Adverse factors affecting giant kelp and associated seaweeds

by Wheeler J. North*

W. M. Keck Engineering Laboratories, California Institute of Technology, Pasadena (California 91125, USA)

My research experiences have been concerned primarily with a single seaweed species, the giant kelp, *Macrocystis* spp. Hence, this paper will emphasize relationships involving kelp. Similarities and applications to other seaweeds will be discussed wherever possible.

Adverse factors will be classified into 3 broad groupings: physical, chemical, and biological. All can be important from time to time. Components of each group can either cause injury or, if they operate over a prolonged period, induce abiotic (non-infectious) or biotic (infectious) disease. Sometimes 2 or more factors, each operating at relatively mild intensities, act synergistically.

Physical factors

Large waves during storms are probably the commonest physical destructive force in the California kelp beds. Wave surge prunes kelp canopies, tears out weakly-attached plants, and can also destroy most, if not all, other seaweed species. Severe physical damage from battering by waves or from grazing can lead to peculiar morphology among seaweeds. Holdfasts and stipes weakened by grazing or burrowing organisms are more susceptible to wave damage.

Many investigators have attributed losses of kelp and other algae during summer to elevated water temperatures characteristic of this season. There is no doubt that adult *Macrocystis* plants in nature display substantial tissue deterioration after surface temperatures reach 20 °C or more for several weeks. Other adverse factors (e.g. nutrient deficiencies, pathogens), however, often appear in conjunction with warm temperatures (cf. Wheeler's contribution).

Water clarity strongly influences submarine light intensity. Although turbidity may fluctuate widely on a short-term basis, consistent patterns often characterize specific areas (estuaries vs rocky peninsulas) when considered over longer terms such as a year. An artificially introduced source of turbidity such as a sewer outfall or a harbor might impair photosynthesis of benthic plants. This, however, has never been specifically documented in California.

Shifting sediments can sometimes bury *Macrocystis* holdfasts. Adult plants in the beds near Santa Barbara can apparently tolerate moderate degrees of burial. Farther south near San Diego, however, we have several times observed that burial is shortly followed by decay of any stipe tissue that may be covered. Blades do not tolerate sedimentary accumulations. They soon become discolored, mushy, and deteriorate.

Chemical factors

Availabilities of certain minor constituents of seawater may vary widely with significant effects on marine vegetation. On a broad scale, fluctuations in nitrate concentrations are probably of greatest importance. Inorganic nitrogen is renewed in coastal waters by inputs from terrestrial runoff and from upwelling. Nitrate concentrations may rise to 10 µg-at/l or more in the lower regions of some kelp beds at the height of the upwelling season. Seaweeds quickly take on healthy appearances under such circumstances, followed by luxuriant production of foliage. Juvenile recruitment is often highest during or immediately following the upwelling season.

Conversely, kelp beds may deteriorate rapidly when upwelling is reduced or the season is short. We recorded one such instance in 1976 when upwelling lasted only from March through June instead of until August or September as usual. We observed no significant upwelling episodes until the following February in 1977. Several kelp beds lost up to about 90 percent of their populations during this low-nutrient period.

Do micronutrients ever attain excessive concentrations, values that might approach toxic levels? Clendenning[1] examined changes of photosynthetic capacity among immature kelp blades exposed from 1 to 9 days to various concentrations of heavy metals that may occur in sewage in trace amounts[1]. More recently, we developed bioassay techniques permitting us to assess effects on juvenile *Macrocystis* growth rate from exposures to trace metals. The growth rate parameter appears to be more sensitive than Clendenning's photosynthesis determinations. Concentrations inhibiting growth have also been reported for some of these trace metals by other investigators for various seaweed species (Bryan[2], Von Stosch[3], Pedersen[4]). Results generally agreed with our findings for *Macrocystis.*

Potential adverse effects by wastewaters can be estimated if we compare chemical substances at concentrations known to be inhibitory with values occurring in a given discharge. Computations indicate that ammonium, copper, and zinc, as they occur in the Los Angeles County Sanitation Districts (LACSD) effluent, would require roughly a 100-fold dilution with seawater to eliminate inhibitory effects. Dilutions of this magnitude are claimed for deep water diffusers such as operate on the LACSD outfalls. Dilution requirements would be less stringent for other outfalls in southern California.

Thus, it appears that marine waste disposal as currently practiced in southern California is probably not toxic to seaweeds. Substantial precautions may be necessary, however, to achieve freedom from such problems. Thus, the LACSD outfall formerly terminated close to a *Macrocystis* bed and was not then fitted with an elaborate diffuser. Toxicity might well have occurred formerly.

Biological factors

Seaweeds are exposed to numerous complex biological interactions (cf. contribution by VADAS) whose effects range from growth stimulation to destruction of entire populations. Adverse biotic interactions considered to be of greatest significance as we have observed them in southern California kelp beds will be considered briefly. These are competition, grazing, encrustations, and anomalies tentatively ascribed to the action of plant pathogens.

1. *Competition.* Sunlight decreases with depth to the bottom. Taller-statured plants such as *Macrocystis* are obviously favored in the competition for light. We have often observed, however, that shorter seaweeds took territory from adult *Macrocystis* after the large plants were torn loose by storms or disappeared during extended warm-water conditions. Sometimes many years elapsed before *Macrocystis* again assumed dominance.

Both plants and animals compete for space on the sea floor. Some plants may produce substances with antibiotic characteristics, one function of which may be to retain space for their offspring after the parent disappears. I have often noted that remains of old *Macrocystis* holdfasts may be colonized exclusively by juveniles of the same or of closely-related species. Rocks encrusted with coralline algae appear to be colonized with difficulty by Laminarian kelps. Small kelp recruits seem to develop more readily where coralline crusts have been severely scraped by foraging urchins. Paine and Vadas[5] noted that the feeding activity of urchins can enhance algal diversity in a *Nereocystis* community by upsetting the dominating role of the larger kelps.

2. *Grazing.* Grazing at times affects seaweed ecology quite profoundly. Many invertebrates and some fishes feed on seaweeds. In southern California, we have found that feeding by 1 or more of 3 urchin species *(Strongylocentrotus franciscanus, S. purpuratus,* and *Lytechinus anamesus)* frequently is more important than all other grazing combined. These urchins can strip almost all algae from very significant areas of bottom and maintain a barren condition indefinitely. Urchin populations in areas barren for long periods tend to be composed of young animals. Apparently juvenile recruitment maintains urchins at high densities but food scarcity prevents development to larger-size individuals. Presence of the canopies of adult *Macrocystis* plants seems to inhibit recruitment into urchin populations. Possibly numbers of planktonic urchin larvae carried into kelp beds by currents are reduced by filter-feeding organisms encrusting the kelp fronds.

Certain kelp beds near major metropolitan centers in southern California disappeared gradually. Many people suspected adverse influences from pollution which increased as the human populations developed. The bottom in the areas devoid of kelp, however, was dominated by extensive populations of urchins. Clark[6] showed that dissolved organics near a large outfall were sufficiently concentrated to supply a significant portion of the daily nutritional requirements of the resident urchin populations. Thus, adverse effects on seaweeds of discharged wastwaters may act through very indirect mechanisms (cf. Kohlmeyer's contribution).

Holdfasts, basal branches, and stipes can be seriously weakened by burrowing organisms. Jones[7] has described the biology of the kelp gribble *(Limnoria algarum).* The dead interior portions of kelp holdfasts harbor complex assemblages of small invertebrates (Andrews[8], Ghelardi[9]). Fishes may rip out pieces of holdfast interiors seeking food therein after a portion of the protective living outer layer of haptera has been stripped away by urchins or other benthic grazers. Holdfasts become greatly weakened when solidity of the structure is disrupted by removal of the interior portions.

3. *Encrustations.* Myriads of animals can occur on surfaces of *Macrocystis* fronds (Wing and Clendenning[10]). *Membranipora* spp. tend to be overall the commonest encrusters in southern California. Periodically, however, other bryozoans, hydroids, mollusks, and annelids may dominate the colonies attached to blades and stipes. Encrustations tend to increase with tissue age. Thus, the older basal regions of mature *Macrocystis* fronds may be densely encrusted while the younger terminal portions may simultaneously be free from attached animals. Encrustations usually neither interfere seriously with frond buoyancy nor with photosynthesis under fully saturating light conditions (Wing and Clendenning[10]). Occasionally, dense populations of heavy organisms such as kelp scallops *(Leptopecten latiauritus)* settle on fronds of *Macrocystis* or *Pelagophycus.* Weight increases as the colonies grow, eventually causing sinking. *Membranipora* encrustations on immature blades can lead to deformed shapes arising from inability of the encrusted portion to expand. Growth may be completely precluded when a young blade is imprisoned by total coverage by *Membranipora.*

4. *Pathogens.* We suspect that various microorganisms attack *Macrocystis,* but much definitive work remains to be done. Mature fronds apparently enter a declining senescent phase quite normally when they are

about 6 months old (North[11]). Scarcity of nutrients may hasten senescence. Thus, it is not always possible to identify whether unhealthy appearance results from natural senescence or because of invasion by pathogens. There are, however, a few adverse conditions whose symptoms and occurrences are sufficiently distinct to separate them from the usual manifestations of senescence. 3 of these disorders are black rot, tumor-like swellings, and stipe rot.

Black rot refers to a darkening of the blades that usually first appears at the tips, then spreads toward the base until the entire structure is involved. Consistency of the tissue softens as color deepens. The blade substance progressively becomes mushy and is sloughed. A plant may display several fronds in which all blades are afflicted while completely healthy fronds attached to the same holdfast form an intertwining mass. Black rot usually occurs during late summer when surface temperatures are elevated. We have, however, observed traces of the malady during winter among tissues approaching senescence. We have found no obvious correlation between proximity to sewage discharges and occurrence of black rot. Scotten[12] was unable to transmit black rot to healthy *Macrocystis* by contact with a preparation made from macerated lesions from afflicted tissues. Affected blades contained an abundant microflora, but he was unable to identify whether any one species might be a causative agent.

Swellings a few mm in size on *Macrocystis* stipes collected near the San Diego sewer outfall off Point Loma were reported by North[13]. Large wart-like protuberances were also observed on stipes of a closely related kelp, *Pelagophycus porra,* from the same location. The abnormalities were observed only among plants lying along the outer edge of the bed and within a band about 0.5 km wide on either side of the outfall. The condition has since been noted repeatedly, always confined to the vicinity of the outfall. Identical swellings on *Macrocystis* stipes have been seen at Palos Verdes, near the LACSD outfall. As far as we know, the phenomenon has never been investigated in vitro.

Stipe rot is a progressive darkening and deterioration near the basal attachment, superficially resembling the sequence of events resulting from black rot among blade tissues. Stipe symptoms seem to involve only 1 or 2 cm of the length, however, and not the entire organ as may occur for black rot. Furthermore, stipe rot is a rare disorder – we have observed it only on 3 occasions – whereas black rot can be common and widespread during the summer. Stipe rot occurred in close association with discharged sewage in all observed cases. Buoyancy forces normally maintain tension in *Macrocystis* stipes. As stipe rot progressed, the tissues weakened and finally parted so that the entire frond above the lesion was lost. Once infected, successive stipes on a given plant apparently contracted the malady and eventually ruptured. Finally only the holdfast and basal branchings remained and these rapidly succumbed. Plants disappeared from an estimated 1 km^2 of bottom in a single incident at the Point Loma Kelp Bed in 1967–1968 (North[14]). Dr Ralph Mitchell of Harvard University has been able to produce the symptoms of this disorder among *Macrocystis* stipes *in vitro* (personal communication).

To summarize, a seaweed community, as illustrated by *Macrocystis* and associated algae, is obviously extremely complex and subject to the continuous interplay of biological, physical, and chemical factors. The role of biotic and abiotic disease is, to date, largely unknown but probably significant, perhaps more than we have been led to suspect. Combined efforts of plant pathologists and marine biologists will be needed to properly assess the ecological and economic implications of disease in the California kelp beds.

* Research support from the U.S. Department of Energy under contract E(04-3)-1275, the Office of Sea Grants under grant no. 04-5-158-13, from Kelco Company, Union Oil Company, and the Fish and Game Commissions of San Diego, Orange, and Los Angeles County is gratefully acknowledged.

1 Anonymous, An Investigation of the Effects of Discharged Wastes on Kelp, p. 124. Calif. State Water Qual. Control, 1964, publ. 26.
2 G.W. Bryan, J. mar. biol. Ass. U.K. *49,* 225 (1969).
3 H.A. Von Stosch, Proc. 4th int. Seaweed Symp., p. 142. Pergamon, New York 1964.
4 M. Pedersen, Physiologia Pl. *22,* 680 (1969).
5 R.T. Paine and R.L. Vadas, Limnol. Oceanogr. *14,* 710 (1969).
6 M.E. Clark, in: Kelp Habitat Improvement Project Annual Report 1968–69, Cal. Inst. Techn., Pasadena 1969.
7 L.G. Jones, in: Biology of Giant Kelp Beds (Macrocystis) in California, p. 343. Ed. W.J. North. Cramer, Lehre 1971.
8 H.L. Andrews, Ecology *26,* 24 (1945).
9 R.J. Ghelardi, in: Biology of Giant Kelp Beds (Macrocystis) in California, p. 381. Ed. W.J. North. Cramer, Lehre 1971.
10 B.L. Wing and K.A. Clendenning, in: Biology of Giant Kelp Beds (Macrocystis) in California, p. 319. Ed. W.J. North. Cramer, Lehre 1971.
11 W.J. North, Nature *190,* 1214 (1961).
12 H.L. Scotten, in: Biology of Giant Kelp Beds (Macrocystis) in California, p. 315. Ed. W.J. North. Cramer, Lehre 1971.
13 W.J. North, in: Kelp Habitat Improvement Project Annual Report 1965–66, p. 18. Cal. Inst. Techn., Pasadena 1966.
14 W.J. North, in: Kelp Habitat Improvement Project Annual Report 1967–68, p. 75. Cal. Inst. Techn., Pasadena, 1968.