized below are just some of the variables determining the nature of the environment and communities considered. However, the patterns evident in the data are strongly suggestive of a causal relationship between wastewater discharge and community structure.

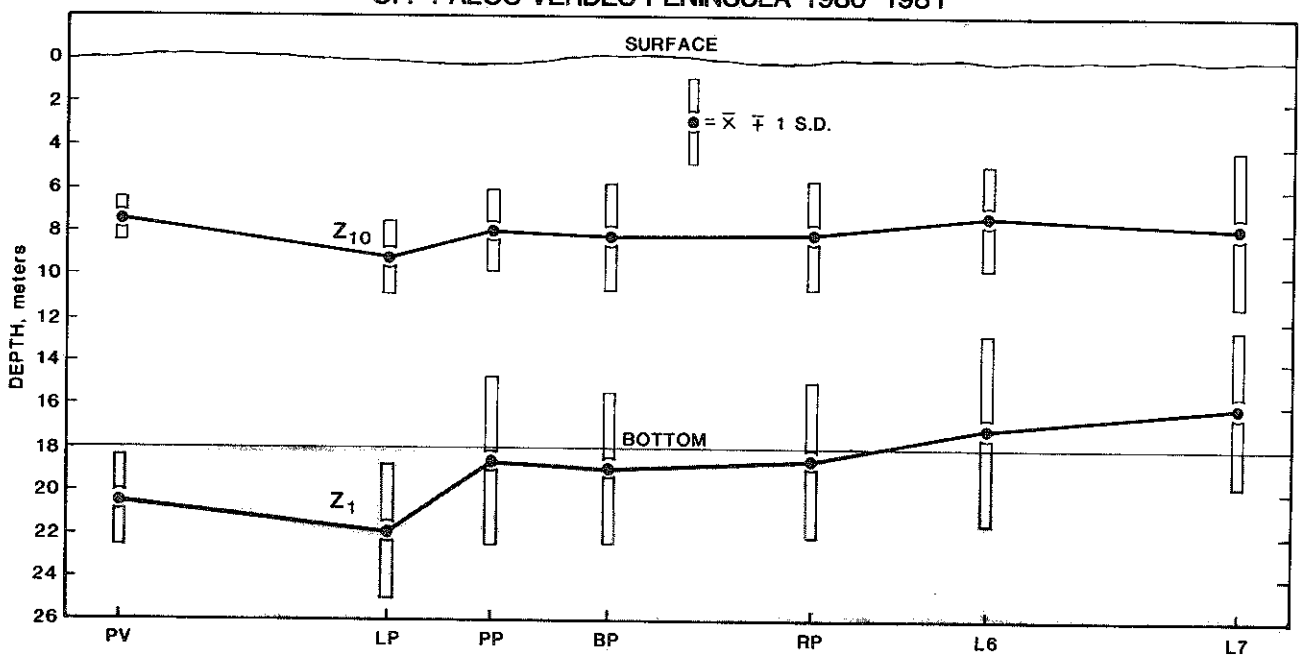
LACSD monitoring in the rocky subtidal includes semiannual biological surveys (band transects) at twelve sites along the peninsula in 18, 12, and 6 M depths and monthly surveys of light energy penetrance at seven sites along the 18 M contour (locations in Figure III).

FIGURE III
ROCKY SUBTIDAL AND LIGHT ENERGY SURVEY STATIONS



Analysis of light energy data indicates a significant ($P < .02$) trend of increasing light energy attenuation with movement west to east along the Peninsula. Data were gathered with a Biospherical Quantum Scalar Irradiance Meter (QSR-240) which simultaneously compares total phytosynthetically active radiation (400 to 700 nannometer range) incident at the water surface with that at depth. This data has been summarized and is presented in Figure IV as profi-

FIGURE IV
MEAN Z_1 AND Z_{10} DEPTHS ALONG 18 METER CONTOUR
OFF PALOS VERDES PENINSULA 1980-1981



les of the Z_1 and Z_{10} depths. These are the depths at which light intensity is 1 and 10 percent of surface illumination. The Z_1 is generally considered the compensation depth, that depth where light is sufficient for photosynthesis to exceed respiration; the average Z_1 has been extrapolated in this analysis and therefore, in most cases, lies at a "depth" greater than the actual station depth of 18 M. The Z_{10} has been suggested to be that depth at which attached algae, such as Macrocystis, have adequate light to grow, compensate for normal

capacity is presently being expanded by nearly 40 MGD to a total of 150 MGD, further reducing discharge from JWPCP. OCSD is scheduled to bring 75 MGD of secondary treatment on line in February 1983 in addition to their present 50 MGD. The City of San Diego plans to increase solids removal efficiency by 25 percent at their plant by addition of more sedimentation tanks and increased chemical addition.

TABLE III

LACSD MASS EMISSION RATES (MER)
UNDER VARIOUS TREATMENT LEVELS

TREATMENT LEVEL	S.S. REMOVAL (%)	COPPER (Kg/day)	TICH[a] (Kg/day)
Advanced Primary, Existing[b] Sludge Dewatering (1977)	55	620	4.71
Advanced Primary, Improved Sludge Dewatering	78	183	3.68
Partial Secondary (200 MGD)	84	148	1.98
Full Secondary	96	109	1.13

[a] TICH = total identifiable chlorinated hydrocarbons, and is predominantly forms of DDT and PCB.

[b] Return of centrate solids to effluent from existing dewatering facilities accounts for approximately half of effluent S.S.

Table III provides examples of four different removal efficiencies that were projected for one facility with the corresponding treatment levels. The examples utilize projections for suspended solids (SS), copper and DDT from LACSD's 1979 301(h) application and 1981 annual report. The table illustrates several effects. Removal of suspended solids is most markedly improved by application of advanced primary treatment, which includes chemical addition, plus improved sludge dewatering to reduce the large contribution of solids from the sludge treatment sidestream. Many trace constituents are associated with the suspended solids and are removed with the solids. Further removal of trace constituents is assumed here as a result of changes in industrial waste source control. Secondary treatment will provide some additional solids removal, but its major effect will be in removal of degradeable organics.

As we have described the present waste discharges into the Southern California Bight we now present LACSD monitoring data that suggest some relationships of a discharge to the rocky subtidal zone. Central to the theme of this symposium is the question: are there any indications that present discharges affect inshore communities and, if so, what are the possible mechanisms involved?

It is well established that wastewater disposal in Southern California causes the alteration of the physical and chemical environment at or near the outfall termini. Chief among these alterations are (1) increased turbidity resulting from suspended particulates in the wastewater plume at depth, and in some cases, additional particulates from locally enhanced productivity due to the input of nutrients, especially ammonia, to nitrogen limited phytoplankton; (2) substrate alteration due to the accumulation of organic particulates and; (3) introduction of potentially toxic substances to the water and sediments. It is also well documented that the biological communities at these depths respond to these alterations in characteristic ways reflected, for instance, in patterns of distribution and abundance of benthic infauna. These physical/chemical alterations of habitat and their biological consequences are dependent upon the level and efficiency of treatment, effluent volume, influent character (i.e., relative contribution of industrial or domestic sources), and the nature of the receiving water.

In those cases where the discharge point is offshore of rocky subtidal habitats, such as Palos Verdes and Point Loma, is there any indication that similar physical/chemical alterations take place in the inshore environment?

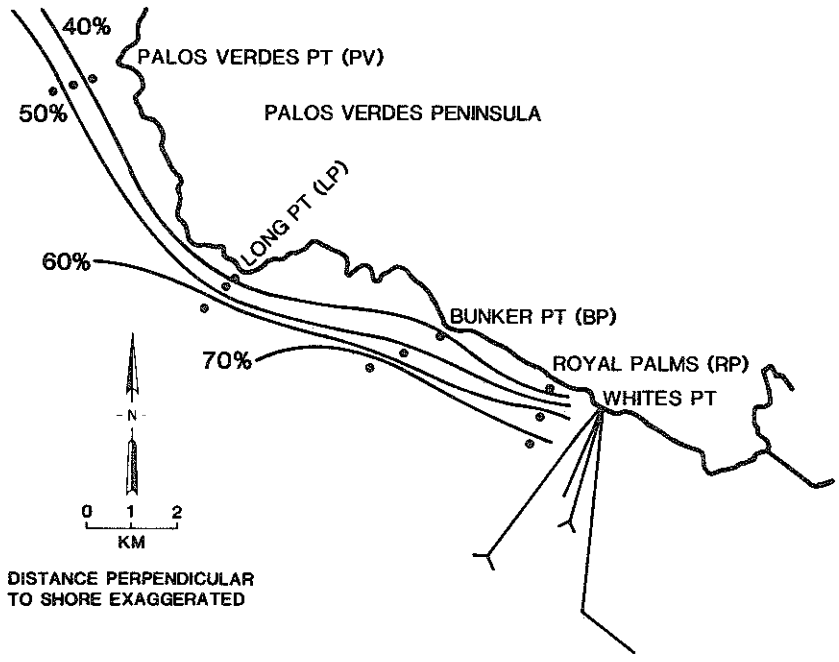
The Los Angeles County Sanitation Districts conduct field studies to monitor the effects of treated effluent, from the Joint Water Pollution Control Plant, discharged off Whites Point. As described earlier, the outfalls

grazing pressure, and to complete its reproductive cycle (Peterson 1974). These data suggest two points: 1) light energy attenuation is apparently uniform across the nearshore shelf at least down to the Z_{10}, which generally lies between 7 and 10 M; and 2) the pattern of increasing light energy attenuation with proximity to the outfalls, evident in the Z_1 profile, is confined to the deeper water column, probably below the 10 M depth.

Is there evidence that the wastewater discharge accounts for the observed reduction in light penetrance? The prevailing subthermocline currents move in an up-coast direction, subjecting all stations west of the outfalls to episodic down-current conditions. Stations located to the east of the outfalls may also be considered potentially downstream in that prevailing surface currents travel in easterly directions. Routine shore and nearshore bacteriological sampling clearly demonstrates that the wastewater field can be driven inshore east or west of the outfalls by currents at Palos Verdes. This does not eliminate the possibility of limited turbidity effects from Los Angeles Harbor waters on the Point Fermin area (Station L7). Data is not available at this time to determine the extent of harbor impacts. The presence of suspended particulates from the LACSD wastewater field would cause increased absorption and scattering of light in the nearshore waters. While this is certainly a cause of some light reduction, the light energy data suggest that the mechanisms interfering with light penetrance are most active in the lower water column. Subsurface movement of the field inshore, driven by seasonal upwelling, may account for some of this turbidity. However, we believe that resuspension of accumulated particulates in the form of fine flocculent material is the dominant cause of increased light extinction in the near-bottom water.

Fine organic flocs are common to rocky subtidal environments, particularly in areas of high productivity where they can accumulate on the bottom. A striking characteristic of the environment along the Palos Verdes Peninsula is the abundance and distribution of floc relative to the outfall termini. The floc burden on hard substrates is heaviest nearest the outfalls and decreases in thickness with increasing distance both longshore and inshore from that point. This distribution was first noted in 1969 (Grigg and Kiwala 1970) and has been a consistent pattern in subsequent surveys in 1977 (Grigg 1978) and those of LACSD since the early 1970s (LACSD 1981). The relationship of this flocculent material to wastewater has been demonstrated in work at UCLA (Sweeney and Kaplan 1980). In 1976, nitrogen isotope ratios of samples of flocculent material from the 12 survey stations were determined. Previous work had found this ratio to be an "effective tracer of sewage discharge" for samples taken in deeper water on the San Pedro Shelf (Sweeney, et. al. 1980). Results are presented in Figure V as the percentage of organic nitrogen of sewage origin in floc

FIGURE V
PERCENTAGE ORGANIC NITROGEN OF SEWAGE ORIGIN
IN FLOC SAMPLES FROM THE ROCKY SUBTIDAL
OFF PALOS VERDES (DATA FROM SWEENY & KAPLAN 1980)



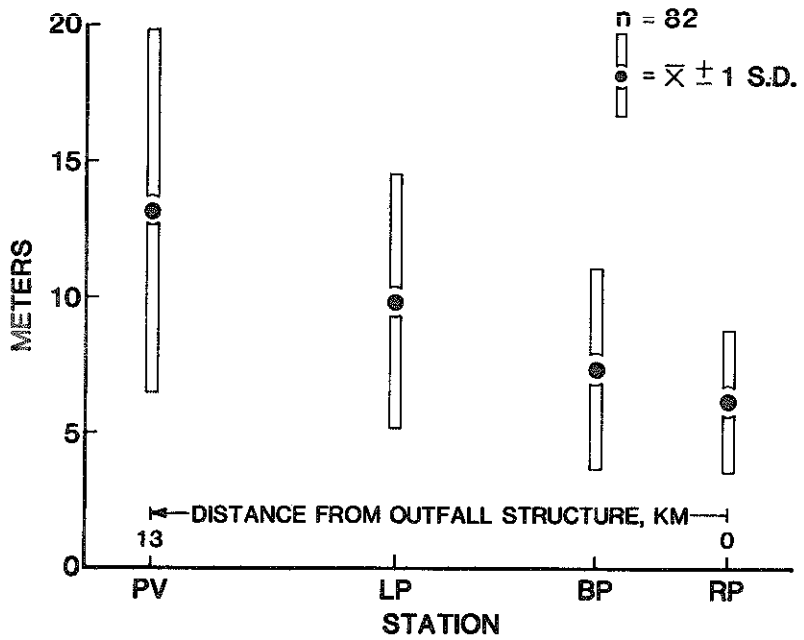
samples. The distribution pattern is virtually identical to that of visual estimates of floc abundance.

Another vector of impact, and one that also labels the flocculent material as to its possible origin, is elevated concentrations of heavy metals and chlorinated hydrocarbons in sediments and floc from the rocky subtidal. In 1978, at stations closely equivalent to the LACSD survey stations, sediments and floc were collected and analyzed for a variety of heavy metals, total DDT and PCB (Grigg 1978). The distribution of these contaminants in the sediments was clearly related to distance from the Whites Point outfalls. Concentrations decreased with increasing distance longshore from the outfalls. Maximum values at Palos Verdes Point, 13 km upcoast, were generally an order of magnitude lower than those found within 0.2 km of the outfalls. However, concentrations at Palos Verdes Point were significantly higher for most substances than found at the control site selected for this study off La Jolla. Concentrations in floc samples tended to be 2 to 3 times those found in the sediment.

Evidence that these flocs are resuspended, resulting in a pattern of increasing near-bottom water turbidity, is provided by horizontal Secchi disc measurements taken during biological surveys over the past several years (Figure VI). These data show a significant trend ($p<.001$) of increasing turbidity two to three meters above the bottom with increasing proximity to the outfalls. These data support the hypothesis that continual disturbance of the greater accumulation of floc at stations near the outfalls results in increased water column turbidity and thus increased light energy attenuation near the bottom.

What are the effects of these alterations on the attendant biotic communities? The first organism to consider is the giant kelp, *Macrocystis pyrifera*, which historically dominated the rocky subtidal habitat. During the

FIGURE VI
MEAN HORIZONTAL SECCHI DISC MEASUREMENTS
ALONG 18 METER DEPTH CONTOUR

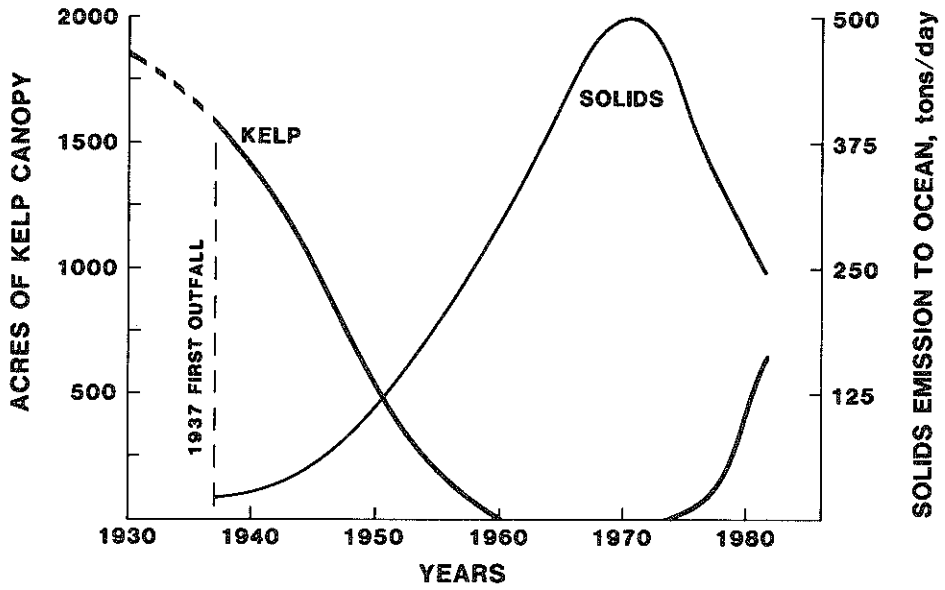


Distance that Secchi disk held by diver 2 to 3 M above bottom is visable in horizontal plane. Means by station of log transformed data significantly different (one-way ANOVA $p<.001$). Results of SNK a posteriori test: PV>LP>BP = RP ($\alpha<.05$).

first three decades of this century, canopy forming kelp beds covered up to 7.3 Km^2 of the nearshore waters along the Palos Verdes Peninsula. In 1937, LACSD began discharging treated wastewater off Whites Point. By 1945, areal coverage of kelp canopy had fallen to 4.0 Km^2 and continued to decrease until kelp beds virtually disappeared in 1958 as shown in Figure VII. In 1967, restoration efforts were initiated by the California Institute of Technology to be followed in 1971 by the California Department of Fish and Game. Initial attempts met with little success until 1974 when a small stand of kelp grew in Abalone Cove from spores produced by mature, transplanted plants. Since that time kelp beds have reappeared along most of the peninsula. Coverage reached 2.9 Km^2 in 1982.

The decline and ultimate disappearance of Macrocystis from the Palos Verdes Peninsula was caused by a wide range of factors both natural and anthropogenic. The coincidence of kelp bed decline and increasing discharge of wastewater followed by reappearance of kelp with the concurrent decrease in MER of suspended solids (see Figure VII) leads to the presumption that this was an important causative agent (Wilson et. al. 1980, Wilson, 1982). The data on physical/chemical alterations caused by the present discharge are supportive of such a presumption. Previous discharge, through smaller and shallower outfalls until 1954, provided an even more direct impact on sedimentation and turbidity in the kelp beds (Institute of Marine Resources 1954).

FIGURE VII
MAXIMAL CANOPY OF GIANT KELP BEDS OFF PALOS VERDES PENINSULA AND MER SUSPENDED SOLIDS FROM JWPCP



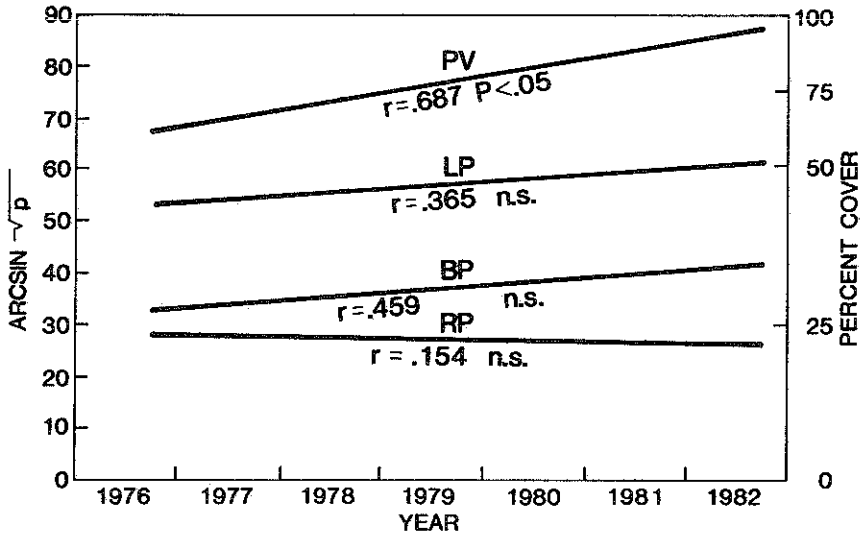
Just as in the past, a complex suite of variables determines the present distribution of Macrocystis. In addition to naturally occurring variation in oceanographic conditions, there are anthropogenic factors other than wastewater affecting kelp beds. These include activities associated with the restoration

efforts themselves, such as transplantation of plants and urchin control, as well as the development of a commercial fishery for the red urchins, Strongylocentrotus franciscanus (a major grazer on kelp), harvesting of competitive algae, and distortion of more natural relationships due to selective fishing pressure on competitors and predators of urchins. In addition, Macrocystis still faces competition from other algae that have established themselves in its absence. The contribution of many of these factors cannot be quantified; however, their presence confounds efforts at relating kelp distribution and abundance to the present discharge. The effects of these factors are generally restricted to inshore of the 12 M depth contour. For instance, there have been no attempts at kelp restoration at greater depth nor do sufficient numbers of urchins or algae occur offshore to support commercial harvest. Therefore, trends in the deeper water communities (18 M) discussed next are more easily related to discharge induced alterations of the habitat.

Results of rocky subtidal surveys conducted over the past several years have demonstrated clear trends in community structure that closely follow the gradients of physical/chemical alteration described above. Surveys are conducted at the 12 sites evenly distributed in the 6, 12, and 18 M depths as shown in Figure III. At each station permanently fixed 20 M band transects are maintained and surveyed every six months. The following comments are indicative of the results obtained during the course of these studies.

The increased water column turbidity and shoreward compression of the Z_1 light zone would be expected to result in decreases in algal abundance with increasing proximity to the outfall termini. Figure VIII shows the results of regression analysis of mean percent coverage of algae along the 18 M contour against time. Two patterns, one spatial and one temporal, are revealed by this

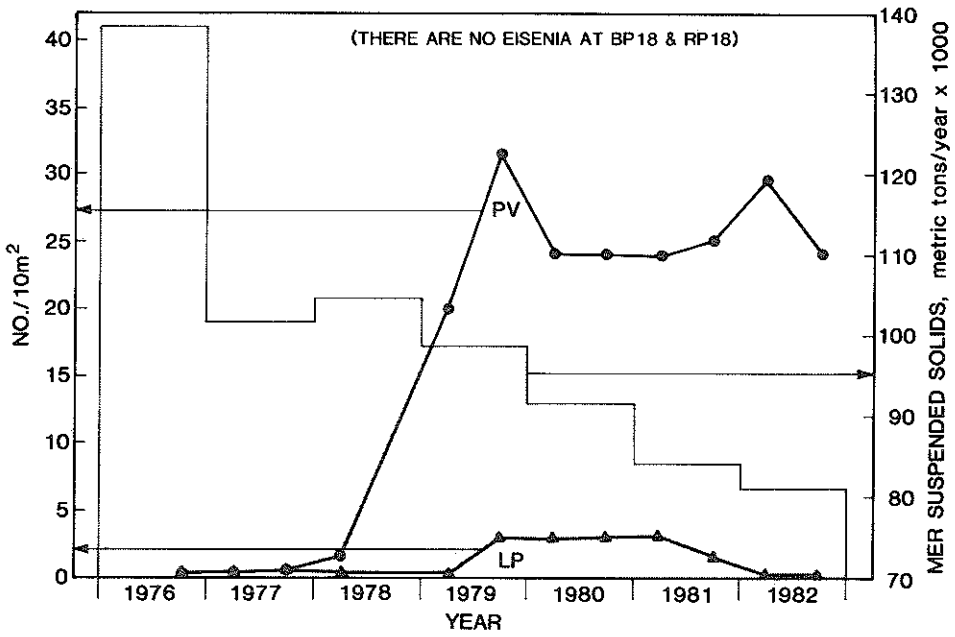
FIGURE VIII
SPATIAL AND TEMPORAL TRENDS IN PERCENT ALGAL COVERAGE ALONG THE 18 METER CONTOUR BY STATION LOCATION (n = 12)



analysis. Spatially there is a strong gradient of decreasing coverage with increasing proximity to the outfall. The dominant algae at all sites are crustose corallines with the contribution of other umbraphilic algae (such as Rhodymenia) increasing with distance from the outfall. At this depth, brown algal species do not become important contributors to abundance until Palos Verdes Point, some 13 Km upcoast from the discharge point. It appears that algal abundance is being depressed as a consequence of increased water column turbidity and light energy attenuation resulting from wastewater discharge. The coating of hard substrate by outfall related floc and associated elevated toxicant levels may also play a role in limiting algal abundance and diversity. In areas of most intense stress (along the 18 M contour within 2 Km of the outfall) the combination of increased turbidity and floc burden appear to prevent the maintenance of even the encrusting coralline algae cover. The dominant algae at this distance are small polysiphonious forms.

If the relationship between wastewater discharge and algal community structure suggested above is causal, one would expect that increases in treatment efficiency would lead to concomitant inceases in algal abundance over time within the rocky subtidal region starting at the point most distant from the outfall. Such an increase is in fact evident in Figure VIII at Palos Verdes Point ($p < .05$). This trend is not evident at stations within 7 Km of the outfall. The increase at Palos Verdes Point is due in part to the establishment of the laminarian, Eisenia arborea (Figure IX). This alga is known to have been absent from this station and area since 1970 when LACSD's qualitative diving surveys began. Eisenia established a healthy stand of $>2/M^2$ since its first appearance in early 1978. Eisenia occurred temporarily at the Long Point Station (within 7 Km of outfall) in 1979-1981, but has since disappeared. This alga has not been observed nearer the outfalls at this depth.

FIGURE IX
Eisenia arborea ABUNDANCE ALONG THE 18 METER DEPTH CONTOUR
AND MASS EMISSION RATE OF SUSPENDED SOLIDS
1976 THROUGH 1982



Much work remains to be done on the relationship of wastewater to kelp bed communities. The relationships suggested above are primarily based upon corre-

lation of events, not demonstration of cause:effect. Particularly needed is quantification of temporal trends in physical/chemical alteration of the habitat that can provide the link between changes in effluent characteristics and changing community structure. Control sites for both the physical/chemical and biological surveys would add greatly to our ability to sort background variation from wastewater induced alterations. Unfortunately, it is unlikely that such a control site representing a completely uninfluenced rocky subtidal community can be found off Palos Verdes because of the extent of trace constituent contamination of sediments in the area.

Despite these shortcomings, results of LACSD monitoring surveys, the studies of others (IMR 1954, SWRCB 1964, Grigg and Kiwala 1970, Grigg 1978, Wilson et. al. 1980), as well as the history of changing wastewater characteristics and the coincident decline and reestablishment of Macrocystis along the Palos Verdes Peninsula, demonstrate a strong connection between wastewater disposal practices and kelp bed community health. While clearly not the only variable determining the past or present distribution of Macrocystis along the peninsula, we believe it is the dominant factor presently acting in the deeper water region (18M) within the historical kelp habitat. In this region wastewater induced alterations of the habitat prevent the reestablishment of Macrocystis and the development of "normal" rocky subtidal communities. Chief among these alterations are decreased light energy penetrance due to suspended particulate and resuspension of accumulated flocculents; substrate burial; and elevated trace contaminant levels. Gradients in the highly altered community structure with respect to distance away from the outfalls are evident at this depth. The algal data presented above is typical of these gradients. Sessile and motile animal components of the communities are also affected. The communities at this depth within 7 Km of the outfalls have remained fairly stable during the course of our

monitoring studies (1976 to present), despite reductions in the wastewater characteristics most likely to cause the observed alterations. However, it appears that at Palos Verdes Point, 13 Km upcoast from the outfalls, conditions have improved sufficiently to allow increased algal abundance and the development of laminarian algae (Eisenia) having, presumably, growth requirements similar to Macrocystis. These increases and the coincident reestablishment and rapid spread of Macrocystis in shallower depths since the mid-1970s after several years of unsuccessful restoration effort encourage us to believe that improvements in treatment efficiency and industrial waste source control during the past decade have lessened the extent of wastewater impacts on rocky subtidal communities including kelp beds. We anticipate that the shoreward compression of habitat suitable for the establishment of kelp caused by the present discharge will be reduced by still further reductions in MERs following further upgrading of LACSD's industrial waste source control and the operation of the secondary treatment facility now under construction at JWPCP.

MONITORING PRESENTLY CONDUCTED AT POINT LOMA AND PALOS VERDES

Susan C. Hamilton*

This paper reports on monitoring programs presently being conducted in two kelp beds in southern California, at Point Loma, and at Palos Verdes. These kelp communities are of interest to this symposium because they are located near major sewage outfalls and they both at different times have been major stands of kelp. Both are well used resources. They are close to large ports which can support commercial interests such as kelp harvesting and fisheries. Additionally, their proximity to urban centers makes them popular for recreational activities such as diving and sportfishing.

Monitoring measurements are here defined as those carried out to comply with legal requirements, or as a public service, or in support of commercial interests. Not included are those normally considered to be research, such as studies done under the auspices of an academic institution.

Two types of monitoring somewhat different in perspective are considered: monitoring that emphasizes waste disposal, and monitoring that emphasizes the kelp community. Measurements made by waste dischargers are legally required by regulatory agencies such as the Regional Water Quality Control Boards of the State of California and the United States Environmental Protection Agency. At Point Loma, the City of San Diego Water Utilities Department carries out an ocean monitoring program mandated by the

* City of San Diego

San Diego Regional Water Quality Control Board. At Palos Verdes, the Sanitation Districts of Los Angeles County conduct studies mandated by the Los Angeles Regional Water Quality Control Board. These regional boards are autonomous; as a result, the requirements differ.

Measurements made by agencies focusing on the kelp community are generally not legally required. Measurements are taken in the public interest or for commercial interests, to protect a valuable resource. The Department of Fish and Game in Los Angeles has long been involved in kelp recruitment and restoration studies at Palos Verdes. Scientists from Kelco, the kelp harvesting company based in San Diego, study the Point Loma kelp community to determine causes of change in canopy coverage and potential sites for seeding and expanding the existing stand.

These two different perspectives, wastes and kelp, naturally lead to different programs. However, data from both shed light on the effects of waste disposal on kelp communities. Scientists from all of the concerned agencies already work together to some extent, and hopefully will continue to do so with future programs.

MONITORING PROGRAMS

Ocean monitoring programs for waste dischargers are detailed in NPDES (National Pollutant Discharge Elimination System) Permits issued by the Regional Water Quality Control Boards. These permits specify limitations on various constitutents of raw and treated sewage as well as those that apply to the receiving waters at the end of the pipe.

Programs designed to determine the fate of wastes in the marine environment center around the outfall diffusers, where the effluent mixes with the seawater. In the case of San Diego, for example, the main pipe,

which has no discharge ports, extends through the kelp bed to a distance of about 3.5 km offshore. At that point, two smaller diffuser pipes, each about 0.4 km long, extend seaward to a depth of about 67 m, where the effluent discharges through a total of 52 ports.
The ports allow sewage to mix with the seawater, and be diluted, and transported away. The question is, how quickly does this dilution take place, and where are the constitutents finally desposited?

CITY OF SAN DIEGO

Station locations for the City of San Diego program are shown on Figure 1. This in-house program began in 1962, the year before the outfall went into operation. Prior to and during construction, beginning in 1956, baseline studies were carried out by scientists from Allan Hancock Foundation and San Diego Marine Consultants.

Ocean monitoring conducted by the City consists of several elements which are listed in Table 1. Water column measurements taken once a month document trends in coliform levels, water clarity, and dissolved oxygen at ten stations close to the outfall and two control stations. Eight stations are located in or near the kelp bed (A-1, A-6, A-7, C-4, C-5, C-6, C-7 and C-8) at depths of 10 and 18 meters. Only a small part of the total program is actually in the kelp bed. This is not a kelp bed monitoring program *per se*, but rather includes some stations in the sample grid that are incidentally located in the kelp bed. The focus is on the waste hence most sampling stations are at diffuser depths rather than kelp bed depths.

Aerial surveys of the kelp bed are done annually during the last quarter of each year by Wheeler North. The results of surveys for the

PARAMETER	FREQUENCY	NO. STATIONS	NO. REPLICATES OR DEPTHS
Water Column			
Temperature	Monthly	12 total/8 in kelp	2
Chloride	Monthly	7 total/3 in kelp	2
Dissolved Oxygen	Monthly	7 total/3 in kelp	2
Transmissivity	Monthly	7 total/3 in kelp	5
Secchi Disc	Monthly	12 total/8 in kelp	
Coliforms	Monthly	12 total/8 in kelp	2
Aerial Survey of Kelp Bed	Annually	Point Loma	
Sediments: Biota			
Species, Abundance, Biomass	Quarterly	15	4
Sediments: Chemical/Physical			
Biochemical Oxygen Demand	Quarterly	15	1
Chemical Oxygen Demand	Quarterly	15	1
Grain Size	Quarterly	15	1
Total Chlorinated Hydrocarbons	Quarterly	15	1
Sulfides	Quarterly	15	1
Phenolic Compounds	Semiannually	15	2
Cyanide	Semiannually	15	2
Radioactivity	Semiannually	15	2
Metals (As, Ag, Pb, Hg, Ni, Cd, Cu, Cr, Zn)	Semiannually	15	2
Trawls: Demersal Fish, Epibenthos			
Species, Abundance, Biomass	Semiannualy	7	1

Table 1. City of San Diego Ocean Monitoring Program

years 1975 through 1982 were on display at this symposium.

Studies of soft bottom communities are done quarterly to determine temporal and spatial changes related to the outfall. Four replicate Van Veen grab samples are taken at fifteen stations at depths of 45 and 60m. The biota retained on a one millimeter mesh sieve are preserved for identification, enumeration, and biomass determination.

Chemical and physical measurements of sediments are carried out at the same stations, some twice a year and some quarterly, as indicated in Table 1. These measurements include biochemical oxygen demand, chemical oxygen demand, grain size, total chlorinated hydrocarbons, sulfides, phenolic compounds, cyanide, radioactivity, and trace metals (Ag, As, Pb, Hg, Ni, Cd, Cu, Cr, Zn).

Otter trawls are taken in January and July in conjunction with the Southern California Coastal Water Research Project (SCCWRP). These are not required in the current NPDES Permit. Demersal fish and epibenthic invertebrates are identified, enumerated, and weighed.

All measurements are reported to the RWQCB and are available to any interested person from them or from the city's laboratory at Point Loma.

LOS ANGELES COUNTY

The Sanitation Districts of Los Angeles County, the largest of the dischargers in southern California, have an extensive ocean monitoring program as well. The elements of the current program, including those not required by the RWQCB, are listed in Table 2. Nearshore subtidal studies are carried out in the area of the Palos Verdes kelp bed. These are the most intensive monitoring measurements made by any waste discharger and certainly have produced much data of value to those studying the recovery of that kelp bed. These surveys, performed twice each year, include discrete counts, percent coverage, and numerical estimates of fish species present.

Discrete counts are made of ten 1.0 m^2 grids along a 20 m transect (every other meter). Permanent markers have been established at twelve stations at depths of 6, 12 and 18 m, for these studies. All discrete non-cryptic organisms, whether sessile or motile, are counted.

PARAMETER	FREQUENCY	NO. STATIONS	NO. REPLICATES OR DEPTHS
Water Column			
Temperature	Monthly	28 total/1 in kelp	profile
Dissolved Oxygen	Monthly	28 total/1 in kelp	6-8
Irradiance	Monthly	7 total/6 in kelp	profile
Transmissivity	Monthly	28 total/1 in kelp	8-10
Secchi and Color	Monthly	40 total/10 in kelp	---
Coliforms	Weekly	5 total/4 in kelp	1
Surface Floatables	Semiannually	2	1
Buoy System (Currents, Temp.)	Continuous	3	3,10-12
Sediments: Biota	Every 5 yrs	44	1
Species, Abundance, Biomass	Semiannually	18	1
Sediments: Chemical/Physical			
Metals, pesticides	Every 5 yrs	44	1
pH, Eh, Fs'	Semiannually	18	1
Organic Nitrogen	Semiannually	18	1
Sulfide (qualitative)	Semiannually	18	1
Sediment Characterization	Semiannually	18	1
Trawls: Demersal Fish, Epibenthos			
Species, Abundance, Biomass	Quarterly	12	1
Nearshore Subtidal Environment			
Substrate composition and relief	Semiannually	12	transect
Bottom transects, discrete counts	Semiannually	12	transect
Bottom transects, % coverage	Semiannually	12	transect
Fish surveys	Semiannually	12	600 m² area
Qualitative surveys	Annually	4	transect
Temperature	Semiannually	12	1
Horizontal secchi	Semiannually	12	1
Indicator species survey	Semiannually	12	transect

Table 2. Ocean Monitoring Program, Sanitation Districts of Los Angeles County.

Within each grid, a 0.25m² area is also examined for percent coverage by non-cryptic plants and animals. Once a year these areas are also photographed and re-examined in the laboratory.

Fish surveys are carried out by divers swimming over an area of about 600 m². Fish are identified to species if possible, and assigned a numerical range or estimate of numbers present.

In addition to these bottom surveys, divers also note substrate composition (percent sand, cobble, or rock), maximum topographic relief, and bottom temperature. A secchi disc, taken horizontally along the bottom with two divers, provides an estimate of visibility.

Once a year a qualitative survey at the 24 m contour is also performed by divers.

DEPARTMENT OF FISH AND GAME

The Department of Fish and Game located in Los Angeles also takes an active interest in the size and condition of the Palos Verdes kelp bed. Much of the work done by this agency is research on kelp restoration, but two elements are monitoring functions. Quarterly aerial infrared photo surveys are carried out to determine the extent of canopy coverage. In addition, routine ecological surveys have been carried out quarterly since 1975. Five stations are monitored for changes in the kelp and associated organisms by divers at established band transects, 30m X 2m. These stations are located at Abalone Cove, Lunada Bay, and Point Vicente.

The monitoring program of the DFG is illustrated in Table 3.

PARAMETER	FREQUENCY	NO. STATIONS
Dive Surveys		
Bottom transects	Quarterly	5
Qualitative observations	Quarterly	5
Aerial Survey of Kelp Bed	Quarterly	Palos Verdes

Table 3. Kelp Community Monitoring Program, Dept. of Fish & Game, Los Angeles

KELCO

Since 1929, when harvesting began, Kelco has been interested in changes in the kelp community that would affect the size of the kelp harvest. Staff biologists have long worked with other scientists on urchin control, kelp plant recruitment, and kelp bed restoration. Until recently these studies were geared entirely toward research and development. In 1979 monitoring measurements in support of these studies began, primarily, in the water column. These have expanded since then to the current levels listed in Table 4.

Continuous recorders at two stations document surface temperature and irradiance in the kelp bed. Additionally, temperature profiles are taken at

PARAMETER	FREQUENCY	NO. STATIONS	NO. REPLICATES OR DEPTHS
Water Column			
Bathythermograph	Weekly	19	profile
Continuous temperature	Continuous	1	1
Irradiance	Weekly	7	profile
Continuous irradiance	Continuous	1	1
Current meters	Weekly	2	2
Drogues	Weekly	2	2
Dive Surveys			
Random samples, 10 m^2	Annually	60	6
Macrocystis			
Urchins			
Competitive seaweeds			
Diver Observations	Daily to Weekly	Random	various
Temperature			
Visibility estimate			
Depth of thermocline			

Table 4. Kelp Community Monitoring Program, KELCO

nineteen stations and irradiance profiles at seven. Drogues and current meters are deployed weekly at two stations at two depths.

Annual bottom studies at sixty stations began in 1981. At each site, six $10m^2$ grids are set out randomly. Macrocystis plants are surveyed for abundance, age, condition, and degree of new recruitment. Urchins are counted and recruitment noted. Divers also make observations of the presence of seaweeds that are competitive with Macrocystis. These stations are located at depths of 9, 12, 15, and 18 meters.

Kelco divers are in the kelp bed weekly and often daily, carrying out various projects. Whenever divers are in the water they record surface and subthermocline temperatures, estimate visibility, and estimate the depth of the thermocline. Routine qualitative observations are made at the same time.

SUMMARY

Monitoring presently carried out at Point Loma and Palos Verdes is summarized in Table 5. These programs have varied over the years for reasons ranging from scientific to legal to budgetary.

Waste dischargers are currently in the midst of the decision-making process with the EPA and the RWQCB's to determine which of these measurements are still appropriate, which are not meaningful, and what other kinds of monitoring measurements should be considered.

This symposium was designed to attract scientists and managers from the academic community, industry, waste dischargers, and regulatory agencies. I hope that this forum will be used by the participants to learn about the science, politics and financial considerations that must be dealt with when working out meaningful studies of the ocean in terms

	CITY OF SAN DIEGO WATER UTILITIES	SANITATION DIST. OF LOS ANGELES COUNTY	DEPT. OF FISH AND GAME-LOS ANGELES	KELCO
EMPHASIS	WASTE DISPOSAL	WASTE DISPOSAL	KELP COMMUNITY	KELP COMMUNITY
YEAR STARTED	1962	1958	1975	1979
PARAMETERS				
Water Column				
Temperature	X	X		X
Salinity/Conductivity	X			
Dissolved Oxygen	X	X		
Transmissivity	X	X		
Irradiance		X		X
Secchi Disc	X	X		
Coliforms	X	X		
Current metering		X		
Drogue studies				X
Aerial Survey of Kelp Bed	X		X	
Dive Surveys				
Bottom transects		X	X	X
Fish surveys				
Est. of visibility		X		X
Temperature		X		X
Qualitative survey		X	X	X

Table 5. Existing Monitoring Programs at Point Loma and Palos Verdes. This table shows only monitoring carried out in kelp bed areas.

of wastes or the kelp community. I also hope that it will foster the cooperation among groups that is essential to address unanswered questions regarding the effects of waste disposal on kelp communities.

THE EFFECTS OF SUSPENDED SOLIDS AND THERMAL DISCHARGES ON KELP

Thomas A. Dean* and Lawrence E. Deysher*

ABSTRACT

Over the past several years we have been conducting a study to determine the effects of the San Onofre Nuclear Generating Station on the giant kelp, Macrocystis. As part of this effort, we have sought to establish quantitative relationships between the production of Macrocystis sporophytes from the gametophyte generation and various environmental variables. These relationships will be used to link possible changes in kelp recruitment with changes in environmental factors that may be brought about by power plant operations.

We determined the effect of physical/chemical variables on sporophyte production by inoculating artificial substrates with known densities of zoospores in the laboratory, outplanting these substrates with known densities of gametophytes to field stations, and observing the densities of sporophytes produced on these substrates after 6 weeks. We concurrently measured temperature, irradiance, sedimentation rate, and nitrogen availability over this outplant period.

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Kelp Ecology Project

Multiple regression analysis indicated that temperature, sedimentation rate, and irradiance (in order of importance) each explained a significant portion of the variance in the density of sporophytes produced. There were no sporophytes produced when temperatures were above 17.6°C or irradiances were below 0.3 $E/m^2/d$. Moderate sporophyte recruitment occurred only at temperatures below 16.3°C and irradiances above 0.4 $E/m^2/d$. We also noted an interactive effect of temperature and irradiance. Irradiances of approximately 1 $E/m^2/d$ were required for moderate sporophyte production as temperatures approached 16°C.

Biweekly bottom temperatures from the San Onfore Kelp bed were plotted against biweekly irradiance levels to determine the frequency of occurrence of conditions favorable for natural recruitment. These "recruitment windows" were relatively rare, and helped to explain the infrequent occurrences of natural recruitment. All natural recruitment events observed over a 4-year period at San Onofre could be traced to four 2-week periods when temperature and irradiance conditions were favorable. However, there were at least four other times when conditions were favorable, yet no recruitment was observed. This indicated that variables which were not measured in this study can also limit sporophyte production.

INTRODUCTION

For the past several years, we have been studying the effects of the San Onofre Nuclear Generating Station (SONGS) on the giant kelp, *Macrocystis pyrifera*. The power plant is located about 19 km north of Oceanside, California, about midway between Los Angeles and San Diego. San Onofre's Unit 1 reactor has been operating since 1968. It discharges heated effluent at a point about 1.5 km from the nearest kelp population (the San Onofre Kelp bed) and has no apparent effect on the bed. Construction began on 2 new reactors in 1973; Unit 2 had been opeating intermittently since January, 1982 and Unit 3 is scheduled to begin operation in 1983. Once through cooling water systems for each reactor will discharge about 830,000 gal/min of heated effluent through diffuser lines. The water will be discharged through 63 ports spaced at equal intervals along each 750 m - long diffuser pipe. At the closest point, the diffusers for Units 2 and 3 are approximately 200 m from the main body of the San Onofre Kelp bed.

Our primary emphasis has been on studying the San Onofre Kelp bed and the adjacent San Mateo and Barn Kelp beds to determine the possible effects of SONGS Units 2 and 3 when they become fully operational. We have undertaken 2 types of studies. The first is a monitoring program in which we will determine SONGS effects on various life stages of kelp by determining growth and mortality in each stage at representative impact and control locations, both before and after Units 2 and

3 begin operation. The second phase of our program is a study of the quantitative relationships between various life-history processes and environmental factors. Determining these relationships will allow us to link possible changes in kelp populations with changes in environmental factors that may result from the operation of SONGS. In this paper, we will discuss the results of one such mechanistic study on the relationships between sporophyte recruitment and various environmental parameters.

The life cycle of Macrocystis consists of an alternation between a microscopic gametophyte stage and a more conspicuous sporophyte. The large Macrocystis sporophytes, which form the distinct kelp canopy, produce microscopic zoospores in specialized tissues called sporophylls at the base of the plant. These zoospores are released into the sea, settle on the bottom, and develop into male and female gametophytes. Gametophytes produce spermatozoa and eggs (oogonia), fertilization ensues, and microscopic sporophytes are produced. (The processes of gametogenesis, fertilization, and zygote development are here collectively termed "sporophyte production"). Microscopic sporophytes eventually grow to adult size and complete the life cycle.

Large adult sporophytes are subject to mortality by storms, grazing by sea urchins, and exposure to exceptionally warm, nutrient-poor water (North 1971; Leighton 1971; Rosenthal, et al. 1974; Gerard 1976; Jackson 1977, Tegner and Dayton 1981). Replacement of these adult plants is dependent on

the recruitment of new sporophytes from the gametophyte generation. In many Southern California kelp beds, significant recruitment events (i.e., those that replace more than 10% of the average number of adults in a bed) occur on average every 2 to 4 years (Rosenthal *et al.*, Dayton pers. comm.; Dean unpublished data).

Recruitment success appears to depend in large part on whether there is successful production of microscopic sporophytes from gametophytes. The critical nature of this step in the life history stems from several observations. First, adult sporophytes produce large numbers of zoospores year round (Anderson and North 1967), and it is presumed that a large number of these zoospores settle and produce gametophytes, thereby producing a continual supply of gametophytes in the vicinity of adult plants. (Gametophytes, however, have never been observed on natural substrates because of their small size and cryptic nature.) Second, during recruitment episodes, extremely large numbers of small, blade-stage sporophytes (about 3 cm in height) are produced. Even though mortality rates for these small sporophytes are extremely high and extremely variable on a small spatial scale, there are generally a sufficient number of survivors in portions of the kelp bed to produce a significant number of new adults. Therefore, the replacement of adult sporophytes depends in large part on whether or not there is successful production of sporophytes from gametophytes.

Our specific goal was to determine quantitative relationships between *in situ* sporophyte production and

temperature, light (irradiance), sedimentation, and nirogen availability. We chose to examine the effects of these particular variables since previous studies have indicated their importance in controlling the process of sporophyte production in Macrocystis and closely related algae (Hsaio and Druehl, 1971; Lüning and Dring, 1975; Devinney and Volse, 1978; Lüning and Neushul, 1978; Neushul, 1978; Lüning, 1980). We were especially interested in observing sporophyte production under natural environmental conditions because the relative importance and possible interactive effects of temperature, irradiance, sedimentation, and nitrogen availability in controlling sporophyte production in situ had not been determined for Macrocystis.

In our studies, the role of sediments and irradiance have been of particular interest because these factors appear to be the most likely to be influenced by the operation of SONGS Units 2 and 3. Predictive models have indicated that SONGS may increase suspended sediment flux in the San Onofre Kelp bed (Reitzel, 1980). Sediments are not expected to accumulate on the bottom in the kelp bed because of the relatively high wave energy there. However, increased sediment flux may lead to a reduction in irradiance, and increased abrasion or short term burial of small microscopic life stages of kelp. The discharge of units 2 and 3 is not expected to have a significicant effect on temperatures in the kelp bed (Koh, et al., 1974). However, we have included temperature in our analysis because it is potentially important to natural recruitment episodes, and because it may have an

interactive effect with other variables such as irradiance. For example, gametogenesis in *Laminaria saccharina* has been shown to require higher dosages of blue light at higher temperatures (Lüning 1980).

METHODS

We determined the effect of physical/chemical variables on sporophyte production by inoculating artificial substrates with *Macrocystis* zoospores in the laboratory, outplanting these substrates with known densities of gametophytes to the field, observing the number of sporophytes produced on these substrates after a given period of time, and measuring the average irradiance, temperature, sedimentation rate, and nitrogen levels over the outplant period.

The outplant substrates consisted of plexiglass plates (30.5 X 10.2 X 0.6 cm) on which seven 10-cm lengths of 0.64 cm diameter nylon line were fastened by means of plastic tie-wraps. This permitted the simultaneous inoculation of a large number of sampling units which could be removed individually from the substrate for sampling.

Zoospores used in the inoculations were obtained from adult *Macrocystis pyrifera* in the San Onofre Kelp bed. Fertile sporophylls were placed in plastic buckets filled with seawater and immediately returned to the laboratory to avoid large changes in temperature over ambient. In the laboratory, the sporophylls were rinsed with filtered seawater, stored overnight in moist towelling at 15°C, and allowed to release zoospores in 1-qt

jars containing filtered seawater. The zoospore solution was diluted to produce an inoculation solution with a zoospore concentration of 1.0×10^5 spores/ml. Substrates were placed in Pyrex baking dishes containing 1.5 ℓ of the inoculation solution and placed in a constant temperature room at 15°C. After 24 hours, the substrates were removed from the inoculation medium and placed in filtered seawater. The following day, one rope was removed from each plate to determine if the inoculation was successful. The plates with remaining ropes were then transported to the field in black plexiglass boxes containing filtered seawater.

Divers using SCUBA took the plexiglass boxes into the water, removed the plates, and attached the plates to PVC racks anchored by steel weights (Figure 1). Each rack held 2 plates: one inoculated with gametophytes and the other an uninoculated control. The control plate was used to determine the number of sporophytes produced from natural zoospore settlement. Racks with inoculated and uninoculated substrates were positioned on the bottom, 2 m above the bottom, and (at one station) 4 and 6 m above the bottom.

A total of 30 different outplantings were conducted between November 1977 and January 1982. Six outplant sites were used in these experiments, three in San Onofre Kelp bed, two in San Mateo Kelp bed, and one in Barn Kelp (Figure 2). The number of stations used varied between outplants.

Substrates were left in the field for 6 weeks then collected and transported back to the laboratory in filtered

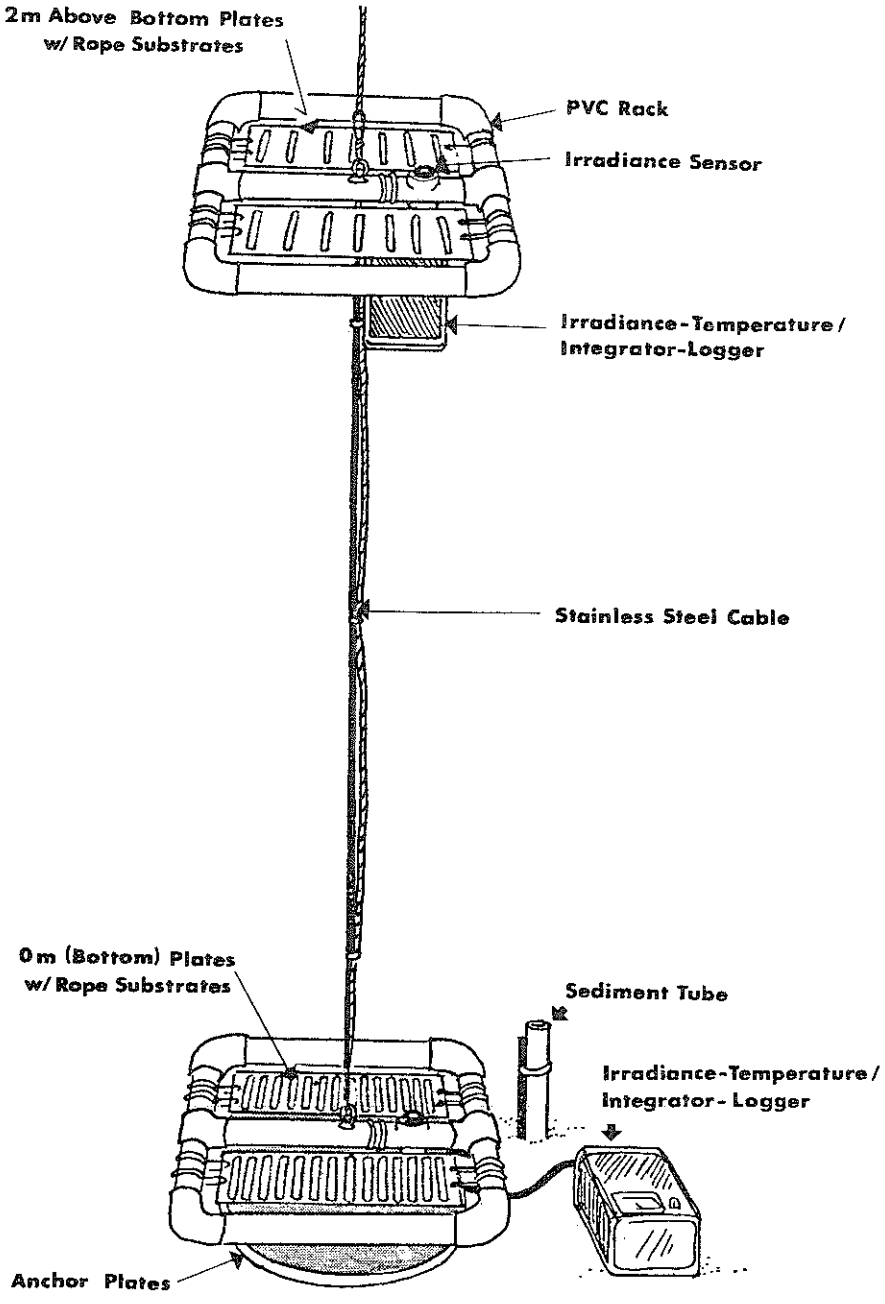

Figure 1. - A diagram of the outplant array showing racks which held outplant substrates on the bottom and 2 m above the bottom. Instruments used to measure irradiance, temperature, and sedimentation rate are also shown.

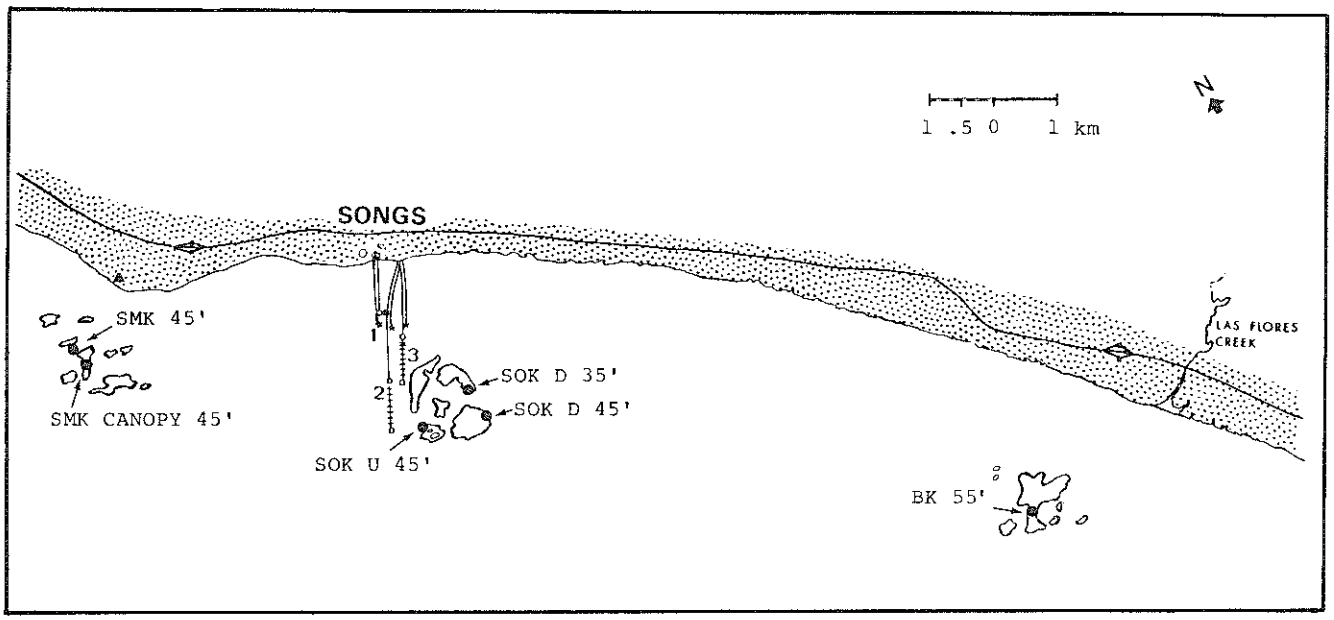

Figure 2. - Location of kelp beds, kelp stations, and San Onofre Nuclear Generating Station features. SMK = San Mateo Kelp, SOK = San Onofre Kelp, BK = Barn Kelp. Dots indicate positions of sampling locations (see text for details). SONGS' intakes are indicated with X's and discharges are indicated with O's. Units 1, 2 and 3 discharges are numbered. Hatch marks along the diffuser lines of Units 2 and 3 indicate areas over which water will be discharged.

seawater. In the lab, the lines were removed from the plexiglass plates and stored in the dark at 2°C until sampled. The lines were examined under a dissecting microscope and the number of sporophytes on each line was determined.

During the course of the outplant experiment we measured temperature, irradiance, sedimentation rate, and nitrogen availability at each station and at each outplant depth.

Temperature was measured using either a Ryan thermograph (Ryan Instruments, Kirkland, Wash.) or temperature recording devices designed by ECOsystems Management Assoc. (Solana Beach, Ca.). Irradiation (integrated photon flux density) was measured with LI-COR 192S flatplate cosine-corrected sensors attached to integrating counters (LI-COR Instruments, Lincoln, Neb.). These sensors measure light over the wave lengths of 400 to 700 nm. While gametogenesis is known to be a function of blue light (400 to 500 nm) (Lüning and Neushul 1978), we felt that a measure of the total photosynthetiacally active spectrum would provide a representative index of the irradiance neccessary for gametogenesis and sporophyte production. Sedimentation rate (vertical sediment flux) was determined by measuring the amount of sediment accumulating in 2.5 cm diameter X 30 cm long tubes over each week. Temperature sensors, irradiance sensors, and sediment traps were placed on, or directly adjacent to outplant racks and were positioned at the same height the above bottom as outplant substrates. Nitrogen availability was measured by obtaining water samples from locations near the outplant sites and at approximately the same depth as outplant substrates. The samples were analyzed for ammonium, nitrate, and nitrite. Values of total nitrogen (the sum of these 3 ions) were calculated. Nitrogen data were from samples analyzed by Southern California Edison, Marine Ecological Consultants, and ECOsystems Management Associates as part of other monitoring programs at San Onofre. A total of 2 to 6 nitrogen values were generally available for each 6-week outplant period.

RESULTS

To determine the relationship between various environmental variables and the numbers of sporophytes produced, we performed a regression analysis with the average density of sporophytes each location (station and depth) during each outplant period as the dependent variable, and the average irradiance, temperature, sedimentation, and nitrogen levels from corresponding places and times as the independent variables. Both dependent and independent variables were log transformed. The regression model used can be represented as:

$$D+1 = C \cdot T^{b_1} \cdot I^{b_2} \cdot S^{b_3} \cdot N^{b_4}$$

where D is the mean density of sporophytes produced and T, I, S, and N are corresponding values for mean temperature, irradiance, sedimentation, and nitrogen. We chose this model because it is flexible and was capable of representing a wide variety of curvilinear relationships of the type we expected based on previous laboratory work. Preliminary analysis indicated that this model was capable of explaining a higher proportion of the variance in sporophyte density than linear expressions or hybrids of linear and log transformed variables.

Temperature, irradiance, and sedimentation rate each explained a significant portion of the variance in the density of sporophytes produced (Table 1). Together, these factors explained 44% of the variance in sporophyte density. Determination of partial coefficients indicated that, once the variance accounted for by other independent variables was removed, temperature explained 25%, sedimentation 11%, and irradiance 10% of the

Table 1 Regression of log transformed physical/chemical variables on log transformed density of sporophytes produced from outplanted gametophytes. Observations from bottom and 2, 4 and 6 m above bottom depths are included.

PARAMETER	D.F.	ESTIMATION	DETERMINATION OF PARTIAL COEFFICIENT
Intercept	1	26.46**	
Temperature	1	-9.26**	0.25
Sedimentation	1	-0.37**	0.11
Irradiation	1	0.63**	0.10
Nitrogen	1	0.02	0.00
Model	4		$R^2 = 0.44$**
Error	97		$1 - R^2 = 0.56$

** = Significant at $P < 0.01$

variance in sporophyte density. Temperature was the most important factor, followed by sedimentation rate and irradiance. Temperature and sedimentation rates had negative regression coefficients while the coefficient for irradiance was positive. Thus, sporophyte densities were highest when temperatures were low, sedimentation rates were low, and irradiances were high.

Nitrogen was not a significant factor in our analyses, but this may have been partly a result of our relatively infrequent sampling of nitrogen. Nitrogen availability is known to change rapidly and our samples which were taken at one-week (or greater) intervals probably did not accurately reflect the amount of nitrogen available to developing gametophytes during the outplant period. Nitrogen and temperature were significantly correlated ($r = -0.52$, $P < 0.01$) and a portion of the variance in sporophyte density may have been wrongly ascribed to temperature instead of

nitrogen. Other experiments that we have conducted in which we have fertilized gametophytes with Osmocote fertilizer indicate that increasing nitrogen availability indeed increases sporophyte production. However, fertilizing to levels that were near the maximum nitrogen concentration observed on the bottom at San

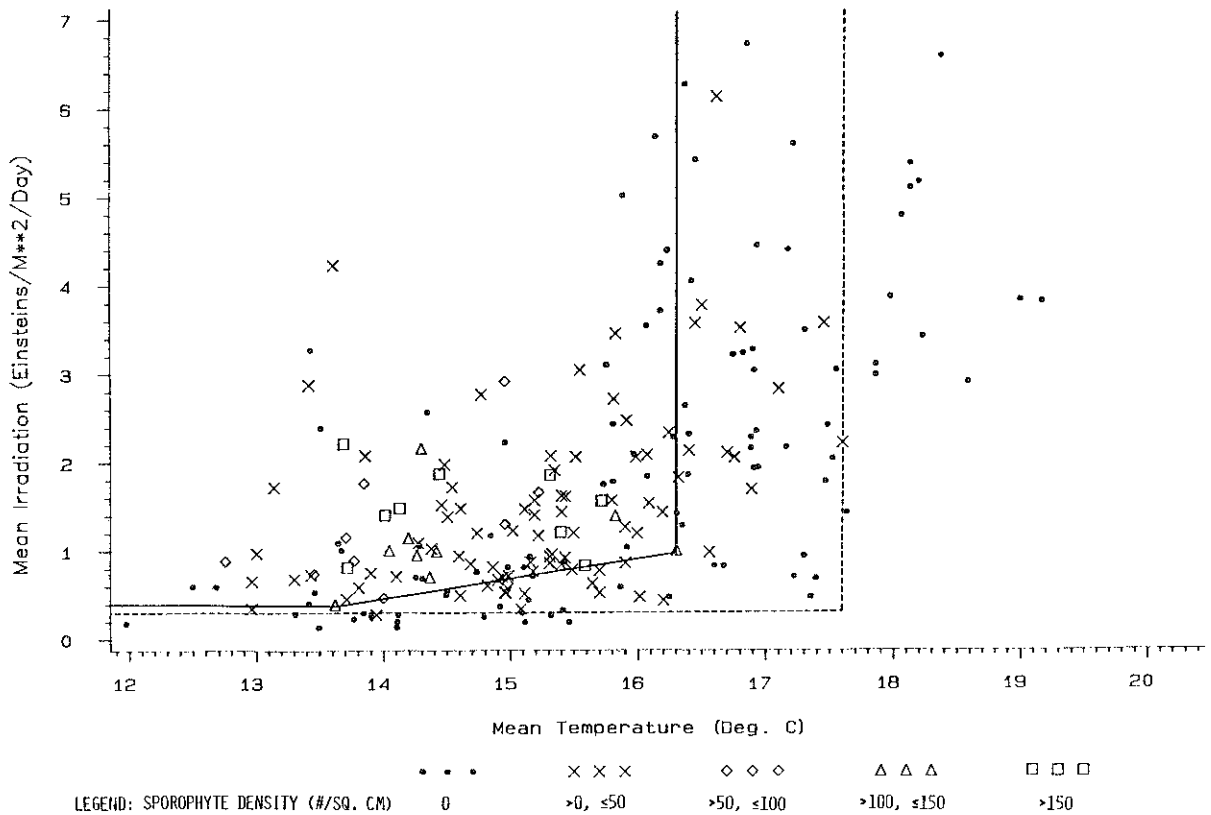

Figure 3. - Plot of mean densities of sporophytes produced from outplanted gametophytes vs mean temperature and irradiance values from the corresponding location and time. The dashed line represents the boundary of temperature and irradiance conditions outside of which no sporophytes were produced. The solid line represnts a similar boundary, but for densities of greater than 50 sporophytes/cm^2.

Onofre only resulted in very modest increases in the density of sporophytes produced. In addition, we observed good sporophyte recruitment (>150/cm^2) in one outplant experiment even though the mean nitrogen concentration was less than 0.2 μg at/ℓ. The role of nitrogen in sporophyte production warrants further investigation, but it appears from our data that, although there is some possible confounding of temperature and nutrient effects, temperature is of prime importance.

The densities of sporophytes produced in our outplant experiments were plotted vs temperature and irradiance to determine possible thresholds for sporophyte production (Figure 3). Several patterns emerge from this plot. First, there were no sporophytes produced at temperatures above 17.6°C or at irradiances below 0.3 E/m^2/d. The apparent temperature threshold is similar to that observed by Lüning and Neushul (1978). Their laboratory experiments indicated a temperature maximum for gametogenesis of between 17° and 20°C. The irradiance threshold was slightly lower than the 0.9 E/m^2/day limit indicated by Lüning and Neushul, but was close to the 0.2 E/m^2/d level we have observed in our own laboratory experiments (Deysher and Dean, unpublished).

It is also evident that higher sporophyte densities (>50/cm^2) occurred only at temperatures below 16.3°C and at irradiances above 0.4 E/m^2/d. These conditions probably more closely reflect the conditions necessary for recruitment on natural substrates. Gametophyte densities are lower and competitor densities higher on natural substrates than on rope

substrates used in our outplant experiments. Therefore, optimal physical/chemical conditions are probably required for successful sporophyte production on natural substrates.

Figure 3 also indicates a possible interactive effect of temperature and irradiance on sporophyte production. Higher irradiance levels (about 1 $E/m^2/d$) were required for production of large numbers of sporophytes as temperatures approached 16°C. Similar interactive effects have been noted by Lüning (1980) in *Laminaria saccharina* a species closely related to *Macrocystis*

The boundary of temperature and irradiance conditions necessary for sporophyte production of $>50/cm^2$ is indicated on Figure 3. Any combination of temperature and irradiance that falls within the boundary represents a "recruitment window", i.e., times when conditions were favorable for sporophyte production and subsequent kelp recruitment. However, it is also evident that not all outplant substrates within this boundary produced large numbers of sporophytes. There were many instances when temperature and irradiance conditions were favorable but sporophyte densities were below $50/cm^2$. There were even few occasions when no sporophytes produced. Sedimentation, and a host of other possible factors which we did not measure (competition, predation, abrasion by drifting kelp, lack of essential micronutrients) apparently can also limit sporophyte production.

In order to determine whether the occurrence of "recruitment windows" as defined by our outplant experiments coincided with natural recruitment events, we plotted the average

biweekly irradiance vs average biweekly temperature from the bottom in the San Onofre Kelp bed (Figure 4). Both temperature and irradiance were measured at sites cleared of Macrocystis and algal understory. We chose a 2-week time interval since this is near the minimum time necessary for production of sporophytes from gametophytes (based on unpublished laboratory studies). The dashed line in Figure 4 represents the boundary line for successful recruitment as indicated by our outplant studies. The majority of the biweekly observations (60%) were outside of the recruitment boundary, i.e., temperatures were either too high or irradiances too low for sporophyte production. The solid line in Figure 4 is a boundary adjusted for the effects of shading by understory algae on nautral substrates. Reed and Foster (1983) indicated that in Monterey Bay, Pterygophora californica (an understory alga also common at San Onofre) reduced irradiance levels by 30 to 90 %. We estimated that the understory at San Onofre reduced irradiances by 0.4 $E/m^2/d$, or by 40% when ambient levels were at 1 $E/m^2/d$. Irradiances on natural substrates, therefore, would presumably be above the threshold when irradiances at the cleared sites were 0.4 $E/m^2/d$ above the boundary condition. If we use this adjusted level for defining the boundary conditions, only 8 of the 67 biweekly intervals measured (12%) were suitable for recruitment. All of the "windows" occurred in spring or early summer (April through July) or late fall (November through December). Four of the 8 periods with favorable recruitment conditions (the circled values in Figure 4) were periods when we believe natural kelp

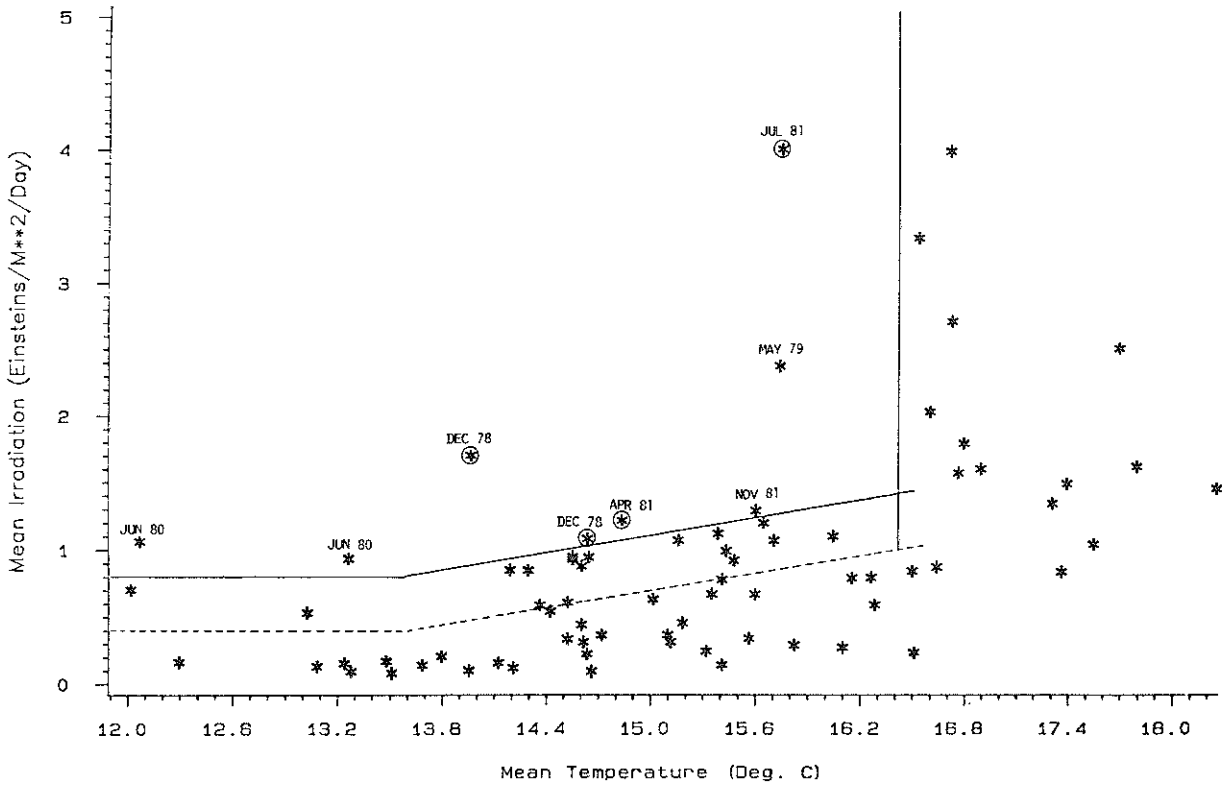

Figure 4. - Mean biweekly temperature vs mean biweekly irradiance values measured on the bottom in the San Onofre Kelp bed from July 1978 through Janurary 1982. Irradiance values are from sites cleared of both Macrocystis canopy and algal understory. The dashed line represents the boundary conditions for sporophyte production as determined in outplant experiments. The solid line represents an adjusted boundary which accounts for a reduction in irradiance by understory algae on natural substrates. Dates are given for those observations above the adjusted boundary. Circled points are those times in which we expect that natural recruitment of sporophytes occurred.

recruitment occurred at San Onofre. Large numbers of small sporophytes were present in the bed in March 1979 and from July 1981 through November 1981. Between March 1979 and July 1981, there were extremely few newly recruited Macrocystis in the kelp bed. We did not observe actual sporophyte production since these life stages are too small to see without the aid of a microscope. However, we estimated, based on a development time of about 3 months from sporophyte production until plants are identifiable in situ, that sporophyte production occurred in late Fall 1978, and in Spring and Summer 1981. Thus, all of the recruitment events we observed could be traced to particlular 2-week periods in December 1978, April 1981, and July 1981 when proper temperature and irradiance regimes existed.

As indicated above, there were extremely few sporophytes recruited between March 1979 and July 1981. During this period, we tagged newly recruited juvenile sporophytes (measuring approximately 30 cm in height) as they appeared on 13 permanent transects located in different parts of the kelp bed at approximately quarterly intervals. Less than 2 new juveniles per 10 m^2 were tagged from August through November 1979, and less than 2 per 1000 m^2 were tagged between November 1979 and June 1981. Thus, there were apparent recruitment "windows" (May 1979 and June 1980) when little or no recruitment occurred. The lack of recruitment at these times may have been due to poor survivorship of microscopic sporophytes rather than lack of production of sporophytes from gametophytes. This appeared to be the case in June 1980. Although temperature and irradiance

levels were well within the boundaries for sporophyte production throughout the month, irradiance levels were extremely low in the following months. Irradiances were less than 0.2 $E/m^2/d$ in July and were less than 0.35 $E/m^2/d$ through mid-October 1980. These low irradiance levels and accompanying high rates of sedimentation may have killed microscopic sporophytes. A second possible cause for the lack of recruitment during these times was that other environmental factors, which were not measured (e.g., predation, competition for space or light, micronutrient limitation), may have prohibited sporophyte production. Competition may have been of particular importance in inhibiting recruitment in May 1979. This followed episodes of heavy recruitment for both Macrocystis and Pterygophora, and competition for space and light may have been especially keen at that time.

SUMMARY AND CONCLUSIONS

The results of our studies indicate that temperature, irradiance, and sedimentation rate were major factors influencing the production of Macrocystis sporophytes from gametophytes. The upper temperature limit for sporophyte production appeared to be approximately 16.3°C. At lower temperatures, the irradiance threshold is at about 0.4 $E/m^2/d$, and appears to increase to about 1 $E/m^2/d$ as temperature levels approach 16°C. The relatively infrequent recruitment of Macrocystis can be explained in large part by the relatively infrequent co-occurrences of temperature and irradiance levels that fall within the necessary

bounds for sporophyte production.

Increases in suspended sediments and subsequent reductions in irradiance that may occur as the result of discharges from nuclear generating stations, discharges from sewage treatment plants, or from increased run-off due to heavy rains or increased land development may lead to reductions in kelp recruitment. If reductions are such that "recruitment windows" are only occasionally affected, the result would likely be a reduction in the average adult population density within the bed. This would result from the adult populations having to persist for longer periods between less frequent recruitment events. Quantitative predictions of these effects on average adult population densities are difficult because of the interactions between densities of adult plants and bottom irradiance levels. Thinning of adult plants could lead to increased irradiance on the bottom and increased probability of sporophyte recruitment and survival. If these reductions in irradiance are more severe and more chronic, such that irradiances are always reduced to below the apparent threshold level for kelp recruitment, then such perturbations will eventually lead to the local disappearance of kelp as adult plants are lost without replacement from the gametophyte stage. Kelp beds or portions of kelp beds that are currently near the critical boundary with regard to irradiance conditions (e.g., deeper portions of kelp beds where irradiances on the bottom are generally low) will be especially susceptible to these changes.

Historical data from the San Onofre region shows that prior to 1957 canopies of the San Onofre, San Mateo, and Barn

Kelp Beds extended to depths of 17 to 18 m. Current canopy positions of these kelp beds, however, extend only to depths of 16 m. In addition, a small kelp bed on a reef at a depth of 17 m midway between San Onofre Kelp and Barn Kelp which was observed in all surveys prior to 1957, no longer has a distinct surface canopy. Similar reductions in the offshore extent of kelp have been noted at Point Loma (Barilotti, pers. comm.) and Palos Verdes (Wilson, et. al. 1980). These losses of kelp canopy may be the result of increases in suspended sediment and associated reductions in water clarity in the Southern California region.

ACKNOWLEDGMENTS

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EFFECTS OF TRACE METALS AND NATURAL ORGANICS ON ALGAE

James S. Kuwabara*

Although many trace metals are essential in plant and animal nutrition, excessively high trace element concentrations produce inhibitory effects on aquatic organisms. Metal concentrations in municipal wastewater have contributed to the concern about effects of these effluents on coastal communities. Effects of zinc (Zn), manganese (Mn), copper (Cu) and cobalt (Co) on Macrocystis pyrifera (giant kelp) gametophytes were studied at Kerckhoff Marine Laboratory within the Kelp Farm Project, headed by Professor Wheeler North of California Institute of Technology. Results of these studies indicated that gametophytes were more sensitive to high trace metal concentrations than were macroscopic sporophytes (Anderson 1982). Chemical speciation calculations suggest that of the 11 trace metals examined, Cu and Zn may exist at inhibitory concentrations near the initial mixing zone of southern California wastewater outfalls.

Our studies (Kuwabara 1982) examined gametophytic development of Macrocystis from zoospore release to sporophyte production (Figure 1). We chose the gametophytic phase because: 1) the relatively short duration of this phase allowed us to conduct the many sequential

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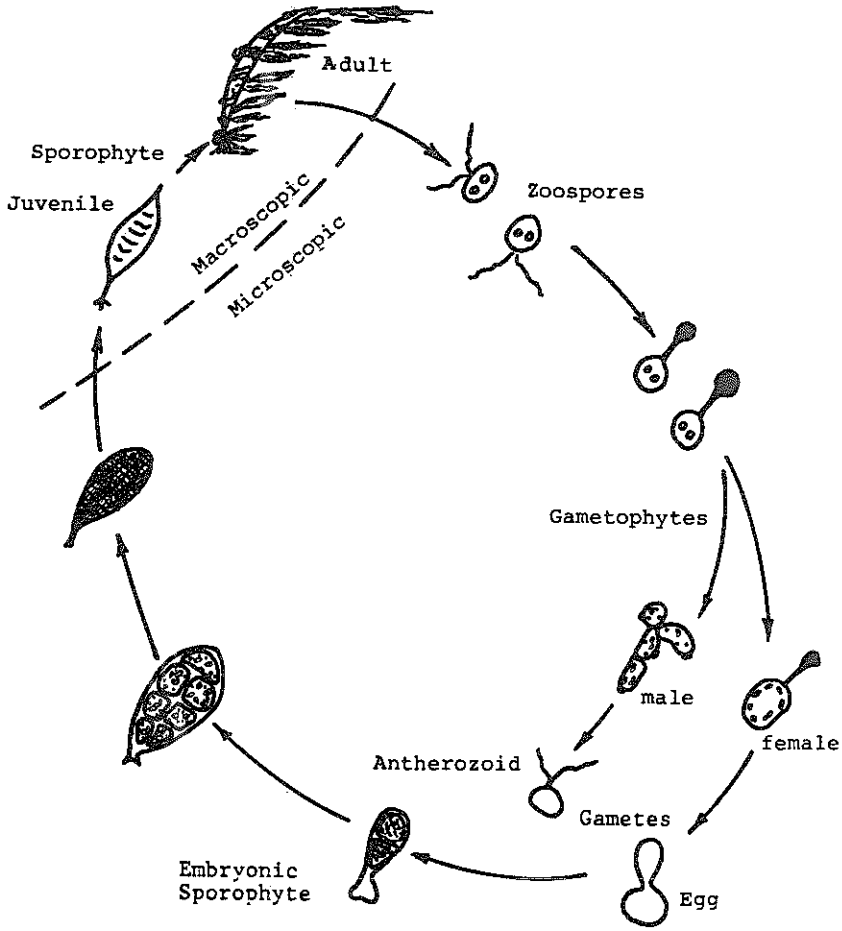

Figure 1. Life cycle of Macrocystis pyrifera (L.) C. Agardh (giant kelp) after North (1971).

experiments needed for a complete evaluation, 2) gametogenesis and sporophyte production provide an unequivocal biological criterion for assessing suitability of growth media, 3) the microscopic size of gametophytes facilitated construction and operation of an ultraclean (non-trace metal contaminating) culturing system (Kuwabara and North 1980). These micronutrient studies were suggested by a dramatic

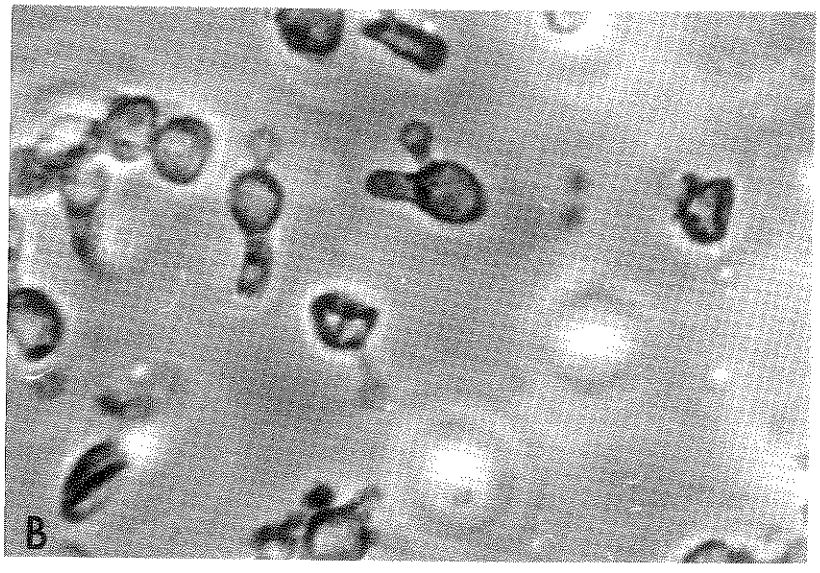

Figure 2. Light photomicrographs (400x) of Macrocystis gametophytes in seawater media: (A) Early sporophytic development observed two weeks after spore release in a culture using MBSW, and (B) gametophytes cultured in NBMW two weeks after spore release (development scarcely beyond spore germination.) After Kuwabara (1982).

difference observed in gametophytic development in unenriched surface water from Monterey Bay, CA (MBSW) and a 1:1 mixture of surface and 300-m seawater collected 3 miles off Newport Bay, CA (NBMW). Gametophytes cultured in MBSW displayed rapid development. Sporophytes were produced from released zoospores within 14 culturing days (Fig. 2A). In contrast, cultures in NBMW showed little or no gametophytic development after 14 days in culture (Fig. 2B). Chemical analysis of these two media indicated that the difference in gametophytic response in these two media could not be attributed to differences in macronutrient concentrations with similar NH_4^+, NO_3^- + NO_2 or PO_4^{3-} concentrations (Table 1). However, differences in trace element concentrations (total iron (Fe), Zn, Mn, Cu, and Co) as high as an order of magnitude were observed in the two media (Table 1).

TABLE 1. Computed chemical speciation for nine inorganic nutrients and for EDTA in: the Aquil formulation (A), used in this study, determined closest to optimal relative to the four trace element variables and MBSW (assuming no adsorption). Analytical concentrations for MBSW and NBMW were reported by North (39). Free ion concentrations for MBSW were computed under the assumption that concentrations of organics in MBSW could be represented by an equivalent EDTA concentration (30 nM) required to produce 20% Cu-organic ligand complexation (41). Symbol "*" indicates that analysis for that nutrient was not reported. After Kuwabara (1982).

Nutrient or Compound	Analytical Concentrations (nM)			Computed free ion concentrations (nM)		Major species (nearest %)	
	A	MBSW	NBMW	A	MBSW	A	MBSW
Metals							
Fe^{3+}	350	72	18	$7x10^{-11}$	$2x10^{-10}$	FeEDTA(100)	$Fe(OH)_3(s)$(99)
Zn^{2+}	160	61	34	$8x10^{-2}$	6	ZnEDTA(100)	$ZnCl^+$(67)
Mn^{2+}	25	22	2	3	7	MnEDTA(65)	$MnCl^+$(64)
Cu^{2+}	15	16	31	$5x10^{-5}$	$8x10^{-3}$	CuEDTA(99)	$Cu(BOH_4)_2$(68)
Co^{2+}	55	30	2	$5x10^{-2}$	4	CuEDTA(99)	$CoCl^+$(67)
Ligands							
MoO_4^{2-}	100	*	*	100	*	Free ion (100)	*
$EDTA^{4-}$	$6x10^3$	*	*	$7x10^{-5}$	*	CaEDTA (89)	*
$NO_3^-+NO_2^-$	$20x10^3$	$6x10^3$ ($0.3x10^3$ as NH_4)	$13x10^3$ ($1.1x10^3$ as NH_4)	$2x10^4$	$13x10^3$	Free ion (100)	Free ion (100)
PO_4^{3-}	$2.0x10^3$	$1.1x10^3$	$1.3x10^3$	0.3	0.1	HPO_4^{2-}(51) $MgHPO_4$(47)	HPO_4^{2-}(51) $MgHPO_4$(47)
I^-	100	*	*	100	*	Free ion (100)	*

Gametophytes were cultured using ultraclean techniques (Kuwabara and North 1980) in Aquil, a chemically defined, artificial seawater medium (Morel et al. 1979). Chemical speciation of Aquil constituents was computed with chemical equilibrium program REDEQL2 (McDuff and Morel

1973). Results of these experiments indicated that optimal free ion concentrations for Zn, Mn, Cu, and Co for gametophytic development are approximately $8x10^{-2}$ nM, 3 nM, $5x10^{-5}$ nM and $5x10^{-2}$ nM respectively. An order of magnitude increase over these optimal concentrations consistently produced inhibition of growth and development (Kuwabara 1982).

Using results from our micronutrient studies, we reexamined our original question: "Why was there such an enormous difference between gametophytes cultured in MBSW and NBMW?" Certain plants can use metals complexed with organic or inorganic ligands (Romheld and Harschner 1979). If Macrocystis can readily use complexed trace metals, it may be inferred that MBSW was deficient in Fe, Zn, and Co for optimal gametophytic growth in the defined medium (Table 1). The rapid growth of Macrocystis in MBSW (Fig. 2A) contradicts this. Reviews of trace metal toxicological research (Hodson et al. 1979, USEPA 1980a-d, Whitton 1980, Pagenkopf 1980) indicate that past studies have attempted to relate toxic effects to total solute metal concentrations. Recent studies have shown that trace metal toxicity to aquatic organisms correlates better with concentrations of certain metal species, i.e. availability and hence toxicity of metals is significantly affected by chemical speciation. Uncomplexed cadmium (Cd), Cu, Mn, nickel (Ni), and Zn ions are apparently more readily assimilated then are complexed forms (Sunda and Guillard, 1976; Anderson et al. 1978; Sunda et al. 1978; Allen et al. 1980; Hart 1981). If this is the case for Macrocystis, then only Mn and possibly Fe in MBSW were close to concentrations suitable for gametophytic culturing (Table 1). The high computed free ion concentrations of Zn, Mn, Cu, and Co in MBSW relative to the optimal

Aquil formulation indicate that plants cultured in this medium should have been strongly inhibited. Free ion concentrations of Zn, Mn, Cu and Co were apparently 70, 2, 300 and 60 times too great, respectively. To achieve the optimal values, the free ion concentrations of Zn, Mn, Cu, and Co in MBSW should be decreased by 98.6, 50.0, 99.7, and 98.3 percent, respectively [for example, 98.6 = 100(1 - 1/70) for Zn].

There are chemical processes occurring in seawater that can cause the required decrease in free metal ion concentration in MBSW. Amorphous ferric hydroxide as well as other inorganic particulates and organic detritus remove trace elements from solution by sorption. Grimme (1968) and Balistrieri and Murray (1982) observed relative adsorption efficiencies onto goethite (α - FeOOH) that correspond to relative overabundance in MBSW (in descending order: Cu, Zn, Co and Mn), suggesting adsorption onto iron hydroxide as a mechanism for control of free metal ion concentrations. This mechanism alone cannot, however, entirely account for the desired decrease in free ion concentration (Kuwabara 1982). Note also that the order of MBSW overabundance (Cu > Zn > Co > Mn) corresponds to the well-known Irving-Williams order of stabilities of chelates formed by metals with ligands (Hg > Cu > Ni = Zn > Co > Mn = Cd > Ca > Mg). Free metal ion concentrations may therefore be decreased by complexation with dissolved organics (Mantoura et al. 1978; Kremling et al. 1981) or with particles coated by surfaceactive organic films (Balistrieri et al. 1981; Hunter 1980).

Recently, micronutrient studies on Macrocystis juveniles (macroscopic sporophytes >5 mg wet wt.) have been completed by Anderson at Caltech. Sporophytes are apparently less sensitive to high trace

metal concentrations than are gametophytes. Concentrations of Cu two orders of magnitude higher than optimal Cu concentrations determined for gametophytes did not produce inhibitory effects on juveniles (Anderson 1982). Anderson suggested that the thick cell wall of the sporophyte relative to the gametophyte may act as a "buffer for high external concentrations or as storage for micronutrients."

In summary, gametophytes are indeed sensitive to trace metals and knowledge of chemical speciation of these metals in culturing

TABLE 2. Chemical speciation of trace metals in municipal wastewater[a] diluted 100 fold by coastal seawater [b]. Metal concentrations (as free ion unless otherwise specified) found to inhibit growth or development of *Macrocystis* and other aquatic organisms are also listed. Metal complexation with dissolved organics was determined with thermodynamic data of Mantoura *et al.* (1978), McKnight (1980) and Alberts and Giesy (1981). Metal sorptive processes were not considered in the computation.

Metal	background Conc. (nM)[b]	Analytical Conc. (nM)	Computed Free Ion Conc. (nM)	Major Species (%)	Inhbiting Conc. (nM uncomplexed)	Reference	Organism
Fe^{3+}	35	180	$2x10^{-11}$	$Fe(OH)_3(s)$ (100)	NR[c]	NR	NR
Mn^{2+}	4	13	4	$MnCl^+$(49)	5	Kuwabara (1982)	*Macrocystis pyrifera*
Cu^{2+}	8	43	$5x10^{-2}$	$Cu[B(OH)_4]_2$ (75)	$3x10^{-3}$	Gavis et al. (1981)	*Thallassiosira pseudonana*
Cd^{2+}	1	11	0.3	$CdCl_2$(42)	400	Sunda et al. (1978)	*Palaemonetes pugio* (grass shrimp)
Zn^{2+}	76	130	70	Uncomplexed (57)	1-10	Anderson et al. (1978)	*Thallassiosira weissflogii*
Ni^{2+}	28	47	30	Uncomplexed (62)	$2x10^3$	Spencer et al. (1978)	*Scenedesmus quadricauda*, *Ankistrodesmus falcatus*
Hg^{2+}	0.2	0.3	$1x10^{-18}$	$Hg(CN)_2$ (100)	20 (total Hg)	Berland et al. (1977)	*Skeletonema costatum*
Pb^{2+}	0.2	4.3	$2x10^{-2}$	$PbCl_3^-$ (64)	1000 (total Pb)	Hrs-Brenko et al.(1977)	*Mytilus galliprovincialis* (mussel)
Co^{2+}	1	1	0.6	Uncomplexed (61)	0.1	Kuwabara (1982)	*Macrocystis*
Ag^+	0.4	2	$4x10^{-6}$	$AgCl_4^{3-}$ (88)	50 (total Ag)	Coglianese and Martin (1981)	*Crassostrea gigas* (Pacific Oyster)
Cr^{3+}	6	89	$6x10^{-6}$	$Cr(OH)_4^-$ (93)	$2x10^4$ (total Cr)	Shepard and Jones (1971)	*Macrocystis*

(a) Analytical data from Schafer (1982) and Wada (personal communication)
(b) Analytical data from Brewer (1975)
(c) Not reported.

media is crucial to understanding and predicting trace metal effects.

Using chemical analytical data for municipal wastewater discharged off southern California (Schafer 1982; Wada, personal communications) and for coastal seawater (Brewer 1975), speciation of previously-researched trace metal toxicants (Table 2) was computed with equilibrium program MINEQL (Westall et al. 1978). Metal chelation with dissolved humic substances (natural organics) was computed using thermodynamic data from Mantoura et al. (1978), McKnight et al. (1980) and Alberts and Giesy (1981). Assuming a 100-fold dilution of municipal wastewater by coastal water (a dilution factor imposed in the "Ocean Plan" by the State of California Water Resources Control Board), results of these computations indicate that of the 11 trace metals examined, Cu and Zn appear as likely candidates capable of producing toxic effects on coastal biota. The computed free ion concentrations are an order of magnitude higher than published inhibitory concentrations (Table 2). Stability of metal ion bonding with algal cell walls appears to follow the Irving-Williams order discussed above (Crist et al. 1981). Toxic effects due to a Cu or Zn overabundance would therefore be promoted because of the strong affinity of Cu and Zn for binding sites on algal cell walls.

Chemical processes not considered in the above computation (Table 2) may, however, decrease the free ion concentrations of Cu and Zn. Metals may be sorbed onto wastewater particulates rendering them unavailable to biota. We at the Geological Survey in Menlo Park, CA are currently examining effects of defined particulates in algal growth media on micronutrient availability and hence algal growth. Secondly, dissolution kinetics are not considered in the MINEQL program. Thermodynamic

equilibrium in an aerobic coastal environment is assumed. In anaerobic wastewater where metal sulfides predominate rather than oxyhydroxides, dissolution of particulate sulfides may initially control metal ion concentrations upon exposure to oxic seawater. Particle coagulation in the initial mixing zone may prolong dissolution and thus the time before thermodynamic equilibrium is approached. Peterson (1974) found 10 times as many particles suspended in waters around Whites Point, CA as in "very clear natural waters" below the thermocline off Corona del Mar and Dana Point, CA. Wide particle size distributions observed in wastewater field samples contribute greatly to the complexity of quantifying effects due to coagulation, adsorption and dissolution.

Biological processes can sometimes mitigate the effect of trace metal contamination. Salmo gairdneri (rainbow trout) and Mytilus galloprovincialis (mussel) are able to acclimate to elevate Cu concentrations (Dixon and Sprague 1981; Viarengo et al. 1981). Experiments with the freshwater alga Selenastrum indicate an ability of this taxa to adapt to near lethal

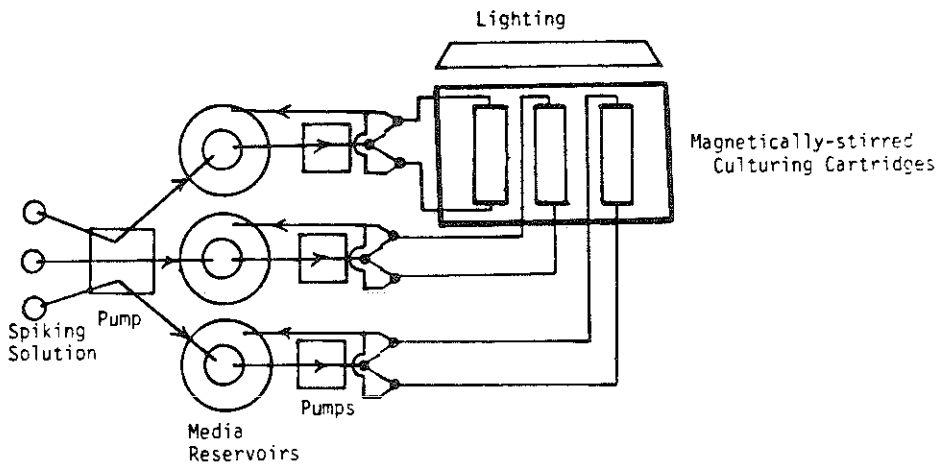

Figure 3. Toxicant Introduction System. Algae are exposed to transient copper concentrations within culturing cartridges. Cartridge filters may be backwashed.

Cu concentrations when Cu is gradually introduced to growth media over a period shorter than one algal generation (<1 d) (Kuwabara 1981). Using a toxicant introduction system developed to control transcient metal ion concentrations at submicromolar levels (Figure 3), Selenastrum gradually (as a ramp function) introduced to Cu over 4 h exhibits a 51% reduction in lag time (time before exponential growth rate resumes) relative to cultures exposed immediately (as a step function) to the same final free ion concentration. Effects of transcient metal ion concentrations need further study. Differences in Cu and silver (Ag) accumulation rates between populations of Macoma balthica (clam) in a contaminated area of south San Francisco Bay and those transplanted from relatively uncontaminated areas (Cain and Luoma in review) indicate the importance of effects due to an organism's environmental history) on toxic response.

On a cellular level, biological adaptive mechanisms may be separated into two categories: cell exclusion and intracellular mechanisms (Leland and Kuwabara 1983). To inhibit metal uptake, some bacteria and algae produce organic exudates that effectively chelate metals and reduce free ion concentrations in the water (Davey et al. 1973; Swallow et al. 1978; Jackson and Morgan, 1978; Bednarz and Cierniak 1979). Stability of complexes formed by Cu, Zn and Cd with excreted algal metabolites also appears to follow the Irving-Williams order (Fisher and Fabris, 1982). As suggested by Anderson (1982), cell wall alginates of kelp may create a barrier to exclude toxic metals. Stigeoclonium (Chlorophyceae) exhibits tolerance to lead by cell wall exclusion (Silverberg 1975). Cell membrane permeablilty may be regulated to control metal flux into the cell (Sicko-Goad 1982). This

process was observed in Cu tolerant strains of Ectocarpus (Hall et al. 1979) and the marine polychaete Nereis diversicolor (Bryan and Hummerstone 1971).

Intracellular detoxication mechanisms have been documented for aquatic organisms. Aquatic animals (e.g., Mytilus (mussel), Scylla (crab), Anguilla (eel) and Zalophus (sea lion) produce metallothionein or other metalloproteins to bind and store excess metals within the cell (Overnell and Coombs, 1978; Lee et al. 1977). Scenedesmus (Chlorophyceae) accumulates excess Cu in intracellular inclusions thereby reducing Cu mobility and protecting more sensitive intracellular organelles (Silverberg et al. 1976). Insoluble intracellular metalloproteins are also found in other plant tissues (Moore and Goyer 1974) in response to elevated Cu concentrations.

The chemical and biological processes discussed above that may reduce metal toxicity should not mislead one into false security about trace metal pollution of coastal environments. This discussion, for example, has been confined to trace metal overabundance. However, chemical processes that reduce toxicity of some metals may also induce limitation through deficiency of other micronutrients (Sunda et al. 1981, Kuwabara 1982). These results have been presented to illustrate the need to better understand and quantify these interdependent processes so that our knowledge may be more skillfully and appropriately applied to this complex coastal problem.

THE SEA URCHIN PROBLEM

Wheeler J. North*

The purpose of this paper is to describe problems arising from overgrazing by urchin populations, relate historical facts concerning urchins and kelp beds at Point Loma and Palos Verdes, summarize research accomplished on the problems (particularly, possible relationships between marine waste disposal and sea urchin persistence), and identify promising areas for future research.

Long-term trends of deterioration began in certain kelp beds around 1940. At first little attention was given to the phenomenon but after a decade of decline, serious concern was expressed by the various user groups (primarily recreational fishermen and the kelp harvesting industry). The concern stimulated funding by the State of a broad-scale research program at the University of California's Institute of Marine Resources (IMR) in 1956. A major conclusion of the IMR study emerged in 1961, namely that sea urchin populations could destroy kelp stands and prevent recolonization of the bottom by flora (North 1964).

At the suggestion of the IMR Director, Professor John D. Isaacs, urchins were cleared from an experimental plot in Mission Bay by

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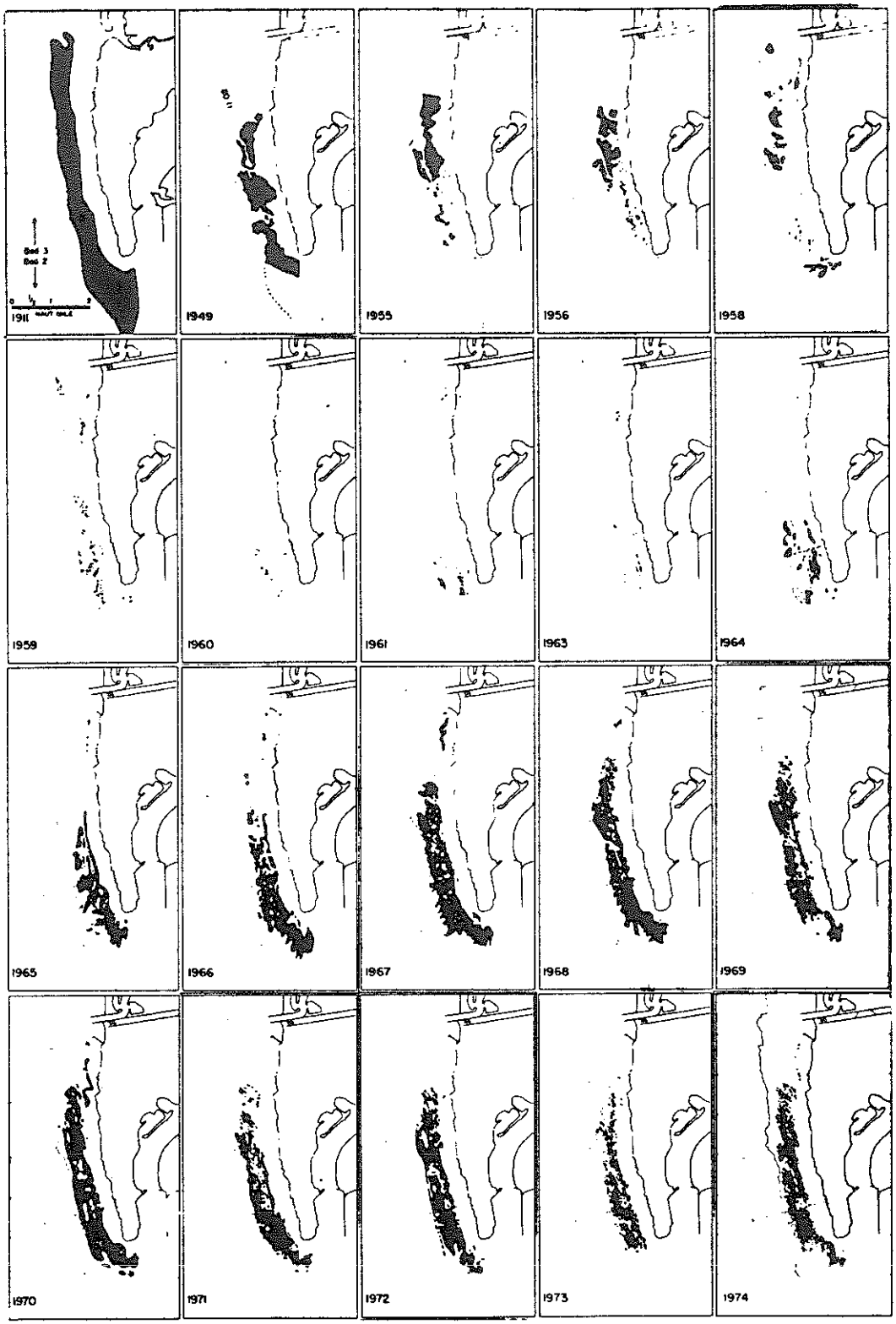
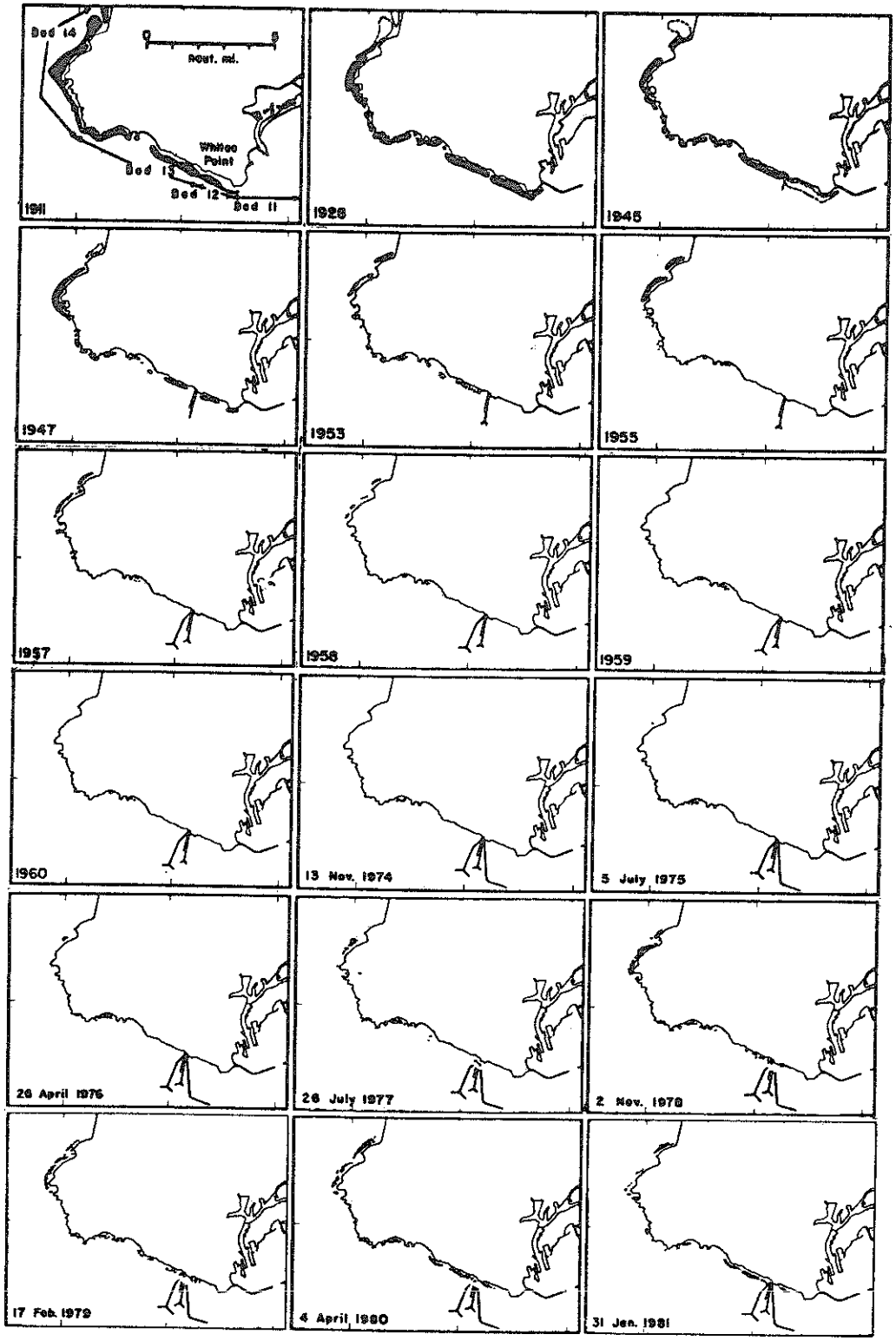
David L. Leighton in 1962, to test the hypothesis that dense urchin concentrations reduced or eliminated seaweed cover. Leighton (SWQCB 1964; IMR 1963) found that seaweeds developed rapidly after urchin dominance was artificially terminated. This finding suggested that urchin control measures, applied on a large scale, might encourage kelp bed restoration.

Effects of urchin control operations were studied experimentally at IMR and subsequently at the California Institute of Technology for several years. All the experiments confirmed Leighton's findings. In areas where dense urchin populations occurred, reduction of average concentrations to less than one *Strongylocentrotus franciscanus* per m^2 (or less than ten *S. purpuratus* per m^2) was invariably followed by a luxuriant influx of attached vegetation. In about 1966, the Kelco Company of San Diego began controlling urchins on a continuing basis in several of their most important leased kelp beds. Personnel from the Department of Fish and Game commenced kelp restoration activities, including urchin control, at Palos Verdes in 1972. Following these efforts, about half of the kelp bed areas formerly existing at Palos Verdes and Point Loma have reappeared (Figures 1 and 2).

During the intervening years, reports have appeared describing destruction of substantial areas of marine vegetation by large urchin populations in many other parts of the world (Cowen *et al.* 1982; Lawrence 1975). There is now so much evidence that urchin populations can create and maintain "barren ground," it seems fruitless to dwell on this once-controversial subject. The interested reader will find many useful citations to published information



1. Historical charts of the Point Loma region, with kelp areas shown as black. Charts for 1963 to 1966 from oblique photos courtesy Kelco Company.



2. Historical charts of the Palos Verdes region, with kelp areas shown as black.

on this subject in the two references listed above. Lawrence (loc. cit.) listed 38 references involving 22 urchin species implicated in creation of "barren ground." The importance of urchin control measures for kelp bed restoration in southern California cannot be over-emphasized. Probably more effort is devoted to controlling urchins than to any other phase of restoration activity.

The causes of ecological imbalance leading to appearance of high urchin densities are of primary interest here. It is also highly pertinent to consider whether marine waste disposal has any positive or negative influence on processes encouraging recruitment, persistence, and survival of urchins.

SEA URCHINS AND "BARREN GROUND"

Differences occur in mechanisms, persistence, and areas involved when urchins overgraze their food resources, reducing the flora ultimately to the "barren ground" status. Catastrophies such as storms can alter available floral biomass (Cowen _et al_. 1982), possibly affecting patterns of food-gathering by urchins. Reductions of urchin predators may eliminate control mechanisms, allowing population increases that lead to a food imbalance (Breen and Mann 1976; Duggins 1980; Simenstad _et al_. 1978; Tegner 1980). Yearly differences in success of recruitment can affect sizes of urchin populations, explaining sudden appearance of "barren ground" (Foreman 1977). Alternatively, urchin densities may be lowered by disease, followed by recolonization of former "barren ground" by seaweeds

(Pearse and Hines 1979). "Barren ground" may coexist with seaweed-covered areas in relatively transitory patchy distributions (Harrold and Reed 1982) or urchin-dominated bottom may occur as virtually the only stable habitat, extending over large areas and for long periods (Chapman 1981; Bernstein et al. 1981; Wharton 1980; North 1964). Quite clearly, understanding and explaining causes for the occurrence of barren bottom at a particular location dominated by urchins can be a complex undertaking requiring detailed ecological studies of both urchin populations and of any nearby stands of seaweeds or other food sources.

MARINE WASTE DISPOSAL AND SEA URCHIN ECOLOGY

Organic-rich wastes might conceivably benefit urchin populations in several ways:

- Enhancement of recruitment
- Nourishment of urchin populations
- Reduction or elimination of factors causing urchin mortality

Adverse effects from such wastes might include:

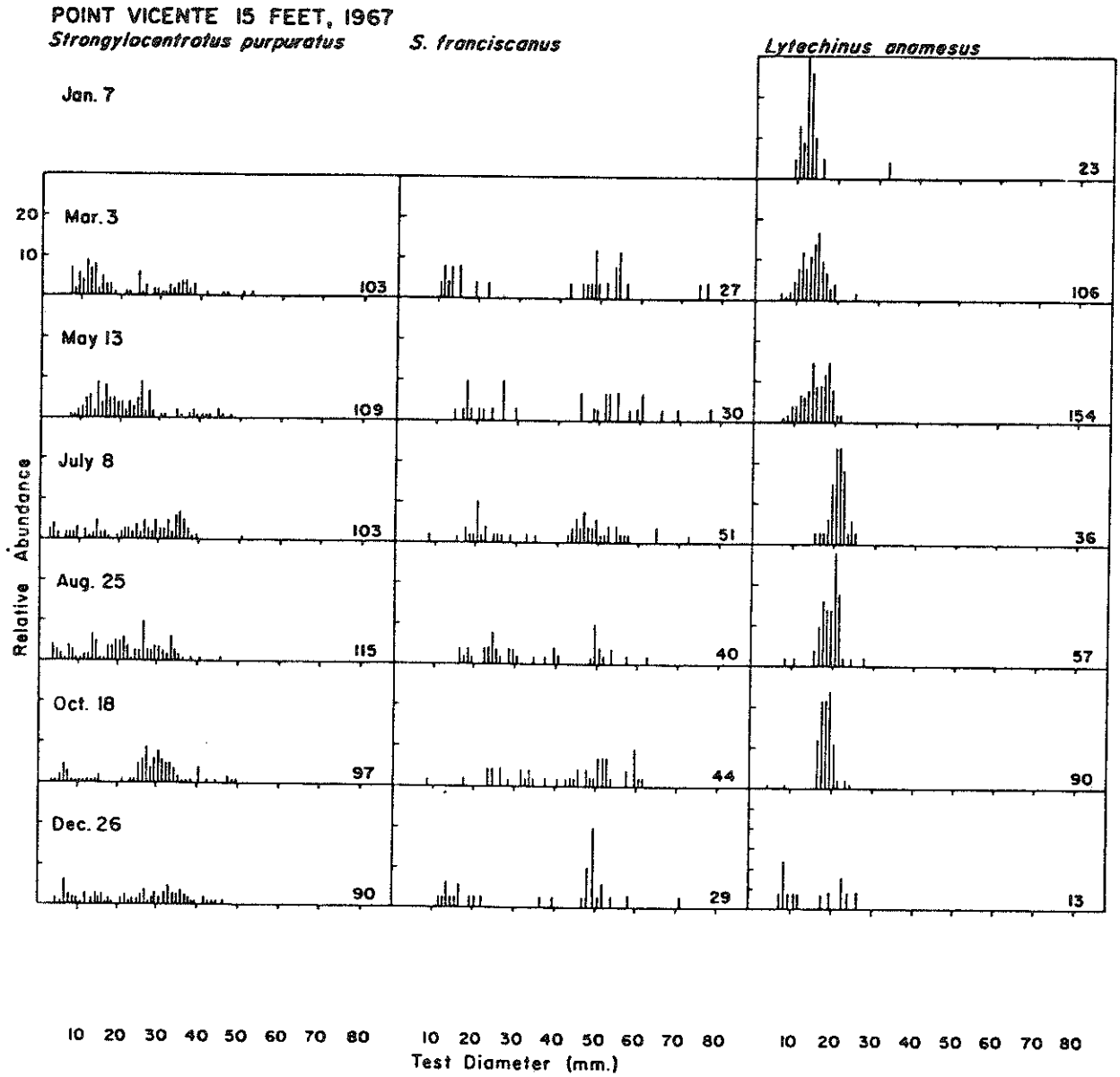
- Toxicity effects
- Converting suitable substrate to a non-suitable form (i.e., rock to sedimentary)
- Reduction of natural food sources such as kelp
- Enhancing factors causing urchin mortality

Although considerable research has been undertaken into possible relationships between discharged sewage effluents and urchin populations at Palos Verdes and Point Loma, many questions remain unanswered and the existence of any relationships remains controversial. This is an area where further studies are needed. Results could be

very important to advancing our understanding of effects from discharged sewage effluent on the kelp bed community. A brief review of existing information should be helpful in defining where we stand today as well as where we might proceed in future studies.

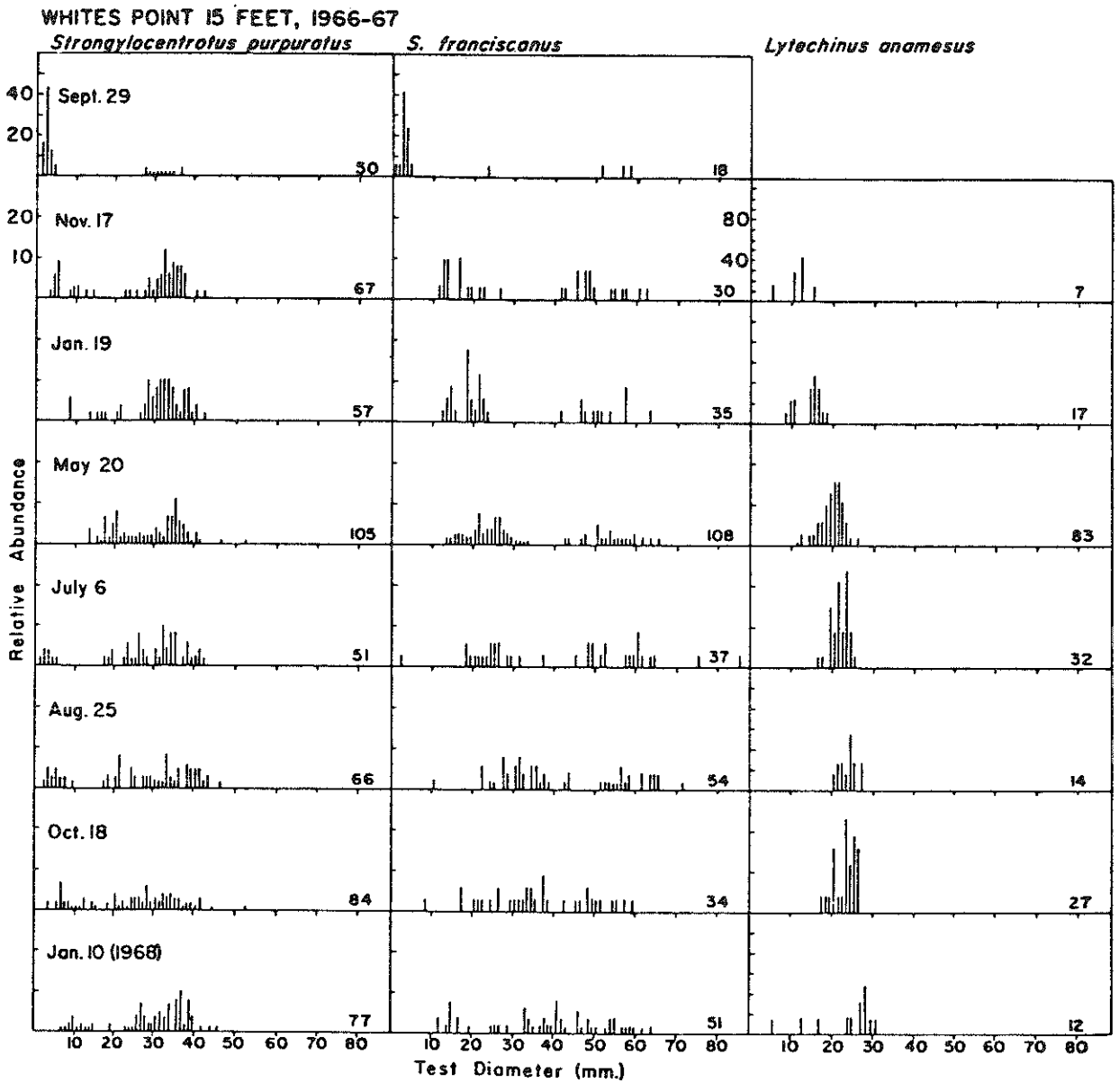
Most of the kelp forests at Palos Verdes and Point Loma had disappeared by 1956-57 when studies commenced at IMR, seeking possible relationships between discharged wastes and kelp bed losses. Nonetheless, the group observed a number of factors other than direct sewage-kelp interactions that caused very significant losses of Macrocystis plants in the remaining kelp stands. Chief among these factors were the warm water temperatures occurring from 1957 to 1959 and grazing by herbivores (primarily fishes and urchins). Urchins occurred in great numbers and soon dominated the bottom in areas where kelp disappeared, regardless of causes of the losses. The "barren ground" was persistent. We observed some stations for longer than ten years and saw no gross changes in the pattern of domination by urchin populations. "Barren ground" was widespread, extending across many km.

Periodic determinations of size distributions of selected urchin populations indicated that the majority of animals in the "barren gounds" were always small (i.e., presumably young individuals--less than 4 cm test diameter for Strongylocentrotus purpuratus and less than 6 cm for S. franciscanus, Figures 3 and 4). Indicators such as gonadal index and gut content examinations suggested that the larger animals were poorly nourished. Recruitment was usually excellent and populations were very persistent, keeping the sea



Size distributions for urchin samples from Point Vicente

3. Size distributions for three urchin species at 15 ft depths off Point Vicente, Palos Verdes, for various dates in 1967. Number of urchins per sampling date given in lower right corners (data by D. Leighton, in Pearse et al., 1970).



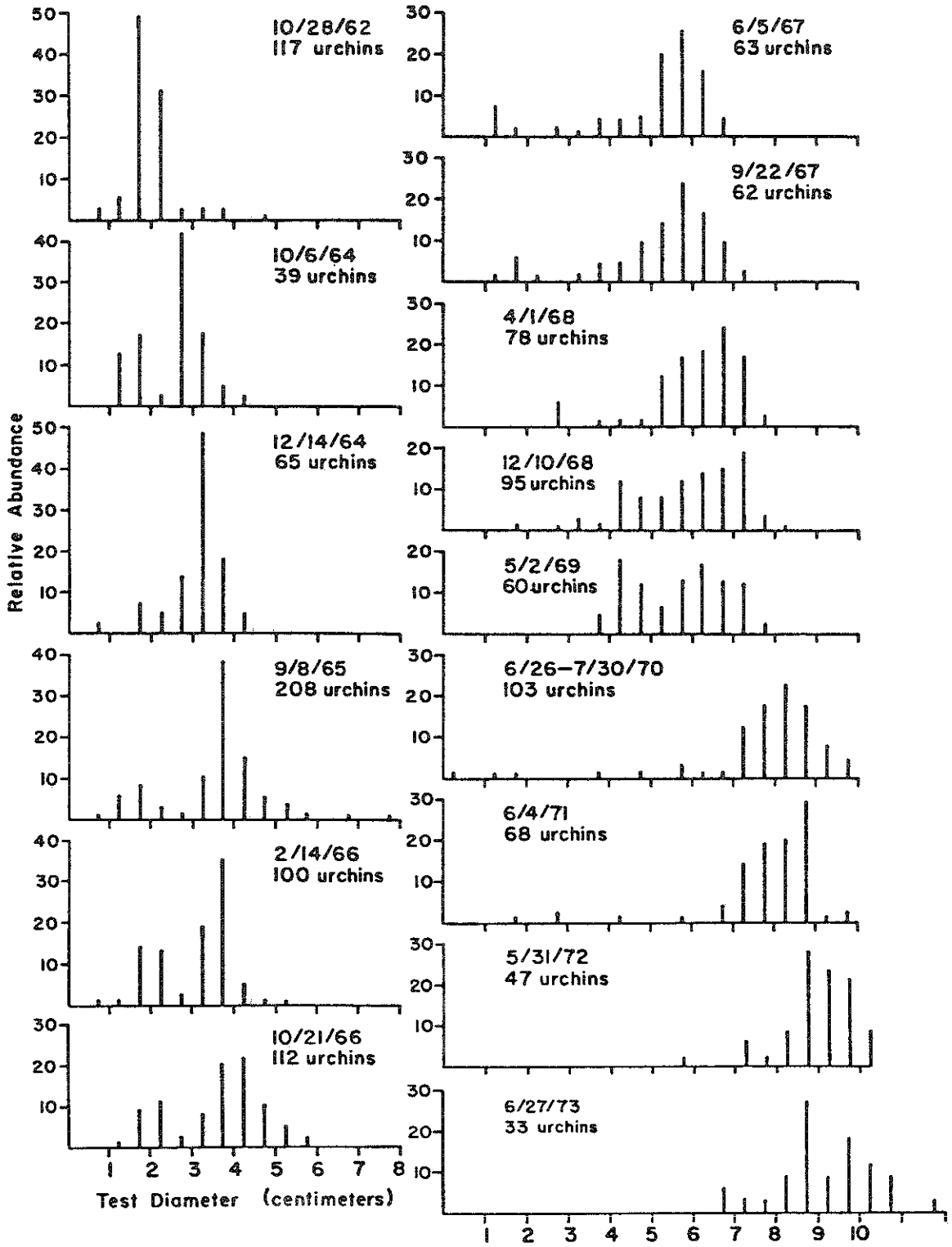
Size distributions for urchin samples from Whites Point.

4. Size distributions for three urchin species at 15 ft depths off Whites Point, Palos Verdes, for various dates in 1966-67. Number of urchins per sampling date shown in lower right corners (data by D. Leighton, in Pearse et al., 1970).

floor in a highly barren state. It appeared as if the high urchin densities were maintained by excellent recruitment even though some mortality factor apparently prevented most urchins from achieving large sizes representative of animals 3 or more years old. Sick and moribund moderately-large animals were often observed, always in a state of very poor nutrition.

Following kelp restoration, size distributions of the urchin populations shifted, with large animals characteristic of kelp beds becoming prominent. Nutritional characteristics also changed, all urchins displaying high gonadal indices and full gut contents. Recruitment appeared to decline, although it was difficult to assess numbers of very small urchins that might be inhabiting kelp holdfasts (which we did not sample). Several years of data, however, failed to indicate that substantial numbers of medium-sized urchins were entering the samples, suggesting that urchin recruitment in established kelp beds was indeed poor (Figure 5). This negative effect on urchin recruitment is an interesting feedback mechanism beneficial to kelp survival.

We compared urchin populations from "barren grounds" off Whites Point and Point Vicente, Palos Verdes, with a population from a persistent "barren ground" at Punta Banda, Baja California, far removed from sewage discharges. Both populations were similar in consisting primarily of small animals and in displaying successful recruiting, judged by the relatively high proportions of juvenile urchins in our samples. The largest urchins from all three locations



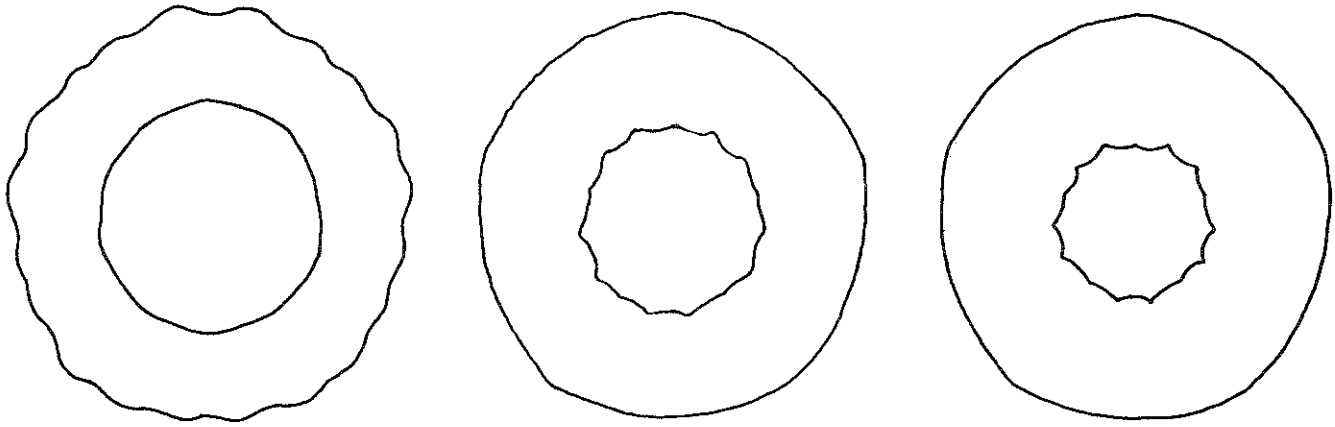
5. Size distributions for Strongylocentrotus franciscanus off north-central Point Loma on the indicted dates. Kelp began returning to the vicinity of the sampling station in 1965.

displayed evidences of severe malnutrition. Proportions of larger urchins were substantially higher for the Palos Verdes populations, suggesting that their environment was more favorable and/or their health was better (Pearse *et al*. 1970). That is, urchins grew larger in a "barren ground" near a sewage discharge compared to a "barren ground" at a site far removed from human influences. Possibly, urchins derived some nourishment directly or indirectly from discharged sewage. One possible nutritional relationship might be uptake of dissolved organics of sewage origin across exposed surfaces of urchins (all outer surfaces of urchins, including the spines, are covered by a thin dermis of living cells, so urchins display very large exposed areas to their environment).

Studies by Drs. Mary E. Clark, Vicki B. Pearse, and John S. Pearse demonstrated that urchins can accumulate a wide variety of dissolved organic substances from seawater at very low concentrations (Clark 1969; Pearse *et al*. 1970; Pearse and Pearse 1971). Computations based on measured uptake rates of dissolved free amino acids (DFAA) at concentrations measured near outfalls by Clark *et al*. (1972) showed that *S. purpuratus* can meet 50 percent of the daily maintenance requirement from DFAA alone (Clark 1969). Sewage contains a variety of other dissolved organics. Hence, we believe there is strong potential for urchin nutrition from dissolved organics in discharged sewage. Other nutritional pathways may exist; for example, films of leptopel and microorganisms (Pearse *et al*. 1970).

If urchins can take up simple dissolved organic molecules and derive significant nourishment therefrom, why did we find that larger

animals inhabiting "barren grounds" appeared to be dying of starvation whereas small animals were healthy? We cannot conclusively answer the question at this time. Clark's (1969) calculations showed that uptake of DFAA by a 1 gm S. purpuratus (i.e., ca. 1 cm test diameter) contributed only slightly more to daily maintenance requirements than uptake by a 10 gm urchin (i.e., 2.5 cm test diameter). These sizes, however, were representative of small animals that were abundant in the Palos Verdes samples (Figures 3 and 4). Similar data are needed for urchins 5 or more cm in diameter (i.e., beyond the sizes commonly occurring at Palos Verdes). One might expect size to affect ability to derive nourishment from dissolved organics, based on morphological changes. John S. Pearse (personal communication) pointed out that as urchins develop, they change from a soft-bodied animal to a creature largely enclosed by the test. This pattern is easily appreciated by merely noting the proportion of the cross-sectional area of the urchin that is occupied by the oral cavity as the urchin grows larger. The ratio of the oral cavity diameter to the test diameter is 0.55 for an 0.47 cm urchin, 0.46 for a 1.60 cm urchin, but only 0.39 for a 2.75 cm urchin (Figure 6). We have depicted urchins of three differing sizes as if they all had similar test diameters, to illustrate relative changes in mouth diameters as urchins grow. Possibly, development from an "open" soft-bodied animal to an "enclosed" form would affect abilities to derive nourishment from DFAA and other organics. Size might also be influential for sustenance of urchins grazing on leptopel (thin films of organics and microorganisms adhering to rocky surfaces)



4.7 mm (mean test diameter) 16.0 mm 27.5 mm

Strongylocentrotus purpuratus

6. Outlines of tests of three different-sized Strongylocentrotus purpuratus drawn to similar dimensions to show proportionate changes in the oral cavity as growth occurs.

and on benthic diatoms (Pearse et al. 1970). Small urchins with their proportionately large mouths might be able to feed more effectively on thin films and diatoms than large urchins with relatively small mouths. These questions will require further research before conclusions can be drawn. We also need to know whether marine waste disposal contributes significantly to leptopel formation, particularly in "barren grounds."

CONCLUDING DISCUSSION

Reductions in numbers of important urchin predators such as sea otters, lobster, and sheephead may have provided an opportunity for proliferation by urchins and other macro-invertebrates. Such proliferation introduced an element of instability to kelp beds

where urchins were plentiful. The instability was manifested as temporary to semipermanent disappearances of kelp and other vegetation in certain areas due to excessive grazing by dense urchin populations. The instability has, to some extent, probably been controlled by natural forces. Thus after urchins destroy standing crops of attached algae, they may migrate in search of food or perish from starvation unless they are in a location where populations can be sustained by organic matter imported by currents. Organic matter from discharged sewage may nourish urchins. For example, measurements of concentrations of dissolved free amino acids near a large submarine outfall indicated that small urchins could derive significant sustenance from this source. Thus dissolved organics of sewage origin could be a factor encouraging the observed persistence of urchin populations near submarine outfalls.

Urchin populations near sewer outfalls are typically persistent. They tend to be composed of small animals, recruit juveniles continuously, and individual turnover is probably high. We compared urchin populations from near the Los Angeles County Sanitation Districts' outfall at Whites Point with a population at Punta Banda, Mexico (far removed from contact with waste waters). The populations from the outfall region contained higher proportions of larger animals than found in the Punta Banda samples. We believe this indicated better survival conditions near the outfall (Pearse et al. 1970). This type of study needs refinement, however, since measurements of available drift seaweeds and their utilization by the two populations were not undertaken. Techniques for making such estimates have recently been developed (Cowen et al. 1982;

Harrold and Reed 1982; Mattison et al. 1977).

Since a substantial and continuing effort is required to control urchin populations in the Point Loma and Palos Verdes kelp beds, we need to know precisely the role, if any, played by discharged sewage in enhancing persistence and survival of urchins. Without such information, our knowledge of ecological effects of marine waste disposal is seriously inadequate. Clearly, more research in this field is needed. Enough is known, however, to suggest rather strongly that important relationships may exist between discharged sewage and the urchin populations of Point Loma and Palos Verdes.

MEASUREMENTS NEEDED TO DETERMINE THE ECOLOGICALLY IMPORTANT EFFECTS OF DISCHARGED WASTES IN KELP BED HABITATS

D. Craig Barilotti*

Enough information is now available to identify many of the ecologically significant effects of discharged wastes in kelp bed habitats. What is needed now are measurements that will permit changes in treatment and discharge methods to be related to any ecologically important effects in kelp bed habitats. Such measurements should enable us to elaborate the mechanisms by which wastes might be transported to kelp beds from the zone of initial dilution, determine the vertical position of the wastes in the water column, provide a measure of waste concentration or impact, and differentiate changes due to discharged wastes from those due to other environmental factors. Provided with this information, engineers and policy makers should then be able to formulate design criteria for waste treatment and discharge that would prevent kelp bed habitats from becoming polluted. This information would also provide a measure of pollution, should it occur.

The kelp beds off San Diego will be used to illustrate the types of measurements needed, because there is a fairly large

* Kelco Division of Merck and Company

amount of information from a variety of sources upon which to draw. These sources include published scientific literature, a variety of reports on the Point Loma treatment plant and outfall, records from the monitoring conducted by the City of San Diego off Point Loma, and data collected by the author. Information will be presented for the following subject areas: measuring wastefield concentrations, vertical wastefield position, wastefield transport, suspended wastefield fractions, waste sediments, and ecological effects. While the paper focuses on measurements in kelp beds off San Diego, it is intended that much of the information will be general enough to apply to other kelp bed habitats as well.

The need for the above information, the measurements required for this purpose, and the appropriate theory, will be the subject of this paper.

Measuring Wastefield Concentrations:

Studies of sediments in kelp bed habitats (Kline and Goldberg, 1970; Grigg and Kiwala, 1970; Myers, 1974; Sweeney and Kaplan, 1980; Grigg, 1978) provide a measure of how far wastefields have reached and the fraction of waste that settles. However, such studies do not indicate the concentrations of materials in the water or the location of the wastefield at a particular time. Since exposure to the wastefield may be important to some organisms, a measurement of the spatial extent of the wastefield is useful in judging the effectiveness of treatment and discharge.

At the present time, coliform counts and dissolved oxygen levels obtained as part of the monitoring program off Point Loma (Hamilton, this symposium), are the only routine measures of wastefield dis-

tribution and concentration. Coliform monitoring records for Point Loma (Table 1), indicate that coliforms are frequently present in high abundance in waters near the bottom, but are rarely found in the surface waters.

A northerly bias is indicated in the direction the wastefield travels off Point Loma, since station A-6 has 26.6% of the counts above 1000+ MPN/100ml, relative to 15.3% at station A-1 (see Figure 1 for the location of the stations). Evidence that coliform bacteria were either not found in the waters near the bottom, or false positive readings from marine heterotrophic bacteria, is provided by Figure 1. During the period of time before the outfall was brought on line, and for several years thereafter, coliform bacteria were either not found in the waters near the bottom, or they were on the average at very low concentrations.

Coliform bacteria counts are a useful indication of wastefield concentration, if it is kept in mind that they are semi-conservative measures because coliforms are inactivated with time in seawater. This semi-conservative nature is more of a problem in surface waters, than at subthermocline depths where sunlight levels and temperatures are low. Coliform inactivation studies (Gameson and Saxon, 1967; Pike et al, 1970; Kapuscinski and Mitchell, 1983), indicate 90% of the coliforms near the surface would be inactivated within 2 to 3 hours due to sunlight and high water temperatures. At depths of 15m or greater, 90% inactivation would take 2 to 3 days using typical values of light and temperature I recorded off Point Loma. In 1967 coliform monitoring studies in Santa Monica Bay showed counts above 10,000 MPN/100ml over 5

Table 1. Percentage of total coliform counts (MPN/100ml) in different abundance categories for data collected by the City of San Diego at their monitoring stations A-1, A-6, and C-7 (see figure 1 for locations of the sampling stations). These stations were located along the offshore edge of the Point Loma kelp bed. Water depth of the stations was approximately 18m. Data was available for the 1969-1977 period when all stations were sampled at both surface and near bottom depths. After 1977, samples adjacent to the bottom were not taken at station C-7.

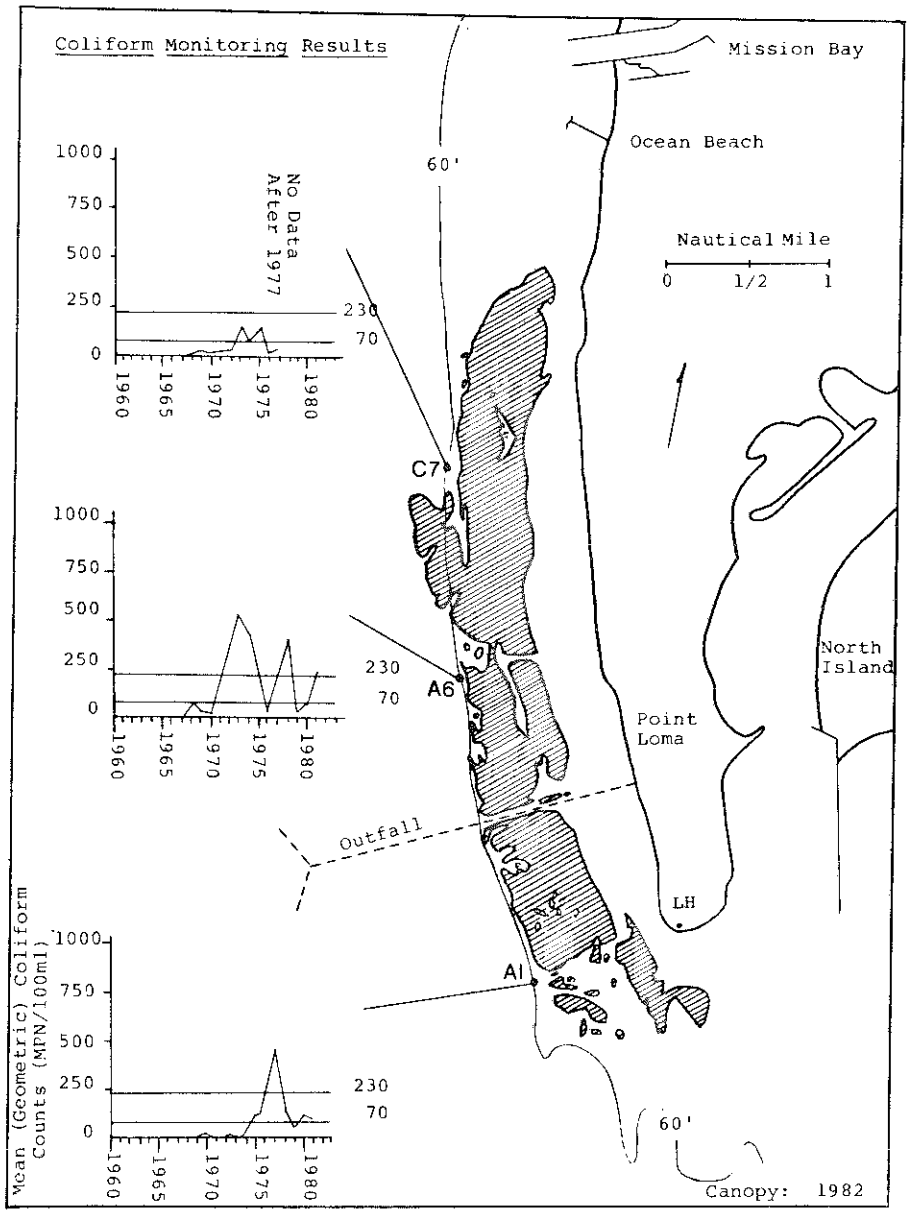
			Percentage of Values Within Each Range				
Station	Depth	N	0-50 (%)	51-100 (%)	101-500 (%)	501-1000 (%)	1000+ (%)
A-1	Near surface	96	83.3	4.2	7.3	4.2	1.0
	Near bottom	85	51.8	10.6	14.1	8.2	15.3
A-6	Near surface	95	88.4	3.2	7.4	0	1.0
	Near bottom	94	33.0	7.4	24.5	8.5	26.6
C-7	Near surface	96	97.9	0	1.0	1.0	0
	Near bottom	84	53.6	7.1	21.4	8.3	9.5

nautical miles from the diffusers (Figure 2); this supports the idea that coliforms are inactivated over periods of days, not hours, at subthermocline depths.

Even though coliform counts may have the drawback of not being a quantitatively accurate measure of wastefield concentration, they are certainly most useful in establishing the presence of a wastefield.

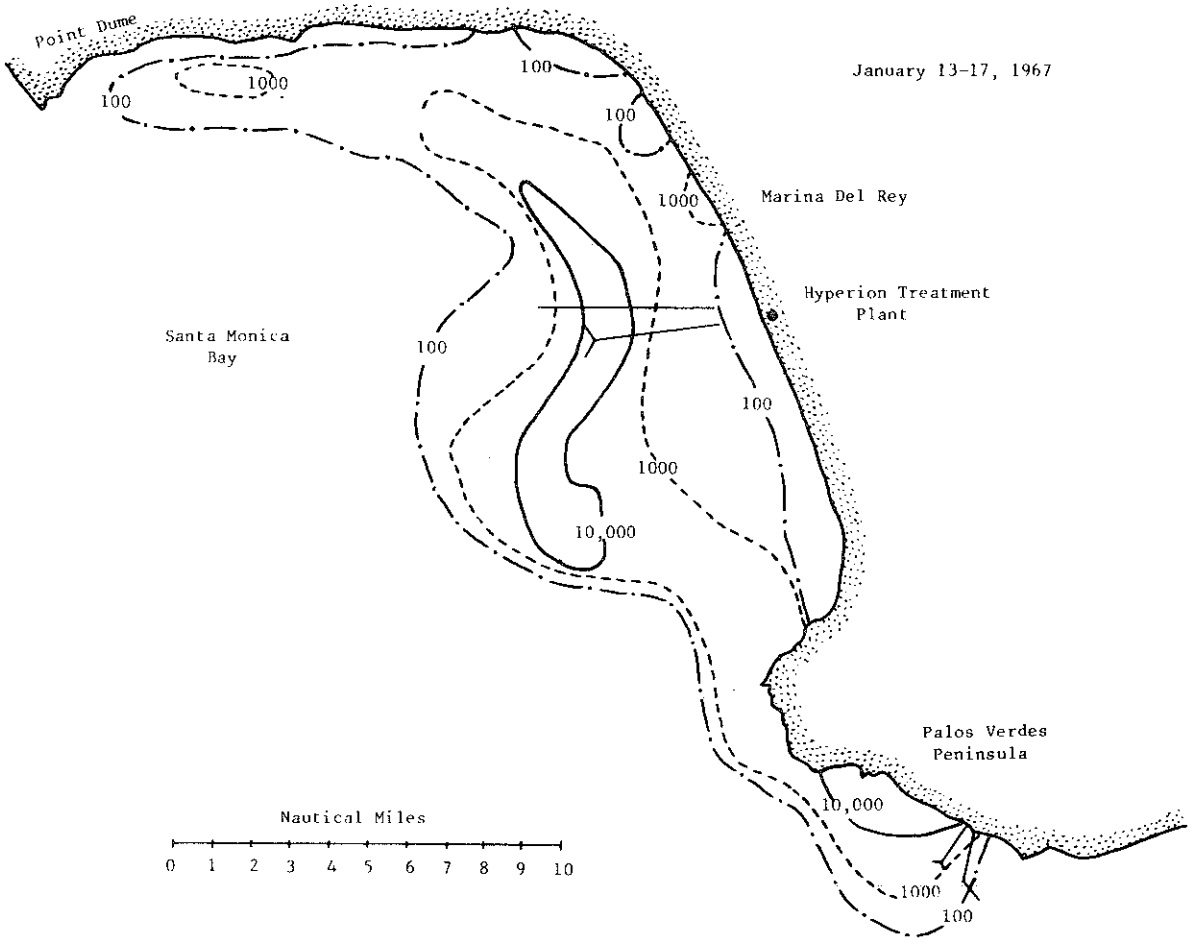
The shortcomings of coliform counts, resulting from temperature and light inactivation, indicates the need for a more reliable routine measure of wastefield concentration. The following methods should be investigated for routine use: 1. Assessment of the abundance of particles below 1.5μ in diameter. Particles in this size range are relatively rare in the sea off southern

Figure 1. Station location and results of coliform bacteria monitoring for waters adjacent to the bottom, and near the offshore edge of the Point Loma kelp bed. The 1982 kelp surface canopy off Point Loma was determined from aerial photographs and diving surveys. The total coliform count (MPN/100ml) data presented in this figure was collected by the City of San Diego. Total coliform monitoring was initiated in 1962, before the Point Loma outfall was brought on line.



California, but abundant in primary wastefields such as those off Palos Verdes, (Table 2 and Peterson, 1974). 2. Counts of

Figure 2. Results of coliform counts from unpublished data collected by the City of Los Angeles. Samples were taken adjacent to the bottom, or at maximum depths of 140 ft. in Santa Monica Bay, and 200 ft. off the Palos Verdes Peninsula. Data was collected January 13th through 17th, 1967. The persistence of coliform bacteria at depths where light and temperature are low is clearly illustrated by this figure. The figure shows total coliform counts above 10,000 MPN/100ml over 5 nautical miles from the diffusers of the Hyperion Treatment Plant. These results are typical of results obtained during the approximate 2 year period of the study by the City of Los Angeles. With an average current of 5 cm/sec over the diffusers towards the south, the maximum extent of the 10,000 MPN/100ml isopleth in this figure represents a travel time of over 2 days.



other microbes are better indicators of waste concentration in shallow water than are coliform. Potential candidates are enterococci (Dufour and Cabelli, this symposium) and coliphages

Table 2. Percentage of total volume and surface area for different sizes of primary waste particulates off the Palos Verdes Peninsula, based on Coulter counter measurements reported by Peterson (1974). Percentages represent the difference between values obtained in the wastefield over the diffusers off Whites Point, and the presumably unpolluted waters off Dana Point at a similar depth. The Dana Point values were subtracted from Whites Point values. All particles were assumed to be spherical for ease of calculation.

	Average Diameter of Particulates (μm)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
% of total particle volume	30.5	9.4	8.0	8.1	8.0	7.2	6.2	5.6	4.6	3.6	2.7	2.4	1.2	1.0	0.9	0.7
% of total particle surface area	66.4	10.3	5.8	4.6	3.5	2.6	1.9	1.5	1.1	0.8	0.5	0.4	0.2	0.1	<.1	<.1

(Borrego et al, 1983). 3. Use of the nonbacterial compound, Coprostanol. This has been used in sediment studies in the New York Bight (Hatcher and McGillivary, 1979). 4. Trace compounds such as silver, copper, and arsenic. Studies with mussels have shown that these compounds occur in elevated concentrations near outfalls such as those off Palos Verdes and Point Loma (C.S.W.R.C.B., 1982).

Vertical Wastefield Position:

An understanding of waste transport to and within the kelp bed requires having an idea of the wasteplume position in the water column, since currents that transport wastes vary with depth (Jackson, this symposium). Since wasteplumes near the discharge point are generally found below the thermocline during periods of stratification (Brown and Kolpack, 1972; Peterson, 1974; Hendricks, 1978), one might expect wastes reaching a kelp bed to also be sub-thermocline. Records of water temperature and coliform concentration

near the bottom off Point Loma at stations A-1 and A-6, indicate that wastefield concentrations above 1000+ MPN/100ml are more frequent at water temperatures below 14°C. Since 14°C is the approximate average annual temperature of the center of the seasonal thermocline in the nearshore waters off San Diego (Cairns, 1968) and within the Point Loma kelp bed (Barilotti, unpublished data for 1980-1983), it is probable that the wastefield is subthermocline at kelp bed depths. Thus when sampling for the effects of discharged wastes, organisms living below the thermocline are more likely to show effects than those living above, and wastefield effects such as increased turbidity would be more pronounced in subthermocline waters.

Wastefield transport:

Drogue studies were conducted in subthermocline waters off the kelp beds at Point Loma between March 1956, and March 1957, to determine where wastes from the then to be constructed Point Loma outfall would be carried. These studies indicate a net subthermocline water movement inshore towards the kelp beds, with a slight northerly bias (Gaul and Stewart, 1960; Water Resource Engineers, 1970). This prediction is largely borne out by the coliform monitoring offshore of the Point Loma kelp bed (Table 1 and Figure 1). For purposes of estimating impacts, it is necessary to measure wastefield penetration into the kelp bed, or measure currents that will allow prediction of wastefield penetration.

The extent of wastefield penetration into a kelp bed is a function of many variables including: depth, the drag of the kelp

as it reduces crosshelf currents, and bottom topography. Evidence from waste sediments on the Palos Verdes shelf at kelp bed depths (Sweeney and Kaplan, 1980; Meistrell and Montagne, this symposium), indicate that the offshore edge of a kelp bed receives a greater impact than areas further into the bed. Current meter studies off central Point Loma (Jackson, this symposium), indicate that the crosshelf currents are reduced by the kelp bed, and wastes are probably confined mostly to the offshore part of the kelp bed.

Drogue studies at south Point Loma, conducted by the author at subthermocline depths, provide some insight into possible wastefield transport in that area (Figure 3). These studies were performed in areas that formerly supported Macrocystis, some of which are inshore of extant stands of kelp. During periods of downcoast flow at the offshore edge of the kelp bed (station C-3), water movement at the other two stations, was mostly along bottom contours, or crosshelf towards shore. During periods when currents are upcoast offshore of the bed, there is generally a crosshelf movement in an offshore direction. Subthermocline currents following bottom contours have been noted previously (Hendricks, 1977; Jackson, this symposium). At south Point Loma, such bottom contours move directly into the kelp. I believe that downcoast currents are associated with onshore transport, while upcoast currents are associated with offshore transport.

This may be explained by the fact that the southern part of the Point Loma bed is on a bathymetric ridge that separates the bight off Silver Strand Beach and the San Diego Bay entrance channel from the waters offshore of the kelp bed. Velocity

Figure 3.

Reuslts of drogue studies conducted off south Point Loma in subthermocline waters during 1981 and 1982. Drogues remained in the water 10 minutes or more.

A. General location of detailed charts shown in B through F. The proximity of the San Diego Bay entrance channel and the bight off Silver Strand Beach can be seen.

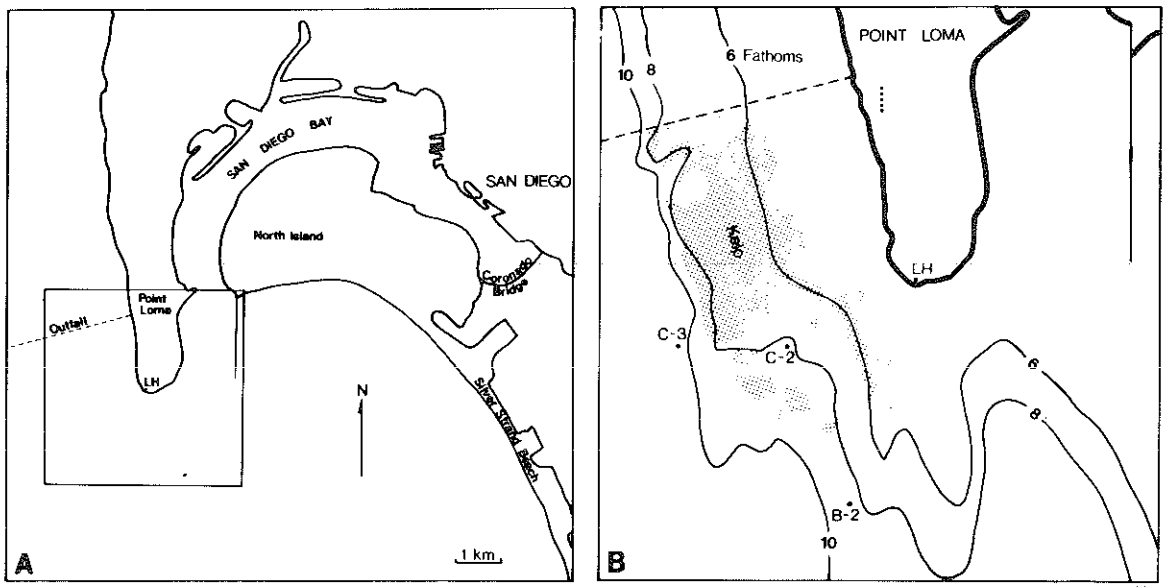
B. Relationship of the kelp canopy to station location during the course of the studies. Kelp formerly grew to depths of over 10 fathoms offshore and to the south of the canopy shown in B.

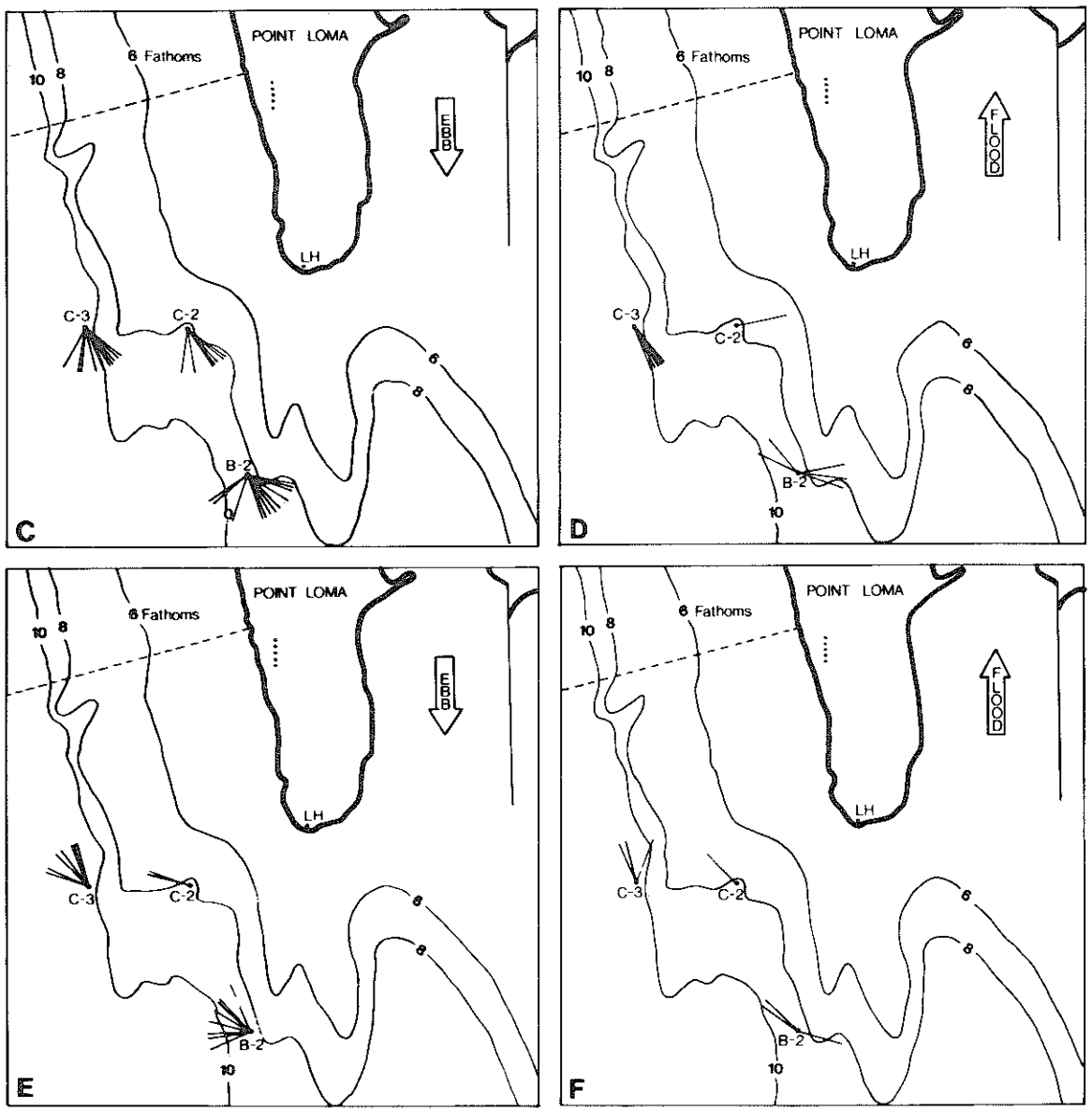
C. During downcoast current conditions at C-3, and ebbing tidal currents in the San Diego Bay entrance channel, currents at stations C-2 and B-2 were predominately along bottom contours, or onshore. These conditions would tend to transport wastes into the kelp bed from the offshore edge. Crosshelf currents with velocity components in excess of 10 cm/sec normal to the isobaths have been recorded at all 3 south Point Loma stations.

D. Similar to C, except tidal currents were flooding out of San Diego Bay.

E. During upcoast currents at C-3, and ebbing tidal currents out of San Diego Bay, offshore currents predominate at stations C-2 and B-2. Wastes along the offshore edge of the kelp bed would be transported away from the kelp bed by these currents. Wastes would be transported into the beds by an inshore source, such as San Diego Bay or the bight off Silver Strand.

F. Similar to E, except the tidal currents are flooding into San Diego Bay.





components, normal to the isobaths in an onshore direction and over 10 cm/sec, have been observed at all three drogue stations at south Point Loma shown in Figure 3. Thus, in this situation, if the wastefield reaches the offshore edge of the bed, it is more likely to penetrate well into the kelp than would be the case further north.

Effects stemming from San Diego Bay or the Silver Strand area, should be separated from possible effects of the Point Loma outfall.

Studies of waste transport have been conducted with drogues and current meters. Prediction of crosshelf currents with current meters, appear to differ from measurements of these currents with drogues (Hendricks, 1978). Therefore, studies are needed to determine why measures with current meters and drogues differ. These studies should provide guidelines for the proper use of each in evaluating waste transport.

Suspended materials:

After the waste material is realeased and diluted it rises and forms a plume that is moved by currents. Some of the material does not immediately settle and has potential impacts that need to be recognized independent of the impacts of other fractions of the wastes. Resuspended waste sediments may have effects similar to particulates suspended in the wastefield. For instance, it has been proposed that turbidity near the bottom is due in part to resuspension of waste particulates by wave surge (Meistrell and Montagne, this

Table 3. Results of coliform monitoring by the City of San Diego at stations A-1 and A-6. Data used in this table were for the September 1963 through June 1981 period. The greater abundance of high coliform counts (<1000 MPN/100ml) at water temperatures colder than 14°C, indicates the thermocline is a likely barrier separating high and low coliform containing waters. The temperature at the center of the seasonal thermocline in San Diego waters averages 14°C annually. The relationships between water temperature and coliform abundance is highly significant ($p<0.01$), based on a standard Chi-Square test for 2x2 contingency tables.

Coliform Counts	Water Temperature <14°C	Water Temperature ≥14°C
>1000MPN/100ml	32	16
≤1000MPN/100ml	31	86

symposium). It may be important to measure separately the ecological effects of the resuspended fraction and the suspended fraction because modifying the impact of these two different fractions may require different waste treatment strategies.

There are two ecological impacts of the wastefield suspended fraction that appear to be significant: toxicant transmport by particulates and the reduction of light reaching the bottom that is needed for the growth and reproduction of seaweeds. Ammonia, one component of the suspended fraction, probably does not have a significant ecological effect in kelp beds as either a toxicant, or a nutrient for plant growth (Jackson, this symposium).

Body-burden studies conducted with mussels (C.S.W.Q.C.B., 1982), suggest that the Point Loma outfall is responsible for possible toxicants in the nearshore waters off San Diego. However, we do not have enough information at this time to assess the possible ecological impact that toxicants in the water column may have. Any investigation of such toxicants must take into consideration that the toxicants are on particulates, and not in solution to any appreciable extent. Techniques similar to those employed with phytoplankton in the study of sewage particulates with attached toxicants (Hardin and Phillips, 1978), need to be developed for determining the effects of waste particulates with toxicants. This needs to be done before any routine research or monitoring studies of water column toxicant effects can be undertaken.

Results of monitoring studies at station A-1 off Point Loma, indicate there has been an increase in turbidity at a depth of 40 feet since the outfall was put into operation during September, 1963 (Figure 4). There is a highly significant ($p<0.01$) statistical

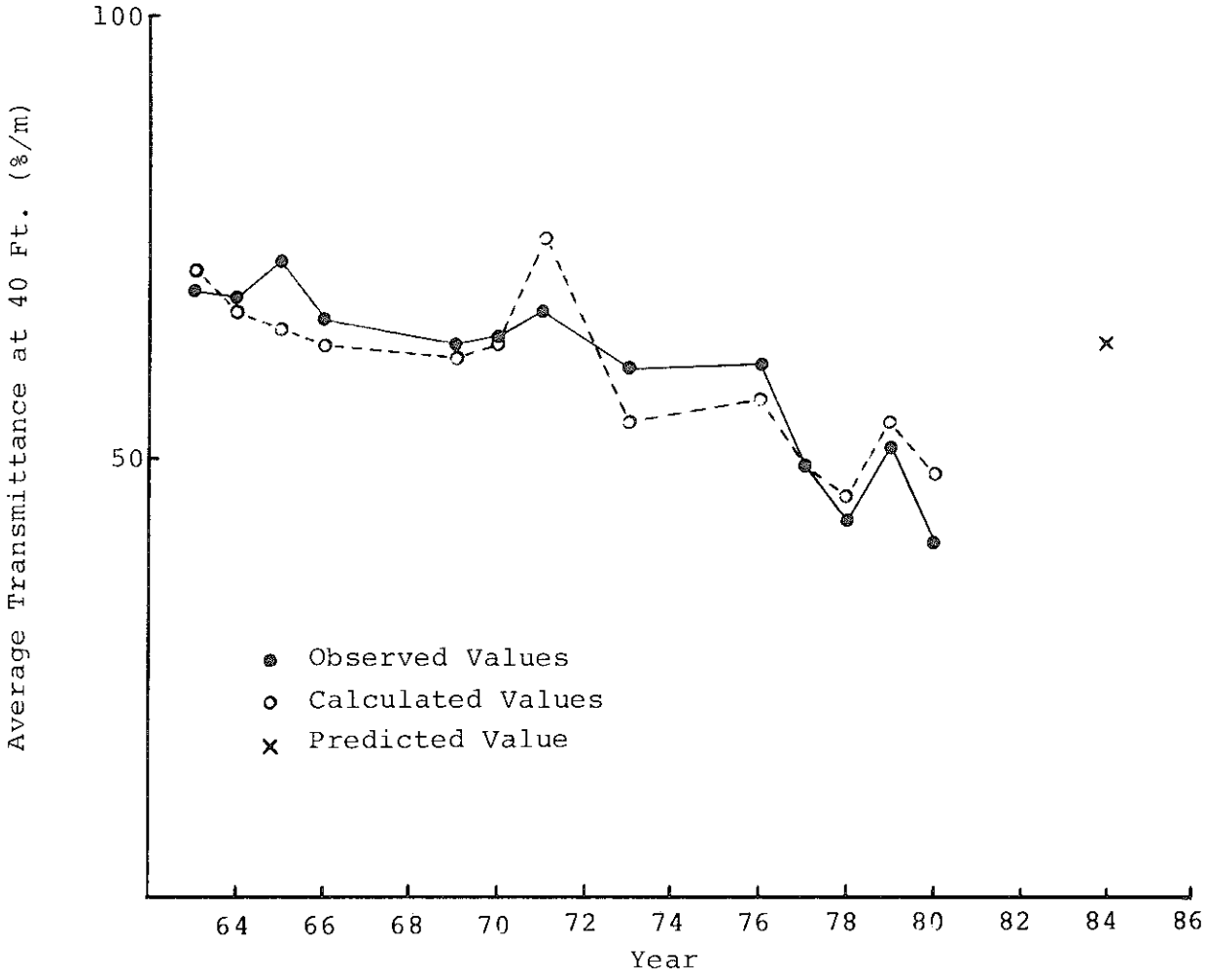


Figure 4.

Changes with time in annual average transmittance at a depth of 40 feet off the Point Loma kelp bed, based on monthly data collected by the City of San Diego at monitoring station A-1. Both mass emission rates [ME (lbs/day)] and a measure of the time the thermocline is at shallow depths [U (%/year)], are significantly ($p<.01$) correlated with transmittance [T (%/m)] in the following regression fit to the data:

$$T = 5.2 - 0.000132ME + 0.685U,$$

where r^2 (multiple) = .77 for the regression.

U (%/year) is calculated as the percentage of time in a year, that the daily water temperature, at a depth of 5 m off the Scripps Institution of Oceanography pier is colder than 14°C, and is used in the regression to provide a measure of natural variability. The predicted value for 1984 is shown to indicate how the model might be used to predict transmissivity if a mass emission rate goal of 86,400 lbs/day were met, and the U was at its long-term average of 18%.

relationship between average annual mass emission rates, and increases in turbidity, when changes due to variations in thermocline position are accounted for. The variation in the thermocline position was accounted for by the percentage of time in a year that the 5m water temperatures off the Scripps Institution of Oceanography pier was colder than 14°C. This temperature is the approximate average annual temperature of the center of the thermocline. This relationship indicates that discharged wastes are responsible in part for the increase in turbidity. Unfortunately, it is not possible from present measurements to separate the proportion of the turbidity increase due to suspended and resuspended fractions.

Relative to ecological significance, turbidity increases associated with mass emission rates, are best measured by determining the amount of sunlight reaching the bottom for plant growth and reproduction. At present, the monthly monitoring of turbidity off Point Loma with Secchi discs, and transmissometer measurements at 4 depths (Hamilton, this symposium), provides a rough measure of the availability of light at the bottom. Of these two techniques, the transmissivity measurements yield more information on the portion of the water column where the subthermocline wastefield is located. The depth at which the Secchi disc disappears is generally above the depth of the thermocline at Point Loma; therefore, the Secchi disc is of limited use for subthermocline wastefields.

A statistical model has been developed for San Onofre which relates transmissometer measurements to light reaching the bottom (Marine Review Committee, 1977). Using this model with transmisso-

meter monitoring records from the City of San Diego for station A-1, a decrease of over 50% in sunlight reaching the bottom is obtained when 1961-1964 is compared to the 1978-1981 period. With our present information, it is not possible to determine the proportion of this decrease due to mass emmission rates, as compared to other factors. To determine the role discharged wastes play in reducing light off Point Loma, we will need simultaneous measures of wastefield concentration, and transmissometer and irradiance profiles through the water columnat proper control stations. Such data would permit development of a statistical model.

Waste Sediments:

There are three important general effects of waste sediments which have been reported for kelp bed communities: 1. interference with the growth and reproduction of benthic organisms during microscopic stages; 2. enhancement of the growth and survival of sea urchins in barren grounds; and 3. increases in the effective concentrations of toxicants that settle out on biologically active surfaces. The effects of sediments have been studied, or enumerated by others (Weaver, 1978; Dean and Deysher, and North, this symposium), so they will not be discussed here. Because there is reason to suspect that waste sediments are at times being deposited in the Point Loma kelp bed, two aspects of measuring waste sediments will be considered below.

The first priority in measuring impacts of discharged waste sediments from the Point Loma outfall, should be to collect sediment on rocks and analyze the proportion due to discharged wastes. The sediments could be collected using techniques

described by Grigg (1978), and analyzed for waste proportions using methods of Sweeney and Kaplan, (1980).

Ecological Effects:

No systematic studies of discharged waste effects in San Diego area kelp beds have been conducted since 1965, when Turner *et al* (1968) initiated what they proposed to be annual surveys to determine changes related to the Point Loma outfall. As a result, possible ecological effects of discharged wastes from the Point Loma outfall must be inferred from anecdotal information, or from studies conducted for other purposes. To measure future changes in kelp bed communities due to the Point Loma outfall, or to be able to contrast kelp bed areas off San Diego with control beds for differences indicative of effects of discharged wastes, periodic biological surveys need to be conducted. The usefulness of general biological surveys conducted by divers to measure changes associated with outfalls off Palos Verdes has been demonstrated (Grigg, 1978; and Meistrell and Montagne, this symposium).

Aerial photographs showing the extent of *Macrocystis* surface canopies can, with appropriate precautions, provide an estimate of *Macrocystis* distribution. These photographs may also help show changes in populations of other organisms in kelp bed communities. In addition to the effects of discharged wastes, many other factors may affect what is photographed. Currents and tides can pull the kelp beneath the water; poor growing conditions can result in few fronds reaching the surface to be recorded photographically; sea urchin overgrazing, *Pterygophora* competition for space and light with *Macrocystis*, and extreme wave surge can all result in

either actual or apparent changes in the distribution of *Macrocystis* as judged from aerial photographs. In order to increase the usefulness of aerial photographs, diving or boat surveys should be conducted to provide "ground truth" and insights into the reason(s) for the change in kelp distribution.

DISTURBANCE MEDIATED COMPETITION BETWEEN MACROCYSTIS PYRIFERA AND ARTICULATED CORALLINE ALGAE

Raymond A. Wells*

The role of storm-induced disturbance on competition between the giant kelp, *Macrocystis pyrifera*, and the articulated coralline algae, *Lithothrix aspergillum* and *Corallina officinalis*, in the shallow subtidal algal community at Santa Catalina Island was investigated. The co-existence of *M. pyrifera* and articulated coralline algae is mediated by storm-caused clearance. Evidence from a "natural experiment" is provided to suggest that articulated corallines are competitively superior to *M. pyrifera* in the study site by virtue of the ability to tolerate strong surge and to prevent *Macrocystis* recruitment. Young *M. pyrifera* sporophytes appear only on bare substratum. It is suggested that in the absence of storms development of a dense *Macrocystis* stand would reduce the abundance of corallines. The timing and intensity of storms which clear articulated corallines determines the distribution and abundance of *M. pyrifera*.

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The giant kelp, Macrocystis pyrifera forms extensive stands along the California coast within which it influences the distribution of other algae (Dawson, et al. 1960; Neushul 1965; North 1964; Foster 1975; Pearse and Hines 1979). Macrocystis beds are subject to fluctuations in population density which have included local extinctions (Rosenthal et al. 1974). Several possible explanations of decreases in kelp population densities have been advanced. Sustained periods of warm water temperatures (MacFarland and Prescott 1959; Clendenning 1971; North 1971; Lobban 1978), nutrient depletion (Zimmerman, pers. comm.) and storm related surge (Rosenthal et al. 1974) have been suggested as causes of natural fluctuations in kelp abundance. Additionally, the subtidal discharge of treated sewage is implicated in the destruction of kelp beds by sea urchin grazing in several locations in southern California (North 1964b, Leighton et al. 1966). Persistence of Macrocystis stands following density reducing disturbances depends upon self-propagation or seeding of new recruits. Colonization by canopy forming competitors of Macrocystis following a disturbance is suggested to inhibit M. pyrifera recruitment (North 1971). Equally important as potentially limiting the distribution of Macrocystis are those factors which influence the ability of recruits to obtain attachment surface. DeVinny and Volse (1978) have found sediments to have a potentially deleterious effect on the attachment and development of Macrocystis gametophytes. Interactions between Macrocystis and non-canopy forming algae may also affect recruitment ability. The influence of competition

for attachment substratum between Macrocystis and non-canopy forming algal species is the subject of this investigation. A thorough understanding of the biotic relationships controlling the distribution and abundance of Macrocystis is prerequisite to assessing the effects of man-induced disturbances. Naturally occurring disturbance has been demonstrated to be an important factor in determining the distribution of marine algae, the presence of some species being dependent upon periodic disturbances (Dayton 1975; Lieberman 1979; Paine 1979; Sousa 1979). In this study I examine the effects of disturbance on competition between the turf-forming articulated algae Lithothrix aspergillum and Corallina officinalis, and Macrocystis pyrifera in a shallow subtidal system. I present correlative evidence suggesting that (1) articulated coralline algae compete for space with Macrocystis by preventing attachment to suitable substratum and (2) the distribution and abundance of M. pyrifera in the study site is determined by surge induced disturbance which removes articulated corallines.

Study Site

This study was conducted in the shallow subtidal region of Big Fisherman's Cove, Santa Catalina Island, California between December 1980 and December 1982. Big Fisherman's Cove is located in a sheltered position on the leeward side of the Island and receives swells only from northwesterly storms which occur infrequently between November and March. The study site is located on the north wall of the Cove and extends from a point at

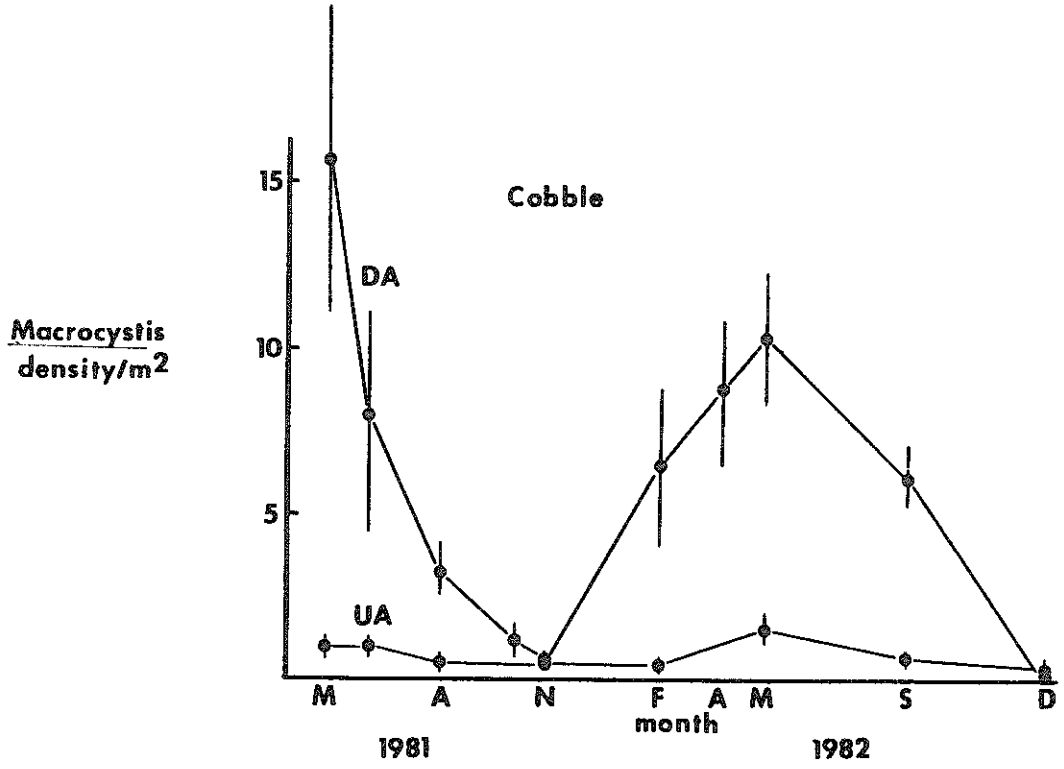

Figure 1. Variation in Macrocystis density on cobble substratum in the e disturbed and undisturbed areas during the study period. Bars indicate standard error of the mean. DA= disturbed area, UA= undisturbed area.

the mouth 60 M inwards. The outermost portion of the site (approximately 30 M of shore) is exposed to swell generated turbulence, primarily in the form of surge which results from rebound off the wall of the Cove. These two areas are subject to different disturbance regimes during storms and are defined for this study as the "disturbed" and "undisturbed" areas. Cobble, or substratum unstable with respect to overturning by surge, and bench rock, or stable substratum, is present under both disturbance regimes.

The study site is at depths between 5 and 8 M on a shelf extending approximately 15 M from the north wall of the Cove

towards the center. The substratum consists of approximately horizontal bench rock which separates large patches of cobble and boulders. Beyond the shelf is a sharp incline ending on a sandy bottom at a depth of 19 M.

Methods

Macrocystis pyrifera is a perennial brown alga with an alternation of an inconspicuous gametophyte and large sporophyte generation (Brandt 1923; Neushul and Haxo 1963). Young sporophytes appear in the early spring (Foster 1975; Ambrose and Nelson, 1982) and may grow to produce canopy by September (pers. obs.). Lithothrix aspergillum and Corallina officinalis are articulated coralline algae which occur together in the study site forming a mixed species turf-like mat. Their life cycles include isomorphic gametophyte and tetrasporophyte generations (Bold and Wynne 1978). Settlement and growth of both species was observed throughtout the year however the greatest amount occurred in early spring (Figs. 4 & 5). These two species were lumped as "articulated coralline algae" for the purposes of this study. The crustose coralline algae Lithothamnion sp.and Lithophyllum sp., and in some cases the crustose holdfasts of articulated coralline were combined in the analyses due to difficulty of field identifications.

Sampling of algae on cobble and bench rock substrata was initiated in March (cobble) and July (bench) 1981 respectively and conducted at three to four month intervals. Several transects parallel to the shoreline were censused. The sampling interval along the 15 M transect lines was 0.25 M. All species present

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          RELATIVE
         FREQUENCY   DISTURBED: BENCH ROCK     UNDISTURBED:BENCH ROCK

                                 50          100            50          100

        NO COVER
 March  CRUST.COR.
        ART.COR.
        MACROCYSTIS


1981    NO COVER
 July   CRUST.COR.    ******                      ***
        ART.COR.      **********************      ************************
        MACROCYSTIS   ***


        NO COVER
 Oct.   CRUST.COR.    **                          *
        ART.COR.      ****************            *************************
        MACROCYSTIS


        NO COVER
 Feb.   CRUST.COR.    **
        ART.COR.      ************************ ************************
        MACROCYSTIS


1982    NO COVER
 May    CRUST.COR.    ***                         *
        ART.COR.      ************************ ************************
        MACROCYSTIS   ********                    *


        NO COVER
 Sept.  CRUST.COR.    *                           *
        ART.COR.      ************************ ************************
        MACROCYSTIS   ***
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Figure 3. The relative frequencies of articulated coralline algae, crustose coralline algae, bare rock (no cover), and *Macrocystis* on bench rock substratum in the disturbed and undisturbed areas.

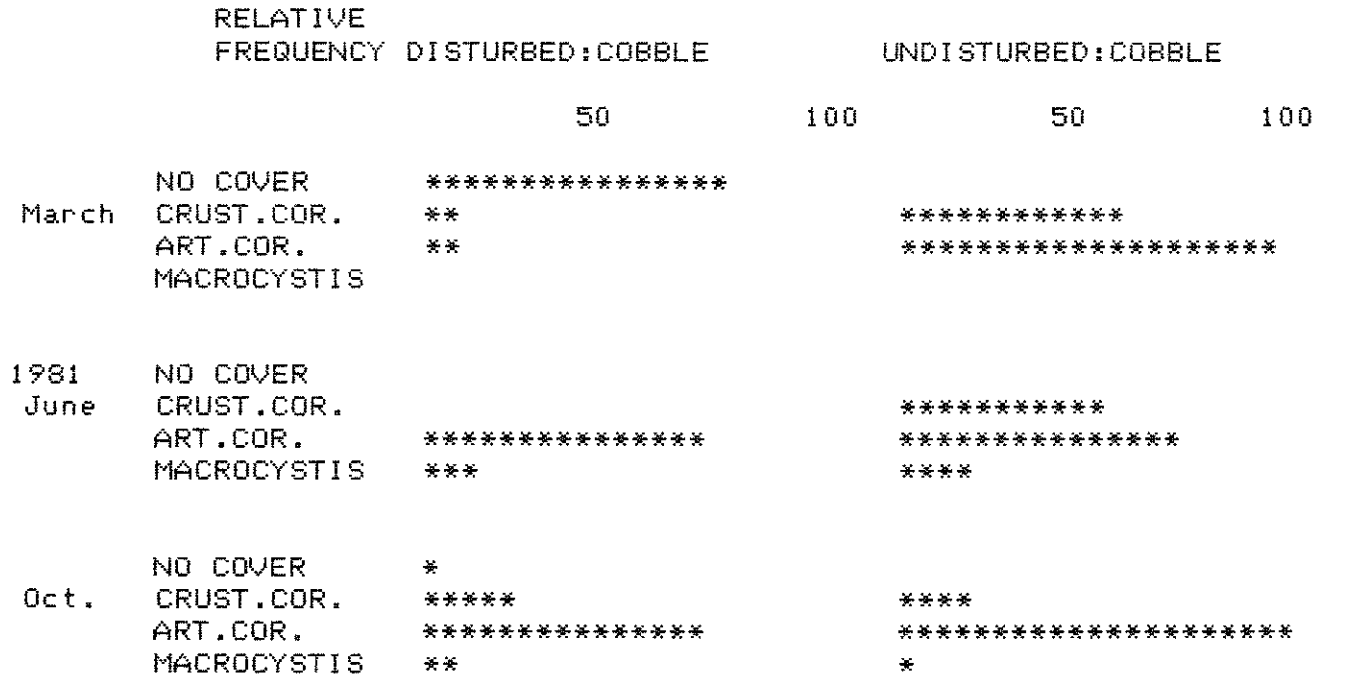

Figure 4. The relative frequencies of articulated coralline algae, crustose coralline algae, bare rock (no cover), and *Macrocystis* on cobble substratum in the disturbed and undisturbed areas.

under or over a point were recorded. Canopy cover from taller species such as Macrocystis and Eisenia was distinguished from that provided by the lower growing turf-like species. Sampling was stratified with respect to both disturbance regime (disturbed and undisturbed) and substratum type (cobble and bench rock).

The frequency of occurrence of articulated coralline algae, crustose coralline algae and bare rock was compared between substratum types within each disturbance regime, and on the same substratum types between disturbance regimes using contingency table analyses. In some comparisons the value in the category of "no cover" was too low to be included in the analysis in which case it was reduced from a 3x2 to 2x2 design. A significance level of 0.05 was chosen for the Chi-square test.

The density of Macrocystis plants was estimated beginning in May 1981 using 1 m2 quadrats arranged checkerboard fashion along transects parallel to the shore line. Twenty quadrats were

SETTLEMEMT SUBSTRATUM	%	RELATIVE FREQUENCY 25 50
N/C	43	**********
Crust.Cor.	38	**********
Bryozoans	19	*********
Art.Cor.	0	0

Figure 5. The attachment substratum of 80 young Macrocystis sporophytes at the one-blade stage, sampled 7 March 1982. The substrata are: no cover (N/C); crustose coralline algae (Crust. Cor.); Bryozoans and articulated coralline algae (Art. Cor.)

censused on each substratum type in both disturbance regimes at each sampling.

The nature of the substratum of attachment of young Macrocystis sporophyte recruits was examined. The type of surface on which small sporophytes not exceeding 2 cm in total length were attached was recorded. The frequency of attachment of recruits to different substratum types was compared to the relative availability of the substrata in a contingency analysis.

Portions of the cohorts of Macrocystis sporophytes recruiting onto cobble substratum in the spring of 1981 and 1982 were tagged to estimate persistence. Plants at the single blade stage with a total length of approximately 20 cm were marked.Forty were tagged in the disturbed area in 1981. In May 1982 a total of 132 plants were marked with the numbers evenly

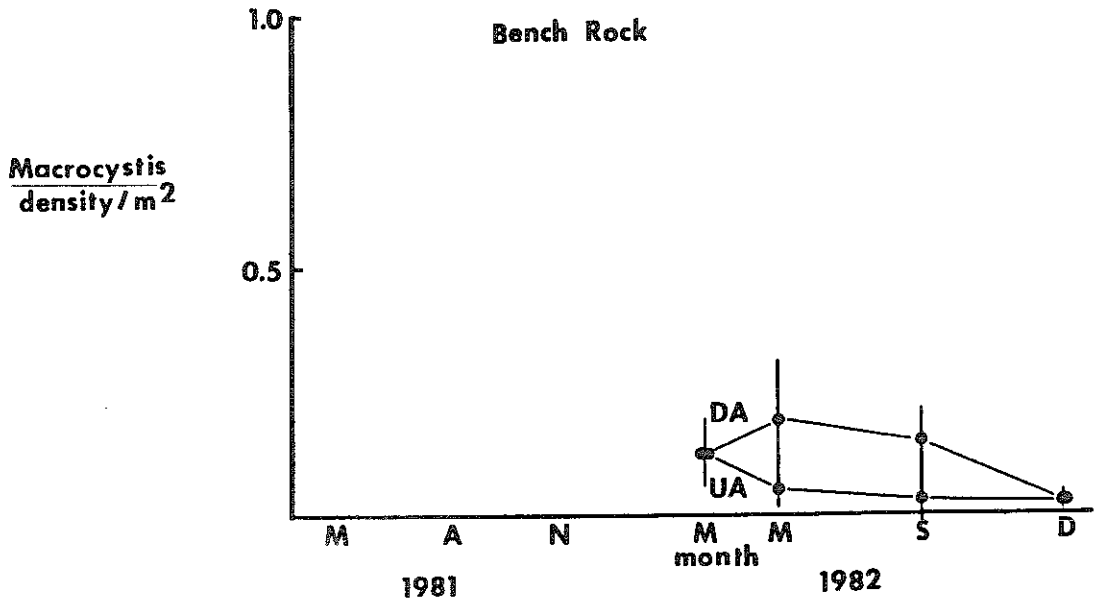

Figure 2. Variation in Macrocystis density on bench rock substratum in the disturbed and undsiturbed areas during the study period. Bars indicate standard error of the mean. DA= disturbed area, UA= undisturbed area.

divided between the disturbed and undisturbed areas. Censuses of tagged individuals were conducted in February 1981, and September and December 1982.

Results

Algal Abundance.

The initial sampling of cobble substratum followed a violent northwesterly storm which denuded a large portion of the disturbed area. (Initially it was felt that larger rocks, or boulders, which were firmly embedded in the bottom would not be subject to surge induced clearance. This was proven to be wrong as battering from the smaller cobble was effective in removing vegetation from boulders.) Bare rock was the most abundant category (Fig. 4). Very little articulated or crustose coralline algae were present. Following the disturbance, the amount of bare rock disappeared by June while the abundance of articulated coralline algae increased through October 1981. Crustose coralline algae increased in frequency from 20% in October to a peak in May 1982 of 92%. A northwesterly storm occurring again in January 1982 slightly reduced the amount of articulated corallines while producing an increase in the amount of bare rock sampled in the February sampling. By May and continuing through September 1982 articulated coralline algae dominated cover with 100% frequency. Canopy cover from Macrocystis increased from 0% to 11% in June 1981 and 52% in September 1982. Macrocystis cover was sharply reduced following the January 1982 disturbance and all plants were removed by a storm occurring in December 1982. Articulated coralline algae were the most abundant category of

cover throughout the study period with a relative frequency of nearly 100% for all sampling dates except June 1981. Crustose coralline algae were present at all dates but with the lowest abundances occurring during the winter.

Beginning with July 1982 no bare rock was present on bench rock in either the disturbed or undisturbed areas (Fig. 3). Articulated coralline algae were dominant in both areas for all sampling dates. On four of the five sampling dates the relative frequency of articulated corallines was 100%. Crustose corallines were low in abundance.

Frequency Distribution Comparisons

Differences between the algal distributions on substrata of different stability was pronounced. The algal frequency distributions differed significantly between cobble and bench rock in both the disturbed and undisturbed areas for all sampling dates ($p<0.01$ all compsarisons). Crustose corallines were more abundant on cobble while articulated corallines dominated bench rock.

The algal frequency distributions on bench rock in the two disturbance regimes were generally more similar and did not differ on two of the five sampling dates (Feb. and Sept., Table I). The differences in the algal frequency distributions on the other three sampling dates were the result of fluctuation in the frequency of crustose corallines, which were low in abundance.

The distribution of algae on cobble substratum, compared between the two disturbance regimes, differed for the first four sampling dates (Table II). By May 1982 and extending through

Table I. Results of a 2x2 contingency table analysis comparing the frequency distributions of crustose and articulated coralline algae on bench rock substratum between the disturbed and undisturbed areas.
Significance level= 0.05.

	Month	Chi-square value	Significance level
1981	July	7.75	$p < 0.01$
	Oct.	4.56	$p < 0.05$
1982	Feb.	2.45	ns
	May	5.24	$p < 0.05$
	Sept.	0.12	ns

September there were no differences between the sites. The increase in similarity between the sites was brought about by a decrease in the frequency of disturbance provided bare rock and an increase in the abundance of articulated coralline algae in the disturbed area. Crustose coralline algae showed a general increase over time in both the disturbed and undisturbed areas.

Macrocystis Density

Macrocystis density on unstable cobble substratum in the disturbed area showed peaks at the first sampling in May 1981 and again in May 1982 reflecting spring recruitment of sporophytes (Fig. 1). Northwesterly storms occurred in January 1981, January 1982 and again in early December 1982. Each of these disturbances sharply reduced *Macrocystis* density and provided bare rock by removing existing vegetation from the substratum (Fig. 4). *Macrocystis* density on cobble substratum in the undisturbed area (0.2 - 1.4 plants/m2), as well as on bench rock

Table II. Results of a 2x3 contingency table analysis comparing the frequency distributions of crustose coralline algae, articulated coralline algae and no cover (bare rock) on cobble substratum between the disturbed and undisturbed areas. Significance level= 0.05.

	Month	Chi-square value	Significance level
1981	March	228	$p < 0.001$
	July	8.3	$p < 0.01$
	Oct.	6.8	$p < 0.05$
1982	Feb.	57.6	$p < 0.01$
	May	1.19	ns
	Sept.	1.31	ns

(Fig. 2) in both disturbance regimes (0.05 - 0.3 plants/m2), remained low and little recruitment was observed throughout the study. The density of *Macrocystis* was significantly higher on cobble substratum than on bench rock in both the disturbed and undisturbed areas (2-way Anova, $p<0.001$). The density of plants on cobble substratum in the disturbed area was an order of magnitude greater than in the undisturbed area. There was no significant difference between the density of plants on bench rock in the disturbed and undisturbed areas.

Macrocystis Persistence.

Twenty percent of the Spring 1981 cohort in the disturbed cobble area survived through the February 1982 census, however none of these individuals were located in December 1982. Survivorship of the plants tagged in May 1982 was higher in the

undisturbed than the disturbed area; in the September census 78.3% of the plants in the undisturbed area were located and 66.7% in the disturbed area. Following the storm disturbance in December 1982 only a single plant (1.4%) remained in the disturbed area and survivorship in the undisturbed area was reduced to 11.7%.

Loss of plants was due to several factors. Macrocystis settled on substrata of all sizes including pebbles and small cobble. Many of the plants on unstable substrata were transported from the site after buoyancy from the pneumatocysts became greater than the weight of the attachment substratum. These plants either floated away or were carried by tidal currents. Tagged plants were recovered as far away as 140 M as well as downslope from the study site to a depth of 19 M. There was also a considerable amount of movement of tagged plants within the study site. Northwesterly storms removed plants by carrying them away while they were attached to the substratum, tumbling the substratum, by tangling the canopies in drifting kelp rafts. The same causes of attrition have been observed in kelp beds at much greater depths (Rosenthal et al. 1974). Removal of Macrocystis sporophytes from the undisturbed cobble area and bench rock, although infrequently observed, is attributed to the last mechanism since no evidence of substratum disturbance was ever found.

Attachment Substratum.

The attachment substratum of eighty young Macrocystis sporophytes at the one-blade stage was examined in the disturbed

cobble area on 7 March 1982. Available attachment substratum consisted of articulated coralline algae, crustose coralline algae, and bare rock. Due to the abraded condition of the rock surfaces it was not possible to distinguish crustose coralline species from the crustose bases of articulated corallines. Additionally, small, recently settled colonies of an encrusting bryozoan were present on bare rock. No quantitative estimate of bryozoan abundance was attempted, however I visually estimated the cover to be less than 10%. Therefore for the purposes of the analysis the number of recruits attached to bryozoans is lumped in the bare rock category.

Forty-three percent of the recruits were attached to bare rock, 38% on crustose coralline algae, and 19% on bryozoans (Fig. 5). No settlement was observed on articulated coralline algae. The distribution of young Macrocystis sporophytes among the substratum types differs from the abundance of the substrata (Chi-2=7.75; d.f.=1; $p<0.01$). Although no comment can be made concerning settlement substratum preference, young sporophytes are found in greater proportions on bare rock than its abundance alone would predict. Settlement occurred on abraded crustose coralline algae and/or the bases of articulated coralline algae in approximate proportion to availability .

Discussion

Observations of settlement substratum and the pattern of Macrocystis pyrifera suggest that (1) articulated coralline algae compete for space with M. pyrifera by preventing attachment to

suitable substratum and (2) the distribution and abundance of Macrocystis is limited by disturbance which removes articulated corallines and makes space available for Macrocystis attachment.

Lithothrix aspergillum and Corallina officinalis are competitively superior to Macrocystis pyrifera in thte study site by virtue of their ability to: (1) withstand strong surge conditions; (2) prevent settlement of M. pyrifera; and (3) rapidly re-colonize surfaces by growth from persistent crustose holdfasts.

Macrocystis was capable of recruiting in appreciable numbers only onto unstable cobble substratum in the disturbed area. The failure of recruitment onto articulated coralline dominated bench rock under the same disturbance regime suggests that water movement alone is not responsible for the difference in M. pyrifera density between substrata. Macrocystis appeared on cobble more than on bench rock in both the disturbed and undisturbed areas. This corresponded to differences in the abundance of crustose coralline algae onto which M. pyrifera was shown to recruit. The large difference between Macrocystis density on cobble substratum between the two disturbance regimes is suggested to be caused by setlement of gametophytes on rocks cleared of articulated corallines by tumbling. Observations of the attachment substratum of young M. pyrifera sporophytes provides evidence that bare rock and abraded crustose/articulated corallines are suitable surfaces for settlement and growth. The competitive interactions with articulated corallines which limit Macrocystis abundance occur at, or shortly following

settlement. Young sporophytes successfully competed for space and were observed to increase substratum space by overgrowing corallines. Macrocystis recruiting in Spring 1982 onto storm provided attachment substratum persisted and grew to form canopy concurrent with an increase in articulated coralline relative frequency to 100%. Corallines quickly regain space following disturbances due to the persistence and rapid growth of their crustose holdfasts. These species are also effective in competitively excluding recruits of Sargassum muticum (another canopy-forming brown alga) by this means (pers. obs.).

The distribution and abundance of Macrocystis pyrifera within the study site is determined by disturbance mediated competitive interactions. Establishment of M. pyrifera on substratum not subject to disturbance is prevented by space-holding articulated coralline algae. Attachment surface is restricted to unstable substratum and is provided on a seasonal basis by storms. Coexistence of these two perennial competitors is likely due to the frequency and intensity of disturbance which prevents dominance by either species. Lieberamn (1979) has suggested this explanation for coexistence of several algal species on cobble in a seasonally devastated site in Ghana. Each year's cohort of Macrocystis is reduced in numbers during the winter, thereby preventing development of extensive canopy and concomitant changes in understory algae. The timing of clearance of articulated corallines allows a window through which Macrocystis can recruit before articulated corallines re-establish. Experimental manipulations simulating disturbance of

cobble at different times of year have demonstrated that surfaces exposed in the summer will become dominated by articulated corallines by the following spring and prevent settlement of other species (pers. obs.).

KELP RESTORATION

Ken Wilson* and Ron McPeak**

Forests, or beds of giant kelp, Macrocystis pyrifera, occur in California waters from San Mateo County to the Mexican border. Kelp forests are reported to be as complex as terrestrial rain forests (Foster 1975) and provide substrate, food, and habitat for a wide variety of marine organisms, including fishes (Feder, et al. 1974), and a myriad of invertebrates, many of which are of direct importance to sport and commercial fisheries. Marine birds and mammals, including the sea otter, also find food and refuge in Macrocystis forests. Forests of giant kelp in California also provide the basis for a kelp harvesting industry whose sales exceed $35 million a year. This industry has harvested as much as 155,000 metric tons of kelp annually in California.

Long-term surveillance of remote kelp forests in central California, within the range of the sea otter, suggests that kelp forests along the California coastline in pre-historic times were relatively stable in comparison with those occuring near large metropolitan areas today. This stability could, in part, be attributed to the effects of foraging sea otters on herbivorous invertebrates such as sea urchins and abalone.

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**Kelco Division of Merck and Company

Following the extirpation of sea otters from California waters in the early 1800's, records indicate that kelp beds remained relatively stable until the mid-twentieth century.

In the mid-forties, kelp forests adjacent to some large metropolitan areas in southern California, began to deteriorate (CSWQCB 1964). This deterioration was attributed to a complex combination of biological changes resulting from man's activities as well as natural factors. Increasingly large amounts of domestic and industrial wastes were discharged from marine sewage outfalls near San Diego and Los Angeles (Wilson *et al.*, 1980). The effluents increased turbidity, diminished the quantity and quality of light available for photosynthesis, and increased sedimentation, burying substrate otherwise suitable for germination and growth of *Macrocystis* (Peterson 1974; Devinney and Volse 1978). Sewage discharges also contained large amounts of potentially toxic chemicals (CSWQCB 1964, Grigg and Kiwala 1970; Grigg 1979).

Pollution problems were complicated by long-term intensive harvesting of lobsters (*Panulirus interruptus*) and sheephead *Semicossyphus pulcher*), important predators of sea urchins, and harvesting of abalone, important competitors of sea urchins. In the absense of these biological controls, sea urchin populations increased significantly (Tegner 1980; Tegner and Dayton, 1981) and through intensive grazing of kelp plants and associated vegetation (CSWQCB 1964; Leighton *et al.* 1966), kelp beds were destabilized. Grazing by urchins eventually contributed to the total destruction of kelp beds off Palos Verdes Peninsula

and the near total destruction off Point Loma. A series of warm water years occurring from 1957 through 1959, also contributed to these declines (Radovich 1961).

In an effort to reverse this trend, kelp restoration operations were undertaken off San Diego in 1963 in what remained of the Point Loma kelp beds. These efforts proved successful (North 1967). Kelp canopies at Point Loma had increased from approximately 25 ha in 1963 to over 800 ha in 1967 (North 1968). Prior to and during the 1963-1967 period of restoration, changes in dredging practices in San Diego and Mission Bay (CSWQCB 1964), and waste discharges into San Diego Bay (CSWQCB 1964; North 1965) probably improved the growing conditions for kelp. A change in oceanographic factors that favored kelp growth, also occurred during this period (Barilotti in preparation). The sum total of restoration, changes in water quality and oceanographic conditions, probably account for the dramatic recovery shown by the Point Loma bed. Kelco Company of San Diego continued the restoration work at Point Loma after 1968.

In 1967, when Dr. Wheeler North of the California Institute of Technology (Cal Tech) began kelp restoration operations off Palos Verdes Peninsula, only two known adult Macrocystis plants remained of the original 600 ha kelp forest (North 1967; CSWQCB 1964). The Department of Fish and Game (DFG) began parallel restoration efforts in 1971 and, by 1974, these efforts produced the first naturally expanding kelp bed seen off Palos Verdes Peninsula in over twenty years. Cal Tech and

DFG began work at eight additional sites on Palos Verdes Peninsula in an effort to establish nuclei of kelp beds which would grow and reproduce to eventually replace former beds. Today, a 280 ha kelp forest exists off Palos Verdes Peninsula.

Improvements in the quality of waste discharges, a growing fishery for red sea urchins, and kelp restoration work, continued to bring about further increases in kelp forests in southern California.

The history of kelp restoration in southern California is discussed in greater detail in Wilson, et. al. 1978 .

Methods:

Kelp restoration methods have evolved considerably since the first efforts were initiated in 1963. Techniques used off Palos Verdes Peninsula and Point Loma will be outlined to illustrate methods commonly employed.

Restoration work may be divided into four aspects: 1) grazer control; 2) kelp transplantation; 3) competitor control, and; 4) monitoring.

Opaleye, *Girella nigricans*, and halfmoon, *Medialuna californiensis*, are the two fish species most commonly associated with grazing damage to *Macrocystis*. These fishes did not cause problems at Point Loma, but did considerable damage to transplanted *Macrocystis* at Palos Verdes in the early 1970's. Fish traps and spearfishing efforts proved inefficient for control. Gill nets were tested and captured large numbers of herbivorous fishes, but they also took large numbers of non-target species.

Fish exclosures were constructed around transplanted kelp, but required excessive maintenance. All efforts to control herbivorous fishes were subsequently abandoned.

Three species of sea urchins, Strongylocentrotus franciscanus, the red urchin; S. purpuratus, the purple urchin; and Lytechninus anamesus, the white urchin, are the invertebrates most commonly associated with damage to southern California kelp forests. Red and purple urchins actually prefer Macrocystis to other species of algae (Leighton, 1966, 1971). Densities of urchins often exceed 50/m^2 at Point Loma and Palos

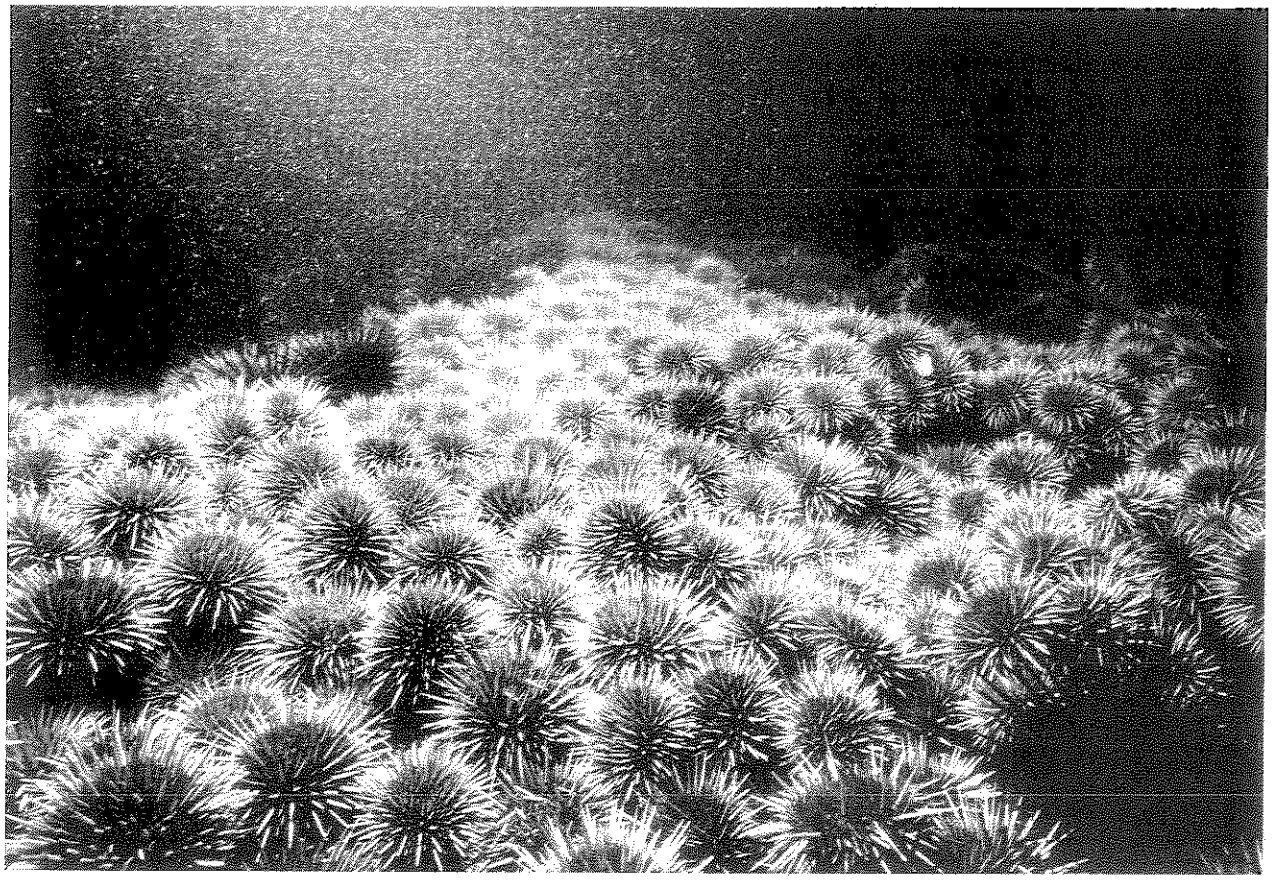

Figure 1: Sea urchin population off So. Point Loma - January, 1982. The population consists primarily of purple sea urchins (Strongylocentrotus purpuratus) which exceed 100/m^2.

Verdes (Figure 1). As few as one urchin per m^2 can prevent the development of Macrocystis. Consequently many of these areas have been urchin dominated since the mid-sixties. Leighton, et al. 1966, suggest that urchin numbers must be reduced over a minimum area of 5,000/m^2 to create a relatively stable kelp stand or to expand existing beds. Four urchin control techniques have been used to accomplish this: 1) hammering; 2) suction dredging; 3) quickliming (CaO), and; 4) commerical fishing.

Hammering:

Hammering is the most selective and least complex method of urchin control because it does not affect non-target species and requires minimal equipment. The most effective hammers for controlling sea urchins are welder's slag hammers, carpenter's hammers with straight claws, or lightweight geologist picks. At low urchin densities (2.0/m^2), divers can control approximately 1,400 urchins per hour. Control rates, at densities of 15.5 urchins/m^2, averaged over 2,700 urchins/hr. Control rates of over 3,000 urchins/hr. were accomplished in areas where urchins averaged 30/m^2 over flat pavement substrate.

Hammering is most cost effective in areas where urchins averaged less than 5/m^2. In these areas, divers can easily control an acre of urchin substrate during a day of diving. For example, Kelco biologists used hammers to control urchins in 50 ha at south Point Loma in 1981. This work resulted in development of 30 ha of Macrocystis canopy at south Point Loma

by summer of 1982. The remaining 20 ha recruited Macrocystis during 1982 and will produce canopy in 1983.

Suction Dredging:

Kelco Company of San Diego is presently using a large suction pump for controlling urchins (Figure 2). The 10 cm

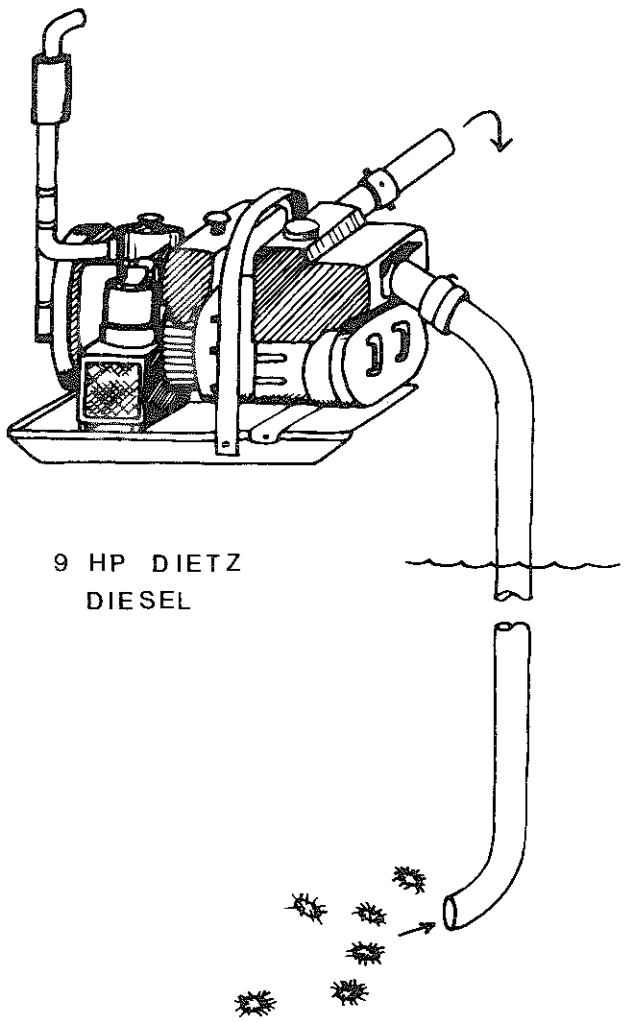

Figure 2. Suction dredge used by Kelco biologists to control sea urchins.

pump is powered by a 9 HP Dietz Diesel and delivers 2800 l of seawater per minute. Divers direct the 10 cm diameter hose to areas where sea urchin densities exceed $30/m^2$. Urchins are

dislodged with a hand rake prior to dredging. The loose urchins are then sucked through the hose to the surface, where they are crushed by the pump and eventually returned to the ocean. The pump is not cost effective in areas of low urchin densities.

The dredge is presently being used where urchins are concentrated by baiting with Macrocystis fronds. Divers collect Macrocystis from nearby kelp beds. Several large mesh bags are each filled with approximately 60 kg of kelp. The bouyant bags of Macrocystis are weighted and taken to the bottom where the fronds are removed. Rocks are used to hold the loose fronds in place. Urchins are concentrated to numbers frequently exceeding $100/m^2$ within two or three days. Divers return with the dredge system to control the population. The dredge technique is still being developed. At present, this technique is approximately half as cost effective as quicklime in high urchin density areas.

Quickliming:

Quicklime or calcium oxide (CaO) was the first used to control dense sea urchin concentrations off Point Loma in 1963 (IMR 1963). Until 1976, it was dispersed in pebblized form upon the surface of the water over the stern of a boat. Using this technique, much of the effectiveness of the CaO was lost during its descent through the water column. Approximately 4.5 metric tons of CaO per hectare were required to adequately reduce urchin densities in water 12 m to 21 m deep.

In 1976, a diver-directed quickliming device (Figure 3) was developed by Kelco Company of San Diego (Wilson, et al.

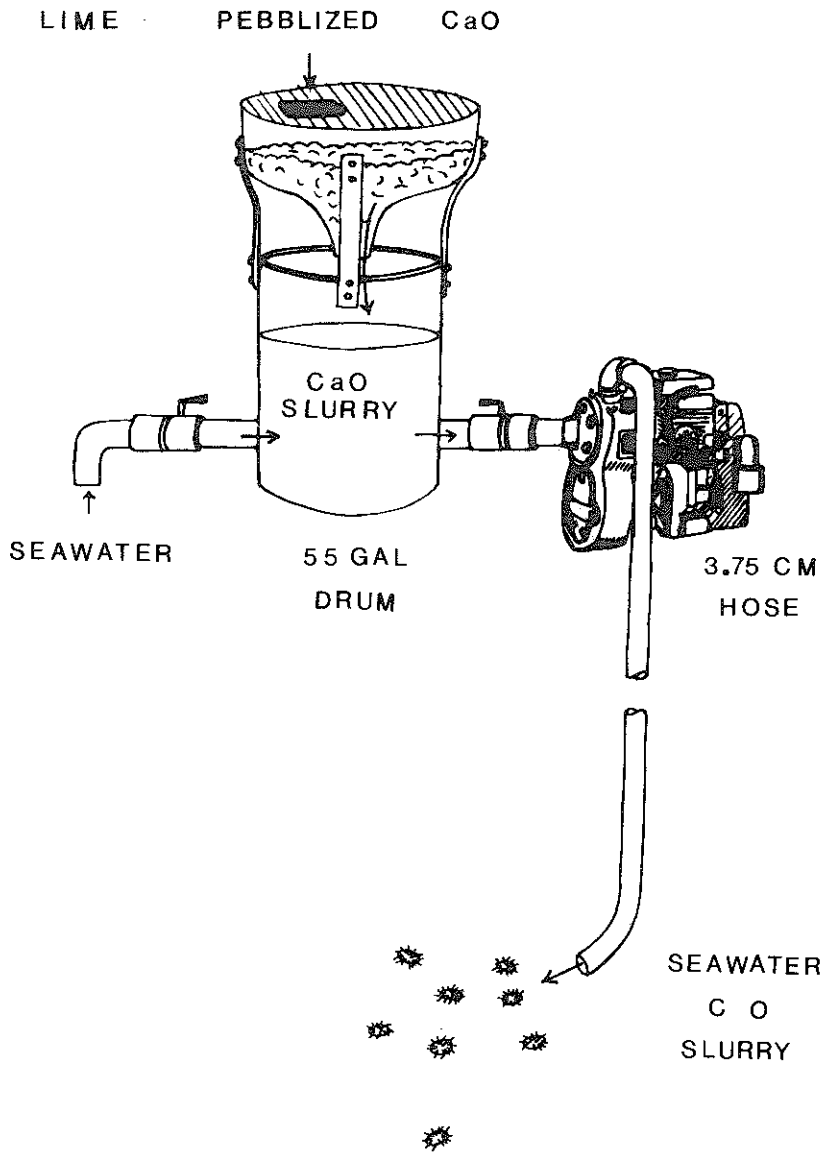

Figure 3. Diver-directed quickliming device.

1978). Using this equipment, pebblized CaO was mixed with sea water to form a slurry and pumped through a 3.75 cm diameter hose to the bottom, where divers directed the slurry upon sea urchin concentrations. This method had several advantages over the earlier technique. These were:

1. Better control - divers were able to more precisely direct the CaO. Furthermore, diver to surface communications permitted the diver-operator to cut off the flow of CaO

if substantial numbers of non-target species were observed, thus minimizing effects on other organisms.

2. Less quicklime - due to increased efficiency of dispersal, the amount of CaO used in treating an urchin-dominated area was reduced to approximately 3.5-3.8 metric tons/ha.

This technique allows one diver to treat .4 ha (one acre) of urchin-dominated bottom in approximately three hours of diving, irrespective of urchin density. Other techniques, particularly hammering, require additional time as the density of urchins increases.

Commercial Fishing:

Red sea urchins have been harvested commercially in California since 1972. There is no commercial fishery for purple or white sea urchins. The affect of sea urchin fishing on the *Macrocystis* community varies considerably, depending upon the numbers and species of the urchin population. Approximately 1.59 million kg of red urchins, or about 4.7 million individuals, were harvested from the Palos Verdes Peninsula, from 1973 through the present (Parker[1], pers. comm.). The commerical harvest of red urchins off Palos Verdes Peninsula, contributed considerably to the return of kelp forest along the Santa Monica Bay coastline and from Portuguese Point to Point Fermin. Presumably, red sea urchins were the dominant species of urchin present in areas being harvested while white and purple urchins were few in number.

San Diego sea urchin landings have increased from 1820

1. David O Parker, Calif. of Fish & Game
1301 W. 12th St., Long Beach 90813

kg in 1972 to approximately 950,000 kg in 1981. Most of the San Diego landings have been taken from Point Loma and La Jolla kelp beds with a small percentage from San Clemente Island. Sea urchin harvesting at Point Loma has aided in establishing kelp where the urchin population was primarily harvestable reds. In areas of mixed urchin composition, urchin harvesting has resulted in slowing the destruction or loss of existing Macrocystis. Nevertheless, it has been necessary to use additional means of urchin control in these areas.

It is likely that harvesting only red urchins will eventually result in corresponding increases in populations of purple and white sea urchins along the coast of southern California.

Transplantation:

Transplanting has been used in areas where no natural stands of Macrocystis exist, or where additional patches of Macrocystis would help restore giant kelp to large areas. If at all possible, restoration efforts should be conducted down current from, and adjacent to, an existing stand of kelp. The presence of a standing crop of Macrocystis plants nearby provides both grazing biomass for herbivores and parent stock to help "seed" surrounding areas.

The following techniques for transplanting large and small kelp plants were used by Department of Fish and Game personnel at Palos Verdes from 1972 through 1982. Transplants should be collected from healthy kelp beds nearby. Large plants should be bagged individually, with the holdfast on top, while smaller plants can be stored several to a bag. Bagged plants

should be immersed in running sea water if possible, or covered with canvas or burlap and sprinkled continuously with sea water to prevent dessication and overheating.

Large kelp plants are best secured to heavy anchor chains (Figure 4). Although difficult to handle, chains with 13 to

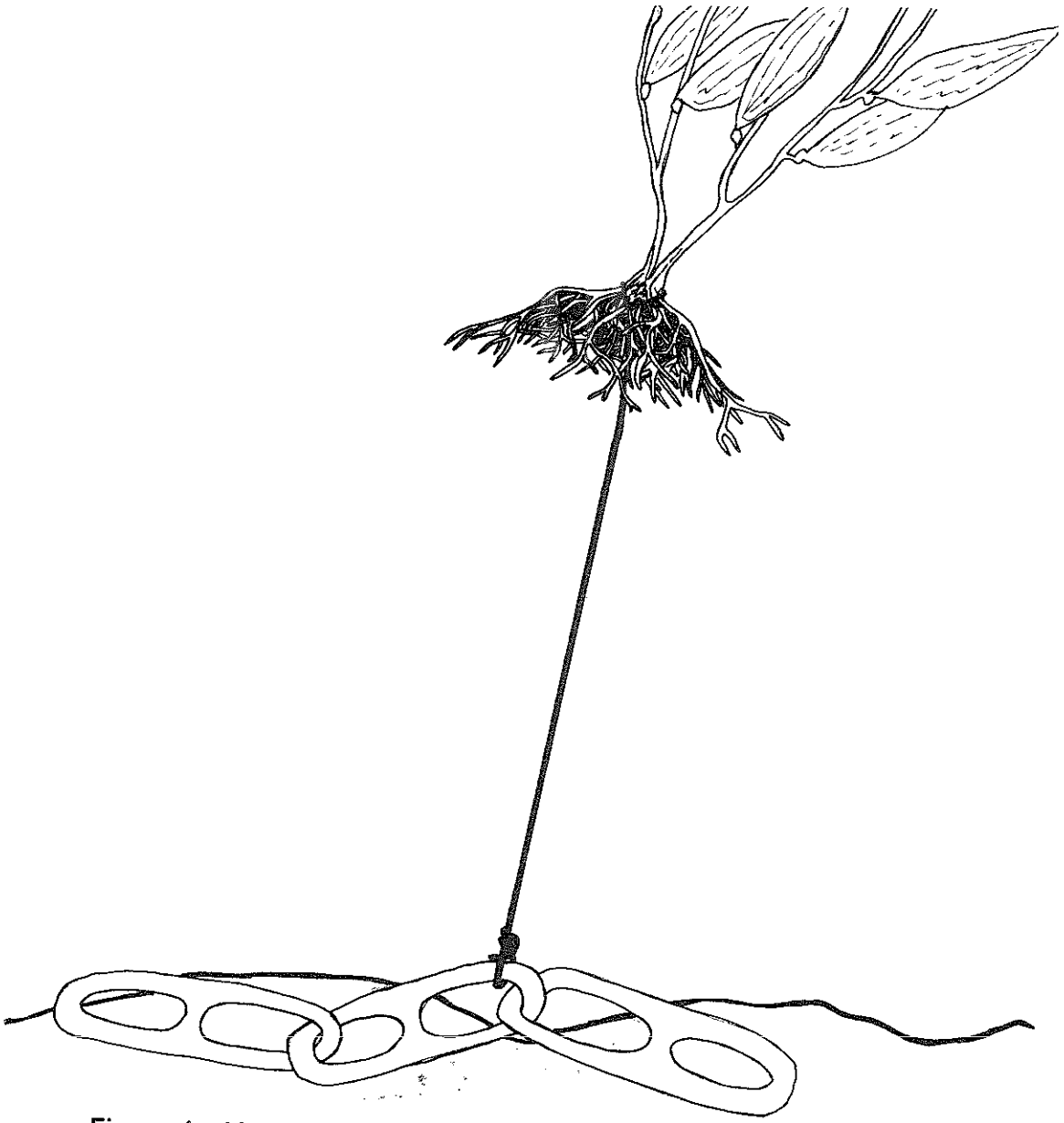

Figure 4. Macrocystis transplant secured to kelp anchor chain.

20 cm reinforced links are most effective. Plants are laced through their holdfasts with 6 mm diameter braided nylon line and tied to floats. These, in turn, are tied by divers onto the anchor chains with 9 mm nylon lines approximately 0.6 m above the anchor chains.

Smaller plants with from 2 to 10 fronds, and up to 3 m in length, can be secured directly to the substrate using one to three circlets of innertube (Figure 5). However, this

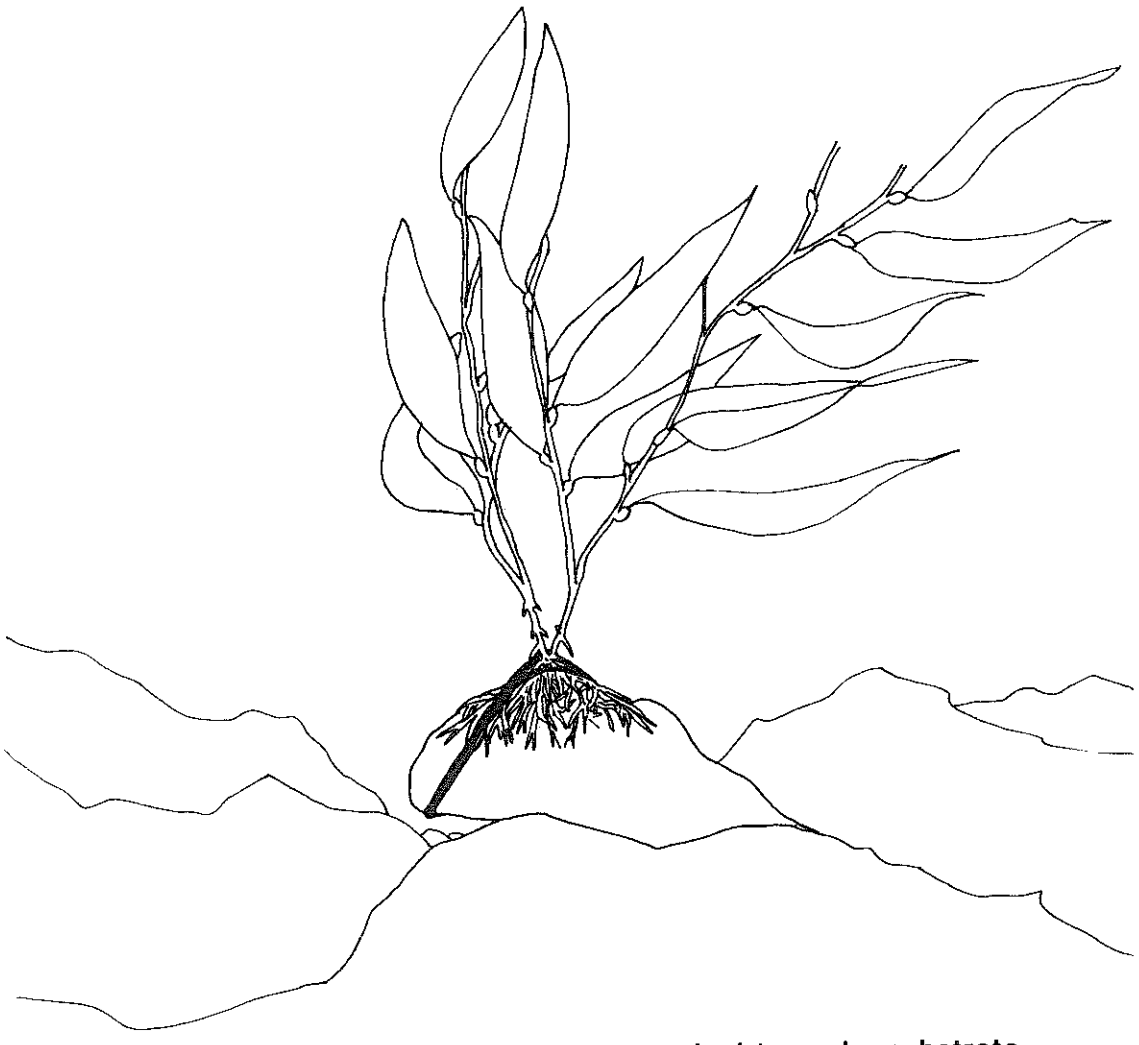

Figure 5. Macrocystis transplant attached to rocky substrate with circlet of innertube.

technique can only be used where rocks or pinnacles are of sizes suitable for attachment of circlets and plants. Where possible, this method is best because it requires minimal handling and allows plants to attach directly to the substrate where they will grow and reproduce naturally.

The rocky bottom at north La Jolla formerly supported a thick Macrocystis kelp bed which effectively shaded the substrate and prevented development of short-statured seaweeds such as Pterygophora californica, Eisenia arborea, Agarum fimbriatum, Laminaria farlowii, and Cystoseira osmundacea. However, by the mid-1960's, a dense subcanopy of these competing species existed, precluding return of Macrocystis into the area (North 1966). Following the loss of Macrocystis off La Jolla in the late 1950's, due to an influx of warm water, these smaller seaweeds developed.

Kelco biologists developed a transplant technique that utilized competing vegetation to anchor young Macrocystis plants. This transplant technique, used at La Jolla, involved securing young Macrocystis plants to the cut "stubs" of Pterygophora and Eisenia. Survival of transplanted Macrocystis could be increased by selecting young plants in good condition, the best possible transplanting site, and by using good transplanting techniques. The best plants for transplanting were 1.5 to 2.5 m high, and had from 2-6 fronds with well-developed blades. They should have a holdfast 5-7 cm in diameter and blue in color (indicative of good growth). The transplant site should be hard, rocky substrate, free of sand, sea urchins

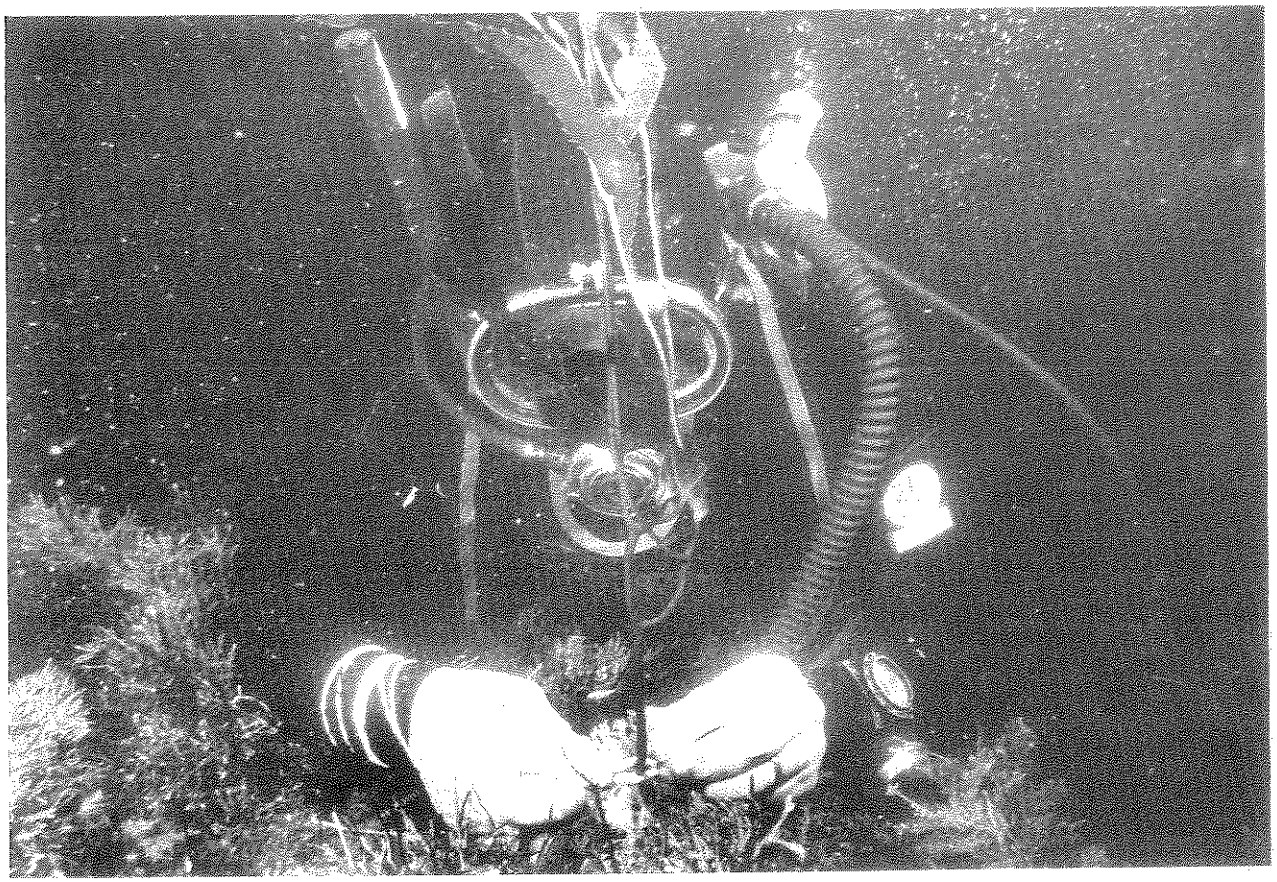

Figure 6: Kelco biologist transplanting juvenile *Macrocystis* at No. La Jolla.

and other competitive seaweeds. It preferably should have substantial relief with large boulders, rockpiles, or reefs.

Using this transplanting technique, young kelp plants were secured to 7 cm high stubs of *Pterygophora* or *Eisenia* with rubberbands (Figure 6). The banded plant was pushed to the base of the stub to minimize the distance haptera must grow to securely attach to rocky substrate. The rubberband should not be tightened over young growing haptera but rather placed over older, tougher haptera on the same plant, preventing cutting through the holdfast. A total of 35,000 young kelp plants was transplanted to several north La Jolla sites from 1973 through

1976 (McPeak 1977). Problems with competitive seaweeds, urchin recruitment and grazing damage prevented transplanted patches of Macrocystis from expanding beyond 14 hr.

Competitor Control:

Subcanopy forming vegetation, as mentioned above, can become so dense that it inhibits settling and growth of juvenile Macrocystis on otherwise suitable substrate. Where necessary, these plants may be cleared using a handheld scythe, filet knife, or hacksaw. However, it is important to remember that these plant species provide food for epibenthic herbivores, often acting as barriers which retard immigration of urchins into newly recruited stands of Macrocystis. Plant competitors should only be removed where in direct competition with recruiting Macrocystis. They should not be cleared where their removal will increase vulnerability of Macrocystis to grazing invertebrates. This technique has not been used extensively.

Monitoring:

Kelp forest monitoring is necessary to document the results of restoration work and efficiently plan future work. Aerial photographs and boat and diving surveys are used to monitor kelp beds. Aerial photographs show fluctuations in surface canopy, while boat and diving surveys provide information on the condition of restored kelp, recruitment of new plants, competition from short-statured seaweeds, recruitment and grazing of sea urchins, and grazing by herbivorous fishes.

Vertical aerial photographs are taken with a handheld 35 mm reflex camera with a 50 mm f 1.4 lens and color infrared

Ektachrome film. Film speed for kelp photography is approximately ASA 200 when photographed through a 25A red filter. Photographic surveys are best conducted in morning or afternoon hours when the sun angle is low, especially in summer months. Under some circumstances, a polarizing filter is useful in reducing glare. The flight altitude can vary depending upon the width of existing beds and required resolution but generally ranges between 1800 and 3700 m. A 20% overlap between adjacent shots minimizes film edge distortion.

Slides are projected onto copies of topographic maps and the borders of kelp canopies are outlined or mosaics of prints are produced. A polar planimeter is then used to calculate the size of surface canopies. Aerial photographic surveys of Palos Verdes Peninsula beds have been done on a quarterly basis since 1974, while Point Loma and La Jolla have been photographed once or twice each year.

Ecological surveys are conducted by kelp restoration workers to help elucidate kelp/sea urchin interactions, to measure the success of restoration efforts, and to plan future work. Kelco biologists established sixty stations throughout Point Loma during 1981. Stations are located at depths of 9, 12, 15, and 18 meters throughout the existing kelp bed and in areas where restoration is planned. At each of the sixty stations, divers conduct six random quantitative samples of $10m^2$ areas. The following is recorded from each of the random areas at each station annually: 1) Density, condition, and age of adults and juvenile Macrocystis; 2) Recruitment of Macrocystis; 3) Species

composition, density, and recruitment of sea urchins, and;
4) Density and composition of competitive seaweeds.

DFG biologists established five 60/m^2 permanent ecological transects in kelp restoration sites off Palos Verdes Peninsula to monitor longterm changes in Macrocystis forests and associated communities. Surveys have been conducted at least quarterly since December, 1975.

Boat surveys, consisting primarily of fathometer tracings to determine actual depth of the outer boundaries of kelp canopies, have been done in conjunction with aerial surveys.

Conclusions:

Kelp restoration operations are generally restricted to sea urchin control and seasonal monitoring. Such operations must be continued to achieve an acceptable level of kelp forest stability. Commercial fisheries for purple and white sea urchins should be encouraged since their development would help contribute to kelp forest stability. Stable kelp forests and elimination of urchin-dominated areas will enhance habitat for a wide variety of animal and plant species and improve southern California's living marine resources.

Kelp restoration work and these studies were conducted by the Sport Fish-Kelp Habitat Project (D-J F27D) of the California Department of Fish and Game and supported by Dingell-Johnson Federal Aid to Sport Fish Restoration funds.

THE RISK OF INFECTIOUS DISEASE ASSOCIATED WITH THE MARINE ENVIRONMENT

A. Dufour* and V. Cabelli**

The disposal of human wastes into the marine environment provides a potential pathway for bacterial and viral enteric pathogens back to man. The discharged waste also provides a source of nutrients which are known to stimulate the growth of autochthonous marine bacteria to levels far above their natural densities (Kaneko and Colwell, 1975; Watkins and Cabelli, 1978). Some of these native marine bacteria, such as Vibrio parahemolyticus have been well documented as human pathogens and their presence in seawater at high densities can be a potential health hazard.

There are two types of exposure to pathogens in marine waters. The first is full body immension, as practiced by swimmers, divers, and surfers. These activities provide ample opportunity for both the ingestion of seawater, which may contain pathogens, and skin contact, which may result in infection under certain circumstances. The second exposure route is via the ingestion of seafood such as marine shellfish and crustaceans, harvested from bed areas contaminated with human fecal material or rich in nutrients.

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The potential diseases which may occur as a result of exposure to contaminated, or in some cases pristine marine environments fall into three major categories; eye and ear infections, wound infections, and gastrointestinal infections. Eye and ear infections have been reported to occur merely as a result of recreational water activity in water that has not received domestic sewage wastes. Since these types of infections have not been associated with waste disposal practices they will be considered with wound infections when assessing the risks posed by autochthonous marine bacteria. The risk of gastrointestinal infection will be discussed from two aspects. The first will be with regard to the ingestion of marine seafood and the second aspect will deal with the direct ingestion of contaminated seawater.

There are three possible approaches to defining the risks that might be encountered by populations exposed to marine environments. Two approaches, the case report survey and the examination of disease outbreaks, are qualitative in nature in that they look at health effects in individuals or groups, and relate the effects back to a marine water activity or some common source exposure. These qualitative approaches do not provide a means of predicting risk, but rather they make us aware that microbiobial pathogen pathways back to man do exist and that precautionary measures should be adopted to cope with these marine health hazards. The third approach, which is quantitative, first identifies a group exposed to a common factor, i.e., polluted seawater, and follows this group for a set period of time during which all of the individuals exhibiting a certain response are counted. The rate of response in a nonexposed control group can then be subtracted from the rate in the exposed group to determine the effect of the exposure. This means of identifying risk factors has led to the development of a functional relationship between water quality

and gastrointestinal illness that can be used for predicting health effects. All three approaches will be used in our discussion of the risks involved with seawater activities and seafood ingestion.

Risk Associated with Autochthonous Marine Bacteria

There are a number of autochthonous marine bacteria which have been reported in the literature as the cause of infection or disease. Table 1 is a partial list of the types of infections or illnesses associated with marine water activities, including wading in seawater and shellfishing. The most frequently reported infections are those involving the skin, such as cellulitis, ulcerations, and wounds. These are usually the result of trauma to the skin, i.e., a laceration or abrasion, a puncture wound due to a fish fin, a cut from a mollusc shell, and even animal bites. Septicemia and otitis externa have been reported

TABLE 1. DISEASE AGENTS ASSOCIATED WITH MARINE WATER ACTIVITIES

	Vibrio			Aeromonas		Mycobacterium	Pseudomonas
	Parahemolyticus	Alginolyticus	Vulnificus	Hydrophila	Sobria	Marinum	Aeruginosa
Disease							
Wound infection	X	X	X	X	X	X	
Cellulitis			X			X	
Ulceration		X					
Septicemia	X	X		X			
Gastroenteritis	X						
Otitis externa		X					X
Associated Compromising Event							
Laceration	X	X		X		X	
Abrasion						X	
Skin puncture		X	X	X	X	X	
Fin/shell cut	X	X		X		X	
Animal "bite"				X		X	
Burn/immersion		X		X			
Near drowning				X			
None		X				X	X
References	Blake, 1979 Fernandez, 1975 Olsen, 1978 Porres, 1977 Roland, 1970 Ryan, 1976 Stevenson, 1953 Wagner, 1981	English, 1977 Pezzlo, 1979 Pien, 1977 Rubin, 1975 Schmidt, 1979 Spark, 1979	Castillio, 1981 Ellington, 1982	Ampel, 1981 Fulghum, 1978 Rosenthal, 1974 Wolff, 1980	Joseph, 1979	Bailey, 1982 Cott, 1967 Flowers, 1970 Jolly, 1972 Miller, 1973 Owens, 1969 Wagner, 1981 Zeligman, 1972	Cobet, 1970

only occasionally and gastroenteritis caused by a bacterium indigenous to seawater has been reported only once.

It is interesting to note that all or almost all of the infections were associated with a compromising event, usually a breaking of the integrity of the skin or extensive skin burns. The latter occur when individuals aboard boats are exposed to gasoline fires and subsequently are immersed in seawater to extinguish the flames of their burning clothing. Similarly, the stress on respiratory tissues caused by a near drowning episode or the maceration of ear canal membranes also can be a compromising event which presents an opportunity for invasion of the tissues by normally innocuous bacteria. The implication of these reports is that some autochthonous marine bacteria are opportunistic pathogens, that is they are avirulent or have low virulence, but can readily take advantage of the weakened defense mechanisms of a host.

One of the indirect effects which result from the disposal of sewage wastes into the ocean is the increase in density of opportunistic pathogens. Some of these bacteria, such as the Vibrio species, are known to grow to high densities in aquatic environments receiving sewage effluents (Kaneko and Colwell 1975; Watkins and Cabelli 1978). This sewage mediated increase in opportunistic pathogens naturally increases the risk to swimmers, divers, and surfers simply because of the greater probability for contact with the organisms.

The information obtained from case reports of seawater assocated illness and infection can be summarized as follows. First, autochthonous marine bacteria can be hazardous to the health of individuals who come in contact with

seawater. Second, the seawater associated illness and infections are almost always preceded by some type of compromise in the victims. Lastly, the risk of illness or infection from opportunistic marine pathogens is virtually impossible to predict.

TABLE 2. MOLLUSCAN AND MARINE CRUSTACEAN ASSOCIATED DISEASE OUTBREAKS FROM 1970 TO PRESENT THE UNITED STATES

	CHOLERA	SHIGELLOSIS	VIBRIOSIS		HEPATITIS	DUE[2]
			V. PARAHEM.	*V. VULNIF.*		
MOLLUSCS						
CLAMS	1				2	17
MUSSELS						
OYSTERS	2			2	2	5
SCALLOPS						1
SHELLFISH[3]	1	1	1		1	9
MARINE CRUSTACEANS						
CRAB			5			5
LOBSTER						2
SHRIMP			4			7

1. REFERENCES - BRYAN, 1980, MMWR, 1979A; MMWR, 1979B; MMWR, 1980A; MMWR, 1980B
2. DUE - DISEASE OF UNKNOWN ETIOLOGY
3. UNSPECIFIED

Risk Associated with Ingestion of Shellfish and Marine Crustaceans

The second means of transmitting infectious agents from marine environments to humans is by the ingestion of seafood, either raw or partially cooked. Table 2 is a partial list of disease outbreaks associated with molluscs and marine crustaceans since 1970. In a majority of the outbreaks the causative pathogen was not identified. Shellfish associated outbreaks in which the etiologic agent was identified were caused by both enteric pathogens and native marine bacteria, such as *Vibrio parahemolyticus* and *Vibrio vulnificus*. Clams and oysters were the shellfish vectors in more than 60% of the outbreaks. Mussels and scallops,

two shellfish found in or near the Point Loma kelp beds, seldom have been reported as the vehicle of transmission in foodborne infectious disease outbreaks. While most of the molluscan related outbreaks in Table 2 were associated with eating raw or steamed shellfish, those due to marine crustaceans were usually caused by improper refrigeration or cross-contamination, by previously used baskets, by washing with seawater or by live crustaceans being mixed with cooked ones. Improperly refrigerated crustaceans provide an ideal environment for the growth of adsorbed bacteria such as Vibrio parahemolyticus. The ability of V. parahemolyticus to grow on improperly stored seafood is reflected in the high frequency of crustacean related infectious disease outbreaks caused by this bacterial species.

The non-filter feeding sea urchins, which inhabit the Point Loma kelp beds in high densities, would not appear to be a source of foodborne infectious disease. However, because millions of pounds of sea urchins are annually harvested from the Point Loma kelp beds (Barilotti 1982) and many of these are used in the preparation of sushi, an uncooked sea food dish, it is possible that they may present a health risk to those who harvest them or to individuals who ingest them. The sharp spines of sea urchins may cause cuts and scratches on divers harvesting them and this could lead to infections by opportunistic pathogens of the type previously described. Conversely, improperly refrigerated sea urchins could be a vector for an indigenous marine pathogen such as V. parahemolyticus in a manner similar to that observed with marine crustaceans.

Although a functional relationship between shellfish associated disease and water quality has not been determined, the many outbreaks of shellfish associated disease described in the literature have clearly established the role

of filter-feeding molluscs as vectors of bacterial and viral pathogens. The illnesses resulting from the ingestion of raw or steamed shellfish are almost always related to harvesting from areas not meeting the traditional recommended standards for shellfish beds. This Food and Drug Administration recommended standard, a median value of 70 total coliforms per 100 ml, with not more than 10% of the samples exceeding 230/100 ml is also the standard adopted by the State of California. In general, shellfish harvested from areas meeting this standard are seldom associated with reported outbreaks of infectious disease.

Risks Associated with Ingestion of Contaminated Seawater

The first attempts to show a relationship between swimming associated health effects and water quality were carried out in the early 1950's by the United States Public Health Service (US PHS) (Stevenson 1953). The studies were conducted at two freshwater sites, one on Lake Michigan at Chicago, Illinois and another on the Ohio River at Dayton, Kentucky, and at a marine site on Long Island Sound. Swimming associated gastroenteritis was not found at the marine site or at the Lake Michigan site. However, the Ohio River study showed that gastrointestinal illness was more frequent than expected in swimmers, based on the illness experience of all members of the study population, when the median coliform density was about 2300 per 100 ml. These studies established the first experimental link between gastrointestinal illness in swimmers and bathing water contaminated with fecal material. However, the design of the US PHS studies were criticized on a number of issues such as swimming being poorly defined, swimming days were not related directly to water quality measurements and the illness inquiry system allowed for possible memory lapses between the swimming episode and the collection of the data.

In 1972 the United States Environmental Protection Agency (EPA) began a series of epidemiological-microbiological studies at marine bathing beaches which were designed to overcome some of the deficiencies of earlier studies. The goals of the EPA study were to determine if there is a health risk associated with swimming in polluted marine waters and what measure of water quality best relates to swimming associated illness, and to establish a functional relationship between swimming associated gastroenteritis and some measure of water quality.

The design characteristics of the EPA studies have been described elsewhere (Cabelli 1980; Cabelli _et al_ 1974; Cabelli _et al_ 1979; Cabelli _et al_ 1982) and therefore only the main features will be discussed here. First, the indicator of water quality was not preselected. Multiple indicators including the traditional bacterial indicators of water quality, bacteria sensitive to nutrient pollution, bacterial viruses and coprostanol, a fecal sterol, were examined. The indicator which showed the best functional relationship to swimming associated illness would be designated the indicator of choice. Second, only swimmers and non-swimmers who had not been swimming in the week before and after the trial day were included in the study, thereby limiting the swimming experience only to the day when the quality of the water was monitored. Third, swimming was rigorously defined as being in the water for more than 10 minutes and completely immersing the head under the water. Fourth, non-swimming control subjects were obtained from among beach goers to eliminate beach effects such as foodborne illness due to concessionnaire food or drink. Lastly, uniform study methods were used at the three study sites, New York City, Lake Pontchartrain, Louisiana, and Boston, Massachusetts.

Volunteer study participants were contacted by telephone 9 to 10 days after the swimming episode to determine if any symptomatic illness had occurred in the ensuing time period. Since symptoms were self-diagnosed and therefore liable to error, multiple symptoms or unmistakably recognized symptoms were used to establish the credibility of the gastrointestinal illness. Gastrointestinal (GI) symptoms and disabling effects were used to generate a new variable called "highly credible" symptoms. The definitions for total GI symptoms and "highly credible" symptoms are given in Table 3. These two health effects responses were used as the dependent variable for analyzing the relationship between swimming associated illness and water quality indicators.

Water quality measurements were made over a five- to six-hour period during peak swimming activity. Usually three water samples per day were collected at two or three sites per beach.

The swimming associated illness rates for total and "highly credible" GI symptoms were obtained by subtracting the illness incidence for non-swimmers

Table 3. Definition of Total and Highly Credible G.I. Health Effects

Health Effects Variates	Definition
Total G.I. Symptoms	Any one of the following: vomiting, nausea, diarrhea or stomachache
Highly Credible G.I. Symptoms	Any one of the following: 1. vomiting 2. diarrhea with fever or disabling condition* 3. stomachache or nausea accompanied by a fever

*indicates individual remained at home, remained in bed or sought medical advice

from that of swimmers. The resulting rate difference was considered to be that portion of gastrointestinal illness attributable to the swimming experience. Each swimming associated illness rate/indicator density coordinate pair was obtained by grouping trial days with geometric mean indictor densities of similar magnitude and pairing the geometric mean of this group with the swimming associated illness data for those days. Correlation and regression coefficients were calculated using the paired gastroenteritis rate/geometric mean indicator density data from all of the trials at the three study areas.

The correlation coefficients, which indicate the strength of the relationship between the indicators and the observed health effects, for all of the indicator organisms examined during the first three years of the study at New York City beaches are shown in Table 4. The strongest association between the paired illness rates and the indicator densities was observed with enterococci.

Table 4. CORRELATION COEFFICIENTS FOR TOTAL GASTROINTESTINAL SYMPTOMS AND THE "HIGHLY CREDIBLE" PORTION AGAINST THE MEAN INDICATOR DENSITIES FOR 1973-1975 TRIALS CONDUCTED AT NEW YORK CITY BEACHES

Indicator	Correlation Coefficients		Number of Points	References[b]
	Highly Credible GI[a]	Total GI[a]		
Enterococci	.96	.81	9	Levin, 1975
E. coli	.56	.51	9	Dufour, 1975, 1981
Klebsiella	.61	.47	11	Dufour, 1975
Enterobacter/ Citrobacter	.64	.54	13	Dufour, 1975
Total Coliforms	.65	.46	11	APHA, 1971
C. perfringens[c]	.01	-.36	8	Bisson, 1980
P. aeruginosa	.59	.35	11	Levin, 1972
Fecal Coliforms	.51	.36	12	APHA, 1971
A. hydrophila	.60	.27	11	Rippey, 1979

[a]See table 3 for definitions.

[b]Literature references for enumeration methods

[c]No data for 1973

All of the other indicators showed a rather weak association to the observed health effects. A graphic representation of the relationship between two of the water quality indicators, enterococci and fecal coliforms, and swimming associated illness is shown in Figure 1. The estimating lines for total GI and "highly credible" symptom rates on enterococci densities have much steeper slopes than those for the symptom rates on fecal coliforms. The overall deviations of the points from the estimating lines also are much smaller for enterococci than for fecal coliforms. The superiority of enterococci to other indicators makes them the obvious indicator of choice for relating water quality to swimming associated illness.

A health effects criterion for marine recreational waters, or more directly a functional relationship between gastroenteritis and enterococci indicator densities is shown in Figure 2. The utility of the criterion is that it can be used to predict the risk of gastroenteritis due to swimming once the enterococci density in the water has been determined. Conversely the variables can be reversed, as they are in Figure 2, where the illness rate was used as the independent variable to calculate a new regression equation for an estimating line that can be used to set a water quality guideline or standard, once an acceptable risk has been selected.

The results of the EPA studies clearly show that the risk of swimming associated gastroenteritis is related to the quality of the water as indexed by a bacterial indicator of fecal contamination. The results also show that correlation of enterococci densities to swimming associated gastroenteritis was stronger than that observed with the densities of any other bacterial indicator. Although the etiologic agent of the swimming associated gastroenteritis is

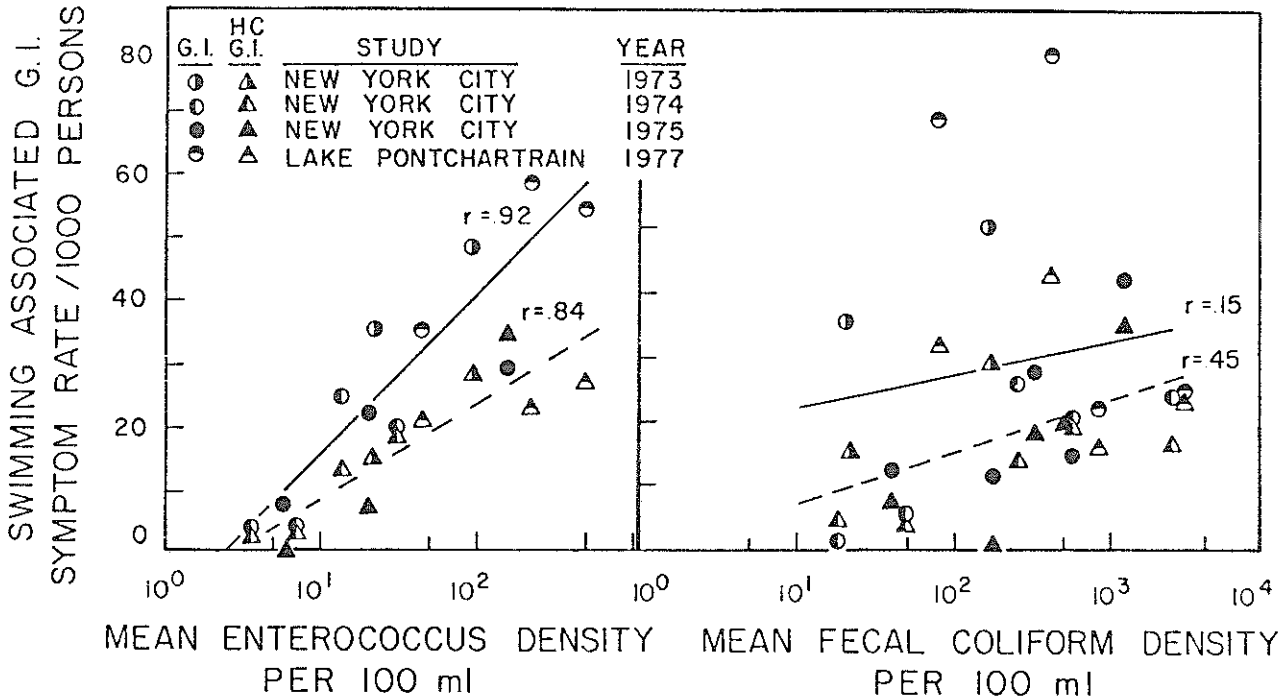

Figure 1.
Linear relationships between swimming-associated rates for G.I. symptoms and mean enterococcus and fecal coliform densities in water.

unknown, it is probably of viral origin. The symptoms are, in fact, strikingly similar to those of rotaviris and Norwalk agent infections (Cabelli, 1981).

Discussion

The two areas of concern relative to health hazards in the kelp bed environment are the risk of infectious disease for divers and the risk of foodborne disease for consumers of seafood harvested in or near the kelp beds. The safety and health of these two groups are directly related to the current standards used to maintain the quality of the water in the kelp beds and the compliance with these standards.

The California guideline for body contact recreational water areas is an

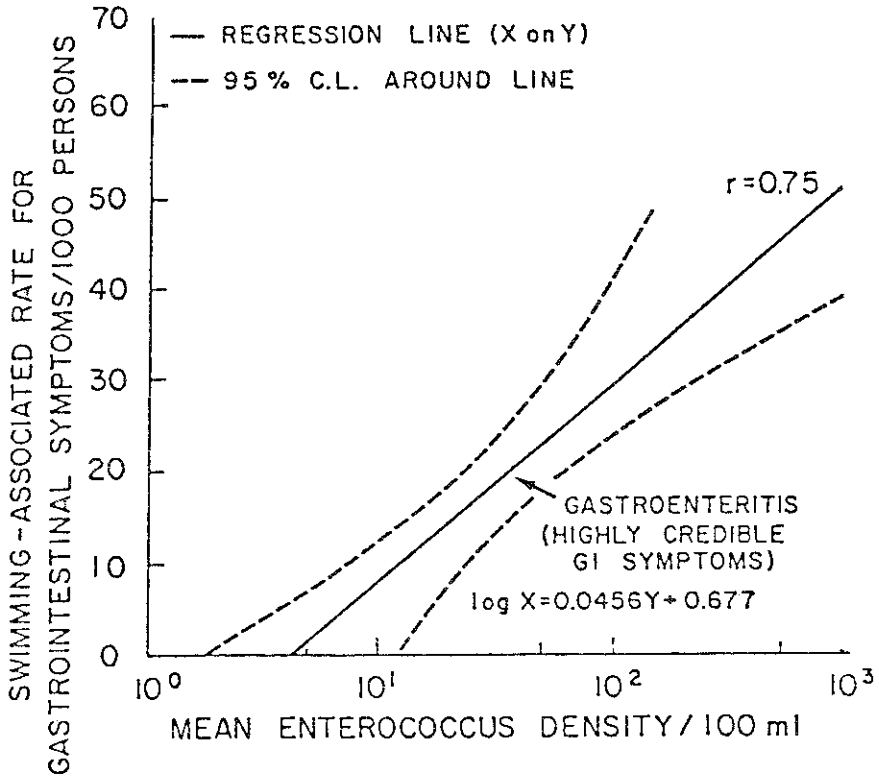

Figure 2.
Health Effects criteria for marine recreational water. Criteria are X on Y regression lines of the mean enterococcus density in the water against the swimming-associated rate of gastrointestinal symptoms.

upper limit of 1000 total coliforms per 100 ml 80% or more of the time or a fecal coliform count not to exceed a log mean of 200 per 100 ml for a minimum of 5 samples in any 30 day period (personal communication, D. C. Barilotti). The 1000 total coliform standard was arbitrarily set by the California Bureau of Sanitary Engineering over forty years ago. The standard was not based on epidemiological evidence, but rather on the perception that it related well with the drinking water standard of that time, that there was no epidemiological evidence of health effects within the standard, that the 10 coliform per ml level could easily be attained and lastly that any less stringent standard might result in waters that would be asthetically unacceptable (Report 1943). The origin of the 200 fecal coliform per 100 ml limit is much less arbitrary.

It was first recommended in 1968 as the equivalent of one-half of the total coliform density measured in the water when a detectable swimming associated health effect was observed in the US PHS studies conducted in the early 1950's (Stevenson 1953). Thus, since a detectable health effect was observed when the total coliform density was about 2300 per 100 ml, it was reasoned that one half of that density would provide a margin of safety for swimmers. It is interesting to note that this value closely approximates the arbitrarily chosen 1000 total coliform value used by California and many other states.

Coliform data for the years 1962 through 1969 given by Barilotti (1982) indicate that at depths of 15 to 20 feet in the dispersion zone of the Point Loma outfall at the edge of the kelp beds there was general compliance with the California standard. Orlob (1975) compiled similar data for the same area for the years 1972 to 1975. He found that surface water samples always had coliform densities lower than 1000 per 100 ml, whereas 36% of the samples obtained at depths of 30-60 feet had coliform densities in excess of 1000 per 100 ml. Bottom samples also frequently contained coliform densities greater than 1000 per 100 ml. Approximately 29% of the bottom samples from the outfall dispersion zone were not in compliance in the years 1973 through 1980 (Barilotti 1982).

The significance of this data relative to the health of divers cannot be assessed with any degree of confidence. The US PHS study indicated a health effect when the total coliform median was approximately 2300 per 100 ml, with a range of 430 to 92,000 per 100 ml. Thus it is possible that health effects might be observed near the bottom, given that greater than 29% of these samples exceeded a total coliform density of 1000 per 100 ml. It should be obvious

however, that there are too many unknown factors which preclude the prediction of health effects. This lack of meaningful data suggests that a valid monitoring program should be developed so that illness in divers, if they occur, can be examined against the data base obtained from the monitoring effort. Although enterococci are not a standard measure of water quality, their application to the monitoring problems related to the kelp beds should be considered if the health risks to divers need to be more closely defined.

The nature of infections caused by autochthonous marine bacteria and some bacterial genera found in sewage effluents, such as Aeromonas and Pseudomonas (Miescier 1977), makes it almost impossible to mount a monitoring strategy that will minimize the risk of infection. Since these infections appear to arise only when an individual has been compromised in some manner, the problem is probably better dealt with through educational means rather than monitoring strategies. There are conventional diving procedures (Pennella 1981), which if followed should protect divers against autochthonous marine pathogens and sewage-borne pathogens as well. Penella has listed the following safe diving procedures:

1. Individuals with open cuts should not dive until the wound is healed.
2. Divers should be fully immunized against diphtheria, tetanus, smallpox, and typhoid.
3. Before and after a dive, divers should irrigate each ear with 2% acetic acid in aluminum acetate solution.
4. Divers should, if at all possible, use a full face mask.
5. After a dive, divers and equipment should be completely washed down with fresh water and the equipment should then be disinfected.

The California standard for shellfish harvesting areas, a median value of 70 total coliforms per 100 ml with not more than 10% of the samples exceeding 230 total coliforms per 100 ml, is not generally applicable to the major commercial seafood product, sea urchins, taken from in and around the Point Loma kelp beds. Sea urchins, unlike the filter feeding shellfish such as clams, oysters, mussels, and scallops, do not concentrate pathogens from ambient waters. Thus, the only hazard to consumers may be from native marine, as well as, sewage carried pathogens which adsorb to the sea urchins or are transients in their gut. However, the presence of these organisms is not necessarily a health hazard. It is only if this seafood is not properly refrigerated during transport to market that these pathogenic bacteria could multiply to densities that present a significant risk to consumers. The record, however, indicates that sea urchins probably are not a vehicle for the foodborne transmission of disease since no sea urchin associated disease outbreaks have been reported in the last ten years.

MODELING KELP GROWTH

Richard C. Zimmerman*

Although the field of simulation modeling is not new, models of biological systems have, for the most part, not been accurate enough in their predictions to be used as management tools. The reason for this is the fundamental lack of detailed information on many important processes. Models are based on theory and experimentation. While the theoretical material from which to construct such models has been plentiful for a long time, data and experiments to explore theories and provide parameters for equations have become available in adequate quantity to begin the construction of ecosystem models only recently. These models must be recognized as research tools, designed primarily for the exploration of ideas, and not as tools to be used immediately for resource management. The predictive ability and mathematical complexity of these models will increase as more data become available, yet we should be very cautious about employing these models for resource management. There is always the danger of "getting the right answer for the wrong reason" with any attempt to predict a particular outcome, and this is an especially insidious problem with mathematical models. A model that appears to work well under a particular set of conditions may perform very poorly under other circumstances. While this can be disasterous

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for resource management goals, a research model is most useful when it fails to be a good predictor. By failing, the model forces a reevaluation of assumptions and experimental results which can often lead to the most valuable breakthroughs in understanding.

Growth models of the giant kelp have been achieved with limited success (e.g. Anderson 1974). The major problem is that Macrocystis is a complex organism and the physiological data are not yet available in the necessary detail to develop a fully mechanistic model of growth. The purpose here is to present one strategy for the constriction of a mathematical simultaion of kelp growth. It uses the most obviously important physical process, such as light intensity and nutrient availability, and tries to relate them to growth of the giant kelp in a physiologically meaningful way. The basic equations used to build this model are described, the sources of the data that could be used to run a model are identified, and areas where we lack sufficient information to characterize particular processes adequately are indicated. The next step in the modeling process will be to translate these equations into a computer simulation model so that these relationships can be evaluated with respect to the data available. The computer simulation will be the subject a future discussion.

THE CONCEPTUAL MODEL

Figure 1 is an energy flow diagram of a growth model of M. pyrifera using the energy circuit language of Odum (1971). The large bullet-shaped structure represents Macrocystis. Storage

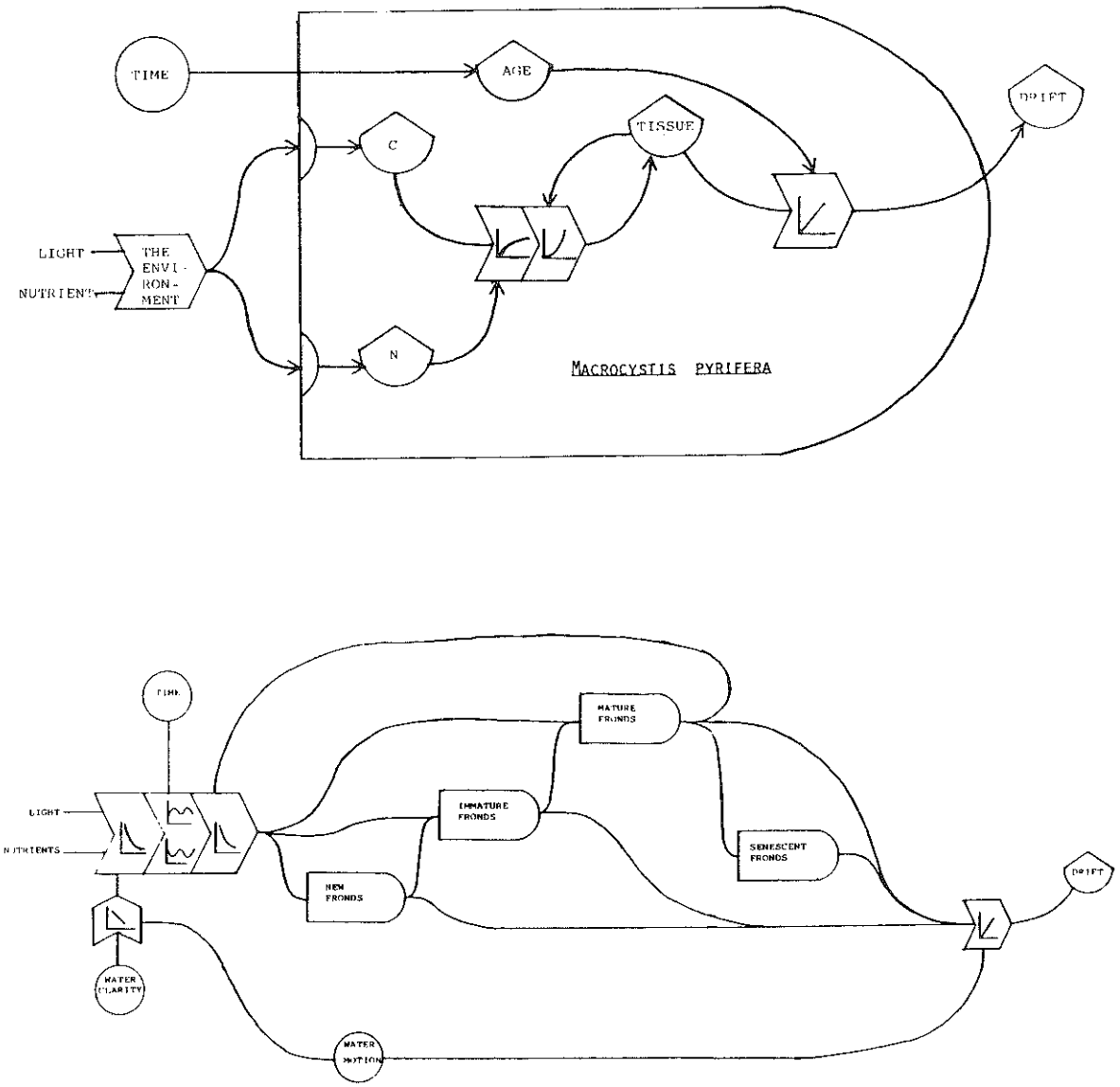

Figure 1. Energy flow diagram for Macrocystis pyrifera. Symbols are after Odum (1971). A) Interaction of M. pyrifera with its environment. B) Energy flow diargam of the major processes occurring within each of the frond types illustrated in (A).

compartments (water tank-like structures) represent energy stored within the system in various forms, such as inorganic nutrients, kelp biomass, and drift. Lines and arrows indicate pathways of energy and material flow from one storage compartment to another. The large arrow-boxes are feedback amplifiers (also called multipliers or work gates). They represent control of energy flow from one compartment to another by a third source. The relationship between energy flow and the substance controlling the work gate is represented by the small graph within the box. Living biomass is represented by storages that have a positive feedback effect on the flow of energy to themselves. The circles represent external, non-depletable "energy sources," such as light intensity, water clarity, and water motion.

Growth is ultimately controlled by light availability. However, the conversion of light into kelp biomass is regulated by other factors such as water clarity, nutrient availability, and canopy density. Water clarity and canopy density affect the amount of light penetrating the water column. Once light energy is converted into carbohydrate, it is then converted into kelp tissue. However, that process is regulated by the amount of nitrogen in the tissue available for the manufacture of proteins and other essential molecules. Internal concentrations of nitrogen are regulated by light intensity and concentrations of dissolved nutrients in the sea water. Growth increases the amount of tissue in the biomass compartments. Biomass is lost through the formation of drift, which is formed by the release of tissue from senescent fronds and when storm-induced water motion tears loose

plants and individual fronds.

MATHEMATICAL FORMULATIONS

The next step in constructing the model is to assign mathematical relationships to the energy flow pathways in Figure 1 (A and B) and all of the feedbacks and forcing functions that make up the system. In order to do this, a set of equations are coupled to represent this flow of energy, with the coefficients asigned to each of the equations ideally based on empirical data.

The amount of kelp present at any time, T, is a function of the standing stock present at time t=0 and the net growth between time t=0 and time t=T:

$$\text{Biomass}_T = \text{Biomass}_0 + \int_0^T \text{Growth}\ dt \qquad (1)$$

This is the fundamental equation of the model. The problem, then, is to define the growth term so that the equation can be solved. Growth is simply the rate of change in biomass over a specified time:

$$\text{Growth} = \frac{d\text{Biomass}}{dt} \qquad (2)$$

These first 2 equations are extremely general and serve to define the overall goals of the model. The following equations will be more specific and more hypothetical.

The rate of change in biomass can be defined by:

$$\frac{d\text{Biomass}}{dt} = G_{max} * f(\text{Cpool},\text{Npool}) - \text{Drift} \qquad (3)$$

where G_{max} is the maximum growth rate, a constant. Dr. Wheeler North's group at CalTech has measured maximum specific growth rates as high as 4-5% per day.

Postulating the Monod model for substrate dependent growth, we can define the function f(Cpool) as:

$$f(Cpool) = \frac{Cpool}{Cpool + K_g} \tag{4}$$

where:

K_g = Monod half saturation constant for growth, i.e. the size of the carbon pool at which growth = 1/2 G_{max} when the carbon pool is the only limiting resource. As long as growth is not limited be the available carbon (i.e. Cpool is large relative to k_g), f(Cpool)=1.

The carbon pool at any time, T, can be represented by:

$$Cpool_T = Cpool_0 + \int_0^T dCpool\ dt \tag{5}$$

and the rate of change in the carbon pool as:

$$\frac{dCpool}{dt} = (Photo - Resp) - CUsed \tag{6}$$

<u>Photo</u>synthesis is the amount of carbon fixed per unit time and is a function of the age of the kelp tissue and the ambient light intensity at that position in the water column:

$$Photo = P_{max} * f(light,age) \tag{7}$$

P_{max} is the maximum photosynthetic rate, and available estimates agree rather closely (Wheeler 1978; Clendenning 1971; Zimmerman 1983). As kelp tissue ages, its photosynthetic capacity changes (Wheeler 1978; Clendenning 1971) Although we don't know the relationship between photosynthesis and age for every frond type,

a first approximation may describe the relationship crudely as a function of the relative position of the tissue along the frond:

$$f(age) = 1 - |Position/FL - .75 * FL| \quad (8)$$

where FL is the length of the frond. As the position approaches a 75 % of the length of the frond, f(age) approaches 1.

For f(light) the Monod saturation equation is appropriate (Wheeler 1978):

$$f(light) = \frac{I_z}{K_p + I_z} \quad (9)$$

where K_p is the Monod half saturation constant for light limited photosynthesis.

I_z, the light intensity at any depth, is given by:

$$I_z = I_o * e^{-kzjc} \quad (10)$$

where:

I_o = surface light intensity
e = Euler's constant
k = extinction coefficient, f(water clarity)
z = depth (m)
j = extinction coefficient of kelp tissue
c = canopy density

Respiration is a function of tissue age and is assumed to follow a pattern similar to that of photosynthesis, although there are no data to support this:

$$Resp = R_{max} * (1 - |Pos/FL - .75 * FL|) \quad (11)$$

R_{max} = Maximum Respiration Rate

It is likely that temperature has a significant effect on photosynthesis and respiration, but no data are available yet to quantify this influence. Further, recent experimental data indicate that photosynthesis and respiration rates can adapt to seasonal temperature fluctuations, and remain fairly constant

(Zimmerman 1983).

<u>CUsed</u> is the amount of labile carbon converted to kelp tissue, and is constrained by the size of the nitrogen pool in the form of the Monod equation for a rectangular hyperbola:

$$CUsed = CUmax * \frac{Npool}{K_n + Npool} \tag{12}$$

where:

CUmax = amt of carbon required when growth is maximal
Npool = the internal nitrogen pool
K_n = the Npool size at which CUused = 1/2 CUmax

In a way analagous to carbon, the size of the internal nutrient pool at any time, T, is dependent upon the original size of the nutrient pool, the rate of nutrient uptake and the rate of nutrient utilization:

$$Npool_T = Npool_0 + \int_0^T dNpool\ dt \tag{13}$$

$$\frac{dNpool}{dt} = Uptake - Nuse \tag{14}$$

<u>Uptake</u> is a function of the ambient nutrient concentration, the age of the tissue and light intensity:

$$Uptake = Upmax * \frac{[N]}{K_u + [N]} * f(age,light) \tag{15}$$

where:

Upmax = maximim uptake rate, a constant
[N] = ambient nutrient concentration
K_u = half saturation constant for nutrien uptake

f(age) is equation (8) again.

For f(light), the Monod equation is appropriate again:

$$f(\text{light}) = \frac{I_z}{K_i + I_z} \tag{16}$$

where: I_z = light intensity at depth, z

K_i = light half saturation constant for nutrient uptake

Gerard (1982 and in prep.) has performed several experiments that allow estimation of these parameters.

Nuse is the amount of nutrient required to construct a unit of tissue multiplied by the amount of tissue built. There are no really solid data available on this parameter. For current modeling efforts, we can assume that the ratio of tissue built to nutrient used is constant. However, chemostat work with phytoplankton indicates that this assumption is probably not correct.

Rosenthal et al. (1974) and Gerard (1976) have shown that drift production is dependant upon plant density and water motion:

$$\text{Drift} = f(\text{biomass, water motion}) \tag{17}$$

Although data are not adequate for the exact form of this relationship to be evaluated accurately, we can make arbitrary assumptions:

$$f(\text{biomass}) = Ce^{kB} \tag{18}$$

where:

C = an empirically fitted constant
k = a density dependent coefficient
B = biomass

and:

$$f(\text{water motion}) = DV \tag{19}$$

where:

D = empirically fitted coeficient of disruption
V = 3-dimensional water velocity

In order to evaluate equation (1) each of the above formulations must included into an integral that becomes too complicated to be solved analytically. However, these equations can be solved by numerical integration on a digital computer, allowing us to evaluate the effect of changes in forcing functions on growth of the giant kelp.

The model is amenable to expansion. The effects of recruitment, grazing, predation on grazers, competition for space with other algae, and pollution effects can all be incorporated into the model, as desired. A modeling approach can never take the place of well designed and executed experiments. Rather, the strength of the model lies in forcing an explicit definition of the system and allowing for the evaluation of hypotheses, assumptions, and experimental results. Eventually a model will emerge that does have strong theoretical and experimental support for the formulations used. Through the long iterative process of model evaluation, modification, and validation of its predictions by experiments and observations, a useful management tool can be developed. Work on a growth model of *Macrocystis pyrifera* is just beginning. The need for more work on all aspects of the giant kelp is necessary if we are to begin to understand how this plant responds to its environment.

SEPARATING EFFECTS OF TEMPERATURE AND NUTRIENTS

Wheeler J. North*

The studies reported herein investigated whether fertilizing kelp plants had any effect in preventing summertime deterioration of kelp canopies (summertime deterioration had previously been attributed to intolerance by kelp tissues to elevated water temperatures). We found that fertilizing did reduce canopy deterioration during a fairly warm period in latter summer, 1982.

Summertime deterioration of Macrocystis canopies occurs commonly in the kelp beds of southern and Baja California, and the phenomenon has long been recognized (Brandt, 1923). Furthermore, Macrocystis does not occur in warmer regions such as tropical waters (Womersley, 1954). Consequently, many workers concluded that water temperatures higher than about 20°C were not tolerated by giant kelp, even though Clendenning and Sargent (1971) reported that light-saturated photosynthesis was highest over a temperature range of 20° to 25°C for one-hour exposures, using tissue samples from the La Jolla kelp bed. Clendenning also reported the maximal range for photosynthesis rose to 25°

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to 30°C for intertidal kelp from Turtle Bay, Mexico, indicating a physiological accommodation to the generally warmer environment there, compared to La Jolla. Jackson (1975) pointed out that summertime deterioration of kelp canopies might, to some extent, result from low concentrations of macronutrients, which typically become low in surface layers after a strong thermocline develops. Jackson's suggestion has far-reaching implications. For example, the southern California kelp beds suffered widespread losses during the warm-water years of 1957-59. Furthermore, much raw material for the kelp harvesting industry becomes lost during warm summers. Finally, there is considerable concern about discharge of heated effluents in the vicinity of kelp beds. Such problems might be ameliorated or eliminated by fertilizing operations if summertime kelp deterioration is partially or completely a nutritional problem, rather than an expression of temperature tolerance. This is clearly a promising area for useful research. Recent studies of Macrocystis at USC's Catalina Marine Science Center suggest that fertilizing may indeed enhance canopy survival during warm water periods.

FERTILIZING MACROCYSTIS DURING SUMMER

During summer 1982, a culturing facility called the Hemidome was operated in Big Fisherman Cove, Catalina Island. The Hemidome consisted of a two-million liter capacity plastic bag suspended within a ring-shaped raft (Figure 1). About 6000 lpm of seawater was pumped in near the bottom of the bag, and the same amount overflowed through ports at the top. Nitrate and phosphate were

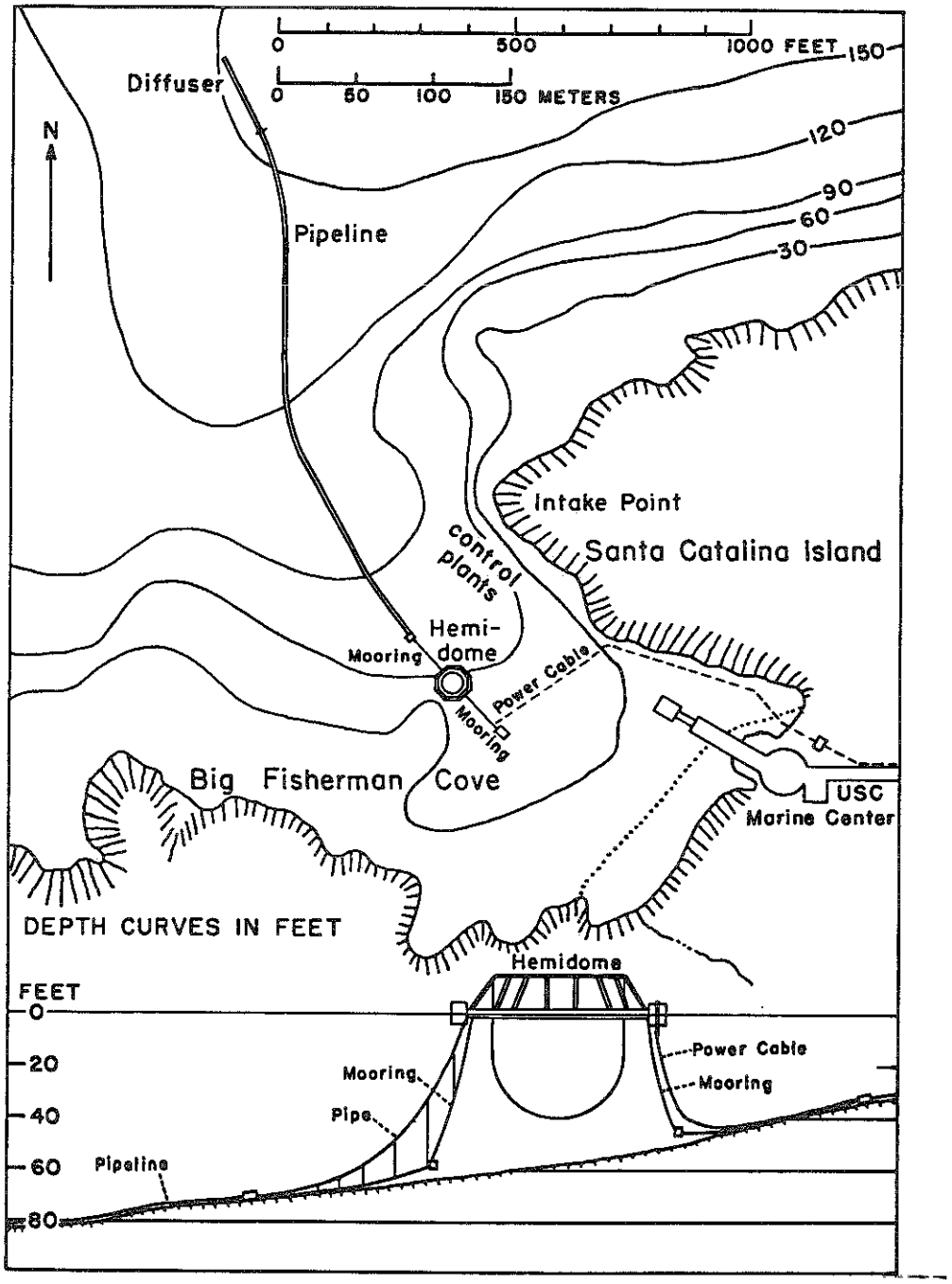

Figure 1. Chart of Big Fisherman Cove, Catalina Island, showing location of the Hemidome facility and control plants (upper diagram), as well as a cross-sectional view of the Hemidome (lower diagram).

injected into the inflow pipe to fertilize 51 adult Macrocystis transplants moored to tie-down rings distributed on 1.5 m centers on the bottom of the bag. Various fertilizing schedules and concentrations were used throughout the summer, but mean N-contents of the kelp tissues were 1.3 percent dry wt or higher for canopy tissues or 1.8 percent dry wt or higher for subcanopy and basal tissues, indicating freedom from nutrient-limited growth (Gerard, 1982). Inflowing water to the Hemidome was drawn from a depth of

Table 1

Changes in tissue N (percent dry wt) during summer 1982 among Macrocystis blades in the Hemidome and control populations. Values represent means and standard deviations, from analyses of 5-6 blades (Hemidome) or 2-3 blades (controls) except when only a single blade was available (no standard deviation given).

		% N content				% N content			
Date	Blade type	Canopy	Subcanopy	Basal	Juvenile frond	Canopy	Subcanopy	Basal	Juvenile frond
		HEMIDOME				CONTROL			
July 13		--	1.92±0.32*	1.82±0.23*	1.68±0.16	--	1.82±0.12*	1.39±0.25*	1.40±0.03
July 27		1.34±0.27	1.92±0.14	1.83±0.18	1.97±0.16	0.83±0.17	1.33±0.26	1.18±0.24	1.23±0.12
Aug 10		2.07±0.40	1.80±0.31	1.75±0.25	2.14±0.43	0.48±0.07	0.72±0.06	0.67±0.08	0.73±0.14
Aug 24		2.80±0.29	2.43±0.46	2.37±0.41	2.98±0.60	0.30±0.12	0.60±0.08	0.57	0.79±0.19
Sept 8		3.05±0.44	2.77±0.28	--	3.31±0.60	0.41±0.09	0.48±0.19	0.45	0.71±0.20

*Samples from fronds that had been harvested.

about 5 m between the start of the experiment on July 1 and August 10, then from a depth of about 13 m thereafter. Temperatures of the inflowing and outflowing waters were monitored continuously. Temperature and macronutrient concentrations show close inverse correlation in these waters (R. Zimmerman, personal communication). With minor exceptions, inflowing water temperature remained at or above 18°C from July 1 to July 10

and was 18°C or more continuously thereafter until September 15. We concluded that naturally occurring macronutrient concentrations were low and provided negligible nourishment to our experimental plants relative to inputs by fertilizing.

We also moored ten control Macrocystis plants outside the Hemidome near Intake Point, about 200 m northeasterly from the Hemidome (Figure 1). A small kelp bed occurs naturally along both sides of Intake Point. Our control transplants were moored at the outside edge of the natural bed inside Big Fisherman Cove, where bottom depth was about 18 m. The control transplants were attached to buoys about 8 m above the bottom, so their holdfasts would be positioned at depths similar to our experimental plants inside the Hemidome (Figure 2). Our temperature data indicate that some upwelling occurred in Big Fisherman Cove during July, August, and early September of 1982, probably supplying macronutrients to the control and the naturally attached plants, in addition to any sustenance they may have received from recycled nitrogen and phosphorus. Depth of the thermocline fell below levels of the control plant holdfasts from about September 20 to the end of November, when our study was discontinued.

We used mean N-content of blade tissues as a measure of the nutritional status of our plants. Analyses indicated that samples from various laminar tissue types (canopy, subcanopy, basal, and juvenile) from plants in the Hemidome tended to display constant or increasing N-contents between July 13 and September 8, 1982 (Table 1). This contrasted strongly with N-contents of samples

from our control transplants, which all declined to concentrations representing severe malnutrition (Gerard 1982, concluded that the critical level representing lack of any nitrogen reserves was an N-content of 1.1 percent dry wt for laminar tissue). In summary, plants in the Hemidome were well nourished and built up nutrient reserves while control plants outside became starved.

Water inside the Hemidome was well mixed. Of 29 vertical temperature profiles conducted between July 13 and September 19, 1982, 23 yielded surface and bottom temperatures within 0.7°C or less of each other. The remaining six profiles occurred at times when upwelling episodes had been in progress for a short time, causing temperature stratification inside the bag. Thus it appeared that the record provided by the thermistor measuring temperature of the outflowing water was a good indicator of conditions to which the kelp canopy was exposed. Between July 4 and August 10, 1982, the outflow sensor yielded temperatures ranging from 17.9° to 22.8°C (Table 2). The Hemidome drew water from about 5 m deep during this period. Temperature range given by the outflow sensor from August 11 to October 19 (when the Hemidome was receiving water from 13 m depth) was 17.2° to 21.2°C. Surface temperatures in Big Fisherman Cove (44 profiling measurements from July 13 to October 23) ranged from 18.5° to 23.0°C (Table 3). The range for temperatures from 12 m deep was 16.3° to 21.7°C. Thus canopies of kelp plants inside and outside the Hemidome received substantial exposures to water temperatures 20°C or higher during summer and early fall 1982.

Table 2

Environmental data summaries from continuously monitoring sensors on the Hemidome. Temperatures from outflow sensor. Insolation values represent maximum and minimum for each day between roughly 0900 and 1600 unless specified otherwise under remarks. All dates represent 1982.

Date	Daily temp. range °C	0900-1600 Insolation nE/cm^{2}sec max	min	Remarks
July 4	18.3-19.0	542	297	Record began at 1052
5	18.4-18.9	590	110	
6	18.6-19.2	540	111	
7	19.0-19.5	627	121	
8	18.8-19.4	525	133	
9	18.7-19.2	521	234	
10	18.9-19.5	519	296	
11	19.3-19.8	527	210	
12	19.4-19.8	529	115	
13	19.5-19.9	651	151	
14	19.5-20.1	591	166	
15	19.2-19.9	598	117	
16	19.3-19.8	650	71	
17	19.7-20.0	582	180	
18	19.7-20.4	541	179	
19	19.3-19.9	525	237	
20	19.4-20.1	512	299	
21	18.9-19.5	508	279	
22	17.9-19.3	500	271	
23	19.0-19.7	665	224	
24	19.4-19.8	508	192	
25	19.7-20.4	493	276	
26	20.2-20.7	498	233	
27	20.5-21.0	504	237	
28	20.8-21.4	511	243	
29	21.2-21.6	492	254	
30	21.5-21.8	492	252	
31	21.8-22.3	552	210	
Aug 1	21.5-22.2	602	85	
2	21.6-22.1	637	99	
3	21.7-22.1	515	226	
4	21.6-22.8	515	237	
5	21.0-22.0	495	194	Gap in record from 0700 to 1300
6	21.0-21.7	498	154	
7	21.0-21.2	509	259	
8	21.0-21.5	501	134	
9	21.2-21.5	504	234	Gap in record from 0900 to 1300
10	21.9-21.0	499	251	

Table 3

Hemidome and Big Fisherman Cove (BFC) water temperature, °C, summer - fall 1982, from vertical profiles on the indicated dates using Martek temperature-depth sensors.

Date	Hemidome		BFC	
	Min.	Max.	Surface	12 m
July 13	19.8	19.9	20.1	18.6
19	19.7	20.0	20.1	16.5
20	15.6	20.1	19.7	19.7
22	15.1	19.0	18.5	17.4
26	19.9	20.6	20.4	20.3
27	20.3	20.7	20.7	20.6
29	21.4	21.4	21.7	20.5
Aug 2	18.5	21.8	21.7	21.7
3	21.9	22.2	22.2	19.7
5	21.1	21.7	21.7	18.1
9	15.4	21.4	21.2	--
10	20.9	21.1	21.6	16.7
12	18.5	18.5	20.9	19.0
16	18.4	18.5	21.4	20.5
18	17.5	18.4	21.1	21.0
20	16.6	18.0	21.1	16.8
22	17.5	17.6	20.3	17.5
25	17.4	17.9	20.1	16.7
27	18.4	19.0	20.7	17.3
29	19.6	20.2	21.5	18.6
Sept 1	18.0	18.2	21.4	20.7
3	18.4	19.1	23.0	16.9
5	18.7	19.0	21.6	18.2
9	17.6	17.8	21.3	16.3
11	17.8	17.9	20.2	16.4
12	18.3	18.8	20.8	18.3
15	17.3	17.8	20.2	17.8
17	18.8	18.8	20.2	19.8
19	18.0	19.2	20.1	18.7
21	17.8	18.7	20.3	18.9
1245 22	18.6	19.8	20.8	19.8
1500 22	19.3	20.0	21.0	20.1
23	18.1	19.3	20.5	17.6
26	19.5	19.6	20.1	19.9
29	19.3	19.4	19.8	19.5
Oct 1	18.9	19.0	20.4	19.0
6	18.8	18.9	20.4	19.3
8	19.1	19.1	20.4	19.6
10	18.9	19.2	20.4	17.9
15	19.8	19.8	20.1	19.7
17	19.7	19.7	20.3	19.5
20	19.5	19.5	20.3	19.6
22	19.4	19.4	19.9	19.6
23	19.7	19.7	20.4	19.8

Experimental plants in the Hemidome suffered considerable tissue loss from sloughing (presumably disease-related), particularly the holdfast region and lower 3 m of the frond bundles. Canopy existed at all times. This contrasted markedly with the control plants which lost practically all their canopies by early August. Basal portions of the control plants remained fairly healthy until the thermocline descended below holdfast levels around September 20. The basal portions deteriorated

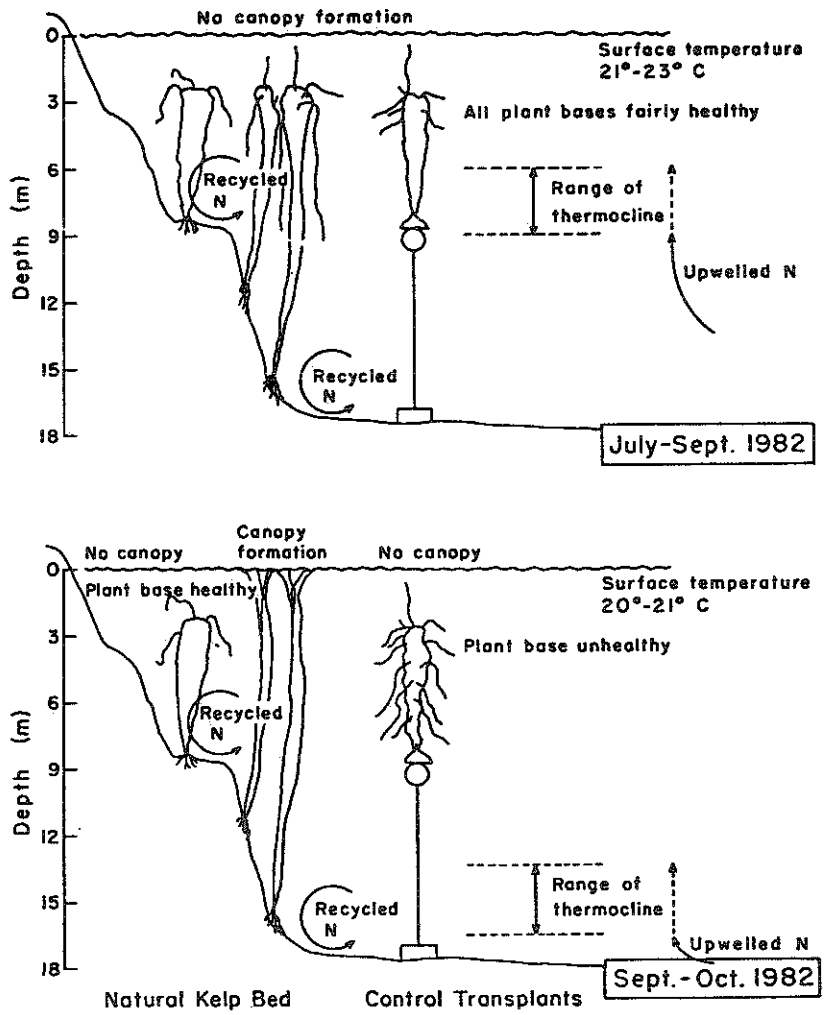

Figure 2. Diagram illustrating conditions in the natural and control stands of kelp plants during summer and fall 1982 and the nutrient sources presumed as existing in Big Fisherman Cove.

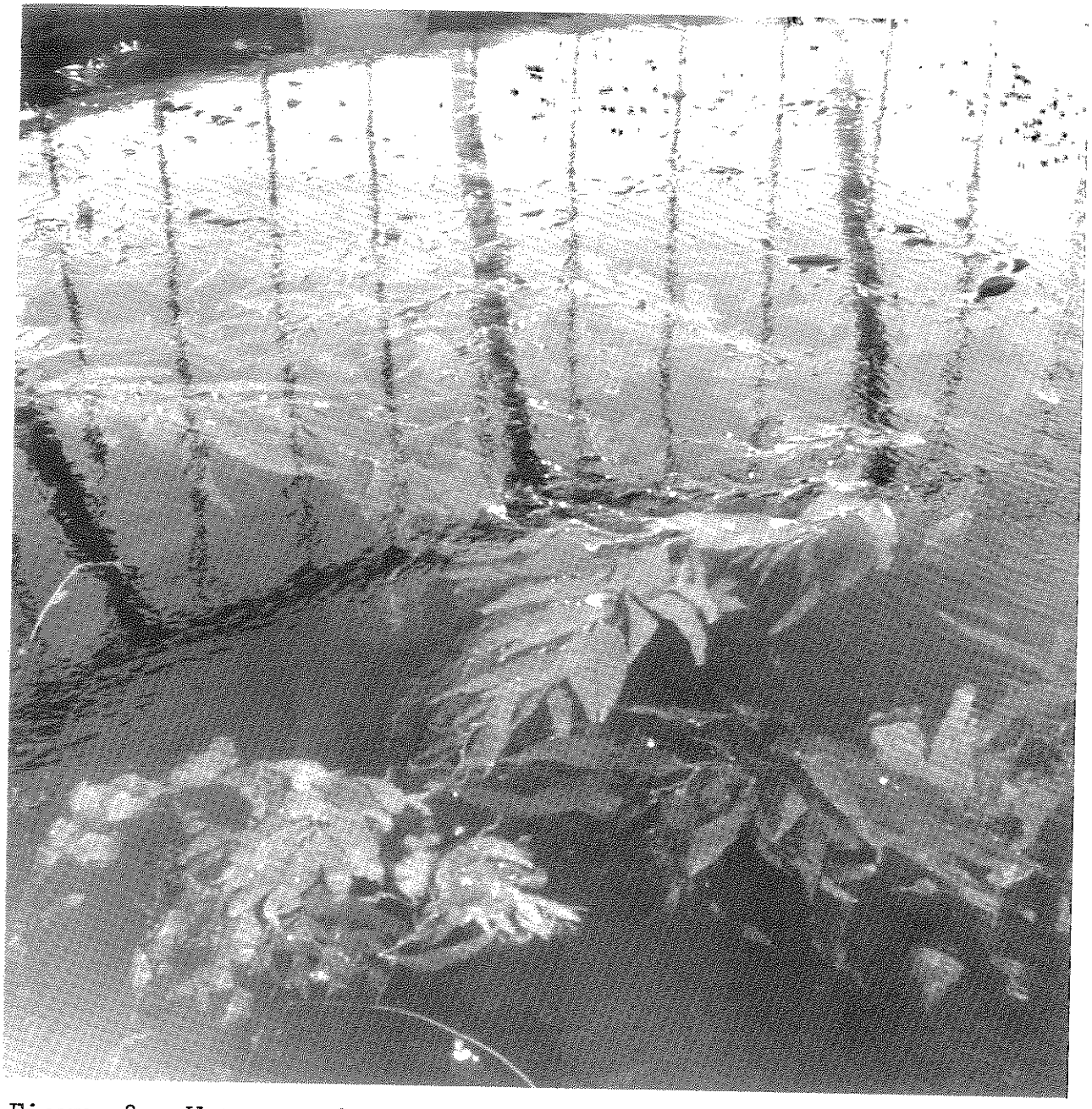

Figure 3. Water surface inside the Hemidome showing dense Macrocystis canopy on August 2, 1982.

thereafter, and these plants began dying in early November, apparently from malnutrition.

Quite interestingly, naturally attached plants near our controls also lost their canopies more or less coincidentally with the controls, but those plants attached at depths of about

Figure 4. Underwater view inside the Hemidome on August 23, 1982, looking diagonally upward. Dense Macrocystis canopy lies in upper half of the photo.

12 m or greater regenerated canopies during latter September. Basal portions of all naturally attached plants remained healthy, regardless of their holdfast depths (see Figure 2). Apparently, all the natural plants received sufficient macronutrients from recycling processes close to the bottom so as to maintain a

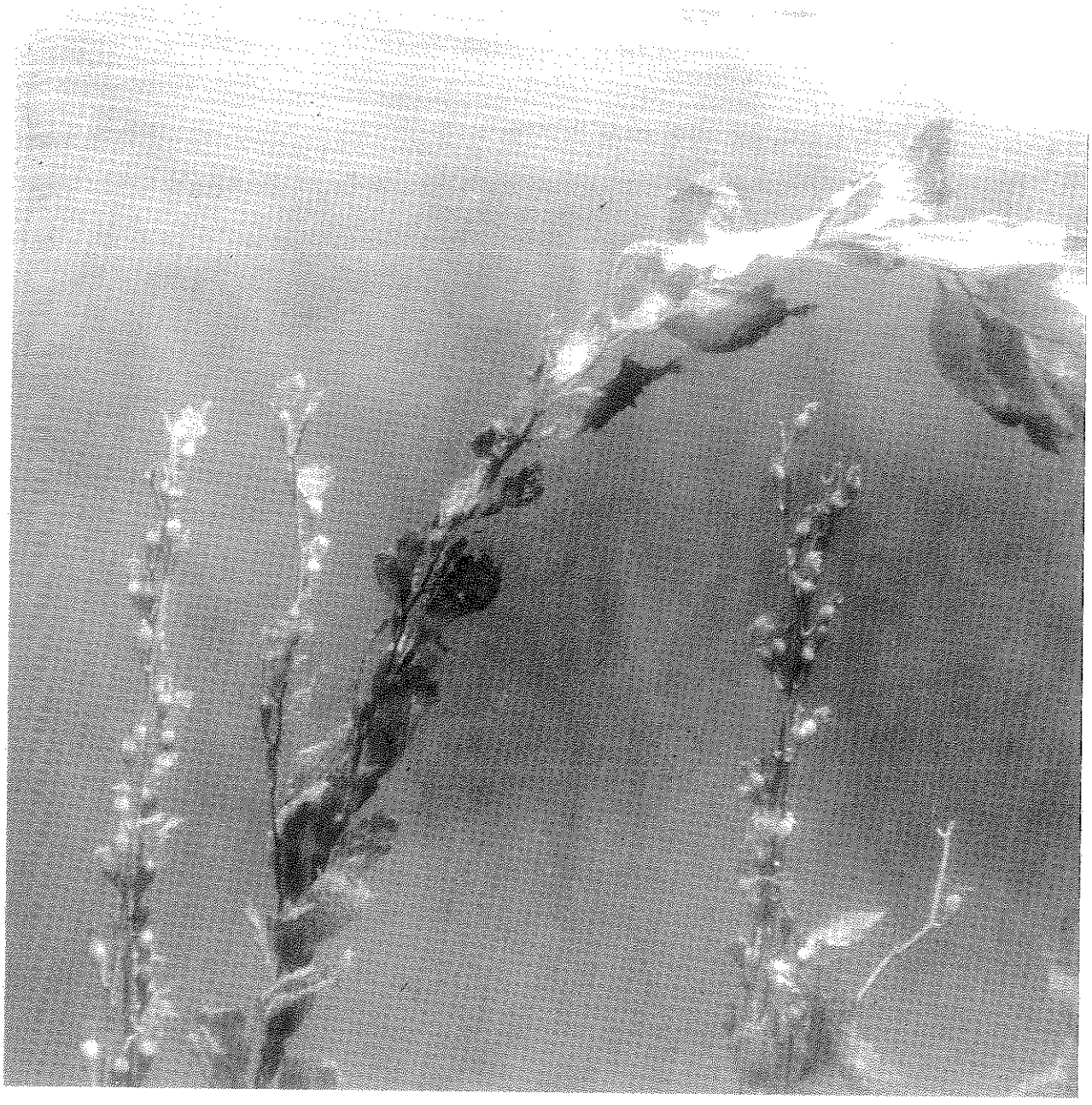

Figure 5. View just subsurface of the single canopy-length frond remaining among the control Macrocystis plants on August 16, 1983. The frond had lost buoyancy so it did not actually lie at the surface in true canopy fashion. Other deteriorating senile fronds shown terminated about 1 m below the surface and were typical of control fronds within the top 3 m of the water column on this date.

healthy status among the basal portions. Those plants attached at depths of 12 m or more apparently received enough macronutrients from upwelling to be able to regenerate their canopies in early

fall. These observations further confirm the beneficial effects of macronutrients in sustaining canopy tissues during periods of elevated water temperature.

CONCLUDING DISCUSSION

Our experiments and observations support Jackson's hypothesis that summertime deterioration of kelp canopies arises at least in part because of poor nutritional conditions above well-developed thermoclines. We should caution, however, that the solution to the problem might not lie in indiscriminate fertilizing of canopies. As noted above, our experimental plants in the Hemidome suffered considerable tissue losses from disease-like lesions, black rot, and stipe rot, as well as from grazing organisms. The disease-like problems worsened for many plants as time passed. We believe that "enclosure effects" in the Hemidome was partially responsible for these difficulties, but buildup of nitrogen to extremely high levels (see Table 1) possibly also encouraged growth by pathogenic microorganisms. Any fertilizing of kelp beds when water temperatures are high should be done cautiously. Clearly, more research is needed, but these preliminary studies do provide hope that corrective actions might be found to counteract the sometimes high losses of kelp tissues associated with elevated water temperatures.

RESEARCH AND INFORMATION NEEDS FOR WASTE MANAGEMENT DECISIONS

Alan J. Mearns*

Resolution of waste management issues requires research that is specifically directed toward resolving the issues. "Good" research is no longer enough. It must be also explicitly relevant to specified near-term and long-range waste management issues. More to the point, it must be directed toward resolving uncertainties among waste disposal and waste management alternatives. There is simply not enough funding available to do otherwise.

During 1982 NOAA's former Office of Marine Pollution Assessment, now known, in part, as the Ocean Assessment Division (OAD), refined a management-oriented strategy for identifying research and information needs for marine pollution assessment and marine waste management. This Symposium on the Effects of Waste Disposal on Kelp Communities offered a unique opportunity to apply that strategy, which we call an "Ocean-Use Management Model". This application also offered an opportunity to entice participants to consider how their research might be more clearly directed toward resolution of uncertainties about management alternatives for mitigating effects of sewage disposal on kelp bed ecosystems. From information presented at this meeting, I made a "brief pass" through the problems and alternatives. As a result of this

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"first-cut," I concluded that the most important information gathering step is to clearly quantify all the resource-use conflicts associated with sewage disposal near kelp beds. Only when this step is completed will we be able to identify meaningful research needs.

OCEAN-USE MANAGEMENT MODEL

The ocean-use management model (Figure 1) is simply an outline or visual aid that provides all concerned parties with a complete view of the decision process leading to solution of an actual or perceived pollution problem. To a marine pollution scientist, the ocean-use management model provides guidance for identifying research needed to make rational marine waste management decisions.

The model first prompts us to carefully identify the existing or proposed activity of concern, such as a specific sewage outfall (step 1, Figure 1). It then asks us to carefully evaluate the actual and perceived problems (ie., the resource-use conflicts) and their possible causes that may be attributable to the activity (step 2). We are then boldly asked to recognize management alternatives - ie., actions that might be taken to alleviate the actual or perceived problems (step 3). Only then do we begin to consider the significant scientific research - prediction of probable outcomes of each of the proposed alternatives (step 4). This is reviewed in more detail below. The model is completed by prompting consideration of the social and scientific judgements and costs of each consequence (step 5), selection of the best course of action (step 6) and the monitoring required to confirm the actual or realized consequences of each alternative (step 7). These steps require cooperation of all involved parties.

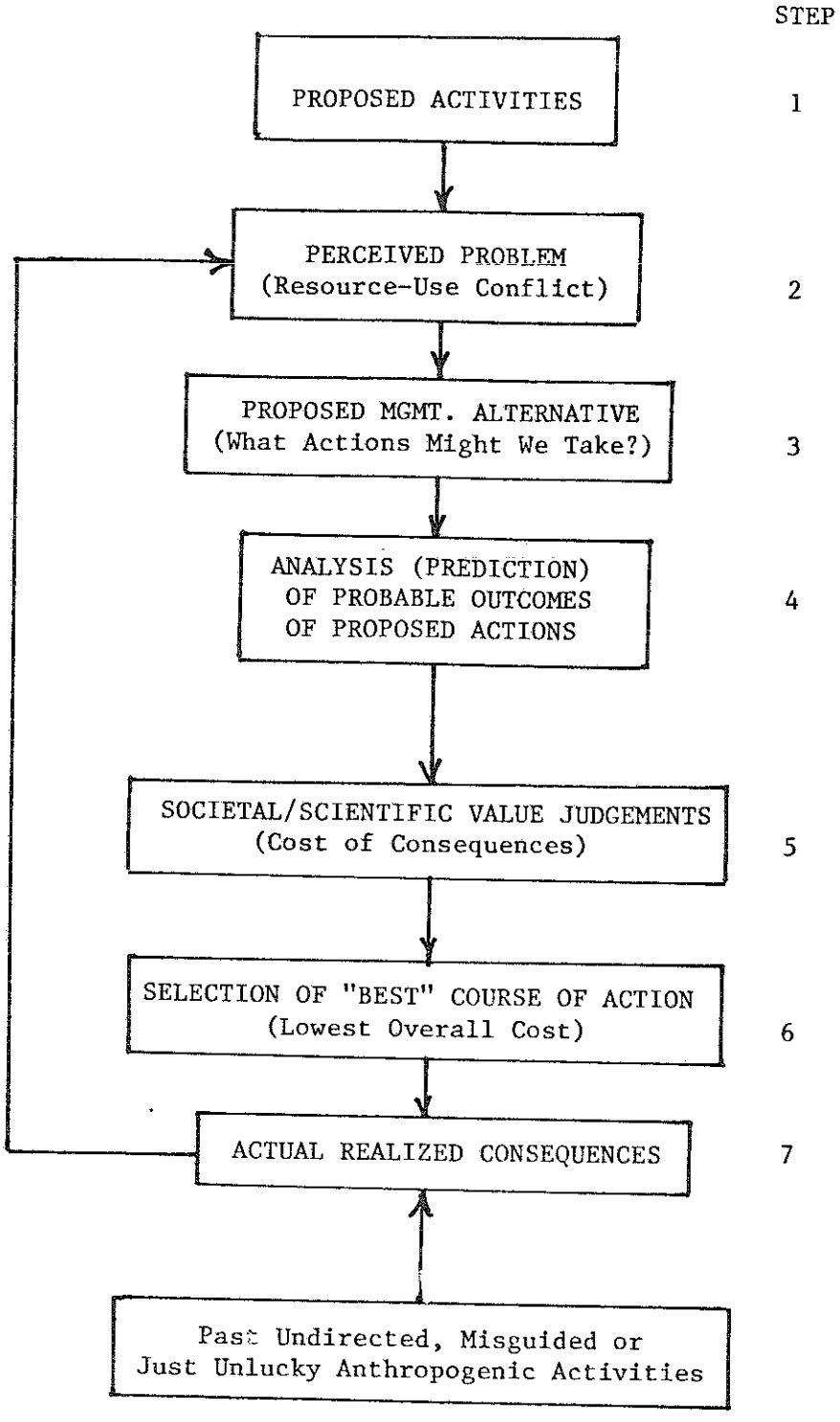

Figure 1. The Ocean-Use Management Model, Expanded to show the major elements of the decision process.

The model is useful to marine ecologists because it helps identify research needed to make specific management decisions. It helps managers because it reminds them what to do with research results once they are in. It does this by giving prior and explicit recognition to resource-use conflicts, possible causative agents, values of each resource, management alternatives for controlling those agents and specifies environmental characteristics and processes most in need of measurement and prediction. Also, because it is directed toward identifying specific outcomes of each management alternative, it automatically guides specification of monitoring programs required to test and validate predictions of the chosen alternative.

The steps most relevant to marine pollution scientists are:

1) At least a brief pass through the entire model such that management alternatives are clearly in mind;

2) Predicting and evaluating ecological outcomes of each alternative.

Predicting ecological outcomes requires specific concern about the magnitude, spatial scales and duration of change in ecosystems for each class of values for each management alternative. This, in turn requires consideration of all relevant mechanisms of impact and all relevant stochastic events which may alter the outcomes.

What is needed to achieve prediction of probable outcomes? For each alternative pollutant source, they include:

1) characterizing the composition and magnitude of key contaminants or pollutants;

2) prediction of:

   a) exposure regimes

b) habitat disruption

c) bioaccumulation of contaminants

d) change in population size and production

e) changes in human health risks

f) changes in other human values (recreational and wilderness)

3) Design and implementation of research and monitoring strategies.

Such activities and steps are obvious to scientists and managers. The main point here is that solution of the conflicts will be hit-or-miss unless research priorities are directed toward actual management alternatives and their consequences and, further, unless the steps are recorded so someone can see where the pieces fit.

APPLICATION TO EFFECTS OF WASTE DISPOSAL ON KELP-BED COMMUNITIES

What can be learned by applying the ocean-use management model to the issue of this conference? To find out, I conducted my own analysis, incorporating data and ideas developed at this conference.

Activity of Concern

The activity of concern is waste disposal in the ocean. This can mean many things to many people; are we talking about power plant discharges, sewage outfalls, dredge spoil dumping, runoff, etc.? Each is an activity requiring its own analysis. I will limit mine to sewage discharges through outfalls. However, we are not dealing with any or all sewage discharges but principally with those in California near kelp beds. But as Foster et al have pointed out in this volume, we must be specific about which kelp beds we are talking about. Likewise, there are

many kinds of sewage discharges (deep, shallow, secondary, primary, etc.). Some exist now, others are planned.

Judging from the course of this conference, a principal concern is with two existing, largely primary-treated sewage discharges; the Point Loma Treatment Plant discharge near San Diego and Los Angeles County's Joint Water Pollution Control Plant (JWPCP) discharge offshore of the Palos Verdes Peninsula. We will focus on these, recognizing that while some information is transferable to other sewage discharges and other waste disposal activities, each requires a separate analysis.

Problem Perception

The first step in our research-decision process is to carefully identify the actual or perceived problems in a stepwise fashion.

Resource Uses. This phrase is expressly meant to identify uses of living and non-living resources to which human value can be attached. This includes non-extractive uses (eg., diving) as well as extractive (fishing, harvesting).

What are the resources of concern in the two areas? Most obvious are the several species of giant kelp, *Macrocystis spp.*, and over 100 species of fish, invertebrates, and seaweeds that are in fact harvested for sale or for direct human consumption. Less obvious are species contributing to aesthetic, wilderness or scientific values, or non-harvested species that are protected by public law (marine mammals).

Users. Users of kelp forest communities include: commercial harvesters who capture and sell fishes, shellfish, and seaweeds; recreational fishermen, divers and subsistence fishermen who capture and consume fishes, shellfish and seaweeds; recreational divers, boaters, and beach-folk who enjoy the view, scenery, awareness or wilderness

values of kelp bed areas; writers, painters, musicians, and film studios who may profit from the same values; and pharmaceuticals and biological supply houses that may profit from harvest of unusual or rare species. Less obvious may be the suite of local, state, and federal regulatory agencies charged by law with enforcing use restrictions or enhancing resources, and where salaries might be viewed as a profit from kelp-bed resources. Likewise, at least in the past, kelp-bed communities were apparently viewed as having an assimilative capacity for processing human and urban wastes.

Space does not permit a more detailed listing; however, serious commitment to a management strategy would be extremely explicit about both users and the value of resources being used.

Resource-Use Conflicts. It is clear from the brief examination of resource-use patterns in kelp-bed communities that anything that reduces stock sizes, diversity, or catchability of resident marine organisms, that reduces their "saleability", that increases health risks from consumption or other use of the resources, that impairs visibility, or that alters the assimilative capacity of the ecosystem, creates resource-use conflicts with one or more user groups.

Sewage disposal, natural oceanographic and climatic fluctuations and overfishing all have played a role in reducing the value of kelp-bed community resources. It is clear from the record of this conference that in years past discharges from the JWPCP outfalls have contributed in a major way to lost commercial value of giant kelp through lost kelp production. Likewise, although productive kelp beds returned to Palos Verdes, harvesting is not now considered a rational use by the state; a clear conflict remains.

Alternatively, it is not at all clear from the record of this or other conferences that values other than commercial and "wilderness" have been measureably lost at Palos Verdes. Likewise it is not clear that sewage disposal off Point Loma has in fact reduced the value of kelp harvesting or any other resource-use there. This is not to say that such resource-use losses haven't been incurred; rather, it is apparent that the value of lost resources has not been adequately quantified and reported. In the context of an ocean-use management approach, this is a serious shortfall and a clear research or information need. That is, any value lost to users, such as those identified, ought to be made explicit. In addition to obvious measures, such as the quantity and quality of harvested organisms or diver satisfaction with visibility, the needed assessment should include some measure of incremental risk of disease imposed on divers (eg., Baralotti,this report, and Dufour and Cabelli, this report) and those costs of fish and shellfish enhancement (eg., Wilson *et al.*, this report) attributable to either sewage disposal activity.

Agents

The next major step in defining our problem is consideration of the sewage-borne agents that may be causing lost value to kelp bed community resources. Production of giant kelp, in commercial quantities, is the only resource value of kelp communities adequately defined in the present analysis. Accordingly, I will continue the analysis by focusing primarily on sewage-borne agents that are or may be limiting production of kelp in commercial quantities. This analysis must be repeated for other lost resource values once they are confirmed and quantified (as noted above).

With few exceptions, our present knowledge of "cause-effect" relationships is primitive, particularly when we consider the multitude of possible materials in sewage and the many ecological interactions that create different kinds of kelp-bed communities (eg., see Foster et al, this report). Nonetheless, progress is halted if possible agents are not considered in advance of defining research needs.

To identify agents that that might depress kelp production (in commercially significant quantities) we need to consider biological processes that limit production. Commercial production is dependent on canopy production. In the short run(days to months), canopies are replaced by vegetative growth, near the surface. Maximal surface vegetative production presumably occurs when other of the plants own needs (respiration, sporophyll growth and spore production) and demands (sacrifices to predators and competitors, storm damage replacement, etc.) are satisfied. These are satisfied when processes such as energy production, nutrient storage, nutrient uptake, photosysnthesis and carbon dioxide uptake are maximized and when losses due to predation and competition are minimized. Therefore, in the short run, we must consider agents that limit one or more of the indicated biochemical processes or that enhance the success of canopy predators and competitors.

In the long run (seasons to years), canopy growth is dependent on recruitment of young plants. Recruitment may come from within the bed or from nearby beds. I am not familiar with how much we know about this. In either case, recruitment is dependent on successful settling of microscopic sporophytes, fertilization of gametes, gamete production,

and gametophyte survival. Therefore, in the long run, we must consider agents that limit one or more of these processes.

It is now appropriate to consider agents in sewage that might limit one or more of these processes. For convenience, I have group agents into several categories, utilizing data in Schafer 1982.

Inorganic nutrients. Los Angeles County discharges about 20,000 mt/y of NH3-N and 5,000 mt/y of total P each year; emissions from Point Loma are about one-quarter of this (4400 mt/y) for NH3-N but is unmeasured for P. These dissolved nutrients should be beneficial to kelp, but they might be detrimental if they encourage growth of light-limiting phytoplankton or competitive species of seaweeds. These nutrients might also be limiting if they are sufficiently concentrated to 'burn' the plants. Measureable enhancement of phytoplankton populations have been documented around several outfalls, but to my knowledge no one has estimated the extent to which such enhancement contributes to reduced euphotic depths near adjacent kelp beds. Likewise, it is not clear that we know to what extent ammonia levels may be toxic or inhibitory to kelp. Finally, it is not clear how much of the measure nutrient input is in fact in a dissolved state. Considering the vast quantities of nitrogen being discharged, these and related questions might be well worth investigating.

Organic Nutrients. Sewage can contain a dilute slurry of biogenic chemicals that may serve as permanent or temporary sources of food for animal predators and competitors of seaweeds. These include carbohydrates, fatty acids, amino acids and larger structures of each (eg., cellulose, sterols,and proteins, respectively) and vitamins (Painter, 1973). To the best of my knowledge there is no data on the

mass emissions rates of these materials in local effluents. But there is evidence that some local species of marine invertebrates are capable of assimilating at least amino acids. Likewise there is evidence that dinoflagellates not only use, but require, Vitamin B12. Thus there may be a need to document emissions of these kinds of materials in wastes.

Particulate Material. Los Angeles County and San Diego City discharge, respectively, about 82,000 mt/y (dry weight) and 27,000 mt/y of suspended solids each year. There is considerable evidence supporting the hypothesis that excess particulate matter has limited kelp production at Palos Verdes by (1) reducing light in the water column or (2) smothering settling habitat for gametophytes and sporophytes. What is not yet resolved is the extent to which the particulate matter is composed of particulates originating in sewage. It might be composed of remains of plankton, enhanced through inputs of dissolved nutrients (see above). If the 'ocean particulate matter' is composed largely of sewage particulates then we ought to know mass emission rates of two forms of those particulates: (1) those that infact remain 'suspended' and (2) those that in fact settle to the sea floor.

B.O.D. Los Angeles County currently discharges 102,000 mt/y of oxygen demanding material, as measured by 5-day biological oxygen demand (B.O.D.); corresponding input from Point Loma is about 29,000 mt/yr. To my knowledge, no one has suggested that B.O.D. might be detrimental to kelp. Plants consume oxygen day and night; but oxygen is produced in excess during daylight hours. However, in darkness it is possible that particulate material rich in B.O.D. may compete with microscopic and juvenile plants for oxygen. The paradox is that we know nothing about the distribution of B.O.D. in the effluents: how much is dissolved, how

much is bound to "settleable" material and how much is bound to "suspended" matter?

Oil and Grease. Los Angeles County currently discharges nearly 12,000 mt/y of oil and grease, ie., all material extracted by the reagent hexane. Corresponding input from Point Loma is nearly 5300 mt/y. We do not know what this fraction contains nor how its contents might affect kelp. However, it ought to contain a large suite of lipophillic substances ranging from mon- and poly-cyclic aromatic hydrocarbons to animal fats and plant fats and waxes. Eganhouse and Kaplan (1981 and in press) have documented such a suite of compounds in slightly different organic fractions of both effluents. Many of the chemicals are candidate toxins and mutagens, provided they reach the microscopic, juvenile or adult kelp plants. We don't know if they do or not. Other constituent chemicals may provide nutriment to bacteria, ciliates and lower animals, some of which may be competitors, symbionts or predators of kelp.

Cyanide (CN). Mass emissions of this routinely measured toxic material are currently 40 mt/y for the LA County discharge, but only 2.3 mt/y for Point Loma. To my knowledge, nothing is known about concentrations of CN in and about kelp beds or about concentrations that can inhibit growth and reproduction of kelp.

Trace Metals. Mass emmissions of several toxic and required trace metals (silver, arsenic, cadmium, copper, mercury, nickel, lead and zinc) are routinely reported for the two discharges. Inputs range from 0.9 mt/y of mercury to 106 mt/y of chromium for LA County, and from 0.1 mt/y of mercury to 24 mt/y of copper for Point Loma. It is well known that filter-feeding invertebrates (such as mussels and scallops) around

outfalls accumulate above-normal concentrations of some of these metals. It is also well-known that none of of these metals undergo biomagnification into fin fish. New information, some of which is presented in this volume, is beginning to identify levels that are required and that are toxic to sensitive life stages of kelp. But, to my knowledge, no one yet knows whether kelp near outfalls are accumulating excess metals nor whether the metals in surrounding sediments and water are in forms that can be toxic to or assimilated by kelp.

Organochlorines There is no question that DDT emmisssions from the Los Angeles County outfalls have contaminated marine organisms throughout the Southern California Bight. Mass emission rates are now orders of magnitude below those of a decade ago (422 kg/yr vs over 20,000 kg/y, respectively); emmisssions at Point Loma are almost trivial (15 kg/y) Isomers and metabolites of DDT are clearly toxic to arthropods and it is possible to suppose that there might be some symbiotic crustaceans whose absence in the past might have been detrimental to kelp production. Likewise it is possible that isomers or metabolites of DDT and other organochlorines might be directly to kelp, ie., especially lipid-rich ova. Similar arguments could be put forward for other chlorinated pesticides and other organochlorines such as PCB's (272 kg/y from LA County and 119 kg/y from Point Loma). Again we find no data available to confirm what levels are toxic to kelp.

Space does not allow detailed continuation or expansion of this analysis. Nonetheless, it is possible to come to a few important conclusions about agents. First, we apparently have extremely inadequate knowledge for judging which agents are the most likely candidates for

limiting short and long-term kelp production; possibilities other than the conveniently measured solids and metals have yet to be convincingly considered and ruled out. Likewise, it appears we need to learn more about the forms of chemicals in sewage and the forms that can cause effects to kelp.

THE DECISION PROCESS

We now bring our attention to the management alternatives, possible outcomes of each of those alternatives and , finally, identification of research needed to help choose among them.

Management Alternatives

Conflicts can only be resolved by removing the offending agent or by having all parties agree to put up with the consequences of making no changes. For sewage outfalls that appear to be limiting the production of kelp, the alternatives are:

1) changing disposal location
2) increasing dilution
3) reducing offending-agent inputs at the treatment plant
4) reducing offending-agent inputs upstream (source control).
5) do nothing

For the first alternative, the point of discharge (the diffuser) might be moved offshore to deeper water or new trunk lines and outfalls might be constructed up- or down-coast of the kelp beds. Or, the entire discharge might be diverted onshore to be treated and disposed. Increased dilution (alternative 2) might be achieved by splitting the flow into several adjacent diffusers. If the offending agents are solids

or B.O.D, then certainly advanced (eg secondary) treatment may markedly improve the situation. If the primary agents are toxic metals or pesticides, advance treatment might also help provided these agents are drawn down into the particulate sludges during treatment. If, however, the offending agents are biogenic solids produced from dissolved nutrients, or if they are other dissolved substances poorly removed by secondary treatment, then tertiery treatment (to remove nutrients) and source control will be required. If the agent is still not removed and the location cannot be changed, then there is no alternative; lost production will have to be accepted.

Outcomes and Consequences of Management Alternatives.

Alternate Discharge Location. If the agents causing lost kelp production decay or are reasonably biodegradeable (such as nutrients, BOD, solids) then this alternative ought to be succesful. The consequences will then focus on values that might be affected at alternate sites, ie., deep-water (eg., Jackson, 1982), up- or down-coast or ashore. However, if the agents are not easily degraded or if they tend to accumulate in biota no matter how remote (eg., DDT and PCB's), the problem may not be solved without source control.

Same Discharge Location. The reduction of solids, B.O.D. and large fractions of particulate-bound chemicals by advanced treatment results in sludges that must be disposed somewhere. Alternatives are obvious to anyone who has followed the issues of sludge management in California: landfills, combustion or some remote ocean disposal site (eg., Jackson, 1982). Costs and impacts to a variety of terrestrial and marine resources must be investigated. The possibility remains that such

treatment may not solve the problem if offending agents are so soluble or so resistant to oxidation that they remain in the final effluent; the question is which are they and are they among the prominent causative agents (eg, some metals, trace organics and nutrients)? Thus as far as the issue of kelp is concerned, it becomes vital to management to be certain projected emissions of nutrients, dissolved metals and dissolved organics are not the agents limiting kelp production.

Consequences of tertiary treatment, to remove nutrient inputs, and/or source control to reduce dissolved chemicals, must be examined. I do not have the expertise to evaluate the many possible consequences of these, but additional costs (social and economic) and investigations would obviously be required.

Data and Information Needs

It is obvious that I have barely scratched the surface of details needed to identify resource-use conflicts, agents, and management alternatives and consequences. Nonetheless, we may have done enough here to make a rough outline or summary of some data and information needs.

I purposely narrowed my analysis to the commercial value of harvested kelp. This narrowing has likely biased the outcome of my analysis. A clear need exists to quantify all the resource use conflicts associated with kelp bed communities near outfalls, to identify the most important ones and to repeat, in detail, the entire analysis through the decision process. Some suggestions for evaluating resource values have been given above. Only when all are considered will we arrive at a list of balanced research priorities.

Despite the limitations I imposed, analysis of the issue of lost

kelp production results in some important directions for research. In my analysis, I conclude there is a startling lack of useful information about the forms of chemical agents in sewage, sea water, sediments and sea weeds that might be limiting to kelp. Whole categories of materials in sewage (eg., B.O.D., cyanide, inorganic nutrients) have apparently been rarely considered as possible or plausible targets for cause-effect research. Explicit statements need to to made, one way or another, about these materials if we are to make and justify rational decisions about the level of sewage treatment required. Likewise, while there has been some intriguing research on trace metal requirements and toxicity to kelp (Kuwabara, this report), we need a mechanism or model for relating the forms and quantities affecting kelp to the forms and quantities discharged under different treatment and source control scenarios (such as noted in Mearns 1980; Mearns and O'Connor, in press and Mearns and Word 1982). The same logic applies to toxic organic chemicals, including organochlorines.

A major gap appears to be inadequate knowledge about the forms of both traditionally monitored materials (nutrients, BOD, metals) in sewage and their transformation to or from biologically active forms in the environments of kelp bed communities. Without such information, or at least hints of answers, we cannot predict what various levels of treatment or source control will achieve.

It also seems that few have considered the possibilities and consequences of changing current discharge locations. What would the kelp "exposure" field look like were present outfalls extended various distances? Conversely, for any agent that one can offer a reasonable cause-effect hypothesis, what might be a suitable terminus location? And

what are the consequences and benefits of that alternative? Modeling could be powerful here.

Again, space does not allow the detailed analysis required. Hopefully, this presentation does provide some brief look at the process that many research sponsoring agencies are now enlisting to help set marine pollution priorities.

ACKNOWLEDGEMENTS

Dr. Douglas A. Wolfe, Ocean Assessment Division, NOAA, Rockville, Maryland, developed the Ocean-Use Management Model and taught me to apply it. I thank Dr. Wolfe, but also take full responsibility for any errors or ommissions in the present analysis.

CHANGES IN INTERTIDAL ALGAE AT PALOS VERDES, CALIFORNIA

Leslie H. Harris*

Intertidal Algae at Palos Verdes

In 1979 I reexamined the intertidal algae at several sites along the Palos Verdes Penninsula that had been studied by Dawson and others in the 1950's. At these sites -- Whites Point, Portuguese Point, and Flat Rock Point -- many more species were found than had been reported since the initiation of sewage discharge in 1937. Impressed by this dramatic increase in both diversity and abundance, SCCWRP decided to make a more complete investigation of intertidal algae both at Palos Verdes and elsewhere along the southern California coastline. The objective was to document the current status of the flora and to trace its historical flucuations in hope of determining the reasons for change.

Fortunately, Palos Verdes has a long history of algal collecting so there were plenty of data to work with. W.A. Setchell and N.L. Gardner visited the Whites Point - Point Fermin area several times between 1895 and 1912. A later compilation of their records by E.Y. Dawson indicated that the turn-of-the-

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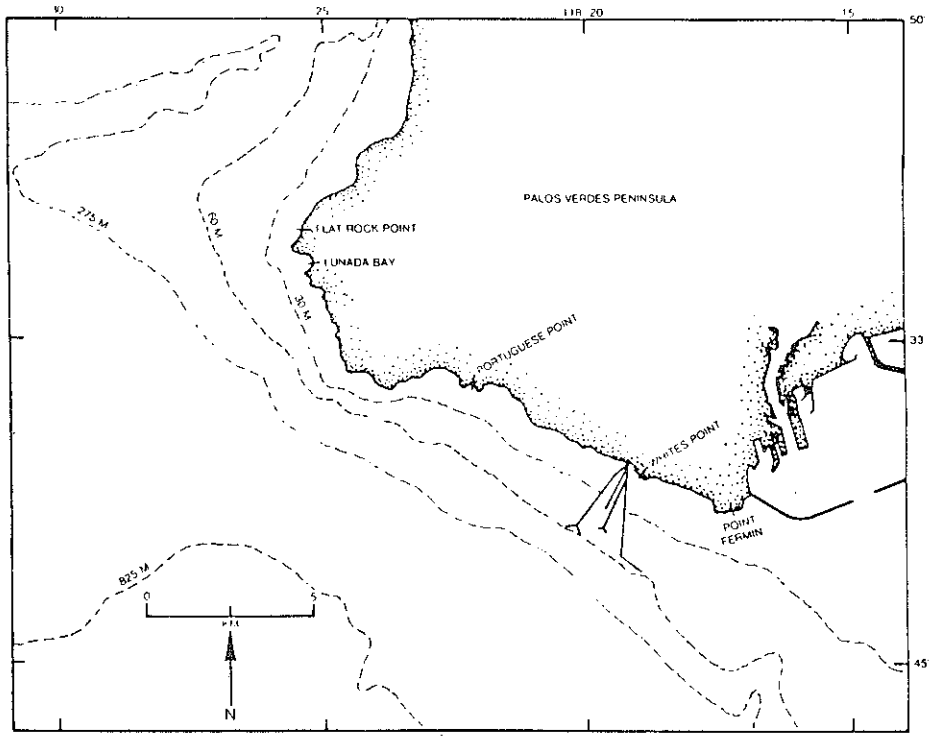


Location of sampling sites.

century flora consisted of no less than 60 conspicuous species. In 1915 E.B. Couch studied the flora of Point Fermin for his master's thesis. J. Goodman, another graduate student, wrote his 1935 thesis on the marine algae of 6 sites on the Palos Verdes peninsula, each site averaging 74 species each. Goodman's was the last study done before shallow-water sewage discharge began in 1937 at Whites Point. Starting in 1956 E.Y. Dawson surveyed the benthic intertidal algae at 42 sites along the southern California coast under the auspices of the State Water Pollution Control Board of California. 5 of his sites were at Palos Verdes and included areas previously seen by Setchell, Gardner, Couch, and Goodman: these areas were Lunada Bay Flat Rock Point, Portuguese Point, Whites Point, and Point Fermin. In 10 station-visits

Dawson found an average of 24 species and a change in the dominant flora from membranaceous red algae and medium-to-large brown algae to articulated corallines and small turf-forming algae, with stunted specimens at Whites Point, and Point Fermin. Dawson directly attributed these changes to the introduction of sewage and other of man's activities.

SURVEYS AT PALOS VERDES

DATE	LOCATION	GENERAL SURVEY (G) TRANSECT SURVEY (T)	COLLECTOR
1895-96	Whites Point area, Point Fermin	G	W. A. Setchell (UCB)
1908	Point Fermin	G	N. L. Gardner (UCB)
1908-12	Whites Point	G	N. L. Gardner
1915	Point Fermin	G	E. B. Couch (USC)
1935	Lunada Bay, Malaga Cove, Flat Rock Point, Bluff Cove, Rocky Point, Resort Point	G	J. S. Goodman (USC)
1956-59	Whites Point, Point Fermin, Lunada Bay, Flat Rock Point, Portuguese Point	T	E. Y. Dawson (AHF)
1968-70	Whites Point, Point Fermin, Lunada Bay, Flat Rock Bay Portuguese Point (Data not available)	T	T. B. Widdowson (CSULB)
1973-74	Whites Point, Point Fermin, Lunada Bay, Flat Rock Point, Portuguese Point	T	R. M. Thom (CSULB)
1975-76	Royal Palms (Whites Point)	T	S. Murray & M. Littler (SAI-BLM)
1979-80	Whites Point, Point Fermin, Lunada Bay, Flat Rock Point, Portuguese Point	T	L. H. Harris (SCCWRP)

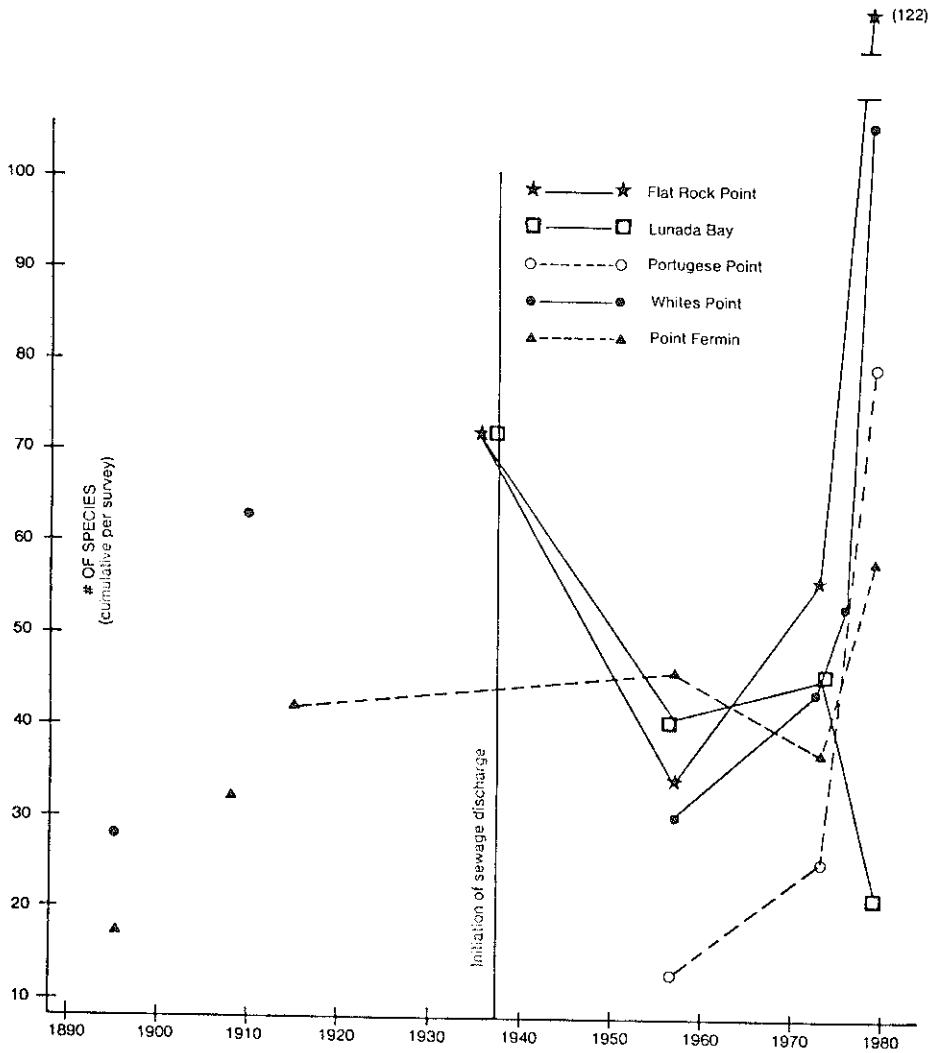
T. Widdowson resurveyed some of Dawson's stations, 1968-1970, including those at Palos Verdes, and concluded from his data that there had been an even more widespread reduction in algae diversity. R. Thom, a graduate student of Widdowson's,

again resurveyed Dawson,s stations in 1973-74, finding an average of 30 species over 14 site visits. He showed a slight increase, but agreed with Widdowson that there had been no substantial change in the area since Dawson's time. Murray and Littler investigated an area 600 m northwest of Dawson's Whites Point station. In 4 visits during 1975-76 they found a total of 56 species, 41 per station visit. Despite the increase in number of species, they agreed that the area was depauperate and represented a stressed environment, and they pointed out parallels between the conditions at Whites Point and those of a sewage-perturbed community on San Clemente Island.

I collected at Palos Verdes in winter 1979/1980 and looked at Dawson's material from his survey (slides of each station, original field notes, and preserved specimens, all stored at the Herbarium of the Allan Hancock Foundation) to make sure my identifications were consistent with his and to correct inconsistencies in the literature. Combining my original summer collections with those from winter, I found an average of 62 species over 8 visits. Abundances had also increased since Dawson's survey, as far as I could tell from the previous literature and photography, and large brown algae and membranaceous red algae were again common. Macrocystis, previously absent offshore, was not only present off the Palos Verdes stations but in tide pools adjacent to the collecting areas at Whites Point and Portuguese Point. Reports from divers said the same general increase in diversity and abundance had taken place in the subtidal as well. This represented a major change,

apparently all within the last 6 years.

Considering the 5 sites individually, the species diversity at Flat Rock Point, Portuguese Point, Whites Point, and Point Fermin was equal to or greater than that shown in the earliest records. Only at Lunada Bay was there a decrease in species, even when compared to Thom's or Dawson's data. This seems to be because this is an exposed sloping ridge near the south side of the bay subjected to rapid and heavy sand movement.



Number of intertidal seaweeds at each station through time. Only data points after 1915 have been connected; no effort was made to collect representative floras before then.

No single factor can explain the decrease Dawson noted in the fifties or has been proven to effect the intertidal algae. Dawson and other researchers pointed out that the

WHITES POINT

ec. 395 an. 396	fall-winter 1908 1912	Jan. 1957	June 1957	Oct. 1957	Jan. 1974	Oct. 1973	Sept. 1975	Dec. 1975	Feb. 1976	May 1976	Jan. 1974	June 1973	July 1979	Nov. 1979	
28	63	22	21	21	29	28	37	37	38	43	24	32	62	77	Total No. of Taxa
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	Spermatophyta
4	7	4	4	4	2	3	3	3	4	4	3	4	7	10	Chlorophyta
9	14	5	3	5	3	4	6	7	8	8	2	6	13	12	Phaeophyta
14	41	13	14	12	24	21	28	27	26	31	19	22	42	55	Rhodophyta

FLAT ROCK POINT

335	Nov. 1956	June 1973	Nov. 1973	(N) Mar. 1973	(N) July 1973	July 1979	Nov. 1979	
72	34	41	37	36	30	85	89	Total No. of Taxa
0	1	1	1	2	1	1	1	Spermatophyta
3	1	2	4	5	2	8	8	Chlorophyta
13	9	9	7	5	6	16	12	Phaeophyta
56	23	29	25	24	21	60	68	Rhodophyta

POINT FERMIN

1895-6 1908	Jan. 1957	Oct. 1957	Jan. 1974	Oct. 1973	(N) Mar. 1973	Nov. 1979	
41	37	31	23	31	30	58	Total No. of Taxa
1	1	1	1	1	1	1	Spermatophyta
1	0	1	1	1	2	3	Chlorophyta
10	5	8	4	6	4	7	Phaeophyta
29	31	21	17	23	23	47	Rhodophyta

PORTUGUESE POINT

Nov. 1957	Nov. 1973	July 1979	Nov. 1979	
13	25	57	56	Total No. of Taxa
1	0	0	0	Spermatophyta
0	2	6	3	Chlorophyta
7	8	15	10	Phaeophyta
5	15	36	43	Rhodophyta

LUNADA BAY

1935	Mar. 1957	June 1957	Oct. 1957	Mar. 1973	Oct. 1973	(N) Feb. 1973	Oct. 1979	
72	30	34	19	33	31	9	22	Total No. of Taxa
0	1	2	1	1	1	1	1	Spermatophyta
4	0	1	1	4	3	1	2	Chlorophyta
23	6	7	5	2	6	3	6	Phaeophyta
45	23	24	12	26	21	4	13	Rhodophyta

PALOS VERDES (cumulative)

273	Total No. of Taxa
3	Spermatophyta
28	Chlorophyta
47	Phaeophyta
195	Rhodophyta

Number of intertidal marine algal taxa found along Palos Verdes, 1895 to 1979.

neighboring sewage discharge produced high levels of turbidity which cut down on light needed for photosynthesis or reproduction and that the discharge also contained chemicals that might have had a deleterious effect on the algae. Widdowson agreed with Dawson that initially sewage discharge had been the primary factor responsible for the decline, but believe that since 1959 human beach usage and aerial fallout of pollutants were

more to blame than water pollution. In addition to sewage or trampling, the presence of large urchin populations at Whites Point (and by extension the other Palos Verdes sites), was thought to be a factor for the low cover of foliose algae in the intertidal. Urchins are believed to be maintained by high levels of sewage-produced organics. Sand scour, as at Lunada Bay, especially during winter storms, is capable of dramatically altering the algal cover. Dawson (1959, 1965), Foster, Neushul and Zingmark (1971). Nicholson & Cimberg (1971), and Cimberg, Mann & Straughan (1973) all concur on the importance of sand movement in altering community structure.

The increase at the other four stations may be attributed to better water clarity and quality resulting from the more efficient system of sewage solids removal started by the Los Angeles County Sanitation District in 1977. The rise in intertidal seaweeds (and Macrocystis pyrifera) coincided with the decrease in suspended solids and the onset of increasing visibility (Wilson and Mearns 1980). There are several other possible explanations. (1) The switch to outfalls in deep water and further offshore in 1957; (2) the disappearance of the effects of the earlier shallow water discharge; (3) the effects of trampling and collecting; (4) long term weather fluctuations, although I have not noticed any effect of either warm or cold water periods.

Abundances of the seaweeds are probably very different from those of 1895-1935, as are patterns of distribution. There is a need for continued observation and sampling of the Palos Verdes

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Abundances of the seaweeds are probably very different from those of 1895-1935, as are patterns of distribution. There is a need for continued observation and sampling of the Palos Verdes intertidal, for work which will help to determine the dominant source of stress of algal communities and to determine patterns of repopulation.

Complete records of the species collected at each station are available in Harris 1980. The SCCWRP 1979/1980 Biennial Report can be ordered thru NTIS, #PB81-158271.

AN OVERVIEW OF BASIC RESEARCH ON KELP AND THE KELP FOREST ECOSYSTEM

M. Neushul*

The purpose of this symposium was to review what is known about the effects of waste disposal on kelp plants and kelp communities. The standard against which waste disposal impacts are measured is the condition of an organism or an ecosystem in it's undisturbed state. Thus we need to carefully review both basic research on undisturbed kelp plants and kelp forests as well as studies of the specific effects of discharged wastes.

When wastes are discharged near-shore, it is known that physical, chemical, and biological mechanisms concentrate contaminants that can change the natural state of marine organisms and ecosystems. The reduction of once-luxurious kelp beds around the Palos Verdes Peninsula in the 1940's was the stimulus for some of the earliest studies of the effects of pollutants on kelp. The first review of the effects of discharge wastes on kelp is that of North (1964) and ultimately led to the kelp restoration efforts, described by Wilson, McPeak, and North in this symposium.

Growing public interested in protecting the marine resources in California coastal waters resulted in the California Coastal Act of 1976 which provides for both the conservation and development of California's coastline. In the

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past, the public has been concerned with accidents such as the Santa Barbara oil spill and oil pollution in general, the factors that led to the loss of the California sardine fishery, the potential effect of sea otters on kelp bed ecosystems and nearshore fisheries, the possible effects of warm effluents and sediment from nuclear and conventional power plants, the effects of kelp harvesting on fishing, and other human activities in the coastal zone. These concerns have often been translated into public demand for research. As noted above, our knowledge of the basic biology of the impacted organism or ecosystem is the standard against which the effects of human intervention and actions are measured. Unfortunately, the basic research data base that marine scientists have had to draw on has often been limited. If conservation stimulated research is to produce the maximum social benefit at the lowest cost, we must develop cost effective research strategies based on prior basic research. Nearly all of the contributors at this symposium had specific suggestions for future basic research. I have considered these here and have also drawn on suggestions made by others during informal discussions at the symposium.

I. STUDIES OF THE GIANT KELP PLANT

One of the fundamental steps in any biological study is to identify the principle organism being dealt with. There is disagreement as to what species of *Macrocystis* occur in California. While the decision of Abbott and Hollenberg (1976) to consider all the *Macrocystis* in California except *M. integrifolia* as the "southern" species, *Macrocystis pyrifera* may appear to simplify and clarify the situation, it does not. There are obvious differences between *Macrocystis integrifolia* and *M. pyrifera*, but varieties or species of the latter are clearly very different and genetically distinct from one

another. I have suggested (Neushul 1971) that there are two species in southern California, namely Macrocystis angustifolia (which forms very large holdfasts) and the small-holdfast-producing Macrocystis pyrifera. The former has a much longer lifespan than the latter. Perhaps the stability of the northern kelp beds of southern California described by Harger in this volume is due in part to the fact that long-lived Macrocystis angustifolia is the species that occurs in the northern part of the Southern California Bight. A priority item in future basic kelp research on morphological and physiological topics discussed here should be to describe the "species" being studied and to clarify the differences between them, regardless of whether they are ultimately given specific or varietal status. Morphological, cytological, anatomical, and physiological studies are needed.

A. Morphological, cytological, and anatomical studies

There has been little work done on the cytology and ultrastructure of Macrocystis. In a recent review of the study of cytology and ultrastructure of macroalgae, Scott and Neushul (1982) cite 12 references that deal with brown algae, none of which specifically deals with Macrocystis. The recent description of the mucilage canal recticulum of Macrocystis (Barrales et al. 1981) is one of the first anatomical studies of this feature of kelp.

Morphologically, there is a need to define the primary and derived organs of the giant kelp. There are differences of opinion as to how the basal dicotomy functions and how the various organs it forms are to be classified. For example, what distinguishes a young frond from a basal meristem and sporophyll? Lobban (1978) feels that the sporophyll, particularly the multi-bladed one, is a reduced frond. Hall and his co-workers in their detailed studies of Argentine kelp plants (Hall 1980) combine all basal

branches, blades, and sporophylls together and consider all of these as meristems. There are, of course, transitional stages between sporophylls and meristems. If we are to learn how fronds are initiated, how sporogenous tissue is formed and generally, how carbon is allocated within the plant we need to develop a satisfactory scheme for defining the morphological components of the Macrocystis plant. The large size of the sporophytes raises the question of translocation. It is essential that the sources and sinks that drive this translocation be studied.

The accumulation of basic biological information about the giant kelp plant is particularly difficult since one must deal both with the sporophyte, the largest known marine plant, and the gametophyte, one of the smallest. The sporophyte is adapted for life first as a transgressive in the boundary layer and surge zones and then as an adult in the current zone. The gametophyte is adapted for survival in the boundary layer adjacent to the sea floor. Thus, in order to understand the morphological and physiological adaptations of this plant to its environment one needs to study both the conditions in the microscopic boundary layer as well as in turf, surge, and current zones in the kelp forest (Neushul 1972; Wheeler and Neushul, 1981).

B. Physiological Studies

A review of current knowledge of kelp physiology with an emphasis on the adult sporophyte of Macrocystis pyrifera is provided in this volume by Steven L. Manley. The reproductive physiology and growth of the gametophyte stage of the life history of the giant kelp is dealt with in the paper by Thomas Dean and Lawrence Deysher. We are now beginning to understand the effects of the environment on the growth of Macrocystis sporophytes and gametophytes in terms of the physiological processes involved. This should allow us to model kelp

development in a meaningful way and perhaps to appreciate more fully how kelp competes with other algae, topics discussed by R. Zimmerman and R. Wells in this symposium.

Dr. Manley's paper on the physiological basis of kelp growth, when considered together with that by Wheeler North on separating the effects of temperature and nutrients, provide some of the basic biological information needed for evaluating the effects of wasted disposal on kelp. The role of light as it effects development by acting both through the photosynthetic light absorption apparatus and through possible photomorphogenic effects, (perhaps through the presence of a phytochrome photoreceptive system) are all areas in need of study. The natural deterioration of Macrocystis beds during the summer months when water temperature is high is probably due more to low nutrients than high temperature as Manley points out. Dr. North's paper further discusses summertime deterioration of Macrocystis canopies and losses during warm water years. North's experiments and observations support George Jackson's hypothesis that summertime deterioration of kelp canopies at least is due in part to poor nutritional conditions. North's recent work has shown that pathogenic microorganisms are encouraged by high nitrogen levels, suggesting that an oversupply of macronutrients could also be detrimental to kelp.

Studies of the growth and development of kelp gametophytes by James Kuwabara in Professor North's laboratory followed the life-history from zoospore release to sporophyte production (see Kuwabara, this volume, Figure 1). Kuwabara's use of an ultraclean culturing system and careful monitoring of the chemical composition of the culture medium provide a unique perspective as to the effects of nutrients and trace elements on the microscopic life-history phases. Optimal free-ion concentrations for zinc, manganese, copper, and cobalt were defined and it was shown that one order of magnitude increase over

these optimal concentrations consistantly inhibited gametophytic growth and development. Kuwabara points out that organic detritus in seawater can remove trace elements by sorption. The cell walls of gametophytes and perhaps also of the sporophyte seem to serve as a protective buffer against high external ion concentrations. As the walls modify ion exchange, they may also serve as a site for the storage of micronutrients. Wall differences between gametophytes and sporophytes may reflect diffent sensitivities to micronutrient levels and contaminants. Kuwabara points out that copper and zinc are candidates that produce toxic effects, in high concentrations.

The laboratory perspective provided by Kuwabara's studies of gametophytes is complemented by the above-mentioned outplanting work of Dean and Deysher in their attempt to establish quantitative relationships between the production on Macrocystis sporophytes by the gametophytic generation and environmental variables encountered in the sea. Their objective was to link possible changes in kelp recruitment with environmental factors that might change near the San Onofre Nuclear Generating Station. They have pointed out that temperature, sedimentation rate, and irradiance (listed in order of importance) explain a significant portion of the variance in the density of sporophytes produced by gametophytes transplanted from the laboratory into the ocean. Using measurements of environmental conditions and records of responses by outplanting gametophytes, Dean and Deysher defined "recruitment windows" which are relatively rare periods when temperature and irradiance conditions near the sea floor were favorable and when recruitment occurred. They point out that over a four year period there were only four 2-week periods when conditions were favorable and when recruitment occurred. However, during at least four other times, conditions were found to be favorable, yet no recruitment occurred. This suggests that some unmeasured variables also limit sporophyte

production by the gametophytic generation in the sea.

C. Environmental Conditions Influencing Kelp Sporophytes and Gametophytes

Jackson has pointed out that current speeds of 10-20 cm/sec are common outside of kelp beds but that these speeds diminish to 2-3 cm/sec in large beds. Thus the "still air" in a land forest is matched by "still water" in a kelp forest. Wheeler (1980) has shown in the laboratory that optimum carbon dioxide exchange occurs when current speeds going past a blade exceed 5 cm/sec. Thus the question of how optimal carbon dioxide exchange occurs can be raised. Clearly, if current alone cannot provide optimum exchange, then we are forced to look at the effects of long-period waves and the "capture" of kinetic energy in the waves by the spring-like kelp fronds and their subsequent recoil to produce stirring around the blades. The long residence time of the water in a kelp bed should result in significant nutrient depletion. Nutrients would only be replenished after a general flushing of the kelp bed occurs. Thus, as Jackson points out, the question of how water gets in and out of the kelp bed is a very important one.

Questions about the biology of the kelp gametophyte emphasize the need to define conditions in the boundary layer. Laboratory data such as that provided by Luning and Neushul (1978) on the effects of temperature and irradiance are of only limited use.

Field studies are needed but the cryptic gametophyte stages of *Macrocystis* have never been found in nature, although methods for the *in situ* study of recruitment, growth, and survival of boundary layer algae have been developed (Neushul, *et al*. 1976). The use of incident light microscopy, and appropriate experimental manipulation of gametophytes transplanted from the laboratory into the sea can certainly tell us much about the cryptic stages of

the Macrocystis gametophyte as they occur in nature.

A major question arises when one attempts to compare the responses of laboratory-grown gametophytes with those transplanted into the sea. In the laboratory, gametophytes can be vegetatively propagated and seem to grow indefinitely. Some of the gametophyte cultures at the University of California in Santa Barbara are now 7 years old. Why should gametophytes be perennial under laboratory conditions and ephemeral in the sea? Paine (1979), who has studied the demography of Postelsia sporophyte populations, feels that the gametophytes of this laminarian are perennial in nature. The very basic question of whether Macrocystis gametophytes are predominantly perennial or ephemeral in nature remains unresolved, although it is extremely important in

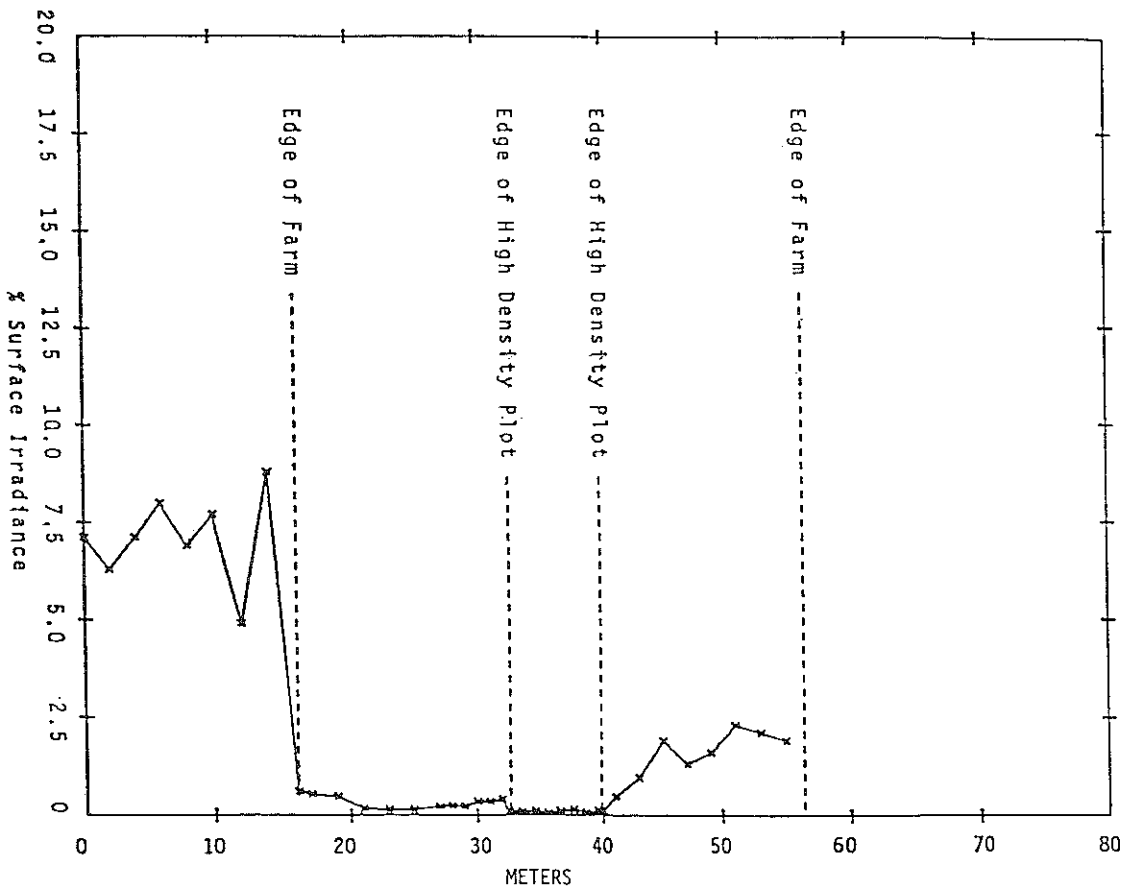

Figure 1. Measurements of light levels made along a transect crossing experimental plantings of Macrocystis angustifolia at Ellwood Pier near Santa Barbara. The transect transverses medium density (one plant per four square meters) and high density (one plant per square meter) plots.

dealing with questions of how the kelp forest ecosystem responds to pollutants, and how the kelp plant reproduces under natural conditions.

Recent experimental plantings of Macrocystis angustifolia in Santa Barbara provide some interesting insights into the responses of kelp sporophytes to environmental conditions and raises new questions (Neushul et al. 1983). By planting at three different densities (one plant per square meter, one plant per four square meters, and one plant per sixteen square meters) it was possible to demonstrate the effects of the decreased light reaching densely-planted kelps on their frond production. Clearly the lower light intensities in denser plantings (Figure 1) had a deleterious effect. Kelp plants in such a habitat over a period of a year, were unable to maintain the initial 25 fronds present when the experiment was started (Figure 2). If one looks at the production of biomass by the kelp plants under a repeatedly

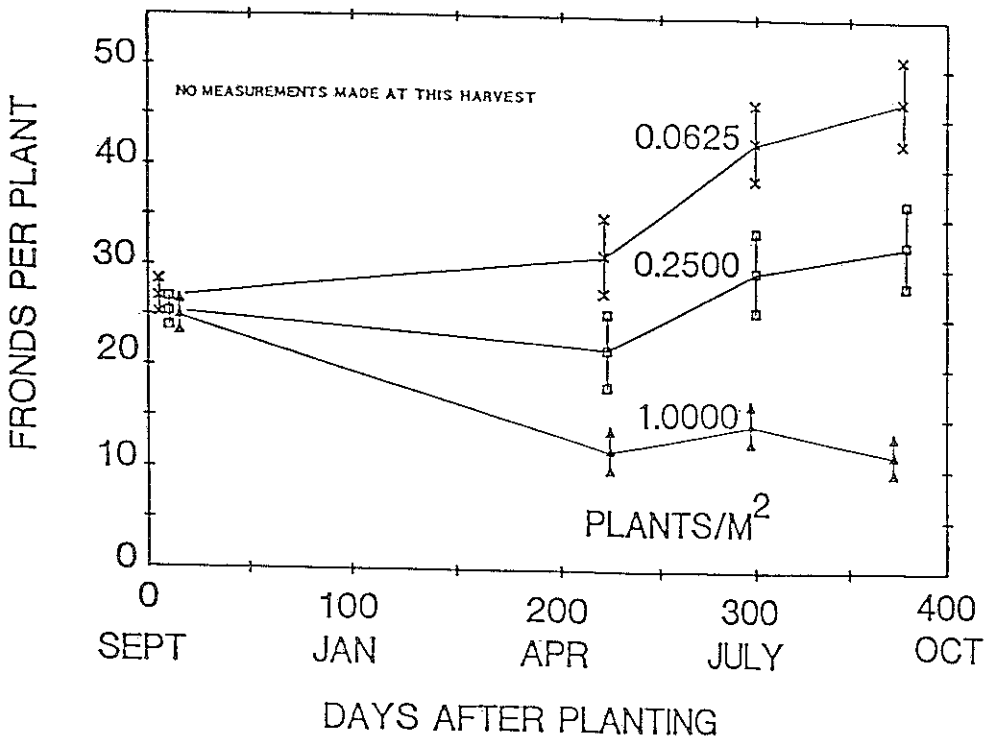

Figure 2. Planting density influences the number of new fronds produced by each plant. The September planting of 25-frond plants at all densities, at the beginning of the experiment, profices a starting point from which high, medium and low density plants diverge.

harvested experimental regime, it is seen that medium density plantings were able to maintain and perhaps increase slightly the frond numbers even when approximately 1/3 of the biomass of each plant was harvested every three months. The opportunity to work with a large sample of plants (722) and to compare them on an individual basis provides some valuable insights into the plant to plant variability seen in a population of giant kelp. The range seen in productivity in this population where a few plants produced as much as one kilogram of wet biomass per day, raises serious doubt as to the usefulness of detailed studies on individual plants for making predictions about how whole kelp beds will respond. Even though studies of large populations are extremely laborious and expensive, they are essential since there is likely to be a great deal of variability in the ways that individual plants respond to environmental conditions. If the effects of pollution on individual sporophytic plants is to be understood, then we must know what sort of plant-to-plant variability to expect since the results one obtains may depend more upon the plant one selects rather than the effect of pollution directly.

Kelp plants are "continuously-deciduous." The fact that 1/3 of the biomass can be harvested every three months with no obvious ill effects suggests that the kelp plant is adapted to produce and lose large amounts of tissue. The net carbon "profit" derived by a plant producing ephemeral fronds is the daily carbon gain per frond over its lifespan minus the amounts lost to respiration, herbivores, and carbon not stored or translocated. Summer and winter fronds of the giant kelp differ, perhaps being adapted to different conditions or being produced under conditions where different resources are available. All of these basic topics are in need of further study to provide a basic standard against which pollution effects can be evaluated.

II. STUDIES OF THE KELP FOREST ECOSYSTEM

Studies of the kelp forest ecosystems of North America began with the comprehensive mapping project initiated by the United States Department of Agriculture prior to the first World War. The recent introduction of remote sensing methods for the study of kelp beds and the utilization of photographic imagery collected along our coast is discussed by Bruce Harger in his paper. This imagery is a useful and heretofore largely-unexploited resource available to us. Dr. J. W. Woessner and Mr. G. A. Brosseau (who did much of the kelp mapping work reported on by Harger) found so many photographs that they were forced to use only those taken every four years since 1955, rather than covering all years. The assembly of photomosaics from some 6,000 reprinted photographs that were used provided 8 photomosaics for each of the 33 coastal California kelp beds. This quantitative historical record is certainly a minimal one. Future studies of these historical records should include all years and should be extended by using the extensive record of harvests. Harger's multiple-linear regression analysis of environmental conditions as these influence harvesting rates in a single bed provide a clear indication of how useful such harvest records can be. The harvest logs that have been studied show that there is an important influence of seasonal factors on the kelp forest ecosystem. The harvesting records collected since 1930 by the Kelco Corporation of San Diego should be compared with measurements taken from photomosaics like those discussed by Harger. Future research work of this sort can give us a solid historical record of the variability and stability of our kelp beds. This record could be a basic standard against which future changes can be evaluated.

A. Generalizations about kelp beds

Aerial photographs show clearly that a specific kelp bed is often highly variable from year-to-year. Michael Foster, John Carter, and David Schiel in their study of five different kelp forests in California, emphasized the natural differences between them and point out the hazards of premature generalization. The complexity of the kelp community cannot be overlooked, a given bed often having multiple layers of vegetation, over 50 species of fish, and numerous invertebrates found in various subhabitats. The giant kelp holdfast alone can contain more than 150 species of animals. The composition of this rich biological community changes with depth and with latitude along the coast as does its response to seasonal factors. For example, Foster *et al.*, point out that *Macrocystis* recruitment occurs regularly in the spring in Carmel Bay kelp forests, while in southern California, Rosenthal *et al.* (1974) observed recruitment only twice between 1967 and 1972. At Del Mar and Dean and Deysher (this volume) recorded recruitment only 8 times between 1978 and 1981. Clearly, the pattern of kelp bed recruitment can be very different in different regions.

A kelp forest with large seasonal and year-to-year changes in the cover of the understory appears to be structured indirectly by storms and substratum characteristics. In contrast a forest with an abundant understory of kelps and algae is apparently affected mostly by competition for light. Other forests with low understory algal cover are structured by substratum characteristics and grazing. Foster and his co-authors point out that the effects of waste disposal are likely to vary with the type of kelp bed, the characteristics of the local environment and the type of discharge involved. They point out the need for long-term studies that concentrate on common species and emphasize the importance of well-designed monitoring programs to detect local effects.

Clearly there is an obvious need for long-term data collection on the submarine features of kelp forests just as there is a need for continued aerial surveillance of the frond cover and additional harvesting data.

B. Measuring ecological variables in kelp beds

The measurement of conditions in kelp beds has been discussed in the paper by Jackson, and that of Craig Barilotti and Rimmon Fay. Jackson points out that the chemical and physical processes in a kelp bed are driven on very large scale.

The size of a kelp bed is of major importance in considering how coastal waters shoal around it, and/or pass through it. Larval settlement, which occurs within periods of hours, can be viewed as taking place within a kelp bed where a body of water can remain for as long as a week. Phytoplankton populations double over a period of two days and larval development after settlement can occur over a matter of five days. Consequently, not only will a larger kelp bed modify water motion and nutrient concentrations, but it can modify the biological community within it. There is a need for new instrumentation that will allow us to more accurately and measure conditions within both large and small kelp beds on a real-time basis.

The effects of grazing animals in a kelp forest ecosystem, are of obvious importance. The review of the sea urchin problem by W.J. North (this volume) emphasizes the fact that sea urchins have been and are still a significant factor in modifying kelp forest ecosystems. North advances the hypothesis that organic wastes enhance recruitment by enhancing the growth of young, but not mature animals and that dissolved amino acids provide as much as one half of the nutrients needed by these animals. This is clearly a hypothesis worthy of further testing.

The mechanisms of competition between Macrocystis and other plants illustrate the importance of competition for space. Competition between Corallina officinalis, Lithothrix, and Macrocystis is documented in the paper by Wells (this volume). The importance of seasonal periodicity in disturbance which makes space available for kelp recruitment raises a number of interesting questions about stability and change in the natural kelp forest ecosystem. If we are to understand the effects of the imposition of human activity such as the release of contaminants, an understanding of stability and change in the undisturbed ecosystem is clearly essential.

III. STUDIES OF THE EFFECTS OF CONTAMINANTS ON THE KELP PLANT AND THE KELP FOREST ECOSYSTEM

The paper by Meistrell and Montagne (this volume) provides an overview of waste disposal in the Southern California Bight and some effects of waste disposal on rocky, subtidal habitats. Changes in sea surface temperature, transparency, the emission rates of solids, and other factors clearly have influenced the numbers and kinds of intertidal seaweed species, the total kelp forest acreage, the abundance of microcrustaceans, and crustacean-eating flatfish in the vicinity of the Los Angeles County sewage outfalls off Palos Verdes where discharge was first started in 1937. A warming trend of ocean waters between 1976 and 1980 and the reduction of solids emmission during this period coincided with increases in kelp, intertidal seaweeds, crustaceans, and flatfish. The adverse effects of sewage discharges around Palos Verdes are less severe in 1980 and 1983 then they were in 1970. These changes are probably a direct result of source control and a reduction in solids mass emmissions from the Los Angeles County discharges.

It is sobering to compare the amount of dissolved and particulate materials contributed by rivers (274,000 metric tons/yr in 1971) with the amounts of suspended solids (226,000 metric tons/yr) released into the sea by California's five largest municipal waste dischargers (see Meistrell and Montagne, Table 2). It is reassuring that this is much reduced over that of previous years and that known toxic components like DDT have been significantly reduced.

Susan Hamilton's paper in this symposium on the monitoring of kelp communities provides a valuable insight into how one might use these measurements to comply with legal requirements. Since measurements focusing on the kelp community are generally not legally required, they are made because of public interest or for commercial interest in protecting the kelp beds. The kelp community measurements at Palos Verdes involve quarterly bottom transects at five stations, qualitative observations at five stations, and quarterly aerial surveys (see Hamilton, Table 3). The kelp community monitoring program sponsored by the Kelco Corporation involves water column measurements, dive surveys, and diver observations. As Hamilton points out, these baseline monitoring measurements can be used to follow the responses of the kelp beds to persistant and chronic pollution. Waste dischargers are currently discussing monitoring measurements with the Environmental Protection Agency and Water Quality Control boards of various regions in California. Thus there is a current opportunity to foster cooperation among groups involved in studying the kelp bed ecosystem and the effects of pollution on the ecosystem, and to design new monitoring approaches that might be more effective then those in the past have been.

One area that received considerable attention during this symposium was that of the effects of settled solids and flocculent materials on kelp

gametophytes and on kelp plants in general. Natural settlement in kelp beds occurs from time to time on rocky bottoms and as outlined by DeVinney in his interesting paper, this settlement has been shown to interfere with gametophyte development. Sedimentation can impact boundary layer organisms by reducing light, and by carrying toxic material. The re-suspension and distribution of toxic and damaging sediments and flocculent materials could well have a widespread adverse effect on kelp recruitment.

Some macroalgae have a remarkable resistance to burial by sediment whereas others are adversely effected. DeVinney defines at least five ways that sediment might damage small organisms like kelp gametophytes. For example, the preliminary attachment of an organism to a sediment particle does not provide a solid substrate for eventual colonization and development. Also, an episode of sedimentation can smother a microscopic organism or removal can occur due to scouring. Perhaps most importantly, sediments can change the chemical nature of the micro-environment surrounding the organism and bacteria and other competitors might be effected, in turn, effecting the microscopic organisms of interest. Clearly there is a need for both laboratory and field measurements of the amounts and effects of sediments. DeVinney's dome collectors, vacuum samplers, and cup collectors are important steps in the development of methods for studying the effects of sediment, that build on some of the earlier findings by Grigg who used similar techniques. As DeVinney points out, a definitive description of the effects of waste discharges on kelp will require a detailed study of both flocculent and sedimentary materials. The effects of waste discharges should be determined by comparing sediments collected near outfalls with those presumably-natural sediments found far away. Only in this way can we determine how outfalls change the amount and composition of sediments and how these might effect and modify the surface micro-environment

occupied by Macrocystis gametophytes and other organisms.

Attempts to establish new kelp beds in southern California have been relatively infrequent and unfortunately, relatively unsuccessful. The most successful kelp restoration efforts (discussed by Wilson and McPeak in their paper) were first initiated in 1963. Restoration work involves grazer control, transplantation of kelp, the control of competitors, and the monitoring of the transplanted plants. Surveys conducted at least quarterly since 1975 by the Department of Fish and Game have shown that kelp restoration off of Palos Verdes has been effective. Similarly, a new kelp bed established on sand at Ellwood by our research group in Santa Barbara has been successful. The reforestation of natural beds and the installation of entirely new ones offers unique opportunities to study both the basic biology of the kelp plant itself and the kelp forest ecosystem as it is re-established or newly established.

IV. RECOMMENDATIONS FOR FUTURE RESEARCH

The preceeding sections of this paper list a number of areas where future research on kelp and the kelp ecosystem is needed, and these will not be repeated here. Many of the questions raised are not new. In 1979, the California Sea Grant Program sponsored a kelp ecosystem workshop attended by sixteen scientists. The purposes of the 1979 meeting were to assess the knowledge of the kelp ecosystem, define and set priorities on current and future California problems and needs in kelp ecosystem research, identify interested scientists and facilities and potential cooperative efforts, and determine the feasibility of a California kelp ecosystem research program. The workshop participants suggested that kelp ecosystem data index and literature indices be established that would help keep track of existing information and

TABLE I

Basic and Applied Kelp Research Needs Listed in 1979

Basic Research Needs
1. Basic population biology (recruitment, growth, mortality, reproduction) of important kelp bed organisms.
2. Role of physical processes in structuring kelp ecosystems -- nutrients, temperature, light, currents, storms, etc.
3. Functional role of biological processes in kelp ecosystems -- competition, predation.
4. Variations in population parameters over large scales of time and space (e.g., latitude).
5. Studies of dispersal phases of kelp bed organisms.
6. Factors controlling *Macrocystis* productivity.
Applied Research Need
1. Biological and socio-economic consequences of possible sea otter management alternatives.
2. Multispecies approaches to biological and economic modeling.
3. Stock (including kelp) enhancement (economic and technical feasibility, biological impact).
4. Economics of various components of kelp ecosystems.
5. Evaluating the adequacy of existing programs for managing kelp bed resources.
6. Categorization of different kinds of California kelp beds by how they function, and determination and location of long-term study sites to monitor the dynamics of the kelp ecosystem on a statewide basis.
7. Short publications dealing with perennial questions from general public on kelp ecosystem issues, such as effects of kelp cutting on sport fishing.

provide a clearing house for others interested in information about kelp biology. Finally, it was felt that it would be worthwhile to initiate a study to determine what major information gaps occur in our knowledge of kelp ecosystems in the State. A few of these objectives have been met in part by presentations made at this symposium. Table I lists the basic and applied kelp research needs as seen in 1979.

In my opinion, this 1983 symposium has provided a valuable list of research topics in need of study, and this published volume will provide a guide to those seeking answers to how pollutants influence kelp plants and the kelp ecosystem. Progress since 1964 (North, 1964) has been considerable, but major questions outlined then, and discussed both in 1979 and at this symposium about toxicity, sedimentation, turbidity, grazing, and disease are still unanswered. The encouraging comments by Dr. Mearns at the close of the meeting suggest that federal funding may be forthcoming that will allow substantial progress to be made in learning how waste discharges effect kelp and kelp communities. Hopefully funding for basic research will also be available from state, federal, and industrial sources so that long-standing problems can be solved, rather than just being listed again.

ACKNOWLEDGEMENTS

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STORM CAUSED CHANGES IN THE PALOS VERDES KELP FORESTS

Kenneth C. Wilson* and Heidi Togstad**

The first months of 1983 were characterized by a series of unusually large storms. Extra long period waves (20 seconds) and a more westerly direction than normal caused considerable damage to the southern California coast including damage to beaches, shorefront homes, and kelp beds.

An extension of the surveys by California Fish and Game that began in 1974 documents the extent of kelp bed loss at Palos Verdes. Areial surveys revealed that the kelp canopy present on January 7, 1983 (about 196 ha or 485 acres) declined by January 31 to only 18 ha (44 acres). By April 14, 1983 only 14 ha (35 acres) of kelp remained (Table 1).

TABLE 1. *Macrocystis* Canopy Acreage for Palos Verdes Peninsula, 06-1974 Through 04-1983.

Date	Area 1 Pt. Fermin to Inspiration Pt.	Area 2 Inspiration Pt. to Pt. Vicente	Area 3 Pt. Vicente to Palos Verdes Pt.	Area 4 Palos Verdes Pt. to Malaga Cove	Total Acres
1982					
01	341.3	46.9	76.4	244.8	709.4
04	279.7	46.9	49.7	127.9	504.2
07	332.0	35.0	66.2	135.2	568.4
10	266.8	41.4	44.2	100.3	452.7
1983					
01-7	306.8	39.6	58.9	79.7	485.0
01-31	16.1	10.1	7.4	10.1	43.7
04-14	20.2	7.4	7.8	0.0	35.4

* California Department of Fish and Game
** Scripps Institution of Oceanography

Boat and diving surveys conducted by biologists from the California Department of Fish and Game and Scripps Institution of Oceanography (R. Butler, pers. comm.) provided information on the extent and possible causes of declines. These surveys revealed substantial loss of and damage to kelp plants and surface canopy-forming fronds following January through March 1983 storms. Substrate and biota were altered in some areas due to sand scouring and disturbance and/or breakage of rocky habitat. Sea urchins present in large numbers in unprotected shallow areas appear to have been dislodged and redistributed, some into deeper water and some onto beaches.

Data from diving surveys revealed long-term changes in urchin/kelp balances that also contributed to kelp forest declines in the previous year and during this storm period.

Surveys in Abalone Cove in April 1983 revealed that many Macrocystis plants, though damaged by storms, appeared healthy and had new growth. These plants are now beginning to contribute to the return of the surface canopy.

Meteorological, wave, and tide data were obtained from the National Oceanic and Atmospheric Administration[3] (NOAA), the City of Huntington Beach, Marine Safety Division, and the California Department of Boating and Waterways[4] for the period between January 1983 and April 1983. These data provided a useful tool for drawing inferences regarding the relationship between weather, ocean conditions, and recent decreases in PVP kelp canopy.

Eight major storms with deep water wave heights greater

than 10 feet were recorded in the January-March period. These are exceptional because of the very long period waves which transport more energy and cause effects in deeper water than normal storm waves. These storms had periods ranging from 17 to 22 seconds (Table 2). By comparison the maximum period in the 15 storms of the previous 3 years was 16 seconds. The high swells, winds, and very low tides combined to cause major changes in kelp forest communities, the most severe event lasting from January 18 to 29, 1983. In this period, heavy seas coincided

Table 2. Storms in which the deep water significant wave height exceeded 10 feet.

Dates	Peak period
Jan 18-20	17 seconds
Jan 23-25	20 seconds
Jan 26-29	20 seconds
Feb 12-14	22 seconds
Feb 18-21	18 seconds
Feb 28-Mar 2	21 seconds
March 8	18 seconds
March 17-18	20 seconds

with the most extreme high and low tides of the year. The most intense seas occurred on 27 and 28 January with 10 to 12 ft (maximum 15) westerly swells being recorded at Huntington Beach and 12 to 15 ft swells with 20 ft breakers at King Harbor, in Santa Monica Bay. Heavy seas, -1.8 and -1.9 tides, and 20 to 35 mph winds combined to result in heavy surge and wind waves which heavily stressed nearshore areas and kelp forest communities.

Discussion

Monitoring operations and reconnaissance dives conducted throughout the period and the review of meteorological and oceanic data suggest major declines in PVP kelp forests from January 1982 to April 1983 can be primarily attributed to oceanic and weather conditions. Kelp forests from Point Vicente to Point Fermin are exposed to heavy winds and seas originating from the south. The beds between Point Vincente and Palos Verdes Point are susceptible to damage from westerly winds and seas, while those from Palos Verdes Point to Malaga Cove would be most likely damaged by storms arising from the Northwest.

Damage to kelp forests may be particularly severe if major storm and sea conditions coincide with periods of minus tides. On these occasions, stress due to wind, waves and surge from heavy swells are felt several feet deeper than they would under mean or high tidal conditions. During minus tides a greater percentage of kelp plants' biomass is at the water's surface increasing drag on fronds and holdfasts. Consequently, in less than 25 ft of water it was not uncommon for entire plants to be ripped loose; while in deeper water, damage to fronds appeared to be more common than losses of entire plants.

The effects of inclement weather and heavy seas were further compounded along the western and southwestern exposures of PVP, from Abalone Cove to Lunada Bay, by the existence of large areas of sea urchin dominated substrate and movements of extant animals into adjacent beds. In such areas, heavy grazing damage to Macrocystis commonly results in substantial losses of plants through weakening of the holdfast and primary stipe rendering plants more susceptible to damage by heavy seas.

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[3] NOAA station 6L9, Huntington Beach and King Harbor harbor patrol observations
[4] Dr. Richard Seymour

Loss of kelp due to storms and sea urchin encroachment will effectively reduce the supply of drift kelp, in the form of senescent blades and fronds, that normally helps to sustain sea urchins. It is likely such circumstances will encourage more active foraging behavior on the part of sea urchins within beds and in barren grounds adjacent to restored kelp beds. When forage is inadequate, sea urchins at the peripheries of kelp beds tend to form active feeding aggregations known as "fronts" which have been observed to move into and destroy beds at the rate of 10m (33 ft) per month (Leighton 1971). The combined effects of sea urchins and other herbivores places increased grazing pressure on remnant stands of kelp and associated vegetation.

In spite of these problems, indications of recovery were observed by DFG personnel in June 1983. Thousands of young Macrocystis plants, 0.3 to 1.0m in height, were observed at Malaga Cove, Palos Verdes Point, Lunada Bay, Golden Cove, Pt. Vicente and Abalone Cove in areas occupied by mature kelp beds prior to 1982-83 storms. This massive germination of Macrocystis and associated vegetation suggests that in the presence of good water quality, normal oceanic conditions, and reduced sea urchin densities kelp forests damaged by storms can recover rapidly.

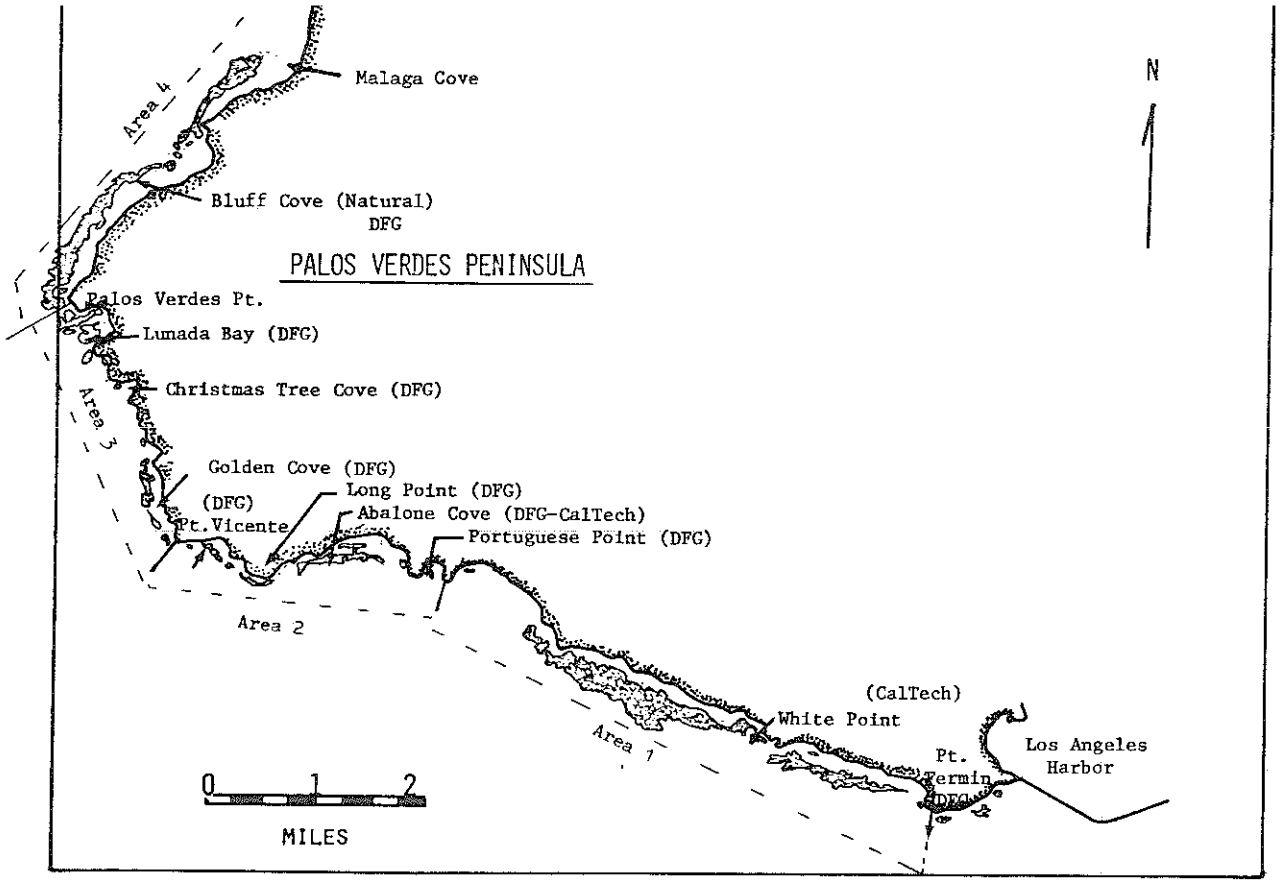


Figure 1-A Macrocystis canopy coverage for Palos Verdes Peninsula, January '82 - 709 acres.

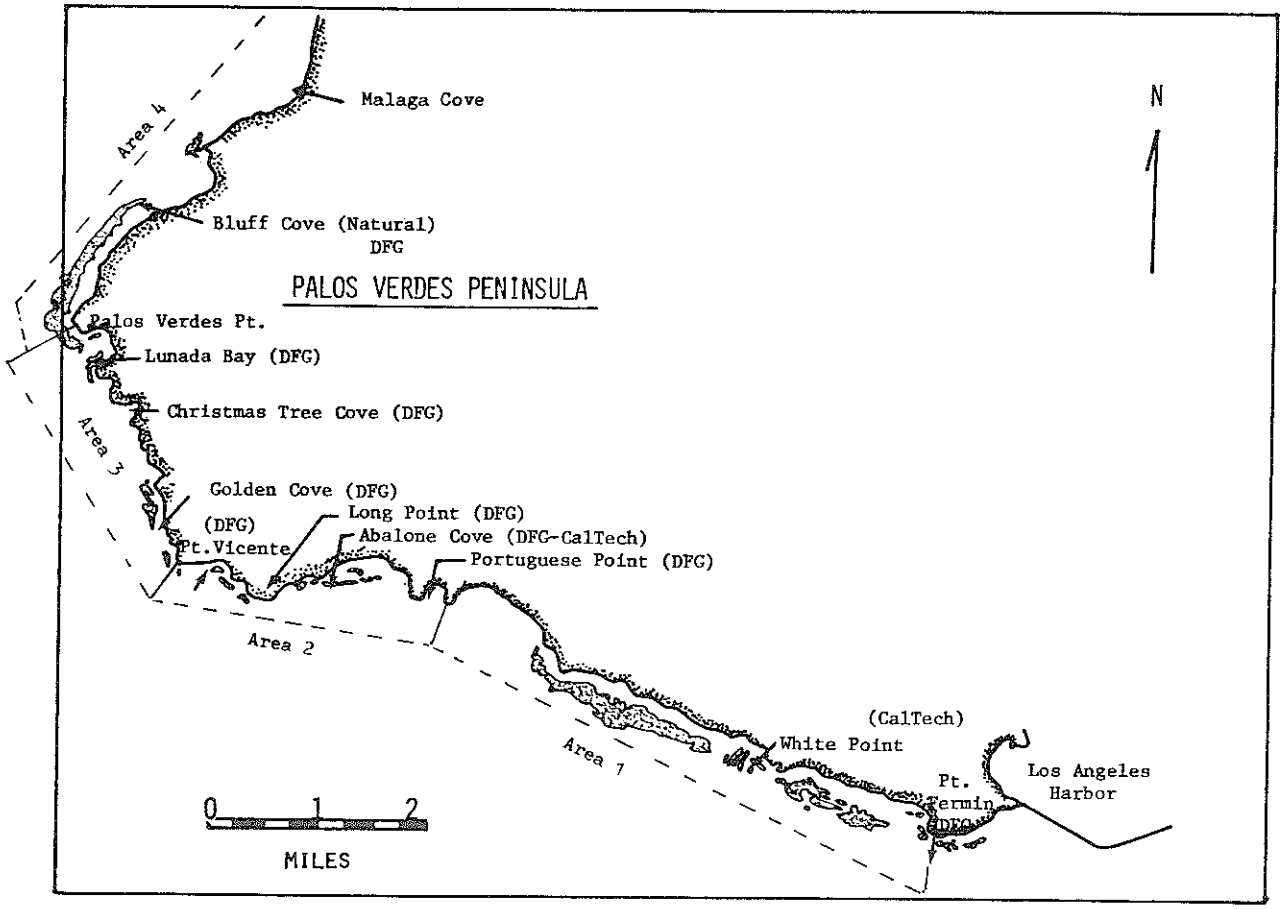


Figure 1-B Macrocystis canopy coverage for Palos Verdes Peninsula, October '82 - 429 acres.

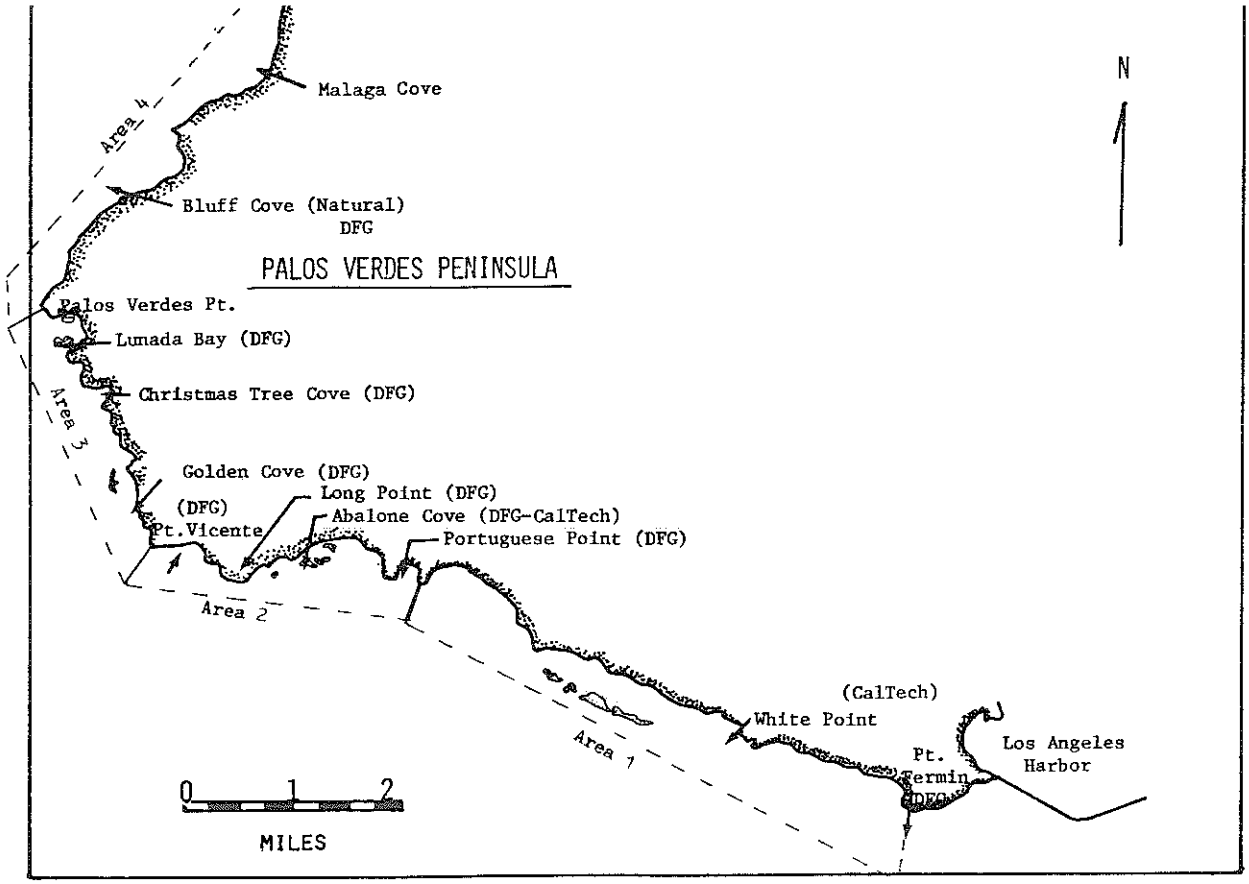
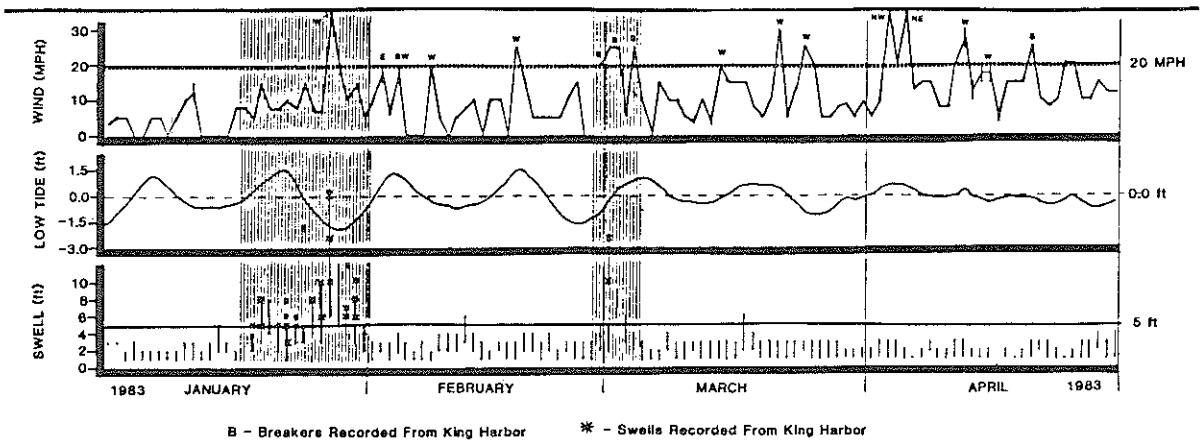


Figure 1C Macrocystis canopy coverage for Palos Verdes Peninsula, April '83 - 35 acres.

FIGURE 2



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