# Chapter 3. Environmental Settings

## 3.1 General Description of the Marine Environment

### 3.1.1 Weather, Oceanography, and Geology

Weather conditions along the coast of California are influenced by oceanographic conditions of the eastern Pacific Ocean boundary current region. Ocean currents can be thought of as a simple combination of the geostrophic current field and the field of Ekman drift (Bakun and Parrish 1980). Large water masses, principally wind-driven, rotate in a general clockwise direction in the North Pacific due to the Coriolis effect, which results from the earth's rotation. The dominant oceanographic feature of the eastern Pacific boundary is the California current, a broad, slow-moving current that originates about 500 km off the Oregon, Washington and southern British Columbia coasts between 45° and 50° N latitude (Hickey 1979, Williams et al. 1980). Driven primarily by wind stress patterns over the North Pacific, it flows southward in a band 500-1,000 km wide and 100-500 m deep at a mean speed of 10-30 cm/sec (Hickey 1979, Williams et al. 1980). Water in the California Current is characterized by low temperatures and low salinity; near the coast and north of Cape Mendocino it originates primarily from the west wind drift and is primarily subarctic in type (Hickey 1979, Williams et al. 1980). The percentage of subtropical water increases towards the south and west (Hickey 1979). The California Current is characterized by large flow variability, and the mean southward flow is only in a large-scale sense (Bernstein et al. 1977, Owen 1980, Parrish et al. 1981).

In contrast to the cold current moving southward along the coast, there is an intermittent northerly moving inshore counter-current, called the Davidson Current consisting of semitropical warm waters moving in a general northwesterly direction. The colder current is predominant along the California coast, especially north of Point Conception, because prevailing winds and currents in that area come from the north and northwest. During fall and winter months, however, these winds weaken and the warm Davidson Current becomes more predominant (Department of Navigation and Ocean Development, 1971).

Inshore of the dominant currents, a general upwelling or rising of subsurface waters occurs seasonally around islands and headlands along the coast. Upwelling along the west coast results from the interaction of the California Current and the winds generated by the North Pacific High (Hickey 1979). Due to the Coriolis effect, these northwesterly along-shore winds entrain surface waters to the west, or away from the coast, a process known as Ekman transport (Thurman 1975, Beer 1983). The transported water is replaced by cold, nutrient-rich, subsurface water. Water is upwelled from depths greater than 60 m south of Cape Mendocino (Huyer 1983). The region of maximum southward wind stress shifts northward from around 25° N in January to about 39° N in July; the strongest winds are observed in July off northern California, where the offshore pressure gradient is steepest. South of San Francisco, upwelling may occur year-round, with a peak in April (Huyer 1983). The offshore extent of the primary upwelling zone appears to be 10-20 km along the entire coast (Parrish et al. 1981, Huyer 1983).

Upwelling is extremely important for the productivity of our coastal waters because the rising water brings nutrient salts into the lighted layers, which results in the proliferation of phytoplankton, the basis of the marine food chain. The two most conspicuous centers of upwelling along the California coast occur at Point Conception (35°N) and Cape Mendocino (41°N) (Sverdrup, Johnson & Fleming, 1942; Jones and Stokes Associates, Inc., 1981).

The coastal climate is primarily controlled by moisture-laden, prevailing northwesterly winds sweeping on shore from the semipermanent Pacific Anticyclone, a high pressure area known as the North Pacific High. The winds resulting from the pressure gradient between the North Pacific High and a low pressure area over the desert Southwest begin in April and continue until the fall. At this time the North Pacific High moves southward reaching about 28° N latitude in February (Huyer 1983). The air temperature variations between day and night are normally small, summers are cool, winters are moderately warm, and there is considerable fog. From south to north, air temperature variations increase and there is a greater contrast between summer and winter. Fog is more frequent and lasts longer in the north (De Santis, 1985).

Rainfall patterns vary with latitude and altitude all along the California coast, with mountainous areas receiving much more rain than lower altitudes. Northcoast areas average about 30-40 inches per year. In contrast, the annual rainfall along the southern California coast averages about 12 inches per year. San Francisco, located approximately in the middle of these extremes, receives about 18 inches of rain a year. The rainy season normally begins by late September, with the greatest precipitation occurring in December and January. The dry season starts about June. Snowfall is uncommon along the coast, except in the northern counties, where it does occur occasionally (Department of Parks and Recreation, 1970).

Ocean surface water temperatures and salinities also vary from an average of 54.5° F and 32.5°/oo salinity in the north, to an average of 67° F and 33.45°/oo salinity in the south. California has, in fact, two very distinct oceans. Point Conception, situated approximately two-thirds of the way down the California coast, marks an abrupt change in the character of our ocean waters. North of Point Conception, the waters are uniformly 10°F colder, and have 1°/oo lower salinity, than the waters south of the Point. North of the Point, the northwesterly winds are much stronger, which tend to make the ocean waters more turbulent (Sverdrup, Johnson & Fleming, 1942; Bureau of Land Management, 1974).

Point Conception is, in addition to being an oceanographic boundary, a biological boundary as well. Southwesterly from Point Conception, a large eddy is formed where the Davidson Current, deflected westward by the Point, is turned southward by the California Current. The abrupt temperature and salinity change at the north edge of the eddy acts as an effective barrier to the mixing of fish and shellfish species acclimated to environmental conditions found to the north and south.

Much of the California coastline is mountainous and characterized by a mix of rocky headlands, cliffs, and beaches, with few major estuaries and embayments. From Crescent City, south to the Los Angeles Basin, only a few alluvial plains are found at the mouths of broad valleys. The shoreline is relatively straight, lacking in barrier beaches and lagoons for protection (Department of Parks and Recreation, 1970; United States Army Corps of Engineers, 1971; National Marine Fisheries Service, 1990).

The morphology of the coastal region and the nearshore subtidal region of California has been shaped essentially by three processes: 1) the convergence of tectonic plates, 2) seismic activity along the San Andreas Fault zone, and 3) sea level fluctuations. California straddles the Pacific and North American plates in such a way that San Francisco is on the North American plate while Los Angeles is on the Pacific plate. The two plates are separated by the San Andreas Fault, which is a relatively straight, northwest–tending fault that extends 992 miles from the Salton Sea through the Coast Ranges to the Mendocino Escarpment (Jones and Stokes Associates, Inc, 1981b; Anderson et al., 1990). Both plates generally move the opposite directions with the American plate moving in a southeast direction while the Pacific plate tends to move northwest. When these plates collided, the North American plate was lifted up and over the other plate producing the Coastal and Transverse mountain ranges.

Anderson et al. (1990) attributed the current geomorphology of the north coast (southern Oregon to Cape Mendocino) to tectonic convergence. This area has undergone significant uplifting as a result of the collision of three plates: the Gorda, Pacific, and the North American plates. While the geomorphology of the central coast (Cape Mendocino to Morro Bay) is attributed to the right–lateral, strike–slip motion of the San Andreas fault more than to the convergence of the two plates. The faulting action has created folded, sheared, and metamorphosed jumble blocks with a north–south orientation (Anderson et al., 1990).

Coincidental to the geologic processes were sea level fluctuations. The fluctuations, which were caused by changes in the worldwide climatic conditions, lead to periods of shoreline advance and retreat (Jones and Stokes Associate, Inc, 1981b). During glacial periods, the shoreline retreated as far as the edge of the present day continental shelf. During interglacial times, the shoreline advanced to near modern levels. Each of these oscillations in sea level lead to varying degrees of erosion of the shelf and coastal mountains. Evidence of this can be found in the presence of broad, gently sloping, wave–cut terraces on land (Anderson et al., 1990). These terraces have been lifted to their present day levels through a combination of seismic activity and the retreat of glaciers. The weight of the ice masses pushed the underlying land down much like the effect of putting weight on a dock does. Much of the land surface of the Oceanside–San Diego area represents a series of marine terraces that were cut into the coastal plain that parallels the Peninsular ranges (Hertlein and Grant, 1954).

The ocean bottom seaward of the California coastline is called the Continental Shelf. This shelf, part of the continent that is presently submerged beneath the ocean waters, is an area where a considerable portion of our marine resources occur. The Continental Shelf off California varies considerably in width. The ocean bottom drops seaward at a moderate gradient to the point where it reaches the Continental slope, and then descends to the floor of the offshore ocean basins. The edge of the shelf normally occurs at a depth of approximately 600 feet. The continental slope starts where the shallow bottom gradient of the shelf increases rapidly from a gradual drop of about three feet in 3,000 feet to a rate of three feet in 300 feet (Ingmanson and Wallace, 1973).

The Continental Shelf, from the Oregon border to Cape Mendocino, is relatively broad (20 to 30 miles) and un-dissected. The coastal shelf from Cape Mendocino to Point Conception, however, is much narrower (3 to 18 miles) and is bisected by numerous submarine canyons, including the Monterey Submarine Canyon. The Monterey Canyon, one of the largest in the world, originates one-half mile offshore from Moss Landing at a depth of 300 feet, and extends into the center of Monterey Bay. A southerly branch, the Carmel Canyon, originates one-quarter mile from the mouth of San Jose Creek. It extends offshore westerly and northerly for approximately 15 miles where it joins the Monterey Canyon at a depth of approximately 3,000 feet and about six miles offshore (State Water Resources Control Board, 1979; National Oceanic and Atmospheric Administration, 1980; NOAA, 1990a).

South of Point Conception, the shelf is characterized by a series of ridges capped by islands and deep basins. Here, the width of the shelf varies from less than two to more than 14 miles. This shelf area is also bisected by a deep submarine canyon known as the Scripps-La Jolla Canyon. This canyon complex is located just north of San Diego. The head of the northern Scripps Canyon branch extends almost to the surf zone, one-half mile offshore, and extends steeply to a depth of 800 feet, approximately two miles offshore, where it is joined by the southern tributary canyon.

The southern tributary, La Jolla Canyon, heads approximately two miles offshore at a depth of approximately 50 feet and joins the Scripps Canyon one and one-half miles to the northwest. The Canyon from the point of merger meanders across the

Continental Shelf for approximately nine miles westward, where it turns south to empty into the San Diego trough at a depth of approximately 2,600 feet (Sverdrup, Johnson & Fleming, 1942, Bureau of Land Management, 1974).

### 3.1.2 Habitat

In the preceding section, the variations in meteorological, oceanographic and geological conditions found along the California coast, from north to south, were discussed. Consequently, these different elements in combination create a variety of distinct habitat types.

The more than 550 species of marine fishes, coupled with the multiplicity of invertebrate species and marine plants that are found along our shores, give ample evidence that a great variety of marine habitat is available. Even though a wide variety of habitats exists, each species is adapted to a narrow range of conditions. As an example, the sandy bottom habitat chosen by a California halibut would certainly not be to the liking of a rockpool blenny who prefers rocky intertidal areas. Therefore, marine habitat types are broken down into categories having similar features such as water depth, distance from shore, and type of substrate. These are: pelagic; benthic (muddy, sandy and rocky bottom); kelp beds; nearshore; intertidal; bays and estuaries; islands; natural and artificial reefs (Fitch, 1963; Eschmeyer et al., 1983; Department of Fish and Game, 1987).

## 3.2 Life History

Giant and bull kelp are members of the large brown algae (Phaeophyta) that are a conspicuous part of the marine environment. These two species, while being members of the same family, have developed different strategies for survival in the marine environment. The most notable is that giant kelp (*Macrocystis pyrifera*) is a perennial (has a life span of more than 2 years) while bull kelp (*Nereocystis luetkeana*) is a annual species.

### 3.2.1 Taxonomy and Morphology

**Giant Kelp**

| | |
|---|---|
| Scientific name........ | *Macrocystis pyrifera* (Linnaeus) Agardh |
| Class....................... | Heterogeneratae |
| Order....................... | Laminariales |
| Family..................... | Lessoniaceae |

The genus *Macrocystis* was first described by C A. Agardh in 1820. There are presently two species of *Macrocystis* recognized living in California: *M. integrifolia*, a shallow subtidal to intertidal species that produces flattened holdfasts and occurs from central California, near San Simeon northward; and *M. pyrifera*, a subtidal species that attaches to solid or soft substrate, produces holdfasts that are either conical or low mounds, and occurs throughout southern and central California.

Neushul (1971a) recognized a third species of *Macrocystis*, *M. angustifolia* growing on unconsolidated bottom (soft sediment) near Santa Barbara. Later authors, however, have not recognized *M. angustifolia* as a valid species, but rather a morphological variation of *M. pyrifera* (Nicholson et al., 1976; Brostoff, 1988). This morph produces holdfasts that are low mounds measuring up to 10 or l5 feet across. Brostoff (1988) used transplant experiments and detailed morphological comparisons to conclude that the Santa Barbara *M. angustifolia* of Neushul was a variation of *M. pyrifera*. For the purpose of this report we consider all *Macrocystis* harvested commercially in California *M. pyrifera*. We will, however, describe the unique habitat where giant kelp grows on soft sediment near Santa Barbara.

Each mature *M. pyrifera* plant consists of a holdfast, a cluster of reproductive blades called sporophylls, and anywhere from a few to several hundred fronds (Figure 3–1). The holdfast is cone-shaped or a mound and is the attachment organ. It is composed of a tangle of rootlike haptera that grow down from the primary stipe and attach to the substrate. The haptera branch frequently to create a dichotomous pattern. The lifespan of a hapteron is probably only a few months, and therefore, continual production and growth by new haptera is necessary to maintain the holdfast with firm attachment to the underlying substrate. When the plant is young, the entire holdfast consists of living haptera. New haptera overgrow the old haptera as the holdfast enlarges with age. Holdfasts that are several years old consist of an inner core of dead haptera covered by living haptera. Only the living haptera attach the plant to the substrate (North, 1971a).

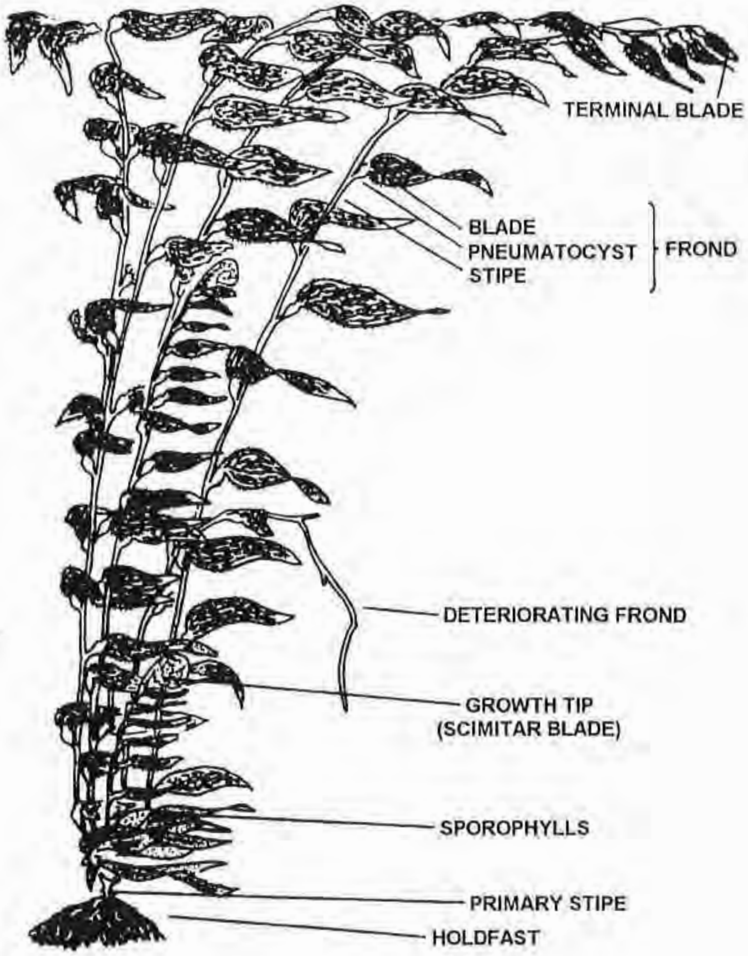


Figure 3-1. Giant kelp morphology.

Large amounts of foliage normally occurs at the holdfast apex. Reproductive blades (sporophylls), basal meristems and frond initials are usually the most numerous blade types within this basal foliage. All blades are attached to a complex branching system of stem–like stipes that also emerge from the holdfast near the apex.

Bundles of fronds extend up vertically from the basal foliage through the water column. Individual fronds consist of a stem–like stipe and numerous attached leaf–like blades. A single bladder, at the base of each blade, attaches to the stipe. The distance between each bladder (internodal distance) decreases from the base upwards. There may be as many as 200 blades on growing fronds. Young fronds have a special scimitar–shaped blade (apical blade) at the distal end. This special blade is also referred to as the apical meristem (see page 3-9 for information on the role that the apical meristem plays in plant growth). All *Macrocystis* fronds originate from the basal foliage just above the holdfast.

## Bull Kelp

Scientific name........*Nereocystis luetkeana* (Mertens) Postels & Ruprecht
Class........................Heterogeneratae
Order........................Laminariales
Family......................Lessoniaceae

The morphology of bull kelp is quite different from that of giant kelp (Figure 3–2). While bull kelp is attached to the substrate by a holdfast, the size of the holdfast is much smaller than that of giant kelp. The holdfast resembles a small disk with haptera emanating as a whorl from the junction between the lower stipe and holdfast. Adult bull kelp plants produce holdfasts that are over 1 foot in diameter (MacMillan, 1899; Abbott and Hollenberg, 1976).

Sporophytes of bull kelp possess a single stipe and pneumatocyst throughout their life span. Much like giant kelp, the stipe of a bull kelp sporophyte is long, reaching length of up to 130 ft, and slender (1/3 inch in diameter). However, the bull kelp stipe does not have the same tensile strength (2.9 MN $m^{-2}$ per stipe) as giant kelp but is more elastic under stress. Bull kelp is able to stretch more than 38 percent of its length before reaching its breaking point (Koehl and Wainwright, 1977). The pneumatocyst gives rise to short dichotomous branches from which between 30 to 64 blades are borne. Since blades occur only on the terminal end of the stipe, the bull kelp canopy provides most of the photosynthetic and nutrient absorbing surface for energy production (Manley, 1985; Nicholson, 1970; Nicholson, 1968). Blade lengths of more than 13 ft have been reported for mature plants but it is typical to find a range of blade sizes (2 to 11 ft) on most plants (Foreman, 1970). The reproductive structures (sori) are located on the blades with mature sori located near the blade tips and immature regions near the base of the blades.

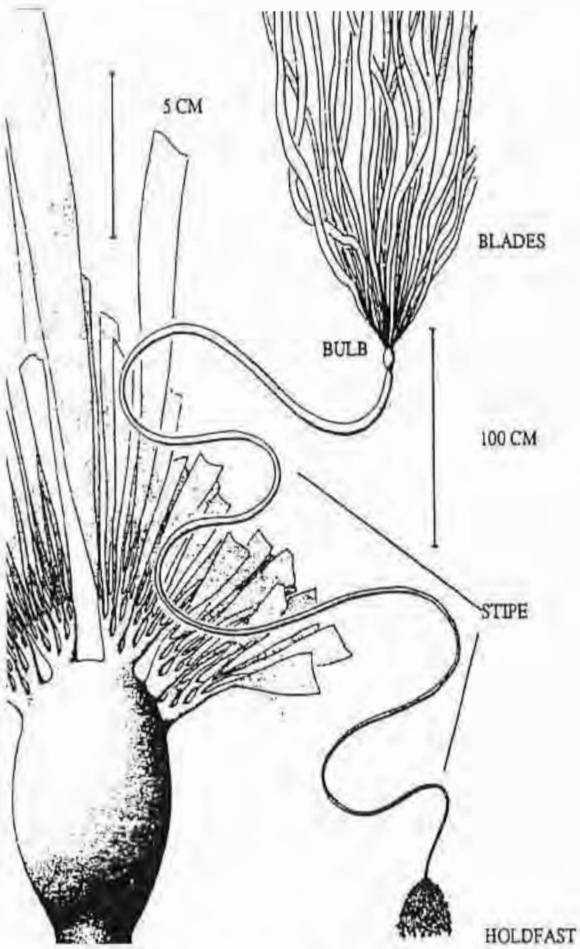


**Figure 3-2. Bull kelp morphology. (Source - Abbott and Hollenberg, 1976)**

### 3.2.2 Distribution

#### Giant Kelp

The genus *Macrocystis* occurs in many parts of the world, but is most widely distributed in the southern hemisphere. In the northern hemisphere, *M. pyrifera* commonly occurs from Baja California Sur, Mexico to Santa Cruz, in central California (Druehl, 1970). A few scattered small patches of *M. pyrifera* occur along the California coast, north of San Francisco (Kalvass, pers. comm.)

Occurrences of *M. pyrifera* in California are frequently controlled by wave exposure and the availability of rocky substrate. Populations of giant kelp frequently form distinct patches that are referred to as kelp beds. Except for the specialized populations of *M. pyrifera* growing on sand near Santa Barbara, holdfasts require solid substrate for secure attachment (North, 1971b). This is especially true along wave-exposed coastlines (Harrold et al., 1988).

The unique kelp beds near Santa Barbara that develop on sand are located in well-protected waters. The large holdfasts of these plants are able to penetrate into the soft bottom for secure anchorage.

The vertical distribution of *Macrocystis* is usually determined by local biotic and abiotic factors. Giant kelp can occur intertidally in protected areas (North, 1971b). However, recruitment of *Macrocystis* to shallow areas may be limited by high light irradiance (Photosynthetically active radiation (PAR)) which has a negative affect on postsettlement stages (Graham, 1996). The inner boundary of *Macrocystis* beds may be determined by where the largest waves normally break and or disturbance-mediated competition for space with algal turf communities (Seymour et al., 1989; Graham, 1997). The outer limit of kelp beds is probably determined by water clarity, since gametophytes and tiny sporophytes require adequate bottom illumination for development (Dean and Deysher, 1983). The offshore edge of *Macrocystis* beds in turbid waters usually occurs at depths of 50 to 60 ft, while in clear water around the channel islands of southern California, the offshore edge of the kelp bed may extend to more than 100 ft (North, 1971b).

#### Bull Kelp

Bull kelp is primarily found adjacent to exposed and semi–exposed shorelines along the Pacific coast of North America, ranging from Unalaska Island, Alaska to San Luis Obispo County, California (Hawkes et al., 1978; Scagel et al., 1987). Miller and Estes (1989) found a large, mature population of *Nereocystis* at the southwest end of Umnak Island, Alaska. The discovery of this bed expands the range of this species approximately 186 miles west of Unalaska Island, Alaska.

Along the central California coast, *Macrocystis* and *Nereocystis* occur together, forming extensive kelp forests in this region. However, from Carmel, California northward to Alaska, *Nereocystis* becomes the dominant surface–canopy species in coastal waters (Abbott and Hollenberg, 1976; Foreman, 1984).

Within the nearshore environment, bull kelp, like giant kelp, is associated with hard substrates such as moderate relief bedrock, nearshore reefs, pinnacles, and boulder/cobble fields (MacMillan, 1899; Hurd, 1916; McLean, 1962; Foreman, 1970). Foreman (1970) noted that bull kelp sporophytes also attached to the stipes of the brown algae *Pterygophora californica*. Bull kelp occurs subtidally at depth of approximately 13 ft to 72 ft (McLean, 1962; Nicholson, 1970; Vadas, 1972).

Distribution of marine algae is not only restricted geographically but also limited by a number of abiotic factors within the nearshore environment (Foreman, 1970; Vadas, 1972, Foster and Schiel, 1985). These factors include water movement, light, temperature, nutrients, pollution, competition, and predation (Foster and Schiel, 1985).

Foreman (1970) reported that bull kelp distribution is limited by the combination of bottom type and wave exposure. Young sporophytes which settle on smooth substrate or small–size cobble beds within areas of violent wave action are swept away before the holdfasts become well developed. However, those plants that settle among boulders, or in areas of moderate relief are protected from wave energy and survive.

### 3.2.3 Life Cycle

### 3.2.3.1 Reproduction and Development

### Giant Kelp

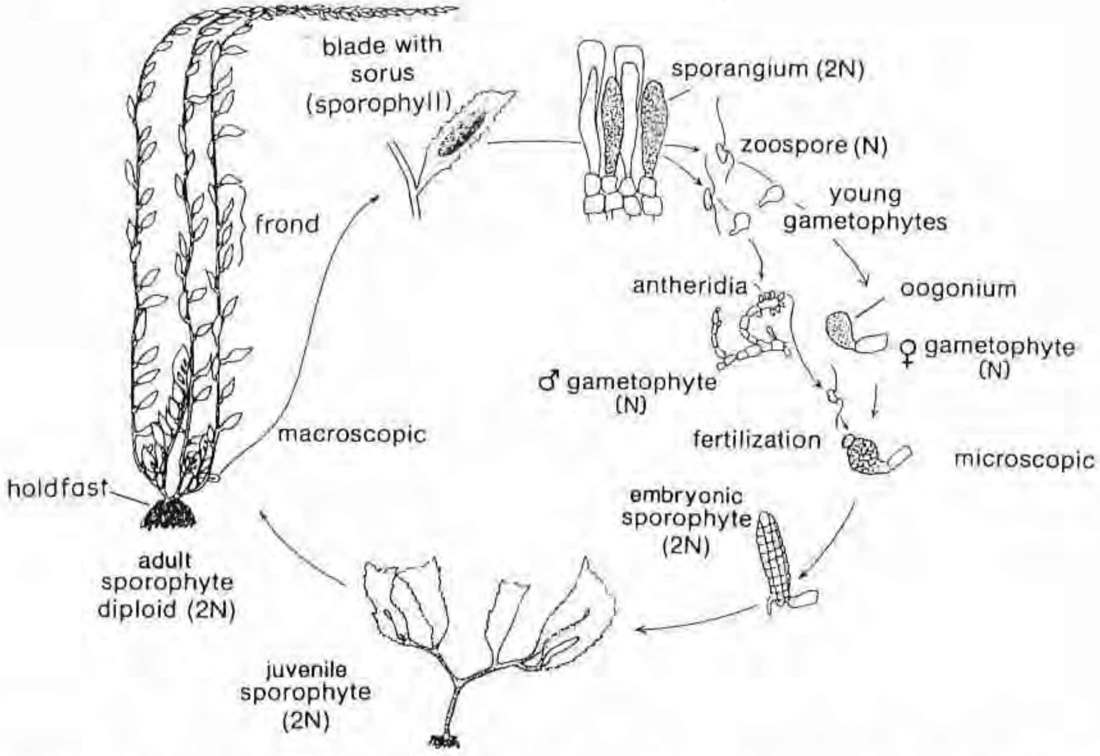


**Figure 3-3. Giant kelp life cycle. (Source - Foster and Schiel, 1985)**

*Macrocystis* has a typical laminarian life cycle, alternating between microscopic gametophytes and macroscopic sporophytes (Figure 3-3). The reproductive blades (sporophylls), located just above the apex of the holdfast, produce and liberate spores continuously throughout the year (Anderson and North, 1967). The liberated spores are transported away from the sporophyte by water movement and their own swimming. Spores that find suitable substrate attach and usually produce germ tubes within a few hours. Spore contents migrate down the germ tube and emerge at the distal end as the first cell of the gametophyte (North, 1994).

As the gametophyte grows it will become either multicellular (male) or remain uni-or-bicellular (female). Gametes are usually produced (gametogenesis) in about two weeks. Many sperm emerge from male gametophytes, while one or more large ova are produced by female gametophytes. Eggs are extruded by the female and fertilization occurs. The zygote undergoes rapid cell division to produce a microscopic embryonic sporophyte (North, 1971b).

Small sporophytes (< 0.25 in long) may develop in a few weeks with suitable illumination and ample nutrients. The tiny sporophytes at this stage are single lanceolate blades just visible to the unaided eye. Other members of the Laminariales (kelps) also produce a single blade that is virtually identical to the blade-stage of *Macrocystis*. A few weeks of additional growth yields an inch long blade, that may be smooth or may have transverse corrugations. Giant kelp is easily distinguished from other kelps at this early stage because a cleft develops at the base of the blade. The basal cleft produces a hole that elongates toward the tip, and divides the 5 to 6 in long blade into two equal halves.

The two blades continue growing and produce additional basal clefts that yield four, then eight blades. The two outer blades become frond initials and each develops an apical meristem (apical blade). The two inner blades become the first basal meristems (North, 1971b). The apical blade is divided by a series of basal clefts that elongate and divide the blade into separate strips of tissue that will become the normal blades along the frond. Eventually the apical meristem produces the 100 to 200 blades of the mature frond. The basal portion of the apical meristem thickens and becomes stipe tissue. The junction between the newly-formed blades and the stipe develops a hollow gas-filled cavity (the pneumatocyst) that buoys the developing frond in the water column. Continuation of blade and pneumatocyst production and growth, plus stipe elongation, eventually results in a fully mature, canopy-forming frond (North, 1994).

The basal meristems also continue to divide by forming basal clefts. The innermost blade of the resulting pair continues as a basal meristem. The outermost blade becomes a frond initial. Every other division, however, produces two basal meristems. This allows the developing young plant to increase the numbers of basal meristems and eventually the numbers of fronds (North, 1994).

Complete sets of blades are usually retained until the fronds are half-grown. Losses of the lower blades begins before the fronds reach the surface and mature fronds usually lack many or all the blades in the ascending stipe bundle (Wing and Clendenning, 1971). In the usual mixture of juvenile, mature, and senescent fronds on an adult plant between 1/3 to 1/2 of the total blade surfaces have been lost by natural sloughing.

The bulk of the blades on a *Macrocystis* frond are formed before the tip of the frond reaches the surface. The canopy blades are pushed into their position on the surface by expansion of submerged internodes. Apical meristematic activity at the surface produces only a small part of the total surface blades (Clendenning, 1971a). The ability of *Macrocystis* to regenerate its canopy rapidly and to dominate large areas along the coast is due to the continuous production of new fronds by established holdfasts and the intercalary growth mechanism. The remarkable speed of canopy formation occurs by small incremental growth distributed through the internodes on the complete frond (Clendenning, 1971a).

**Bull Kelp**

Reproduction in bull kelp undergoes a cyclic alternation of generations similar to that of giant kelp and other Laminarians. The large plant known as bull kelp represents the sporophytic phase while the microscopic gametophytic phase is unrecognizable in nature (Figure 3-4). During it's sporophytic phase, spore production begins several weeks after the blades reach the surface (Foreman, 1970). Biflagellate spores are formed within fertile patches (sori) on the blades. Sori are borne at the base of each blade (near the pneumatocyst), with maturing sori progressing towards the blade tip during blade growth and subsequent sloughing. These patches are continually produced throughout the summer and fall. As the spores reach maturation, the sori are abscised from the blades (Nicholson, 1970; Amsler and Neushul, 1989). The abscission of sori is unique to *Nereocystis* and is thought to insure a wider dispersal of spores than might otherwise be obtained (Gadgil, 1971; Walker, 1980).

Upon settlement, germination begins, closely following the process described for *Macrocystis* above. Germ tube formation and transfer of spore contents occur within 48 hours of settlement. Over the course of several weeks, somatic growth gives rise to multibranched filamentous plants. By the ninth week, differentiation of gametophytes become apparent with the production of antheridia and oogonia. Under sufficient light and nutrient levels the gametophytes reach sexual maturity in approximately 10 to 11 weeks (Hartge, 1928; Vadas, 1972). At this point motile sperm are released from the antheridia and fertilization of the oospores (eggs) takes place. The resulting zygotes grow as sporophytes.

Hartge (1928) felt that *Nereocystis* differed from other laminariales because gametophytic growth took far longer to reach maturation than any other laminariales; the antheridial gametophyte was more branched and extensive than those described for other brown algae; and the gametophyte of *Nereocystis* could live through several years. Vadas (1972) reported that under poor light conditions the gametophyte would continue to grow vegetatively for over a year. When light conditions improved gametophytes began producing reproductive structures. This seems to support Hartge's work.

The developing sporophyte is largely unrecognizable as *Nereocystis* until it reaches a height of about 5 cm. Prior to this point, the plant consists of a short stipe and single blade. The juvenile plant becomes recognizable when zones of weakness appear on the primary blade, which precedes splitting. At the end of the first week of growth the development of a small swelling occurs at the junction of the blade and stipe. A short time after the appearance of the ping–pong ball shaped pnuematocyst, the first dichotomous splitting of the blade takes place. The process of splitting begins at the bottom of the blade and results in two equal sized blades. Elongation of the blade and stipe continues during this process giving the plant a spindly appearance. The pnuematocyst maintains its spherical shape through the second dichotomous splitting of the blades. During this phase, the splitting takes place at the top and bottom of the blades. The juvenile plant is approximately 21 days old at this time. The apophysis (wide, hollow portion of the upper stipe) develops and the third dichotomy begins at about 41 days. The apophysis is initially filled with loosely woven filaments which later disappear forming a continuation of the pnuematocyst. The stipe elongation rate increases considerably while blade elongation remains constant. At about 60 days of age, the plant increases growth of both the stipe and blades. This rate is maintained until the sporophyte reaches the water surface at which point the stipe elongation rate decreases. By the time the surface is gained the plant has developed on average 30 blades. Once at the surface, the stipe and blade elongation rates decrease while the plant increases in biomass. The increase in biomass results from an increase in radial growth of the stipe, blade thickening, and continued dichotomy of the blades (Foreman, 1970).

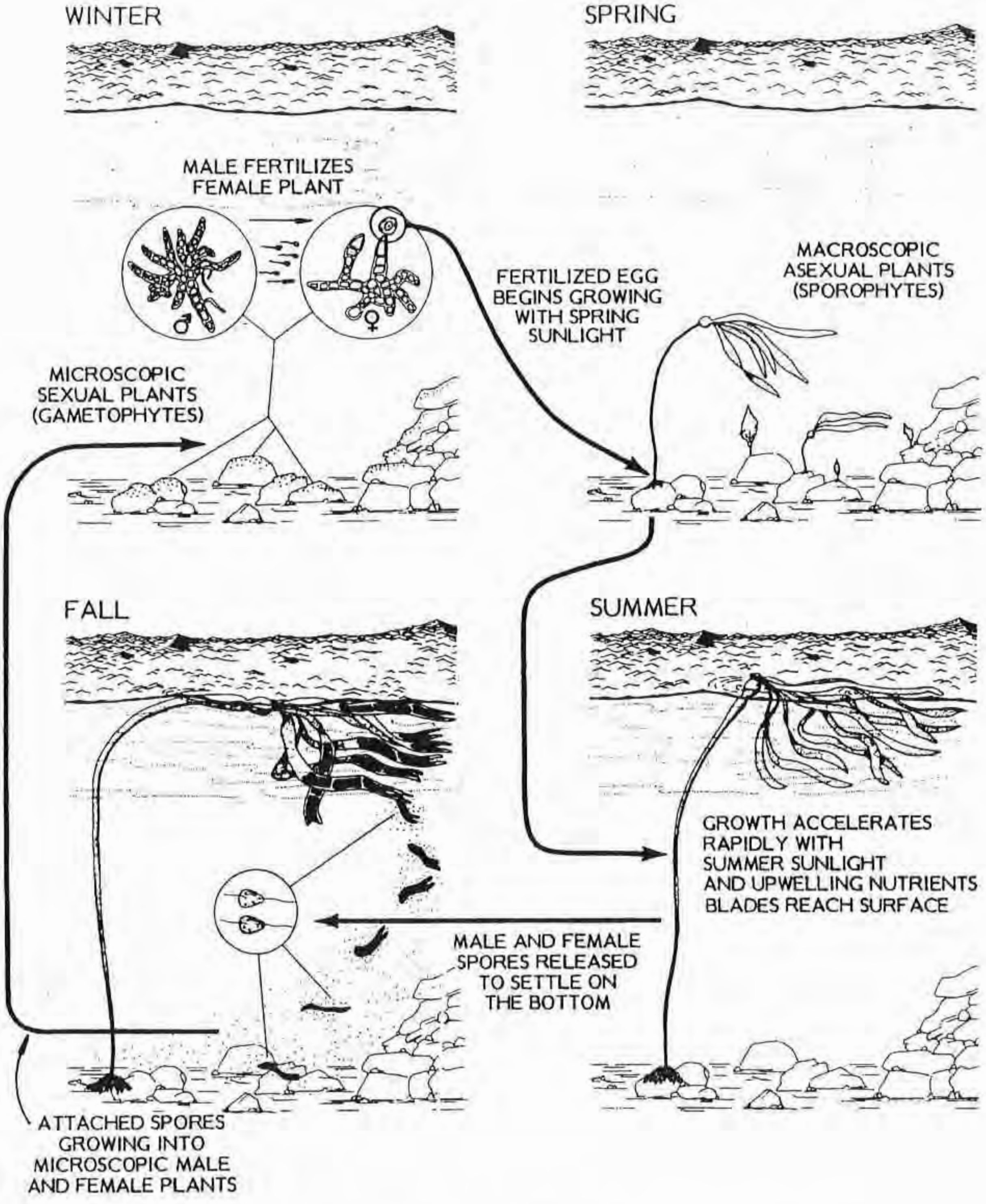


Figure 3-4. Bull kelp life cycle. (Source - Tera Corporation, 1982)

### 3.2.3.2 Dispersal and Recruitment

**Giant Kelp**

Giant kelp plants have tremendous capacity to produce spores. They begin production when they reach a size ranging from two to eight stipes at an age of nine to twelve months (Anderson and North, 1967). Release rates as high as 76,000 spores/min./cm$^2$ were recorded by Anderson and North (1967). Peaks in spore production tended to appear in late spring-early summer, while a secondary peak was sometimes noted in fall and early winter.

Reed (1987) found that vegetative biomass of a giant kelp plant greatly influenced spore production. Removal of 75% of the vegetative fronds resulted in a drastic decrease in sporophyll and spore production.

Some authors have suggested that effective spore dispersal in kelps is limited to a few meters and that recolonization of an area results from spores being released from drifting fertile plants (Dayton, 1985; Schiel and Foster, 1986). Evidence of relatively dense recruitment has been observed more than a mile away from stands of fertile adults (Ebeling et al., 1985; Reed et al. 1988). Reed et al. (1988) measured the weekly variation in recruitment of *Macrocystis* off southern California on replicate frosted glass slides placed at different distances from stands of fertile adult plants. Recruitment density rapidly declined with distance from the adult stand; significantly lower recruitment was observed as little as 10 ft from the adults. Spores settled as far as a mile from the source. Recruitment out to a mile appeared to occur uniformly and coincided with recruitment at the spore source and at all intermediate distances. This suggests that dispersal over long distances was probably by individual spores rather than via clumps of drifting plants as suggested by previous studies (Reed et al., 1988).

The distance over which propagules can successfully colonize new sites depends on processes that increase the time they remain competent while being dispersed (Reed et al., 1992). Algal spores can contribute to their own nutrition, via photosynthesis, during dispersal (Amsler and Neushul, 1991). Laboratory experiments revealed that spores of *Macrocystis* did not die after they stopped swimming; most germinated in the water column and retained their capacity to produce viable sporophytes. The viable planktonic stage of *Macrocystis*, therefore, is not necessarily restricted to the spore but may include later life history stages (Reed et al., 1992). The laboratory results provide biological evidence that spores and germlings of giant kelp can remain competent in the plankton for extended periods of time, which is consistent with' previous findings that their dispersal can occur over greater distances than previously thought possible.

A minimum density of at least 1 spore/mm$^2$ was needed for successful recruitment of *Macrocystis* (Reed, 1990). This minimum density was probably determined in part by the maximum distances that could separate male and female gametophytes while still allowing fertilization to occur. Density-dependent mortality occurred whenever there was recruitment. The requirement for spores to settle at relatively high densities, coupled with the large difference in size between spores (0.01 mm) and early recruits (20 mm), insures that density-dependent mortality will occur at early stages (Reed, 1990).

Good recruitment of giant kelp usually occurs following storm disturbances that remove or thin populations of adult *Macrocystis*, allowing light to penetrate to the bottom. Dayton et al. (1984) followed survivorship of *Macrocystis* that recruited at Point Loma, California following storm disturbances in 1973. The recruitment occurred during an upwelling period in May and June 1973, following a major reduction in surface canopy. The new recruits appeared in patches in very high density. Dayton et al.

(1984) followed 1,543 recruits, of which 300 survived to 5 cm; and 259 survived to 1 to 2 m; 35 of these reached the surface to produce canopy at the age of nine months.

A phenomenal example of recruitment following destruction of adults by a storm occurred at San Clemente Island after a severe storm in January 1988 (R. McPeak, pers. obs.). The storm was deemed the worst in 200 years and referred to as a "200 year storm." Nearly all adult *Macrocystis* were either uprooted or snapped at the base. Tremendous recruitment of giant kelp occurred almost immediately after the storm and canopies reached the surface at San Clemente Island within six months of the storm.

Good recruitment of *Macrocystis* also occurs following a die–off of sea urchins. Die-offs of sea urchins and subsequent recruitment of giant kelp has been observed off Santa Cruz, California (Pearse and Hines, 1979), Point Loma, California (McPeak and Barilotti, 1993), and Soledad Bay, Baja California, Mexico (McPeak, pers. obs.). When sea urchins die, the bottom is released from grazing. Settling spores and embryonic stages of giant kelp are then able to survive.

**Bull Kelp**

Since bull kelp is an annual plant, it is imperative that spore production and release begin as early as possible. Foreman (1970) estimated that reproductive maturity is attained when *Nereocystis* sporophytes are about 11 weeks old or 2 to 3 weeks after plants reach the surface. This time line is based on his observations of developing bull kelp at Salt Point, Sonoma County. Burge and Schultz (1973) observed that plants initiated in late March in Diablo Cove had developing sori prior to reaching the surface in May and that spore release via abscission of the sorus began as early as June. Foster et. al. (1979a) observed a similar time scale at Greyhound Rock and China Rock near Half Moon Bay, San Mateo County. It has been reported that *Nereocystis* beds located in protected areas near Crescent City, California have begun spore production as early as February (Van Hook, pers. comm.). Burge and Schultz (1973) noted that new plants initiate at least through August, and sori develop and mature through March of the following year. These conditions would account for the overlap of annual sporophyte generations. In general, bull kelp spore production begins as early as June and lasts until fall and winter storms remove most of the adult sporophytes (Scagel, 1947; Nicholson, 1968; Foreman, 1970; Burge and Schultz, 1973).

Throughout the course of the typical growing season (June to October), changes occur in the fertility of *Nereocystis* blades, the maturity of the sori, the number of sori per blade, the average area of the sori, and the total reproductive tissue per blade. These changes have been recorded for beds in Barkley Sound, British Columbia (Leaman, 1980). This information is not yet available for bull kelp beds in California. However, preliminary studies conducted in Port Orford, Oregon on peak sori production mirrored Leaman's results (Fanning, pers. comm.). *Nereocystis* blade fertility (number of immature versus mature and released sori) reached a peak in early July as did the number of sori per blade (1.7 sori/blade), and the total area of reproductive tissue per blade (60 $cm^2$). To illustrate this point, imagine a single plant with 30 5–foot blades. In July, each blade will contain at least one immature sorus, approximately two mature sori, and will have 2 to 3 sori release scars. Thus an average plant will have 30 immature sori, 60 sori that are ready for release, and has already produced 60 to 90 sori, which have released spores. These maxima were followed by a slight dip, a lesser peak in late July and subsequent decline in all levels through August. A slight upswing in number of sori, average sori area, and immature sori occurs in September/October with the averages of the three variables being 0.45, 28 $cm^2$, and 10% respectively (Leaman, 1980). This increase comes as the density of the beds are diminishing because of shortened day length and decreasing light levels as well as increases in the frequency and intensity of storms.

Bull kelp has evolved a unique way of releasing its spores which seems to enhance dispersion (Amsler and Neushul, 1989). As the blades lengthen and mature, the sori gradually differentiate from the laminae. The sori gradually become a greenish–brown as they mature reaching a dark brown to black color prior to being released. As the spores are developing a darker pigmentation, the opposite is occurring in the surrounding tissue. The cells at the perimeter are undergoing a clearing of pigmentation and this cleared area is the locus of separation (Scagel, 1947; Walker, 1980). The clearing is caused by the senescence and autolyzing of the non–fertile cells (paraphyses) around the sorus (Walker, 1980). This leads to a mechanical weakening of the tissue and aids in the release of the sorus from the blade. Amsler and Neushul (1989) found that individual plants usually abscised sori in pulses. They observed that all fertile blades on a plant would have the same number of sori and these sori would be of the same maturity level (Walker, 1980). Spore release followed a pattern of abscission of a "cohort" of sori from a plant on a single day or over a 2 to 3 day period followed by a short period (< one week) without sorus release and then another pulse (Amsler and Neushul, 1989). On occasion, the sorus will remain attached for a considerable time and sporulation may go on without actual separation of the sorus; in this case the patches gradually become blotched and finally completely colorless as advanced sporulation takes place (Scagel, 1947; Walker, 1980).

The timing of sori separation was also monitored by Amsler and Neushul (1989) in the field and in the laboratory under simulated day and night conditions. They found, in field observations, evidence of sori release at dawn but none during daytime or nighttime. In the laboratory, separation of sori occurred 79.1% of the time at dawn (2 hours prior to sunrise and 4 hours after sunrise). This pattern was consistent for plants collected at different sites in central California (Piedras Blancas, Spooner Cove, and Point Joe). The residual percentage of abscission was equally divided between the other two periods and similar numbers of released sori were recorded (Amsler and Neushul, 1989). In British Columbia, bull kelp appears to release sori in conjunction with lowest low tide series of the month (Foreman, pers. comm.). Amsler and Neushul (1989) did not observe this phenomenon in central California.

Nicholson (1970) found that most spores were released from the sorus within the first hour of separation from the plant. Laboratory investigations support these observations. Spore release was significantly higher during the first hour after abscission (51.5 %) than any other hourly interval. After four hours, 94.2% of spores had been released (Amsler and Neushul, 1989).

The production of spores and the rate of spore release from the bull kelp sori is significantly higher than other macroalgae. Tera Corporation (1982a - c) found that about $3.5 \times 10^5$ spores/ml were released from sori collected from Diablo Cove. The rate of spore release averages $2.3 \times 10^5$ spores/cm$^2$/min with a maximum of $4.5 \times 10^5$ spores/cm$^2$/min (Amsler and Neushul, 1989). As mentioned previously, giant kelp has a maximum release rate of $7.6 \times 10^4$ spores/cm$^2$/min. Thus bull kelp's release rate is approximately 6 times faster than giant kelp.

Once released into the water column, the spores become a part of the plankton with a limited ability to direct their movement within the water column through use of two flagella and an eyespot (Walker, 1980). In Diablo Cove, Burge and Schultz (1973) observed sori accumulated in gullies surrounded by buff colored clouds of swarming zoospores. In addition to being motile, bull kelp spores are capable of photosynthesis. This ability, which is also shared by giant kelp, *Pterygophora californica* and *Laminaria farlowii*, enables the spores to conserve carbon reserves for germination and early growth or for prolonged planktonic viability (Amsler and Neushul, 1991). Thus the spores of kelp and of other marine macroalgae species seem to be more similar to planktotrophic benthic invertebrate larvae than the spores and seeds of other plants (Amsler and Neushul, 1991).

The method in which *Nereocystis* disperses its reproductive material is probably adaptive in: 1) maximizing the photosynthetic potential of the spores by releasing them at dawn, 2) spreading the vertical and temporal distribution of spores to maximize their dispersal potential. The release of the sorus, which is heavier than the spores, insures vertical distribution of spores within the water column. Since currents are variable at different depths and over time, wider dispersal of spores can be accomplished (Wheeler, 1980; Amsler, 1988; Amsler and Neushul, 1989), and 3) maximizing the chance that the other spores will settle in the same habitat in which the parental plants have successfully matured (Amsler and Neushul, 1989).

Recruitment into suitable habitat is essential for the survival of a population or subpopulation (Gadgil, 1971). While studies have determined the density of *Macrocystis* spores necessary to ensure recruitment into an area, little to no work on this topic has been done for *Nereocystis.* The density of young sporophytes at the point of recognition as bull kelp have been reported by various workers. Foreman (1970, 1984) reported densities of juvenile bull kelp sporophytes (5–15 cm in length) ranged from 200 to 400 plants/$m^2$ at Salt Point, and in British Columbia, equaled less than 100 per $m^2$ . The mortality rate of these plants was high. Nicholson (1968) reported mortality rates of 48% for intertidal plants while Burge and Schultz (1973) recorded a rate of approximately 35%. In all these cases, healthy bull kelp beds developed but these examples only give a partial indication of the volume necessary to ensure success.

### 3.2.4 Age and Growth

#### Giant Kelp

Giant kelp plants are perennial and may live for more than 7 years (Rosenthal et al., 1974; Dayton et al., 1984). However, the average life-span for an adult is about 1 to 2 years (Dayton et al., 1984; Dean et al., 1983). The individual fronds that makeup the plant, live six to nine months, while the blades live about four months (North, 1971c; Gerard, 1976). Continued existence of a plant, therefore, involves constant replacement of lost and dying fronds by juvenile material arising from frond initials just above the holdfast.

Giant kelp uses energy from sunlight to produce organic compounds (photoassimilates) that are used for growth. This is the process of photosynthesis. Giant kelp is remarkably different from land plants of similar size in that it possesses the capacity for photosynthesis in all parts of the sporophyte above the holdfast, as well as at successive stages of its asexual and sexual reproduction (Clendenning, 1971c). The pneumatocysts and cylindrical stipes have about the same photosynthetic capacity per unit area as the blades. The sporophylls at the base of the plant, the planktonic spores they release, the gametophytes that develop from the spores, and the blades of all sizes on sporophytes possess photosynthetic capacities (Clendenning 1971c).

*Macrocystis* tissues are composed of two regions, an outer cortex and an inner medulla (Parker, 1971a). Sieve tubes, located in the medulla, are involved in the movement of photoassimilates from photosynthetically active blades in well-illuminated regions, to growing tissues where light is insufficient to support photosynthesis. The movement of the products of photosynthesis is translocation (Parker, 1971b) and it is through this process that young fronds receive photoassimilates for growth from longer fronds.

The pattern of import and export of $^{14}C$-labeled assimilates was studied in a population of *Macrocystis* in southern California by Lobban (1978). Actively growing tissues imported and did not export. As a blade reached maturity it began to export, at first only to the apex that formed it, later also down the frond to sporophylls and frond initials at the base of the frond; and into the apical regions of juvenile fronds.

Good growth in *Macrocystis* requires ample light for photosynthesis, cool water rich in nutrients, and translocation of photoassimilates to the growing areas of the plant.

There are many abiotic factors that affect the growth of *Macrocystis*, including temperature, nutrients, and light. Considerable seasonal, year-to-year, and even daily differences in these variables occur within the range of giant kelp forests. The effects of one variable on *Macrocystis* growth can vary depending on the other variables. These interactions have demonstrated importance for *Macrocystis* (Lüning and Neushul, 1978; Dean et al., 1983).

Giant kelp must obtain all of its nutrients from the water because holdfasts do not serve in nutrient uptake. The plants take up nutrients through all frond tissues. DeBoer (1981) suggested that nitrogen, phosphorus, iron, and perhaps manganese and zinc may limit growth of macroalgae in nature. North (1980) concluded that copper could also be limiting for *Macrocystis*.

Inorganic nitrogen concentrations vary widely in nearshore waters. They are particularly high during upwelling or periods of terrestrial runoff (North et al., 1982). Inorganic nitrogen levels are typically low in summer and fall in southern California. Levels are especially low during periods when warm water masses move into the region from the south, or when the water is thermally stratified (Jackson, 1977; Wheeler and North, 1981; North et al., 1982; Zimmerman and Robertson, 1985).

Water temperatures and nutrients are indirectly correlated (Zimmerman, 1983; Zimmerman and Kremer, 1984) and it is often difficult to separate the combined effects of these on growth of giant kelp. Best growth of giant kelp occurs during periods of upwelling, when temperatures are low and nutrient levels are high (North, 1971b). In southern California, nitrates drop to very low levels (below about one micro gram atom/liter) when ocean temperatures reach about 59° F. (Zimmerman and Kremer, 1984). A plot of mean frond elongation rates against the mean monthly nitrate concentration showed a clear relationship between the two variables. Growth rates were reduced when the estimated nitrate concentration dropped below 1.0 micro gram atom/liter (Zimmerman and Kremer, 1984).

Reduced nitrogen concentrations may have been responsible for the poor growth and massive loss of *Macrocystis* during the warm–water period in the late 1950s (North, 1971b; Jackson 1977, North et al., 1982). Negligible amounts of nitrate were found above 59°F (Jackson, 1977, 1983; Gerard, 1982a; Zimmerman and Kremer, 1984). Deepened isotherms associated with the 1982-84 El Niño resulted in severe nutrient limitation and very poor kelp growth (Zimmerman and Robertson, 1985). Frond growth rates were so low at Santa Catalina Island during this El Niño event that terminal blades formed before reaching the surface, eliminating the formation of canopy.

Inorganic nitrogen (nitrate, nitrite, and ammonium) concentrations in the water must be in the order of 1-2 micro gram atoms/liter to support a giant kelp growth rate of 4% increase in wet weight per day (Gerard (1982a).

Adequate light is also essential for the growth of *Macrocystis*. Adult plants are usually insensitive to changes in subsurface light because they usually form a surface canopy and can translocate the products of photosynthesis toward the holdfast and juvenile fronds (Parker, 1963). Light transmission to the bottom is affected by the amount of light at the surface, the water, dissolved and suspended material in the water, and shading by attached plants (Foster and Schiel, 1985). Water clarity or turbidity is influenced by plankton abundance, wave action, or terrestrial runoff (Quast, 1971c; Clendenning 1971b). *Macrocystis* plants, themselves, have a great impact on light that reaches the bottom and may reduce irradiance by over 90% (Neushul, 1971b; Dean et al., 1983; Reed and Foster, 1982).

There are many ways to evaluate growth of *Macrocystis*. One can measure elongation rates of fronds, changes in tissue weight, or changes in area of tissue (Clendenning, 1960; North, 1971c; Gerard, 1976; Gerard, 1982b; Kain, 1982; Jackson et al., 1985).

North (1971c) proposed a mathematical model for frond elongation that modified the equation for simple logarithmic growth. Growth (G) in North's model represented the frond elongation rate normalized to a "standard" length of one meter. The model allowed comparison between measurements on fronds of differing lengths by mathematically adjusting their elongation rates to corresponding values when both were one meter long.

North (1971c) compared mean values of standard growth rates, G, from samples taken from kelp beds between Pacific Grove, California and Turtle Bay, Baja California Sur, Mexico. Mean G values ranged from 5.6 to 8.0% per day.

González-Fragosos et al. (1991) evaluated frond elongation rates during autumn-winter, spring, and summer in shallow water (25 ft depth) kelp in Bahia Papalote, northern Baja California, Mexico. Frond elongation was maximum during the spring and minimum during the winter. Average frond elongation rates varied between 0.3 to 11% per day during the study period.

Hernandez (1996) followed growth rates in a control and a harvested *Macrocystis* bed in Bahia Tortugas, Baja California Sur, Mexico. Frond elongation growth rates in the control bed were at a maximum during the winter and at a minimum in the summer.

Clendenning (1960) reported elongation rates of 2 ft per day as common and described the growth as the fastest recorded for any plant, terrestrial or marine. Coon (1981a) noted that evaluations of the growth rate of *Macrocystis*, and its designation as "the fastest growing plant," are based on comparisons of the elongation rates of single fronds, only a portion of an entire plant. Coon (1981a) considered the *Macrocystis* plant a complete organism rather than a collection of fronds of varying sizes. He described the growth of intact entire adult plants living in the sea, by measuring changes in all the fronds on a few plants. The plants exhibited symmetry in structure, with distinct frond pairs. Component frond growth rates were highly variable and decreased with increasing frond length. Tissue gains were offset by tissue losses due to breakage and sloughing. The growth rates of whole plants varied between 6.4% and 8.9% per day over short intervals (2 to 5 days). Total growth for plants measured in spring and fall averaged 1.4% and 0.9% per day, respectively (Coon, 1981a).

Suspended particles may affect water clarity and reduce bottom illumination. Lüning (1981) suggested that the lower limit of kelp is where light is reduced to 1% of that at the surface. In addition, the quality of light that reaches gametophytes can affect reproduction. Blue light is necessary for development of gametes but is not necessary for growth of the gametophytes. Dean et al. (1983) estimated that *Macrocystis* gametophytes outplanted on artificial substrata in the San Onofre kelp forest must receive the light necessary to become fertile within 40 days. Beyond this time mortality is too high and few survive.

Foster and Schiel (1985) indicated that growth of gametophytes of a variety of kelp species in southern California is generally optimal at 62° F while fertilization is optimal at 54° F. Deysher and Dean (1984) noted that sporophyte production is dependent on a variety of physical and chemical factors and that these factors interact to determine the eventual success of sporophyte recruitment.

### Bull Kelp

Bull kelp, as mentioned in Section 3.2, is an annual species having a life span of about one year. Early investigators first reported that *Nereocystis* was a perennial (Foreman, 1970). However, this theory was corrected by several investigators (Setchell, 1908; Fallis, 1915; Nicholson, 1968; Foreman, 1970) when they demonstrated that *Nereocystis* sporophytes which reached the surface in one year, rarely survive into the next year and new sporophytes are not seen until the spring. Most sporophytes are dislodged during winter storms and no new plants are seen until early spring. Foreman (1970) observed that some late developing sporophytes (those that did not reach the surface prior to winter) survived into the next season and that, while these plants were heavily coated with epiphytes, the plants did produce new blades and reach sexual maturity. He concluded, that under favorable conditions, *Nereocystis* could be considered a facultative biennial.

As an annually occurring plant, bull kelp has developed an accelerated growth rate to utilize optimal environmental conditions (light, high nutrient levels, water clarity) to insure continued survival. Recent *Nereocystis* growth studies have focused on the plant as a whole (haptera, stipe, and blades) instead of concentrating on a single aspect as had been the case in earlier research.

Nicholson (1968) and Foreman (1970) examined the rate of growth of *Nereocystis* in field studies. Both researchers measured elongation of the stipe and blades of developing sporophytes, with Nicholson's work including haptera growth rates, and Foreman including weight changes. The result of their work is a clearer picture of how growth occurs in *Nereocystis*.

After initiation, sporophyte development (haptera, stipe, primary blade) is slow for the first 3 to 4 weeks. The total growth rate is less than 0.1 cm per day. When the sporophyte reaches a height of 5 to 10 cm, the stipe elongation rate increases to approximately 1.7 cm per day while blade elongation increases to 1.0 cm per day. For the period from the 100–cm stage to attaining the water surface, the growth rate is phenomenal. The stipe can grow up to 12.7 cm per day, or more, depending on the depth of water (Foreman, 1970; Burge and Schultz, 1973)). Blades grow at a rate of about 1.6 cm per day and the haptera grow at a rate of 2.8 mm per day. Just prior to the sporophyte reaching the surface, blade growth accelerates to a rate of 9 cm per day. Nicholson (1968) found that once *Nereocystis* reached the surface, stipe elongation stopped. However, Foreman (1970) reported that stipe lengthening significantly decreased but did not stop. Both investigators showed that blade elongation continues at a rate ranging from 6 to 8 cm per day. At maturity the growth rate of the holdfast increases to 3.8 mm per day. Total plant growth rates for this species range between 22 and 27 cm per day (Nicholson, 1968; Foreman, 1970; Burge and Schultz, 1973).

*Nereocystis* biomass undergoes an interesting transition during its growth. Total plant biomass is divided equally between the stipe and primary blade when the juvenile sporophyte is about 5 to 15 cm tall. However, during the midwater growth phase, the stipe accounts for approximately 56% of the biomass. Once the sporophyte reaches the surface, blade growth accounts for about two–thirds of plant biomass. This increase is the result of radial growth and dichotomy of the blades (Nicholson, 1968; Foreman, 1970). On average, a mature plant will have 40 or more blades (Foreman, 1970).

Growth in this species is not confined to any one area of the plant although a number of investigators (Sheldon, 1915; Fallis, 1915; Hurd, 1916; Frye, 1930; and Scagel, 1947) have shown that the most rapidly growing portions of the plant were the upper stipe and the basal region of the blades. Nicholson (1968) found that the primary growth in juvenile plants occurs at the base of the blades, the upper stipe, and the holdfast. At maturity, growth arises at the bases of the blades and at the lower stipe where new haptera are produced. Rapid elongation of the stipe and subsequent blade growth is probably a result of necessity. As an annual plant, *Nereocystis* needs to reach maturity during optimal environmental conditions to acquire energy for spore production, haptera growth, and to replace blade material lost due to spore production (Nicholson, 1968; Amsler and Nueshul, 1989).

Water temperature plays an important role in the growth of *Nereocystis*. Mean sea surface temperatures over the distributional range of *Nereocystis* vary from 13°C to 15°C at the southern end to 4°C to 10°C off the Aleutian Islands (Druehl, 1970). Lüning and Freshwater (1988) examined the temperature tolerances of several northeast Pacific marine algae. They reported that *Nereocystis* was able to survive one week at temperatures ranging from -1.5°C to 18°C. They classified the laminariales as cold–stenothermic seaweeds, meaning that these species are "fine tuned" to their environment and require a stable thermal climate (Lüning and Freshwater, 1988). They also concluded that a species' upper temperature limit was a conservative taxonomic trait and determines the southern limit of its distribution.

PG&E (1987) reported that the population of bull kelp in Diablo Cove was adversely affected by the warm water discharge from the Diablo Canyon power plant. Plants in contact with the discharge experienced deterioration of blade tissue, which resulted in early death. This observation, in combination with that of Lüning and Freshwaters' (1988) research may in part explain the decline of *Nereocystis* that occurs during periods of increased water temperature (El Niño events).

Tera Corporation (1982b) examined the effects of temperature and light on gametophyte and young sporophytes of bull kelp. They demonstrated significant differences in the effects of temperature and light on germination in contrast to growth. Whereas spores would germinate under a range of temperatures (9, 13, 13.8, 17, 21, 25°C) and at the same approximate rates (except 25°C), growth was significantly lower at 21°C. Light did not markedly affect germination but did have a strong effect on growth as is to be expected. The optimal temperature for initial growth was between 13°C and 17°C at 77 to 110 $\mu E/m^2/s$ (Tera Corporation, 1982b).

Fertility of bull kelp gametophytes is linked to water temperature and light levels. In laboratory studies, the fertility of both male and female gametophytes was found to be optimal at 16.7°C to 17.8°C, with a higher percentage of fertility with increasing light intensity. There was a two day difference in development between male and female gametophytes. Approximately 65% of males were fertile 10 days into the experiment while females reached about the same level of fertility at day 12 (Tera Corporation, 1982b). This delay is expected due to the higher energy demands necessary to produce ova (Srb et. al., 1965). Sporophyte development occurred within the same range of temperatures and light levels discussed above (Tera Corporation, 1982b).

Vadas (1972), in laboratory culture of *Nereocystis* gametophytes and sporophytes in Puget Sound, found that the effective temperature limits for reproduction in both these generations was 3°C to 17°C. Burge and Schultz (1973) reported that sporophyte development was first seen each spring at Diablo Cove in central California after sea floor temperatures declined to yearly lows following fall and winter maxima. Sporophyte development occurred at 10°C and 11.2°C in 1967 and 1968, respectively. From this research, it would appear that *Nereocystis* is capable of developing across a range of low water temperatures but is inhibited by high water temperatures (>18°C). The biggest factor in growth of *Nereocystis* is the availability of light and quantity of light (Vadas, 1972; Burge and Schultz, 1973). Plants depend upon light as a source of energy necessary for the photosynthetic process and changes in light intensity or duration due to season or depth of immersion affect the metabolism and growth of algae (Wort, 1955). In laboratory culture, gametophytes did not reach sexual maturity when light intensity levels were at or below 15 foot–candles. There was also a retardation of sporophyte growth at these same light levels (Vadas, 1972).

Vadas (1972) also measured light intensity at various water depths adjacent to and beneath both primary and secondary kelp canopies. Light levels below the surface canopy decreased by 99.6% and below the secondary canopy were reduced well below the minimum level necessary for growth. Thus in established kelp communities there appears to be insufficient light for recruitment and growth of bull kelp (Vadas, 1972). Similar results were found in studies of two other brown algae, *Laminaria hyperborea* and *Desmarestia aculeata* (L) (Kain, 1966; Chapman and Burrows, 1970; Kain, 1971).

### 3.2.5 Nutrient Uptake

**Giant Kelp**

Giant kelp must obtain all of its nutrients directly from the water because holdfasts do not serve in nutrient uptake. DeBoer (1981) suggested that nitrogen, phosphorus, iron, and perhaps manganese and zinc may limit growth of macroalgae in nature. North (1980) concluded that copper could also be limiting.

Gerard (1982a) studied nitrate uptake rates *in situ* by enclosing blades of *Macrocystis* in bags. She developed a mathematical model that described nitrate uptake by whole plants for specified concentrations and vertical distributions of nitrate. The model indicated than an adult plant should be free of growth limitations when nitrate concentrations throughout the water column are about 1 to 2 **u**M.

Nutrient uptake rates in *Macrocystis* vary for different tissue types (Gerard, 1982a; Manley, 1985). Rates generally increased along the frond from apex to the region of mature blades, then declined towards the base. Gerard (1982a), however, found highest rates of nitrate uptake at the apex with a declining gradient basally. Manley (1985) found that phosphate uptake rose significantly within four days of when blades were transferred from a high to a low phosphate medium. The uptake rate almost tripled within eight days.

Light, temperature, and water motion can also affect the uptake rates of nutrients by *Macrocystis*. Gerard (1982a) found an inverse relation between the nitrate uptake rate and water depth. She noted that nitrate uptake rates among deeply shaded *M. pyrifera* blades were 26 to 33% lower than for well illuminated blades. Wheeler (1978) reported a 48% enhancement of nitrate uptake when plants were illuminated but no enhancement for uptake of phosphate or ammonium. Uptake rates of phosphate increased by a factor of 1.6 for a temperature increase of 50°F to 68°F. The rate declined at temperatures above 77°F.

Water motion significantly enhanced uptake of nitrate, ammonium, and phosphate (Wheeler, 1980). Water motion could be either unidirectional or as turbulence. Gerard (1982b) reported that nitrate uptake became saturated at 3 cm $s^{-1}$ in her field experiments. She concluded that water motion in surface layers always exceeded this critical value, even within dense canopies during calm seas.

There is evidence that luxury uptake of nitrogen and phosphorous occurs in *Macrocystis* (Gerard, 1982c; Manley and North, 1984). Reserves accumulated during times of abundant nutrient supplies are utilized at times of scarcity. The stored nitrogen may last for up to 30 days (Zimmerman and Kremer, 1984).

North (1994) concludes that uptake and incorporation of nutrients by whole *Macrocystis* plants is extremely complex; being influenced by tissue type, recent history of the tissue, and environmental conditions that may differ throughout the water column.

**Bull Kelp**

An essential part of plant development is the ability to absorb nutrients from the surrounding water. Since a bull kelp plant consists of a long stipe with blades emanating from a single pneumatocyst, the plant has to be capable of acquiring nutrients through the epithelial tissue of the stipe or of translocating energy and nutrients from the fronds to the rest of the plant. The latter is indeed the case. Riggs (1915), Nicholson (1968), and Schmitz and Lobban (1976) showed that photosynthesis occurred within the blades and that the associated energy is transported to the stipe and holdfast. Energy in the form of carbohydrates (mannitol) is moved via the medulla of the blades through the stipe to the medulla of the holdfast. Sieve filaments, which appear to be analogous to sieve tubes in terrestrial plants, are the major component of the medulla and are embedded in the filament of the stipe and holdfast (Nicholson, 1968; Schmitz and Lobban, 1976). Thus energy and nutrients taken up by the blades can easily be transported to areas of rapid growth such as blade bases and haptera. Removal of the blades either by natural (storms, predators) or by human–induced causes (motoring through a bed, harvesting) would result in loss of energy production and death (Nicholson, 1968; 1970; Foreman, 1970; 1984).

Nicholson (1968) and Schmitz and Lobban (1976) measured the rate of translocation of photosynthates in *Nereocystis*. The translocation rate for this species range from 110 mm/hour to 570 mm/hour and is much slower than the translocation rate of *Macrocystis* (780 mm/hour). One possible explanation for this difference may be due to the morphology of both plants. *Nereocystis* has a single stipe with fronds only at the water's surface, and although the blades may vary in size, all are undergoing some amount of photosynthetic activity. Energy in the form of carbohydrates only needs to be transported to the stipe and haptera. In contrast, *Macrocystis* has numerous fronds of varying ages and positions in the water column. Young fronds are shaded by the canopy of older fronds and are acting as energy sinks more than energy contributors. Thus the higher rate of photosynthesis and translocation of energy in *Macrocystis* is probably necessary to accommodate the development of new fronds, as well as the continued growth of young fronds (Schmitz and Lobban, 1976).

The seasonal and microhabitat variation of nutrient levels influences the growth of *Nereocystis* populations (Dawson, 1966; Rosell and Srivastava, 1984). The nutrients that seem to be most important to the development of *Nereocystis* are macro–nutrients: nitrogen (in the form of nitrite), phosphate, potassium, calcium, and magnesium, as well as, micro–elements: boron, iodine, and zinc (Rosell and Srivastava, 1984). In addition, *Nereocystis* has the ability to accumulate a variety of other metallic and nonmetallic elements from sea water (Whyte and Englar, 1980b). The exact role they play in *Nereocystis* growth is unknown. However, there is some evidence that divalent cations (i.e. calcium, magnesium, strontium) are bound to alginic acid, which is a constituent of the cell walls, and their concentrations parallel the rise and fall of vegetative growth in this species. Other elements such as iron, aluminum, and silicon are probably bound to proteins and polymeric compounds. To what extent these minor elements are limiting to *Nereocystis* growth has not been determined as yet (Whyte and Englar, 1980a, b; Rosell and Srivastava, 1984).

### 3.2.6 Productivity

**Giant Kelp**

Giant kelp is highly productive. Coon (1982) compiled the available information on biomass and productivity of eastern north Pacific *Macrocystis*. Gerard (1976) studied a single site in central California for over 2.5 years and found that giant kelp biomass varied from 0.7 to 6.3 wet kg/m$^2$ (3.12 to 28.0 tons/acre). The standing crop biomass for a southern California forest of giant kelp ranged from 3.0 to 22.0 wet kg/m$^2$ (13.36 to 97.93 tons/acre).

A variety of techniques have been used to measure productivity of *Macrocystis*. These include the following: field harvests (Clendenning, 1971b), growth measurements (Gerard, 1976), changes in oxygen content of forest water (McFarland and Prescott, 1959; Jackson, 1977), field measurements of radioactive carbon uptake (Towle and Pearse, 1973), and extrapolations from laboratory measurements (Wheeler, 1978).

Gerard's (1976) study in central California revealed that monthly productivity varied between 0.4 wet kg/m$^2$ and 3.0 wet kg/m$^2$, with an average of 23 wet kg/m$^2$/yr. (= 102.4 tons/acre/yr.). She concluded that giant kelp biomass in the central California site turned over 6.6 times per year (productivity of 23 wet kg/m$^2$/yr. divided by a mean biomass of 3.5 wet kg/m$^2$ = turnover rate of 6.6 times/yr. ).

The high productivity of kelp helps contribute to the productivity of ecosystems via the transfer of carbon through the decay of algal drift. Harrold et. al. 1998 evaluated the importance of macroalgal drift exported from nearshore forest of giant kelp to adjacent submarine- canyon and continental-shelf habitats. In the study, they estimate the rate of carbon flux from *Macrocystis* drift to the Carmel Submarine Canyon to be 45.2 mg C / m$^2$ / d$^2$ and that drift kelp can account for 20-83 % of the total particulate organic carbon that reaches the sea floor. Their conclusion is that drift macroalgae can provide significant enrichment of organic carbon to the benthos above ~~the~~ that provided by vertically sinking particulate organic material.

### Bull Kelp

The productivity of bull kelp is great due to the senescence of sori throughout the summer and fall months in addition to the loss of blade tips via erosion by water motion. Foreman (1984) suggested that the standing crop is roughly equal to the biomass lost by *Nereocystis* through sporophyte mortality and attrition of laminae. Gotshall et. al. (1986) reported estimates of the number of bull kelp stipes present in Diablo Cove, San Luis Obispo County kelp bed for a 12–year period (1970 to 1971, 1973 to 1987). Using these estimates and total plant weights developed by Foreman (1970) for his Class 8 plants (plants 80 days older or older), the biomass production of *Nereocystis* in Diablo Cove averaged 9 kg/m$^2$ (40.5 tons/acre). For the period 1975 – 1982, biomass declined from a high of 45 kg/m$^2$ (200 tons/acre) in 1975 to a low of 1.09 kg/m$^2$ (4.8 tons/acre) in 1982. Barnes and Kalvass (1993) estimated the 1989 bull kelp biomass for Van Damme Bay near Fort Bragg, California. They reported a biomass potential of 640 metric tons (705 short tons) at 1.4 kg/m$^2$ (6 tons/acre). These numbers are comparable to *Nereocystis* biomass in British Columbia, Canada (Coon et. al., 1979).

In partial compliance with regulations adopted in 1996 for bull kelp harvest in a 300 series bed, the bed 312 lessee, Abalone International Co., conducted a biomass estimate survey and reported the results to the Department as part of the bed lease application process (Van Hook, pers.comm.). The survey was conducted in late November in the 205 acres estimated as growing kelp bed within bed 312. Survey results estimated 2.55 plants per m$^2$ for an estimated biomass of 27 tons per acre. Though the Abalone International survey revealed a much higher biomass per unit area than the Van Damme survey noted above, plant density was very similar (Van Damme - 2.7 plants/m$^2$). Most of the explanation for the higher biomass in bed 312 is due to the greater weight per plant as that survey was conducted at the end of the growing season and limited to mature sporophytes.

Nicholson (1970) experimented on bull kelp's ability to regenerate tissue by removing all but 5 or 10 cm of each blade. In her experiment, the rate of blade growth initially decreased (< 2 cm/day) then increased to a rate of 2.2 and 3.0 cm/day for the 5– and 10–cm blades. Total length of blades increased to a maximum (usually 2–5 m) but their bases continued to show growth. This was evident by the increased distance between tag marks on the blades. Nicholson felt that the rate of erosion at the tips was approximately equal to the rate of growth at maximum blade length (Nicholson, 1970). Based on her research, *Nereocystis* contributes considerable amounts of organic material to the surrounding kelp bed community.

## 3.2.7 Natural Mortality

### 3.2.7.1 Abiotic Factors

**Giant Kelp**

There are many abiotic factors that cause mortality in *Macrocystis*. Moving or shifting sediment can scour or bury established populations of giant kelp in rocky areas (Weaver, 1978). During severe storms, gravel, cobble, and disintegrated rocky reefs become wave-driven projectiles that can cause mortality of *Macrocystis*. Dayton et al. (1989) reported extensive mortality, at a depth of 68 feet, off Point Loma, caused by these projectiles during the "200 year storm" (see below).

The substrate that giant kelp attaches to is important in determining survival. *Macrocystis* usually needs solid rocky substrate to develop into a canopy-producing population. The exception to this would be the population of giant kelp that has developed on soft sediment near Santa Barbara (as previously described in this document). The type of substratum that *Macrocystis* attaches to affects the nature of wave damage to the population. Plants that attach to hard rock substrata are more likely to have stipe breakage and canopy loss, while plants on soft bottoms (i.e.. mudstone, siltstone) are likely to be torn off the bottom completely (Foster, 1982).

Giant kelp develops on cobble bottom in several San Diego County areas (i.e. San Onofre, Tourmaline near La Jolla, and Imperial Beach). *Macrocystis* survives well in this cobble habitat when the ocean is calm. Plants may be dislodged, frequently with the cobble still attached, when the ocean is rough, or stormy conditions prevail. Following storms, beaches near cobble habitats are frequently littered with cobble-bearing *Macrocystis* (McPeak, pers. obs.).

Storms and large swells also cause the greatest mortality of *Macrocystis* in other habitats (Cowen et al., 1982; Dayton et al., 1984; Foster and Schiel, 1985; Dayton, 1985; North, 1986; Seymour et al., 1989). In southern California, storms cause a gradient of damage to *Macrocystis*, ranging from "scars" of single holdfasts to cleared areas several acres in size resulting from massive entanglements following unusually severe storms (Dayton et al. 1984). Destructiveness from storm-generated swell may exceed the numbers of individual plants torn loose by a storm. Rosenthal et al. (1974) observed that loosened plants become entangled with, and dislodge, attached plants. The drifters pick up additional plants, resulting in a "snowball" effect (Rosenthal et al., 1974). As many as 19 detached plants have been observed in one drifter (Rosenthal et al., 1974). Dayton et al. (1984) noted that the average number of detached plants in each drifter at Point Loma was 4.7 (range 1 to 19). Plants that were killed by encounters were usually less than 2 years old or more than 4 years old. Entanglement effectively culled out young plants with small holdfasts that were not securely attached, or older plants with decaying holdfasts.

The decade of the 1980s was one of the stormiest in California history causing significant damage to the giant kelp forests of the State (Dayton et al., 1989; Seymour et al., 1989). Unusually powerful storms struck the California coastline during the winter of 1982-1983, an El Niño period (Namias and Cayan, 1984; Seymour et al., 1984). In addition, the worst storm in 200 years (the "200 year storm") devastated forests of giant kelp in southern California January 17-18, 1988 (Dayton et al., 1989; Seymour et al., 1989). The waves associated with this storm exceeded 33 ft in height in offshore waters, near San Nicolas Island, and 20 ft in height along the coast of San Diego. Drag and inertial forces associated with the January 1988 storm were about twice as high as forces associated with the previous worst storms of the century (i.e. 1982-1983) (Dayton et al., 1989). Mortality of *Macrocystis* exceeded 90% at some Point Loma sites being studied by Scripps researchers (Seymour et al., 1989). Significant damage was also noted off San Clemente Island, in southern California and as far south as Cedros Island, in Baja California, Mexico (McPeak pers. obs.).

Microscopic stages of giant kelp (gametophytes and sporophytes) are also affected by abiotic factors, such as sedimentation, light, temperature, and nutrients. Devinny and Volse (1978) found that light sedimentation (10 mg/cm$^2$) interfered with spore settlement. Deposits sufficient to cover germlings developing from settled spores, led to high mortality.

The health of *Macrocystis* forests in California is strongly influenced by the relationship between temperature and nutrients (Tegner and Dayton, 1987). Water temperature and nutrients are inversely correlated (Zimmerman, 1983) and it is often not possible to separate the combined effects. Unusually deep thermoclines during El Niño conditions expose plants to warm temperatures and low nutrients for several months. Such adverse conditions cause widespread destruction of *Macrocystis* populations (North, 1994). Giant kelp survives well when there is a thermocline and the base of plants are exposed to nutrient-rich cold water. A superb example of this occurred off Point Loma during August 1971. Sea surface temperatures reached 77° F in surface canopies at that time (McPeak, pers. obs.). Canopies began to deteriorate immediately when the water became warm. The deterioration penetrated to the thermocline, a depth of about 15 feet. Surface fronds disintegrated, dropped to the bottom, and filled depressions to a depth of several feet. The basal portion of the forest (below the thermocline) was bathed in cool, nutrient-rich water. The plants survived and formed canopy again by late 1971.

### Bull Kelp

Within the physical environment of the coastal waters a number of factors (substrate, light, nutrients, temperature) play a significant role in the life of marine fauna and flora. For *Nereocystis* the most influential factor is light availability (Vadas, 1972). Bull kelp needs high light levels for growth and sexual maturity of gametophyte as well as sporophyte growth. Reduction of light caused by plankton blooms, storm turbulence, periods of overcast or foggy conditions, or overshadowing by other algae can inhibit or significantly reduce growth (Vadas, 1972; Dayton et. al., 1984; Miller and Estes, 1989).

Secondary to *Nereocystis*' light requirements are nutrient levels and water temperature. Typical of most marine plants, *Nereocystis* growth and development is also dependent on the amount of available nitrates and phosphates in the ocean. The level of these two elements is usually high in the spring due to the degradation of plant and animal material in the winter (Dawson, 1966). These elements are brought to the surface as wind direction shifts from onshore to offshore and upwelling begins. There is also a clear relationship between temperature and nutrient concentrations. Temperatures above 16°C show no measurable amount of nitrates while temperatures below 16°C show increases in the amount of available nitrates (Jackson, 1983).

The destructive nature of storms and their effects on giant kelp forests is well documented as has been shown above. However, little work has been done to document these effects on bull kelp forests and must be inferred from our knowledge of *Macrocystis*.

The timing and frequency of storms has a varying affect on *Nereocystis*. Foreman (1970) found that spring storms were the principal cause of mortality in young sporophytes. If the frequency of storm was about one per week the mortality rate equaled 50%. However if storms were absent for three to four weeks the survival rate among juveniles increased. The principal causes of this high level of mortality were due to the smallness of the developing holdfast in comparison to the rest of the plant, and settlement on unsuitable substrate. Spores that attach to smooth surfaces with no protective relief or to small cobble stones are easily swept away by surge and sand souring (Rigg, 1915; Foreman, 1970). The longer a plant has to develop between high energy episodes, the better its chances of survival.

Summertime storms have little effect on this species. *Nereocystis* is more abundant in the presence of severe and persistent disturbances such as exposure to large swells. The ability to survive under these conditions is due to the resiliency and strength of the stipe of this plant. Koehl and Wainwright (1977) found that *Nereocystis* stipes can stretch approximately 38% of stipe length and has a breaking stress of 2.9 MN $m^{-2}$. In addition, Koehl and Alberte (1988) demonstrated that the location of the long, thin fronds at the terminus of the pnuematocyst, allowed the blades to collapse together into a more streamlined bundle and experience lower drag per blade area at a given flow rate. This allows bull kelp to withstand greater wave motion and currents without breaking or becoming detached.

Adult sporophytes that break lose during summer storms have often been grazed near the base of the stipe and the holdfast. This weakening of the stipe causes it to break under turbulent conditions (Foreman, 1970). Those plants that detach can become tangled with attached specimens and the increase in drag can cause those sporophytes to become dislodged and wash up onto the shore (Koehl and Wainwright, 1977).

During winter storms, *Nereocystis* canopies are typically removed by wave action. This is a result due more to the life history of bull kelp than any other factor. Because this species is an annual, mature plants have virtually stopped absorbing and translocating energy by late fall, resulting in weakened holdfasts. The increase in wave energy in combination with shortened day length (reduced light levels) and the decline in photosynthetic activity within these plants results in their death.

In conjunction with increased wave energy is the increase of sediment in nearshore waters. Sediment affects *Nereocystis* by decreasing water clarity and subsurface light levels. As pointed out in Section 3.2.7.1, light is the most limiting factor to growth in bull kelp. Burge and Schultz (1973) reported that unusually heavy rains and runoff during the winter of 1968–69 resulted in turbid waters during the late winter/early spring. Subsequently, *Nereocystis* sporophytes were not seen in the vicinity of Diablo Cove until the middle of July, 1969. The decrease in nearshore light levels inhibited the growth and development of bull kelp for three months and the resulting bed was reported to be one–quarter of the size of the bull kelp bed in 1968 (Burge and Schultz, 1973).

The decrease in salinity levels caused by freshwater run–off has an impact on bull kelp. Brown (1915) found that exposure of *Nereocystis* to freshwater for periods of up to one week would cause the fronds to deteriorate and fall off. Bull kelp experiences little noticeable damage from reduced salinity levels if exposure to run–off occurs for less than three days,.

Hurd (1915) found that young sporophytes could adapt and survive in salinities as low as 15 parts per million if the reduction in salinity was gradual. However, if the salinity was reduced suddenly, by an influx of freshwater run–off, the sporophyte would develop blisters and wilt.

### 3.2.7.2 Parasites and Disease

**Giant Kelp**

Our knowledge of kelp diseases is increasing as interest in marine microbiology increases (Goff and Glasgow, 1980; North et al., 1986). Microorganisms have been found associated with tissue deterioration on stressed *Macrocystis*, but it is not known if these microbes are causative agents or represent an incidental appearance, taking advantage of local circumstances (North, 1994).

Black rot, a common disease among canopy blades of *Macrocystis*, generally occurs during the summer and fall, when water temperatures are above normal (Scotten, 1971). Black rot is a darkening of the blades that usually first appears at the tips and then spreads toward the base. The blade softens (as color deepens) and becomes mushy, eventually sloughing (North, 1979). The size of the bacterial population on *Macrocystis* blades correlated with water temperatures, being high in summer and low in winter (North, 1994). Giant kelp tissues exude an active substance during late winter that inhibits bacterial growth (Scotten, 1971).

North (1979) observed a condition called "stipe rot" on three occasions. The observed disease occurred in close association with discharged sewage. Stipe rot is a progressive darkening and deterioration near the basal attachment stipes. The rot only involves a few inches of tissue on the stipe and not the entire organ as in black rot (North, 1979). As stipe rot progresses, the tissues weaken and the entire frond above the lesion is lost. *Macrocystis* plants disappeared from an estimated 250 acres off Point Loma in 1967-1968 (North, 1968a). Similar areas with diseased plants were observed at Point Loma in the mid-1980s (McPeak, pers. obs.).

**Bull Kelp**

Little information exists about the diseases and parasites of bull kelp. There is only one reported parasitic algae that commonly occurs on *Nereocystis*. The brown algae, *Streblonema* sp., is thought to cause distortions on the stipe of bull kelp that range from pustules (galls) to extended rugose areas. Setchell and Gardner (1925 reported that these infections could have slight to disastrous effects depending on the extent of death in surface and underlying cells. The weakening of stipe tissue could result in plant loss under adverse weather conditions (Apt, 1988).

Bull kelp does not seem to be susceptible to black rot disease, which affects *Macrocystis* and *Egregia* in the spring and summer months, or to stipe blotch disease, which infects two other genera of brown algae, *Alaria* and *Laminaria*. Both of these conditions can cause considerable damage to blades and stipes and result in hugh losses of kelp biomass (Andrews, 1976). In addition, *Nereocystis* is not affected by a fungus that infects its predominant epiphyte *Porphyra nereocystis* (Kerwin et.al., 1992).

### 3.2.7.3 Mortality Caused by Animals and Plants

**Giant Kelp**

Many species of animals graze *Macrocystis*, but only a few species (sea urchins, fishes, amphipod and isopod crustaceans) cause mortality (Dayton, 1985; Tegner and Dayton, 1987). Sea urchins are by far the most important grazers in California in terms of frequency and extent of damage to forests of giant kelp. Lawrence (1975) reviewed the general literature regarding worldwide destruction of algal stands by sea urchins, while Harrold and Pearse (1987) reviewed the ecological role of sea urchins and other echinoderms in kelp forests. Foster and Schiel (1985) noted that in sites where sea urchins were abundant, their effects have generally been documented in three categories: (1) wholesale removal of algae; (2) the alteration of species diversity via feeding preferences and selective removal of algal species; and (3) the provision of cleared primary substratum suitable for kelp recruitment.

The rapid denudation of *Macrocystis* and other species of algae in California has been well studied by many researchers (Leighton et al., 1966; Leighton, 1971; North, 1974; Dean et al., 1984; and Harrold and Reed, 1985).

Three species of sea urchins commonly graze forests of *Macrocystis* in California: red sea urchins (*Strongylocentrotus franciscanus)*, purple sea urchins (*S. purpuratus*), and white sea urchins (*Lytechinus anamesus*). Leighton (1966) showed that the two *Strongylocentrotus* species preferred *Macrocystis* to other species of algae tested in the laboratory.

Grazing by *Lytechinus* has been observed, especially in deeper water, but is usually superficial and not as destructive as that by the two species of *Strongylocentrotus* (North, 1994). Dean et al. (1984) observed that white sea urchins on a cobble bottom at San Onofre rarely consumed adult *Macrocystis*. The *Lytechinus* did eat young stages of giant kelp and apparently prevented the San Onofre kelp bed from extending offshore. White sea urchins were observed consuming giant kelp that was transplanted offshore of La Jolla in 1976 (McPeak, pers. obs.).

The impact of purple and red sea urchins at Point Loma has been well documented (North,1964; Leighton et al.,1966; North and Pearse, 1970; Leighton (1971); Tegner, 1980; Tegner and Dayton, 1991, Tegner et. al. 1995a). Leighton (1971) noted that mixed populations of red and purple sea urchins destroyed a *Macrocystis* kelp bed off south Point Loma. The sea urchins, which had formed "fronts" (dense concentrations of grazing sea urchins), were monitored along transects for three months. The purple and red sea urchins attacked holdfasts and basal portions of fronds on adult *Macrocystis*. Fronds were severed and drifted away, while the remaining living material of the holdfast was consumed in place. The sea urchins destroyed the kelp forest at the rate of 33 ft per month and turned the bottom into "barren grounds" as described by Lawrence (1975). Similar grazing and mass destruction of giant kelp at Point Loma was reported by Glantz (1992a). Besides the direct removal of kelp plants through urchin grazing, Tegner et. al. (1995a ) also documented the loss of plants by a combination of biotic and abiotic factors. Red and purple sea urchins sheltering in the holdfasts of Macrocystis and feeding on the haptera eventually created cavitation damage, which leads to structural failure of the holdfast when the plants were stressed by large waves.

Dean et al. (1984) found both moving and stationary aggregations of red sea urchins in the kelp forest at San Onofre. The aggregations were observed at the same time and within 100 m of one another. The stationary aggregations probably subsisted mainly on drift kelp and had no effect on kelp recruitment or adult abundance. In contrast, red urchins in large, motile aggregations (fronts) ate nearly all the macroalgae in their path. The motile aggregations formed after 2 years of declining kelp abundance. Dean et al. (1984) proposed that the scarcity of drift algae for food resulted in a change in the behavior pattern of the red urchins and thus lead to the formation of these aggregations.

Harrold and Reed (1985) described a situation at San Nicolas Island, an exposed island site, where the biotic status alternated between an urchin barrens and a kelp-dominated community. There were no significant changes in urchin densities at the study site during switches from one status to the other. Climatic conditions (i.e. presence or absence of major storms) determined which state prevailed. When algal biomass was plentiful, drift weeds were abundant and were captured by sea urchins inhabiting crevice environments. If the standing crop of *Macrocystis* and other algae was substantially reduced by a severe storm, drift became scarce, sea urchins left their crevice habitat to forage, attacking the remaining vegetation. This behavioral change among urchins led to the appearance of barren areas. Harrold and Reed (1985) observed that calm weather, low temperatures, and abundant nutrients produced strong algal recruitment, resulting in less sea urchin foraging and increased survival of the *Macrocystis*. The availability of drift, therefore, altered the feeding behavior of the sea urchins, allowing more algal recruitment. The status returned to its original condition of a high standing algal biomass and urchins inhabiting crevices.

Some studies have indicated that urchin recruitment into barren areas, after they have formed, may maintain the populations of urchins at high densities so that the barren status persists for many years (North, 1983; Pearse et al., 1970). Some sea urchin barren areas have persisted for more than 13 years (North, 1994).

Harrold and Pearse (1987) indicated that the ecological impact of sea urchin grazing often seems to be "all-or-none." That is, sea urchins intensely graze and consume almost all macroalgae, or they graze little if at all and instead feed on pieces of kelp litter. There seem to be "threshold" conditions that must prevail before sea urchins begin to graze attached plants. If the threshold is met or exceeded, the sea urchins abandon their cryptic habitats and switch to an active grazing mode of feeding that results in the formation of deforested areas (Harrold and Pearse, 1987).

Ebeling et al., (1985) studied Naples Reef, near Santa Barbara, and found that winter storms had different effects on the kelp forest community. A storm in 1980 removed all canopies of giant kelp but spared most understory kelps. The large accumulation of detached drift kelp, mostly *M. pyrifera*, disappeared following the storm. Red and purple sea urchins emerged from their shelters to find alternative food. They destroyed most living plants, including the surviving understory kelp. A storm in 1983 reversed the process by eliminating exposed urchins, while clearing rock surfaces for widespread kelp settlement and growth. Extensive canopies of giant kelp developed by the end of 1984, despite elevated water temperatures during the summer and fall of 1983.

Amphipod and isopod crustaceans also graze and destroy populations of giant kelp in California, however, the frequency of intense grazing by these animals is very low compared to sea urchins. Tegner and Dayton (1991) noted mortality of *Macrocystis* off Point Loma in 1985 due to grazing by gammarid amphipods, including *Ampithoe humeralis*. The isopod, *Idotea resecata*, is a common inhabitant of kelp forests and normally feeds upon but does not cause mortality of *Macrocystis*. In 1979, however, tremendous populations to *I. resecata* were observed grazing the basal fronds, sporophylls, and holdfasts of giant kelp at the west end of San Nicolas Island (McPeak, pers. obs.). Several acres of giant kelp forest were eliminated by the combined effects of grazing isopods and sea urchins.

Mortality of giant kelp due to fish grazing by opaleye (*Girella nigricans*) and halfmoon (*Medialuna californiensis*) was reported by North (1972). The fish nibble on blades of giant kelp that are encrusted with bryozoans and other invertebrates. Harris et al. (1984) found these two species of fishes were important grazers of small *Macrocystis* sporophytes on a local scale off Naples Reef, near Santa Barbara. They reported fishes grazed 59% of the sporophytes (< 10 cm tall) that were concealed in turf of ephemeral algae, while 94% of those on open reef quadrates were grazed.

**Bull Kelp**

The primary grazers of *Nereocystis* are red abalone (*Haliotis rufescens*), red and purple sea urchins, a variety of trochid snails (*Callistoma ligatum*, *C. annulatum*, and *Tegula* spp.), limpets (*Collisella pelta*), and miscellaneous crustaceans (Nicholson, 1968; Burge and Schultz, 1973). North of Point Conception, *Nereocystis* is the predominant food item of red abalone (Cox, 1962). Ebert (1968) reported that juvenile abalone, particularly the flat abalone (*H. walallensis*), and to a lesser extent the pinto (*H. kamtschatkana*) and the red, are often commensal with red sea urchins in bull kelp communities of central California. He found that small abalone (<7 cm) occurred under red sea urchins, presumably moving and feeding on seaweed with the urchins. The extent of *Nereocystis* mortality caused by abalone grazing has not been quantified to date.

Sea urchin grazing, as mentioned in the giant kelp section, exerts a enormous amount of pressure on kelp forests. The extent of this pressure on bull kelp forests has been documented by a number of researchers (Paine and Vadas, 1969; Breen et. al., 1976; Pearse and Hines, 1979; Duggins, 1980; Pace, 1981). Breen et. al. (1976) found that red sea urchins controlled the seaward boundary of bull kelp beds. When red sea urchins were removed from the area, the density of the *Nereocystis* beds increased and there was recruitment of sporophytes to greater depths. Foreman (1970), working at Salt Point, California, reported young sporophyte densities of between 200 to 400 plants per meter$^2$ in the absence of urchins. Pace (1981), working in Barkley Sound, found that the density of *Nereocystis* was 4.6 plants/m$^2$ in the presence of *S. franciscanus*. Urchins were then removed and the density of bull kelp sporophytes increased the next spring to 13.9 plants/m$^2$. In addition, *Nereocystis* doubled its occurrence throughout the study area. At the start of the experiment, bull kelp was found in 5 of 11 plots with sea urchins. Following removal of the sea urchins, *Nereocystis* occurred in 10 of the 11 plots. Similar results were reported in Torch Bay, Alaska when sea urchins (*Strongylocentrotus* spp.) were removed (Duggins, 1980). In the year following urchin removal, kelp biomass increased from zero standing crop to about 60 kilograms wet mass/m$^2$, with *Nereocystis* contributing to the bulk of the weight and increased species diversity. A species' ability to influence the nearshore environment has far reaching implications and gives credibility to the managing of marine resources as a whole ecosystem rather than species by species.

Burge and Schultz (1973) reported that mortality of young bull kelp sporophytes was extremely high in the presence of algivores but they did not quantify their observations. In addition to grazing of developing plants there is a significant amount of mortality caused by grazing on mature *Nereocystis*. Nicholson (1968) reported finding sporophytes in the intertidal zone and on the shore that had limpet scars in the stipes and pneumatocysts. The limpet, *C. pelta*, will rasp away tissue of the upper stipe and pnuematocyst resulting in deep cavities that weakens the integrity of the thallus. Markham (1969), in his study of epiphytes living on mature *Nereocystis*, reported that epiphytes were absent from the lower portion of the stipe. This lack of epiphytic growth was due to grazing by a variety of molluscan species including *Margarites* spp. and *Lacuna spp.* Koehl and Wainwright (1977) reported that 90% of detached sporophytes found as solitary individuals and 55% of tangled specimens had broken at a flaw in the stipe caused by abrasion or a sea urchin bite.

Bull kelp forests provide protection and food for a number of fish (Burge and Schultz, 1973; Leaman, 1980; Bodkin, 1986). Most of these species feed on small crustaceans (shrimp, crabs, isopods, amphipods), polycheates, molluscs, echinoderms, and bryozoans that occur on, around, or below the canopy. Any ingestion of *Nereocystis* is probably incidental to the other food items and does not result in significant loss of plants. A number of fish are herbivorous (i.e. opaleye, kelp greenling, giant kelpfish), however there has been no direct mention of feeding on *Nereocystis* until recently.

Hobson and Chess (1988) reported that blue rockfish (*Sebastes mystinus*) will ingest bull kelp sori during upwelling periods when preferred food items (gelatinous zooplankton) are unavailable. *S. mystinus* seems able to utilize only algal tissues that include the zoospores of *Nereocystis*. The zoospores of *Nereocystis* have a cell membrane instead of a cellulose cell walls, thus making the spores easier to digest (Hobson and Chess, 1988).

Epiphytes growing on bull kelp can cause mortality. As many as 50 different species of epiphytic algae may colonize the blades and stipe *Nereocystis* (Markham, 1969). The most common epiphytes are the filamentous green algae *Enteromorpha* sp., the filamentous red algae *Antithamnion* spp., and the foliose red *Porphyra nereocystis*. As the summer progresses, the combined weight of these epiphytes can overcome the buoyancy of the pnuematocyst and cause the entire plant to sink beneath the surface. At this point, the photosynthetic activity of the blades is reduced and the blades come within reach of the primary grazers, sea urchins (*S. franciscanus* and *S. purpuratus*) and abalone (*Haliotis* spp.). The second source of mortality due to epiphytes is the subsequent increase in the drag coefficient caused by their growth. During storm conditions this increase may facilitate the detachment of adult sporophytes (Foreman, 1970). No direct measure, or estimate, of the loss indirectly caused by epiphytic growth on *Nereocystis* populations has been made.

### 3.2.8 Competition

**Giant Kelp**

Giant kelp in California competes with many other species of macroalgae for light, substrate, and nutrients. Dayton et al. (1984) described distinct patch types of macroalgae composed of species that could be categorized into vegetation layers distinguished by distinct morphological adaptations. These layers include (1) a floating canopy (*Macrocystis*, *Pelagophycus porra*, and *Nereocystis*) supported at or near the surface by floats; (2) a stipitate, erect understory in which the fronds are supported well above the substratum by stipes (*Pterygophora californica*, *Eisenia arborea*, and *Laminaria setchellii*); (3) a prostrate canopy in which the fronds lie on or immediately above the substratum (*L. farlowii*, *Cystoseira osmundacea*, and *Dictyoneurum californicum*); (4) a densely packed algal turf of articulated coralline algae (especially *Calliarthron* spp.) and many species of foliose and siphonous red algae; and (5) encrusting coralline algae such as *Lithophyllum* spp. and *Lithothamnion* spp.

Competition between *Macrocystis* and associated macroalgae frequently affects local distribution (North, 1994). Interference with recruitment by *Macrocystis* and other algae through shading by adults of all species is a common competitive mechanism (Edwards, 1998; Reed and Foster, 1982; Pearse and Hines, 1979; Foster, 1975a). Stipitate kelps such as *P. californica* and *L. setchelii* can also shade the bottom with their understory canopies, inhibiting recruitment of *Macrocystis* juveniles. Occasionally, giant kelp recruits within dense patches of *Pterygophora* during the winter, when foliage of this stipitate species is minimal. The recruits of giant kelp, however, generally do not survive after *Pterygophora* adds foliage in the spring, decreasing light to the developing plants (R. McPeak, pers. obs.).

Studies at Catalina Island revealed a negative association between *Macrocystis* and the introduced species, *Sargassum muticum* (Nicholson et al., 1981; Ambrose and Nelson, 1982). *Sargassum* grew well at elevated temperatures, while giant kelp did poorly and vice versa. Articulated and crustose corallines were competitively superior to *Macrocystis* at Catalina Island because they tolerated strong water motion that destroyed the giant kelp (Wells, 1983).

Foster (1975b) studied patterns of algal succession that occurred on concrete blocks that were placed in a *Macrocystis* forest. The substrates were initially colonized by rapidly–growing ephemeral species. These were later replaced by perennials characteristic of the kelp forests. *Macrocystis* colonization was greatest during spring. Encrusting animals competed with plants for attachment space on the substrates. Encrusting animals were favored when grazing fishes and sea stars were excluded from the blocks by caging (Foster, 1975a).

The inner border of the *Macrocystis* zone in southern California (i.e. San Diego County) is often dominated by *Egregia menziesii*, a floating species better adapted to withstanding wave action (North, 1971b). The offshore border of the *Macrocystis* bed near San Diego is dominated by elk kelp, *Pelagophycus porra* (North, 1971b). This species is better adapted to lower light conditions in deeper water and outcompetes *Macrocystis* at depths greater than 70 feet.

Algal competition frequently produces patchy distributions within kelp forests (North, 1994) and small areas become dominated by species other than *Macrocystis*. Dayton et al. (1984) studied three aspects of competition and patch dynamics in California kelp forests: (1) persistence of the patches; (2) inertia (resistance of the patches to invasion by other species); and (3) resilience (ability to recover after invasion by another species). The research by Dayton et al. (1984) was conducted in three very different habitats: along the exposed coast of Point Loma, in the protected waters at Birdrock, Catalina Island, and along the exposed coast of central California near Pt. Piedras Blancas.

Dayton et al. (1984) studied how *Macrocystis* competed with several patch types at Point Loma, including stipitate kelps *Pterygophora californica*/*Eisenia arborea* and prostrate kelps *Laminaria farlowii*/*Cystoseira osmundacea*. Many of the species that compete with giant kelp are quite long-lived (i.e. *Eisenia* >12 yrs, *Pterygophora* >11 yrs, *Laminaria* = 6 yrs, *Cystoseira* = 6 yrs). Persistence was high among patches studied in the Point Loma kelp forest, with borders remaining virtually unchanged throughout the ten year study period. The ten years encompassed passage of more than one generation of the dominant species within a patch. Giant kelp was able to invade patches of *Pterygophora* when entangled bundles of *Macrocystis* drifters caused cleared areas in the *Pterygophora* patch and swamped the area with spores. Dayton et al. (1984) noted that the overstory and understory relationships were similar at Birdrock, Catalina Island, and Point Loma. *Macrocystis* suppressed the ephemeral understory of *Dictyota flabellata* and *Pachydictyon coriaceum* at Catalina Island.

At Pt. Piedras Blancas, *Macrocystis* dominated the deeper, more stable substrata while *Nereocystis* dominated the shallower, more exposed localities, or areas with unstable cobble substrata. Patches of *Pterygophora* and *L. setchellii* were common on the inshore edge of the canopy-producing kelps. The *Pterygophora* and *Laminaria* were better adapted to withstand the surge and swell and *Macrocystis* was not able to penetrate these patches.

Various natural forces such as storms and grazing by sea urchins may partially or completely eliminate established patches. The nature of successful new colonizers in such cases depends on availability of reproductive propagules moving into the cleared area. Dayton and Tegner (1984) called this "scramble competition." Dayton et. al. (1984) noted that tall-statured kelps such as *Macrocystis* are more impacted by storms and large swell than their stipitate competitors such as *Pterygophora* and *Eisenia* or prostrate competitors, *L. farlowii* and *Cystoseira*.

**Bull Kelp**

*Nereocystis* is an opportunistic colonizer that takes advantage of substrate clearing caused by storms, sand scouring, or other natural disturbance (Paine and Vadas, 1969). While bull kelp can rapidly recruit to a newly cleared location, its longevity as the dominant canopy–forming species depends on environmental conditions being conducive for its survival and detrimental for its major competitor *Macrocystis*. Bull kelp, as mentioned in Section 3.2.2, is found at depths of between 3 to 21 meters in areas that experience a high to moderate degree of wave force. *Nereocystis* is also able to exist in sea urchin–dominated areas that lack perennial algal cover and have high light levels (Pearse and Hines, 1979). If these conditions exist in the recruitment area then bull kelp will become the dominant species and exert considerable influence on the recruitment of red and brown algae below its canopy. However, if the conditions are the opposite (shallow, protected waters free of sea urchins) then giant kelp spores can become established during the summer/fall and develop over the winter months when *Nereocystis* is declining. In the spring, a dense *Macrocystis* canopy can reduce the understory light levels, shading out *Nereocystis* sporophytes as well as *Laminaria dentigera* and *Pterygophora californica* and foliose red algae. *Nereocystis* is competively subordinate to the dense canopy–forming perennial *Macrocystis* (Miller and Estes, 1989).

*Nereocystis* is unable to compete with or "invade" established assemblages of understory algae. The understory is composed of several layers: a stipitate, erect group in which the fronds are suspended above the bottom (*Pterygophora californica*, *Eisenia arborea*, *L. setchellii*), a layer of prostrate canopy in which the fronds lay on the substrate (*L. farlowii*, *Cystoseira osmundacea*, *Dictyoneurum californicum*) and a dense turf community composed mostly of articulated coralline algae, foliose and filamentous red algae (Dayton et. al., 1984). The denseness of these layers can prevent bull kelp spores from reaching and settling the substrate. Thus, the spores are transported away by bottom currents. In situations where spores do penetrate the ground cover, light levels below the secondary and tertiary canopies are less than one percent of surface light and are suboptimal for development of *Nereocystis* gametophytes and young sporophytes (Vadas, 1972).

### 3.2.9 Kelp Community

The kelp forests of California are among the most productive communities in the sea (Foster, 1979). The kelp forests influence, or lessen, the effect of winds, water currents, and nutrient fluctuations within and inshore of these areas (Leaman, 1980; Jackson, 1983). The most noticeable demonstration of this is seen on windy days when wind riffles appear on the outside of a kelp bed and calm water on the inside. The ecological importance of giant and bull kelp has been well documented. They provide food, habitat, and substrate for a wealth of invertebrates, fishes, birds, marine mammals, and even other plants. (Limbaugh, 1955; North, 1971a; Burge and Schultz, 1973; Miller and Geibel, 1973; Foster et. al., 1979a; Leaman, 1980; Coyer, 1984; Foster and Schiel, 1985; Gotshall et. al., 1984; Snider, 1985; Bodkin, 1986, 1988; DeMartini and Roberts, 1990).

*Macrocystis* and *Nereocystis* are fairly unique among marine algae because they extend throughout the water column. Thus, kelp forests can be divided into three types of habitat: the canopy, stipe or midwater, and holdfast/seafloor. Each of these levels provides refuge for a unique set of inhabitants as well as crossover species. Due to the vertical aspect of kelp plants, Clendenning (1960) estimated that the surface area of the plants in an average *Macrocystis* kelp bed is 15 times the surface area of the bottom of the plants not including the additional area and complex structure provided by the holdfast. Giant and bull kelp also provide additional habitat in the form of drift kelp and beach wrack.

### 3.2.9.1 Invertebrates

**Giant Kelp**

The canopy environment has been studied by a number or researchers (Limbaugh, 1955; Wing and Clendenning, 1971; Miller and Geibel, 1973; Feder et al., 1974; Bernstein and Jung, 1980; Coyer, 1984, 1986). The canopy habitat is a dynamic habitat that is ephemeral, subject to change, and submergence (Feder et al., 1974).

The community of epiphytes growing on blades of *Macrocystis* in canopies of southern California is simple, consisting primarily of the bryozoans *Membranipora membranacea*, *Hippothoa hyalina*, and *Lichenopora buskiana*; the serpulid polychaete *Spirorbis spirillum*, and hydroids *Obelia sp.* and *Campanularia sp.* (Bernstein and Jung, 1979). Two species of nudibranchs, *Corambe pacifica* and *Doridella steinbergae* mimic *Membranipora* and feed exclusively on it. These nudibranchs are frequently encountered in the canopy. Wing and Clendenning (1971) found tremendous populations of motile animals on fronds of giant kelp encrusted with the bryozoan *Membranipora*. The total number of motile animals on canopy fronds increased with increasing weight of *Membranipora*. Tiny copepods were usually the most numerous motile animal in canopy samples taken by Wing and Clendenning (1971). Twelve of twenty-three summer canopy samples had motile animal populations greater than 100,000 per $m^2$ of plant tissue.

Coyer (1984) reported 11 species of gammarid amphipods from *Macrocystis* canopies at Santa Catalina Island in southern California. These species accounted for the major portion of invertebrate biomass in the canopy. Copepods were more numerous than gammarid amphipods but accounted for very little of the total biomass of invertebrates in the canopy. Mysids and shrimps were a minor component of the canopy numerically but contributed a major portion of the biomass. Gammarid amphipods, mysids, and shrimps in the canopy were larger in size compared to the same groups at lower levels in the forest.

Coyer (1986) found that molluscs comprised only 1.0% (by numbers) of the invertebrates associated with fronds in the canopy. The fewest numbers of molluscs was found in the canopy zone compared to lower levels. Only one mollusc, a nudibranch *Polycera tricolor*, was more abundant in the canopy than in lower levels.

Feder et al., (1974), recorded 30 species of invertebrates, of which 25 were considered characteristic of the canopy habitat; and 59 species of fishes, of which six were considered characteristic.

Miller and Geibel (1973) evaluated the macro-organisms (larger than 10 mm) living in the canopy of a central California *Macrocystis* forest. They estimated the number of macro-organisms per ton of kelp and per acre of forest cut at about 10 ft. Sections of *Macrocystis* canopy were cut and gently floated over a burlap blanket (20 X 30 ft), where the motile animals were prevented from escaping during counting.

Samples were taken at three different times between February and early August 1970. The mean number of organisms per sample varied considerably during the course of the study. The isopod, *Idotea resecata*, far outnumbered all other species of macro-organisms in the samples and averaged about 7,500 per acre (Miller and Geibel, 1973). The other common species averaged (per acre) as follows for the three samples: kelp crab, *Pugettia producta* - 300; *Calliostoma* snails (3 species)- 700; *Tegula* snails (3 species)- 3,000; and fishes (8 species)- 1,000.

The tangled mass of fronds rising from the bottom to the surface constitutes the midwater level. This level extends from about three feet above the holdfast to three feet beneath the surface. Many of the animals described from this level also occur in the surface canopy or around the holdfast. Organisms that enter the mid-level are motile forms that are free to climb or swim, and sessile forms that attach to the kelp (Feder et al., 1974). Feder et al. (1974) listed 29 species of invertebrates observed by diving in the mid-level zone of which, five species of invertebrates were considered characteristic of this habitat. Wing and Clendenning (1971) found incredible numbers of small motile invertebrates associated with surfaces of *Macrocystis* at mid-level. One kelp sample collected from a depth of 25 ft, yielded 12,000 copepods from an area of kelp tissue 4 in$^2$ in size. The following are descriptions of a few of the species encountered in this region. For more information consult Limbaugh (1955), North (1971a), Coyer (1984, 1986), and Foster and Schiel (1985).

Crustaceans (amphipods, isopods, decapods, etc.) are numerically the dominant animals in kelp forests. Coyer (1984, 1986) studied the motile invertebrate assemblage associated with giant kelp at Santa Catalina Island. Crustaceans were very abundant in the mid-level and numbered nearly 6,900/kg of plant tissue (Coyer, 1984). The following four species of gammarid amphipods were by far the most common crustaceans encountered in the mid-level: *Microjassa litotes*, *Gitanopsis vilordes*, *Anoroides columbiae*, and *Porcellidium viridae*. The isopod, *Idotea resecata*, is one of the more common inhabitants of the mid-level. This species grazes on *Macrocystis* and appears to prefer the portion of the blade near the point of attachment of the pneumatocyst (Jones, 1971). These crustaceans are well adapted for life on giant kelp. They have seven pair of legs, each leg with hooked tips to help cling to the substrate.

Coyer (1986) recorded 41 species of molluscs on fronds of giant kelp at Santa Catalina Island. Molluscs comprised only 1.6% (by number) of all invertebrates associated with the mid-level. The mean number of species of molluscs encountered in the mid zone was 15.6. *Granulina marginata* and *Crepidula* sp. were by far the most abundant molluscs in the mid-level zone.

Foster and Schiel (1985) list many species of molluscs that feed upon giant kelp in the canopy and mid-level. In central California, three species of *Tegula* (*T. pulligo*, *T. montereyi*, and *T. eiseni*) and three species of *Calliostoma* (*C. annulatum*, *C. ligatum*, and *C. canaliculatum*) commonly occur on fronds of *Macrocystis*. Smaller snails, *Mitrella carinata* and *Lacuna unifasciata*, are often the most abundant gastropods on mid-level fronds in southern California (Jones, 1971). *Mitrella* feeds primarily on detritus while *Lacuna* feeds directly on giant kelp stipes.

Holdfasts, which vary in size from a few cm$^3$ to more than 120,000 cm$^3$, provide a complex crevice environment for animals. Holdfasts may contain thousands of small animals; some using the crevice environment for hiding, others using tissues of the holdfast for food (Ghelardi, 1971). Andrews (1945) found over 23,000 individual animals in five holdfasts of *Macrocystis* that he collected in central California. The holdfast structure is also a very favorable environment for early development of urchins and abalone.

Ghelardi (1971) described three sub-habitats of *Macrocystis* holdfasts: (1) small holdfasts composed entirely of living plant material (haptera), and large holdfasts consisting of (2) living outer shells, and (3) dead centers. He noted three categories of animals living in these sub-habitats: (1) animals most frequent and abundant in living portions of both large and small holdfasts, (2) animals most frequent in dead portions of large holdfasts, and (3) animals equally abundant in dead or live portions of holdfasts. Polychaetes, isopods, and gammarid amphipods were the most frequent and abundant groups encountered by Ghelardi (1971) in holdfasts. He identified more than 130 species of animals in holdfasts of giant kelp off La Jolla, California. The most abundant and frequent species of the three major groups in the living portion of the holdfasts were: gammarid amphipod, *Ampithoe rubricata*; polychaeta, *Phyllodoce lineata*; and isopoda, *Janiralata rajata*. The most frequent and abundant species in the dead portions were: gammarid amphipod, *Eurystheus thompsoni*; polychaeta, *Jasmineira* sp.; isopoda, *Cirolana parva*. These animals and the other species that occupy holdfasts of giant kelp are important sources of food for fishes and invertebrates. For more detailed information on the animals that inhabit holdfasts of giant kelp in southern California see Ghelardi (1971) and Snider (1985).

Snider (1985) examined the emergence patterns of demersal zooplankton inhabiting holdfasts of *Macrocystis* pyrifera at scales of 24 hours, a lunar cycle, and a year in a kelp bed off Point Loma, California. Gammarid amphipods and copepods numerically dominated the emerging zooplankton over all three temporal scales. Three general patterns of emergence were observed over the course of a diel cycle: (1) night emergence exhibited by amphipods, isopods, and shrimp, (2) day emergence shown by copepods and medusae, and (3) variable emergence exemplified by mysids and ostracods.

Snider (1985) found seventeen species of resident gammarid amphipods to be numerically abundant in kelp holdfasts, however, only eight species were abundant in the emergent fauna. The gammarid amphipods *Batea transversa* and *Lysianassa dissimilis* were consistently the most abundant species of emergent amphipods. Small inconspicuous organisms emerged during the day while large, conspicuous organisms emerged at dusk or during the night.

An interesting isopod, the gribble, *Limnoria algarum*, lives in holdfasts of giant kelp (Jones, 1971). This species burrows into older haptera, creating tunnels. A row of small holes on a hapteron indicate that gribbles are at work. These isopods feed on the haptera.

Brittle stars are very abundant in holdfasts of giant kelp. Andrews (1945) found brittle star densities up to 300/m$^2$ in holdfasts in central California. *Ophiothrix spiculata* and *Amphiolis pugetana* were most abundant in holdfasts in central California.

### Bull Kelp

Since bull kelp is an annually occurring species and declines in abundance for several months each year, the animals and plants that utilize these forests are opportunistic colonizers, moving in each spring from perennial algal species as the young bull kelp sporophytes begin to grow. Thus, the invertebrate assemblage found in the canopy are similar to those found associated with *Laminaria* or *Pterygophora* as well as the giant kelp forests of central California (McLean, 1962; Burge and Schultz, 1973).

Due to the physical differences between giant kelp and bull kelp (see cover page), the animals that live on *Nereocystis* stipes are limited to epiphytic algae and sessile invertebrates as well as amphipods, isopods, and snails, which move up and down the stipe (Andrews, 1925). Markham (1969) noted a total of 14 genera and 23 species of epiphytes on *Nereocystis* stipes in Washington state. The species found included three species of Chlorophyta, three Phaeophyta, and 16 Rhodophyta. Seven of the red algal species are in the genus *Antithamnion*. Of sessile invertebrates, *Membranipora membranacea* is the most abundant followed by hydriods (*Obealia* sp.) and barnacles (*Balanus* spp.). The motile animals consist of caprellid amphipods, *Idotea* sp. and top snails (*Callistoma* spp.).

Several benthic surveys have been conducted within bull kelp beds and have provided a detailed picture of this community (McLean, 1962; Burge and Schultz, 1973; Foster et. al., 1979a and b; Gotshall et. al., 1984, 1986). Only one study looked directly at bull kelp holdfasts as habitat and food for invertebrates. Andrew (1925) reported that the abundance of invertebrates is greatest in and around the holdfast, with upwards of 40 species being identified living within the haptera. On examination of nine holdfasts, he found 2605 individuals which rivals the numbers found in giant kelp holdfasts. The species most commonly found in the holdfasts are amphipods, *Idotea* sp., caprellids, *caprella* sp., nudibranchs, polychaetes (*Nereis* spp.), blood worms (*Amphiporus bimaculatus*), brittle stars (*Ophiopholis* spp.), crabs (*Pagurus* sp., *Cancer* spp.), chitons (*Leptidochitonia lineata*, *Mopalia ciliata*), sea urchins (*Strongylocentrotus* spp.); and young abalone (*Haliotis* spp.). The holdfast can be considered nursery areas for immature forms, and a refuge for some maturing and a few adult forms (Andrew, 1945).

In addition to the holdfast providing forage material and protection, the surrounding environment is also utilized by various invertebrates and fishes. Foster et. al. (1979) surveyed beds of giant and bull kelp between San Francisco and Monterey. The seafloor beneath the *Nereocystis* canopy was covered by several algal species. The understory algal cover was composed of approximately thirty species, of which *Polyneura latissima*, *Desmarestia* spp. and encrusting corallinaceae (*Lithothamnium crassiusculum*, *L. microsporum* and *Lithophyllum lichenare*) were most abundant. Beneath the algal cover are tube polychaetes, hydroids, encrusting sponges, cup corals, anemones, barnacles, colonial tunicates, bryozoans, erect sponges, clams, and solitary tunicates. Sea urchins, abalone, sea stars (*Pisaster brevispinus*, *P. ochraceus*, *P. giganteus*, *Asterina miniata*, and *Pycnopodia helianthoides*), and crabs (*Cancer* spp.) were abundant in crevices and on the substrate beneath the bull kelp (Foster et. al., 1979a, b).

Gotshall et. al. (1984) compiled 5 years of subtidal survey data from three transect sites in Diablo Cove. This information supports Foster's description of the subtidal environment beneath *Nereocystis* beds. As mentioned before, the abundance of all these animals, except sea urchins, was higher in giant kelp beds than in bull kelp beds. Red sea urchin densities within *Nereocystis* beds was approximately 2.57/m$^2$ while only 0.64/m$^2$ in *Macrocystis* beds (Foster et. al., 1979). The density of purple sea urchins was also higher in bull kelp beds than giant kelp beds. Pearse and Hines (1979) observed similar densities in their studies off Point Santa Cruz. There is no clear reason why urchin abundance is higher in bull kelp beds versus giant kelp beds although it may be related to the abundance of understory algal cover. Morphological difference between the two species allows more surface light penetration in *Nereocystis* beds, and in turn, a higher abundance of subcanopy algae, which probably attracts sea urchins.

### 3.2.9.2 Fish

#### Giant Kelp

Giant kelp provides forage and shelter for a large number of fishes, many of which are important to recreational and commercial fisherman (Quast, 1971a and b; Feder et al., 1974; Foster and Schiel, 1985; Bodkin,1988). Kelp forests support large numbers of mysids, amphipods, and other small invertebrate prey and provides hiding places, both of which are of particular importance to juvenile fishes. Tropical fish families such as Pomacentridae, Labridae, Serranidae, and Kyphosidae are dominate in southern California kelp forests. In contrast, temperate families such as Scorpaenidae, Hexagrammidae, and Embiotocidae are dominant in central and northern California kelp beds (Foster and Schiel, 1985).

Kelp improves the habitability of an area for fishes by providing reference or orientation points throughout the water column (Quast, 1971). Demersal fishes are reluctant to move beyond visual range of their habitat and the reference points provided by kelp probably encourages them to extend their feeding zones upwards in the water column (Quast, 1968a). The columns of kelp act as guideposts to the bottom and provide special refuge and foraging areas.

DeMartini and Roberts (1990) studied the relationship between fish and kelp density in southern California and found that in areas where the bottom is relatively flat, fish and kelp density is positively correlated. They looked at 14 fish species and found that fish and kelp density were significantly related for 18 of 30 life stages. In contrast, Stephens et al. (1984) suggested that the presence of giant kelp may have little effect on the abundance of most fish species in a high relief environment. Attraction of kelp canopies for adult fishes was small or inconsequential in kelp beds where the bottom relief was high (Stephens et al., 1984; Ebeling and Laur, 1988).

Holbrook et al. (1990) studied the effect of giant kelp on the local abundance of seven species of fishes in southern California and found that six species had a positive relationship and one had a negative relationship with giant kelp. Of the six species which had a positive relationship, kelp surfperch (*Brachyistius frenatus)* and giant kelpfish (*Heterostichus rostratus*) had the strongest correlation between kelp density and fish abundance. Kelp rockfish *(Sebastes atrovirens)* was absent from reefs without kelp, however there was no strong correlation between kelp density and fish density. The abundance of young-of-the-year kelp bass (*Paralabrax clathratus*) was positively related to the amount of kelp on the reef, however this was not the case for adults. Changes in the understory algal community caused by giant kelp appeared to benefit black surfperch (*Embiotoca jacksoni*) and pile surfperch (*Damalichthys vacca*). The importance of giant kelp for fishes is strongly related to habitat requirements by different life history stages of a species. They note that a prolonged absence of giant kelp may lead to a lower local abundance of adults for species that recruit to kelp such as kelp bass and many rockfishes.

Ebeling et al. (1980) compared the fish community between a mainland kelp bed and a Channel Island bed. They documented changes in the community associated with habitat (canopy, mid-water, and benthic), year, and water quality parameters. They found that canopy assemblages were simpler and less variable than benthic assemblages, annual variation was relatively small, and mid-water planktivores exhibited the greatest variation.

Car (1989) investigated the relationship between fish recruitment and macroalgae at Santa Catalina Island, and found that the density of juvenile kelp bass, kelp surfperch, and giant kelpfish was significantly greater in areas with giant kelp than in nearby reef areas devoid of kelp. Abundance of the Island kelpfish (*Alloclinus holderi*) and several *Gibbonsia* spp. was lower in areas with giant kelp.

Hartney (1996) investigated homing behavior and site fidelity of señorita ( *Oxyjulis californica),* blacksmith (*Chromis punctipinnis)*, and kelp bass in a kelp forest at Santa Catalina Island. All three species had a limited home range. Approximately 80% of the tagged señorita and 100% of the tagged blacksmith returned to the site of their initial collection. However, none of the tagged young-of-the-year or juvenile kelp bass returned to the site where they were first collected.

Feder et al. (1974) examined the fish community associated with giant kelp canopy habitat off southern California. They recorded 59 species of fishes, six of which were considered characteristic: the kelp pipefish (*Syngnathus californiensis)*; topsmelt *(Atherinops affinis)*; kelp surfperch; manacled sculpin (*Synchirus gilli)*; kelp gunnel (*Ulvicola sanctaerosae*); and the kelp clingfish (*Rimicola muscarum*).
Foster and Schiel (1985) reported that the kelp gunnel, kelp clingfish, and the manacled sculpin were also common in giant kelp canopies off central California.

Pondella and Stephens (1994) noted that the abundances of newly recruited kelp bass, opaleye (*Girella nigricans*), and giant kelpfish increased with the emergence of giant kelp on the breakwaters in King Harbor, Redondo Beach.

Juvenile rockfishes recruit to central California kelp forests in tremendous numbers during the upwelling season from spring through summer (Burge and Shultz 1973). Initial recruitment occurs in May and juveniles remain in the canopy until the winter storms commence (Foster and Schiel, 1985). Singer (1985) studied seven species of rockfishes that recruit to giant kelp forests off central California, and noted that three species commonly recruited to the canopy. The copper rockfish (Sebastes caurinus), and the gopher rockfish (S. carnatus) initially recruit to the canopy in late June and July. Kelp rockfish recruit to the canopy in central California in late July and August. While in the canopy, copper rockfish feed primarily on calanoid copepods, with harpacticoid copepods and zoea also eaten. The gopher rockfish feeds almost exclusively on calanoid copepods. The kelp rockfish feeds mainly on gammarid amphipods and calanoid and harpacticoid copepods, as well as mysid shrimp. He also noted that juveniles and adults of most species had similar foraging patterns. The lack of aggressive interactions among species and the large differences in intraspecific foraging strategies indicated that competition for food was probably negligible.

Limbaugh (1955) noted 62 species of fishes that he observed in or around giant kelp canopies in southern California. Four species preferred the canopy habitat: topsmelt, kelp surfperch, kelp gunnel, and kelp pipefish. He also noted that juveniles of nine species were common in kelp canopies. In southern California, the kelp clingfish is probably tied closest to the kelp canopy and eggs of this inch-long fish were frequently encountered there. Limbaugh (1955) reported that eggs of other fishes were observed far less frequently in kelp canopies. The kelp surfperch is one of the relatively few fishes that forages in kelp canopies off southern California. It preys extensively on gammarid amphipods and copepods in the canopy (Hobson and Chess, 1976).

Larson and DeMartini (1984) compared the abundance of fishes between a kelp forest and an adjacent cobble reef without kelp in southern California. Areas with kelp supported a greater standing stock of fishes (except for *Paralabrax clathratus*). They concluded that low relief reefs with kelp, even in moderate densities, are necessary to support a large diversity and biomass of fishes.

Patton et al. (1994) identified fish grazing as a major factor controlling the distribution of giant kelp on rocky substrate in southern California. They identified four fish as being the primary grazers of giant kelp in southern California: halfmoon, opaleye, garibaldi (*Hypsypops rubicundus*) and sheephead (*Semicossphus pulcher*).

Miller and Geibel (1973) recorded the following species in their collections from central California: striped kelpfish (*Gibbonzia metzi*); penpoint gunnel (*Apodichthys flavidus*); rockweed gunnel (*Xererpes fucorum*); kelp gunnel, kelp clingfish, saddleback sculpin (*Oligocottus rimensis*); juvenile rockfishes, *Sebastes* spp.; and pipefish *(Syngnathus* spp.)

The midlevel zone extends from three feet off the bottom to three feet below the surface. Feder et al. (1974) listed 56 species of fishes observed by diving in the midlevel zone, eight of which were considered characteristic of this habitat: kelp bass, kelp surfperch; white surfperch (*Phanerodon furcatus*); rubberlip surfperch (*Rhacochilus toxotes*); blacksmith, senorita, opaleye, and halfmoon (*Medialuna californiensis*).

During the summer, rafts of giant kelp form as a result of natural sloughing or due to physical trauma on the plants caused by grazing animals or storms. These rafts become home to numerous juvenile and adult fish (Dawson and Foster, 1982).

**Bull Kelp**

A bull kelp forest typically consists of older plants near the surface and an understory canopy composed of young *Nereocystis* sporophytes of different heights and either pure or mixed stands of *Laminaria* spp. or *Pterygophora californica* (Foster et. al., 1979; Foster and Schiel, 1985). The understory provides cover for fish as well as invertebrates. Bodkin (1986) compared the fish assemblages and abundance in *Macrocystis* and *Nereocystis* beds in central California. He found that species composition was similar but *Macrocystis* beds supported a higher biomass of species (2.4 times). Also, he reported that the abundance of rockfish (*Sebastes spp.)* was 4.5 times greater in giant kelp beds than in bull kelp beds. Bodkin (1986) encountered the following midwater species in *Nereocystis* beds during his surveys: blue rockfish, (*Sebastes mystinus*); olive rockfish (*S. serraniodes*); kelp rockfish, black rockfish (*S. melanops*); juvenile rockfish; señorita, tube–snout (*Aulorhynchus flavidu*), and jacksmelt (*Atherinopsis californiensis*). Ecological studies on the fish of *Nereocystis* beds conducted in British Columbia, Canada and at Diablo Cove, California produced similar midwater species lists (Leaman, 1980; Gotshall et. al., 1984).

Fish diversity and abundance is greater at the bottom than the other two regions (midwater and canopy). Gotshall et. al. (1986) developed a list of over 30 fish species seen during benthic surveys conducted in Diablo Cove. The most diverse and abundant group continued to be rockfish (*Sebastes* spp.), followed by greenlings (*Oxylebius pictus, Hexagrammos decagrammus*), lingcod (*Ophiodon elongatus*) and cottids (*Artedius corallinus, Orthonopias tracis, Scorpeanichthys marmoratus*). Bodkin (1986) also reported greater diversity for benthic fish within *Nereocystis*. Nineteen species were identified as common in both giant kelp and bull kelp; however, the biomass of fish associated with *Macrocystis* was 34% greater than the biomass found in *Nereocystis* (Bodkin, 1986). For more information on this topic see Burge and Schultz (1973), Leaman (1980), and Gotshall et. al. (1986).

Leaman (1980), examined the ecology of fishes in a bull kelp bed in British Columbia. He looked at species assemblage, seasonal dynamics, food habits, and growth of selected species. Kelp forest fishes were grouped into the following categories: neritic resident, neritic associated, neritic transient, benthic resident, benthic associated, and benthic transient. The spiny dogfish, *Squalus acanthias*, would be considered a neritic transient species because it is only occasionally found in kelp beds while kelp surfperch are neritic residents. He also classified kelp bed fishes according to their feeding habits: predator, grazer, and planktivor. He found that two pairs of the four most abundant benthic fishes were directly competing for food resources (primarily caprellid amphipods). He concluded that food was not a limiting resource during his study period since few fish had empty stomachs. In contrast, he found little dietary overlap between neritic fishes. He noted that neritic and benthic fishes exploited the increased spatial heterogeneity that is provided by the holdfast, stipe and laminae. He found no correlation between fish diversity and kelp density.

### 3.2.9.3 Birds

Kelp provides three different habitats for birds (Foster and Schiel, 1985): 1) kelp forest - living attached kelp in association with rocky or sandy habitat, 2) drift kelp - detached kelp that may be found floating far out to sea in the pelagic zone, and 3) kelp wrack - detached kelp that is deposited on the beach. The canopy and mid-level regions of kelp beds provide habitat for many different species of birds. Some of the birds associated with kelp canopies are also found with drift kelp away from shore. Shorebirds commonly forage for food in the kelp wrack washed ashore.

### Giant Kelp

Many species of birds perch on giant kelp canopy or scavenge for food among its fronds. Large numbers of elegant terns (*Sterna elegans*) and Heermann's gulls (*Larus heermanni*) have been observed roosting on kelp canopy off central California (Foster and Schiel, 1985). These birds pick small fishes from the canopy by surface plunging (Angell and Balcomb, 1982). Several other species of gulls have been observed scavenging on surface kelp canopy, notably the western gull (*Larus occidentalis*) and Bonaparte's gull (*L. philadelphia*) (Foster and Schiel, 1985). The great blue heron (*Ardea herodias*) and the snow egret (*Egretta thuls*) are often seen perched on kelp canopy stalking prey at the water's surface.

Shorebirds, such as the willet (*Catotrophorus semipalmatus*) and the wandering tattler (*Heteroscelus incanus*) may forage on the surface of kelp forests. The northern phalarope (*Phalaropus lobatus*) has been observed feeding on plankton within openings giant kelp canopies in central California (Foster and Schiel, 1985).

There are several species of birds that frequent the mid-level region of giant kelp forests. Brandt's cormorant (*P. penicillatus*) and the pelagic cormorant (*P. pelagicus*) are most closely associated with California's kelp forests (Ainley, pers. comm. in Foster and Schiel, 1985). Brandt's cormorants feed almost exclusively on fishes that inhabit the mid-level habitat among fronds of giant kelp (Hubbs et al., 1970). The pelagic cormorant has similar feeding habits to Brandt's. Horned grebes (*Podiceps auritus*) and eared grebes (*P. nigricollis*) are commonly observed in kelp forests. One of their major food items is mysids and it is probable that they feed on the swarms of mysids that occur within the mid-level of the kelp community (Foster and Schiel, 1985). The seaward fringe of kelp forests probably supports the greatest diversity of birds. Loons, grebes, cormorants, and scoters are all foot-propelled pursuit divers that may forage along the edge of kelp beds (Foster and Schiel, 1985). Diving birds such as loons, cormorants, pelicans, and grebes also utilize the mid-levels of bull kelp when available.

### Bull Kelp

Along the north coast, bull kelp is the dominant canopy–forming species. When the *Nereocystis* canopy is fully developed, a number of nearshore and marine birds forage in and around the beds. Sowls et. al. (1980) reported that 42% of California's breeding seabirds reside in northern California. Large portions of the state's breeding population of fork–tailed storm–petrals (*Oceanodroma furcata*), Leach's storm–petrals (*O. leucorhoa*), double–crested cormorants (*Phalacrocorax auritus*), common murres (*Uria aalge*), rhinoceros auklets (*Cerorhinca monocerata*), and tufted puffins (*Lunda cirrhata*) inhabit this part of the coast. Six other species also have small breeding populations in this region: Brandt's cormorant (*P. penicillatus*), pelagic cormorant (*P. pelagicus*), black oystercatcher (*Haematopus bachmani*), western gull (*Larus occidentalis*), pigeon guillemot (*Cepphus columba*), and Cassin's auklet (*Ptychoramphus aleuticus*). Studies on the feeding ecology of various seabirds show that the major components of their diets are fish (rockfish, sculpin, gunnels, kelpfish) and invertebrates (amphipods, euphausids, isopods) associated with kelp beds (Briggs et. al., 1987). As mentioned in the giant kelp section, deep diving birds such as loons, cormorants, pelicans, and grebes utilize the kelp beds while foraging for food.

### 3.2.9.4 Mammals

**Giant Kelp**

Like sea birds, marine mammals utilize the kelp beds in a variety of ways. North (1971a) lists the sea otter, gray whale, killer whale, harbor seal, and California sea lion as mammals associated with kelp forests in California. The sea otter (*Enhydra lutris*) exhibits the closest association with canopies of giant kelp of all the marine mammals. The main portion of the sea otter population presently occurs along the mainland in southern and central California from Gaviota Point, Santa Barbara County to Pillar Point, San Mateo County. Until recently, the sea otter population along the mainland had generally increased at about 5% per year since the 1930's. Based on the results of a spring rangewide count, the mainland population peaked in 1995 (n = 2377). Each succeeding spring count suggested a population decline was occurring until the 2000 count (n = 2317), which was over 10% higher than the preceding count (Wendell, pers. comm.). Sea otters were also reintroduced into southern California at San Nicolas Island, beginning in 1987. A total of 140 animals were translocated from central California to the island from 1987 through 1990. A resident population of about 23 animals were observed at San Nicolas Island in 2000 (Hatfield, pers. comm.).

The preferred habitat of the sea otter in California is in giant kelp canopy near rocky substrata with deep crevices (Woodhouse et al., 1977). If surface canopies are present, otters sleep in them, and are often seen with strands of kelp draped over their bodies, presumably to prevent them from drifting away (Kenyon, 1969). Sea otters are most commonly found in protected inshore waters in central California during the winter, when storms remove canopies in deeper, unprotected water. Otters gradually move out into offshore canopies as these reform in the spring and summer (Jameson, pers. comm. in Foster and Schiel, 1985). During the severe winter of 1982-83, sea otters in central California were observed inhabiting the few small shallow patches of giant kelp that remained (Foster and Schiel, 1985). Sea otter distribution, however, is not limited to kelp bed habitats. They have reoccupied areas nearshore with soft-bottom and offshore habitats that do not support kelp bed communities (Wendell, pers. comm.)

Kelp forests also function as nursery areas for female sea otters with pups. When seas are rough, females often leave their pups in surface canopy while they forage (Sandegren et al., 1973). During winter storms, when canopy is reduced, increased competition between mother-pup pairs may occur for space in available canopy (Sandegren et al., 1973).

Sea otters are frequently found rafting in beds of *Macrocystis* or foraging in them. The otters consume an amount of food equivalent to 23-33% of their body weight each day (Costa, 1978). They feed upon epibenthic invertebrates while foraging from the low intertidal out to depths of over 60 m, and on invertebrates on kelp fronds. Sea otters in central California commonly feed upon *Tegula* spp. and crabs associated with giant kelp (Woodhouse et al., 1977).

Gray whales, *Eschrictius robustus*, migrate yearly from their summer feeding grounds in the Bering and Chukchi Seas to their winter breeding grounds along the coast of Baja California, Mexico. Cow-calf pairs migrate northward along an inshore route that takes them along the outer edges of kelp beds or within beds of giant kelp (Foster and Schiel, 1985). Cow-calf pairs may use the inshore route that passes near kelp forests for two reasons: 1) kelp forests may provide protection from predation by killer whales, and 2) kelp forests may provide food for the nursing cow. Baldridge

(1972) described the attack of a pod of killer whales on a cow-calf pair near a kelp forest off Carmel Bay, California. The cow escaped into the kelp, while the calf was cut off from the forest and subsequently killed. Gray whales may also feed upon dense swarms of mysid shrimp within or along the edge of kelp beds (Wellington and Anderson, 1978).

Pinnipeds (seals and sea lions) are frequently seen in forests of giant kelp. The three common species of pinnipeds in California are expanding at 6 to 12% per year. The California sea lion (*Zalophus californianus*) population was estimated to have between 167,000 and 188,000 animals when last assessed in 1998. The California breeding stock of the Northern elephant seal (*Mirounga angustirostris*) was estimated at 84,000 in 1996. The third common pinniped, the harbor seal (*Phoca vitulina*), was estimated at 30,293 animals based on a 1995 survey (R. Reed, pers. comm.). Harbor seals frequently rest in canopies of giant kelp. Both harbor seals and sea lions forage around forests of giant kelp and in deeper water for a variety of prey items. Elephant seals usually forage in deep water, offshore of kelp beds. They may pass through forests of giant kelp on their way to the offshore feeding grounds.

#### Bull Kelp

Marine mammals utilize the bull kelp beds in the same manner they do the giant kelp beds. Sea lions and harbor seals have been observed foraging in northern California kelp beds for rockfish, crab, and octopus in the summer and fall (Warner, pers. comm.).

The movement of sea otters into the Diablo Cove area may be partially responsible for the decline of *Nereocystis* in the area. Sea otters, by removing macro–invertebrate herbivores (sea urchins, abalone, turban snails) can have a profound effect on algal community structure and succession in the nearshore marine environment (Estes and Palmisano, 1974). Gotshall et. al. (1986) noted the change in bull kelp abundance and increase in subsurface algae (*Laminaria* and *Pterygophora*) as early as 1976, approximately two years after the otters began to feed within the cove.

### 3.2.9.5 Representative Communities

Extensive beds of kelp occur along the California coast. The composition of these beds differs from site to site depending upon many variables. Foster and Schiel (1985) provide a good view of the distributional variation among sites in California by describing ten sites that have been studied in some detail. Five of the sites are in central California and five are in southern California. Added to these descriptions is a depiction of two often overlooked byproducts of kelp forests, drift kelp and beach wrack.

#### Central California

##### Greyhound Rock

This site is located approximately 15 miles north of Santa Cruz and 2 miles south of Año Nuevo Island, the northern limit of large beds of *Macrocystis pyrifera*. Greyhound Rock is a *Nereocystis luetkeana* forest that has been surveyed several times (Yellin et al., 1977; Foster et al., 1979a, b; Foster and Reed, 1980; Foster and Heine, 1981; Foster, 1982). The substratum is composed of mudstone ridges interspersed with sand that terminates in a large sand plain at about 65 ft depth. *N. luetkeana* occurs on the tops of ridges at depths of 25 to 45 ft. There are sparse stands of understory kelps *Pterygophora californica* and *Laminaria setchellii* along with foliose red algae beneath. This site is fully exposed to northwest swells and the water is usually turbid. Inshore of the bull kelp forest, the rocky ridges are covered with multiple layers of foliose red algae along with scattered patches of understory kelps, *Dictyoneurum californianum* and *L. setchellii*. Large foliose red algae are rare seaward of the *Macrocystis* bed.

### Sandhill Bluff

There is a *Macrocystis pyrifera* forest at this site, which is located about 6 miles south of Greyhound Rock. This site is described in the literature cited for Greyhound Rock and in Cowen et al. (1982). The rocky substratum is relatively flat mudstone interspersed with sand patches. The rock terminates in sandy bottom in deeper water (45 to 55 ft) beyond the kelp bed. The kelp forest is in the lee of a small point and is slightly protected from the northwest swell. Giant kelp forms surface canopy at depths between 20 to 45 ft. The bottom inshore of the kelp bed is dominated by foliose red algae similar to Greyhound Rock, however, these plants are attached to a dense cover of bryozoans, sponges, and tunicates. Understory algal cover is reduced beneath the *Macrocystis* canopy. Foliose red algal cover is greater offshore of the kelp bed.

### Point Cabrillo Kelp Forest

This forest is located in southern Monterey Bay off the Hopkins Marine Station in Pacific Grove. It has been extensively studied (Lowry and Pearse, 1973; Miller and Geibel, 1973; Devinny and Kirkwood, 1974; Lowry et al., 1974; Gerard, 1976; Harrold, 1981; Reidman et al., 1981; Breda 1982; Hines, 1982; Watanabe 1983, 1984a, b). The surface canopy is *M. pyrifera* and *Cystoseira osmundacea* that grows attached to large granite outcrops and boulders in an area very protected from swells. *Macrocystis* grows in very shallow water (about 10 ft depth) at this site. Extensive beds of surf grass, *Phyllospadix*, patches of feather boa kelp *Egregia menziesii*, and in summer, dense masses of the floating reproductive fronds of *C. osmundacea* occur inshore of the giant kelp. *Cystoseira osmundacea* also occurs intermixed with *Macrocystis* out to 45 ft. Beyond 45 ft, the rock is replaced by sand. The kelp *Dictyneuropsis reticulata* forms a sparse understory beneath the surface canopy and the bottom is dominated by foliose red algae and encrusting corallines.

### Stillwater Cove

The Stillwater Cove forest of giant kelp is located inside Carmel Bay. The site has been described by Andrews (1945), Foster et al. (1979 a, b), Foster (1982), and Reed and Foster (1982). Stillwater Cove faces south and is protected from northwest swells. The conglomerate and sandstone bottom is a mosaic of plateaus and pinnacles surrounded by relatively flat rock and fields of small boulders. *Macrocystis integrifolia* occurs from lower intertidal to a depth of about 3 ft. Both *Cystoseira osmundacea* and *Egregia menziesii* occur with the *M. integrifolia* and seaward into the *M. pyrifera* forest. The understory kelp *Laminaria setchellii* occurs in patches down to about 25 ft, while *M. pyrifera* occurs at depths between 6 and 100 ft and terminates at the sand bottom in deep water. Dense stands of tall (over 3 ft tall) *Pterygophora californica* occur beneath the *Macrocystis*. Articulate and encrusting corallines cover most of the flat substratum beneath the *Pterygophora*.

### Granite Creek

The site is located south of Monterey and was studied by McLean (1962) between 1959 and 1961. At the time of the study, the most abundant canopy kelp was *Nereocystis luetkeana*, growing on an irregular granite bottom fully exposed to swells. Both *Nereocystis* and *M. pyrifera* have occurred at the site since the early study (Foster and Schiel, 1985). In 1959-1961, *Egregia menziesii, Cystoseira osmundacea* and *M. pyrifera* formed a mixed canopy inshore of the *Nereocystis* at depths from 0 to 33 ft. The bottom in the inshore area was covered by articulate and encrusting corallines and an occasional patch of *Laminaria setchellii. Nereocystis* grew attached to the irregular substratum between 33 ft and 66 ft. Rock was replaced by sand offshore. The understory beneath the *Nereocystis* was dominated by dense stands of large palm kelp, *Pterygophora californica*. This site is now dominated by *Macrocystis* and has been since the mid–80's (R. McPeak, pers. obs.).

## Southern California

### Campus Point, Goleta

This site is located at the northwest end of Goleta Bay, approximately 10 miles northwest of Santa Barbara. The description below is based upon Neushul et al. (1976) and Foster and Schiel (1985). Campus Point is protected from most swells by Point Conception to the west and the Channel Islands to the southwest. The bottom at this site is low relief mudstone interspersed with extensive sandy areas and occasional rocky outcrops. *Macrocystis pyrifera* (*M. angustifolia* in Neushul et al., 1976) occurs between depths of 15 and 65 ft. The inner edge of the *Macrocystis* forest is bounded by patches of feather boa kelp, *Egregia menziesii*, and bottom cover is composed of articulate corallines, fleshy reds, and various species of brown algae. *Pterygophora californica* grows in dense stands beneath the *Macrocystis* canopy.

### Anacapa Island

In contrast to the mainland, waters around the Channel Islands are generally clearer and high relief rock is more common. The following description is based upon Neushul et al. (1967) and Clark and Neushul (1967), who surveyed along a transect through a giant kelp forest from a depth of 0 to 130 ft. Clark and Neushul (1967) recognized three broad zones along the transect. The shallow zone, from 0 to 25 ft, was dominated by abundant understory kelps (*Eisenia arborea* and *Laminaria farlowii*) and surf grass (*Phyllospadix torreyi*). The wide mid-depth zone occurred from depths of 25 ft to 110 ft. It was dominated by giant kelp growing over understory kelps *Agarum fimbriatum* and *Pterygophora californica*. *Macrocystis* did not occur below depths of 110 ft. The deep zone was dominated by *Agarum fimbriatum* and various species of small red algae.

### Santa Catalina Island

The relatively warm waters of Santa Catalina Island contain species not found in the more northern areas that have already been described. One of the more conspicuous of these is the elk kelp, *Pelagophycus porra*. The Catalina site is located on the leeward side of the island and the description is based upon Dykzeul and Given (1979) and Foster and Schiel (1985). The shallow subtidal zone east of Big Fisherman's Cove is composed of metamorphic (schist) boulders of varying size that terminate in sand at about 115 ft. The bottom is dominated by understory kelp, *Eisenia* *arborea*, from 0 to 25 ft. Several species of brown and red algae are common in the shallow water. *Macrocystis pyrifera* occurs from about 25 ft to 65 ft. The understory beneath its surface canopy is relatively reduced. There are patches of *Cystoseira neglecta*, *Sargassum muticum*, *Dictyota flabellulata*, and *Pachydictyon coriaceum*, especially where surface canopy is thin. The deeper water outside of giant kelp canopy is dominated by understory algae *Eisenia arborea*, *Agarum fimbriatum*, and *Laminaria farlowii*. *Pelagophycus porra* can be found on the sandy bottom at depths below about 70 ft.

Del Mar

The bed of giant kelp at Del Mar is isolated by surrounding sand. Rosenthal et al. (1974) characterized this kelp forest during their study done between 1967 and 1973. Plants in this stand occur on mixed sandstone and siltstone bottoms, with large areas of sand and silt among the rock. The depth of this low relief is between 45 ft and 65 ft. The understory vegetation beneath the giant kelp canopy at Del Mar was relatively sparse, with only a few *Pterygophora californica* and *Laminaria farlowii* and a few foliose browns and reds occurring. Most of the bottom was covered with encrusting corallines.

Point Loma

The Point Loma kelp bed is located along the western edge of Point Loma between the entrance to Mission Bay and San Diego Bay. The kelp forest has varied considerably in size since the early 1900s (North, 1969; Dayton et al., 1984). The bed was 4200 x $10^3$ $m^2$ in 1989 (North, 1994). Turner et al. (1968) described the Point Loma kelp bed using four transects along the coast. Foster and Schiel (1985) combined the four transects to present an idealized view of the Point Loma kelp bed. The kelp forest at Point Loma occurs on a broad, gently-sloping mudstone-sandstone terrace, with pockets of sand, cobbles, and boulders. There are also areas of pinnacles that occur within the kelp forest (R. McPeak, pers. obs).

*Macrocystis pyrifera* is common from about 20 ft to 70 ft on rocky substrata. The inshore area is dominated by surf grass *Phyllospadix torreyi*, feather boa kelp *Egregia menziesii*, and *Cystoseira osmundacea*. Dayton et al. (1984) described distinct patches of *Pterygophora/Eisenia* and *Laminaria farlowii / Cystoseira osmundacea* that occurred within the giant kelp bed. Elk kelp, occurs in deeper water (60 ft to 110 ft), outside the bed of giant kelp, or occasionally mixed with the giant kelp (Dorr, 1992).

### 3.2.9.6. Drift Kelp and Kelp Wrack

Plants that drift offshore, commonly known as kelp "paddies", may live for several months and become an important seaweed dispersal agent as well as provide habitat for many small invertebrates and both juvenile and adult fishes (Dawson and Foster, 1982; Kingsford, 1995). Detachment of kelp plants occurs mainly in winter, but the yearly variation in seasonal mortality of kelp is great (Hobday, 2000). Mitchell and Hunter (1970) observed 21 species of fishes belonging to 15 families under kelp paddies drifting off southern California and northern Baja California, Mexico. Many seasonal migrants (i.e. yellowtail, dorado, yellow fin tuna) frequent floating kelp. The floating kelp is used as a fish attracting device by commercial passenger fishing boats, especially during summer months. Estimated annual biomass of drifting kelp is as high as 376,000 tons in the Southern California Bight (Hobday, 2000).

Some of the drift kelp ends up on the beach as wrack which is important as habitat and food for various intertidal invertebrates such as shore crabs, sea urchins, beach hoppers (*Orchestroidea* spp.), and sand flies (Yaninek, 1980). Wrack is also a source of organic detritus which can support foodwebs that include benthic suspension feeders, nearshore fishes, and shorebirds. After being broken down and fragmented by physical processes and detritivores, fragments of wrack can be washed back to sea to provide food for filter feeders, grazing gastropods, and fish (Kirkman and Kendrick, 1997). Wrack remaining on the beach supports an abundant community of insects and crustaceans (Yaninek, 1980). Bradley and Bradley (1993) hypothesize an increase in wintering shorebird populations along the rocky Palos Verdes Peninsula is related to larger amounts of wrack generated by increased local kelp abundance.

Although important for some organisms, kelp wrack is often viewed as a nuisance to beach goers. Beaches in southern California are regularly cleared of kelp, which is transported to landfills for disposal (Larson and Vejar, pers. comm.). The effects of wrack removal are not well studied, but at the least it reduces the amount of food and habitat available to beach organisms as well as the amount of organic debris washing out to the ocean bottom. Regular removal of wrack also prevents the development of the invertebrate communities which can provide food for shorebirds. In Australia, among the main concerns for increased removal of seaweed wrack were the disturbance of shorebirds and their habitat and the need to assess the relative importance of wrack in recycling nutrients and detritus to the nearshore ecosystem (Kirkman and Kendrick, 1997). These issues need to be researched in California as well.

### 3.2.10 Importance of Habitat Loss, Degradation, and Modification

The coastal region of California has been the focal point of human habitation and commerce throughout its long history and this continues to be true today. This habitation has contributed to changes in the complexion of the coastline and of the nearshore marine environment. In 1900 for example, there were 381,000 acres of tidal marshes and mudflats. By 1980, only 10 percent of California's wetlands remained untouched (NOAA, 1990b). Harbor and marina development, as well as run–off and sewage discharge, are only a few factors that have lead to the modification, degradation or loss of habitat in the coastal zone.

#### 3.2.10.1 Coastal Development

Since the 1800s, improvements have been made to natural anchorages such as Humboldt Bay, San Francisco Bay, Monterey Bay, and San Diego Bay. In addition, new harbors and marinas were created to accommodate the increase in the coastal population and changes in recreational activities (California Department of Navigation, 1977; Department of Finance, 1992). Subsequent changes to the coastal landscape have had indirect, and in some cases, direct effects on kelp forests. The creation of breakwaters, installation of discharge pipes, and the dredging of channels leads to physical displacement of marine plants in addition to changing water currents, turbidity, and sedimentation (Foster and Schiel, 1985). The demise of giant kelp canopies on Dago Bank has been attributed to the dumping of rock, shale, and mud removed during the widening of the main channel and the West Basin of Los Angeles Harbor from 1920 to 1930 (Schott 1976). North et al. (1993) report two instances of possible impact on kelp forests from construction. There was a serious decline in the kelp bed off Dana Point in 1969 and a temporary disappearance of "Barn Kelp" (kelp patches offshore of Camp Pendleton, San Diego County) from 1979 to 1986. High turbidities that were observed in these beds during the critical periods of decline may have been caused by construction (North et al., 1993).

Two large subtidal areas influenced by sediment plumes from landslides along the central California coast (Lone Tree and Big Sur) were surveyed and compared to nearby control areas for impacts from sedimentation. In the Lone Tree site, *Nereocystis* was the canopy forming kelp, while at the Big Sur site the canopy was dominated by *M. pyrifera*. At both areas, brown algae were more abundant at the unimpacted sites (Konar and Roberts 1996).

### 3.2.10.2 Waste Disposal

Sewage and thermal discharges as well as oil spills and leaks have the potential of impacting forests of giant and bull kelp. The effects of sewage discharge can be negative or positive, depending upon the amount of nutrients in the discharge, turbidity and sedimentation created by the discharge, and toxics in the discharge. Domestic wastes contain nutrients that may nourish kelp and may increase plankton productivity as well. These wastes may also contain significant amounts of sludge particles that increase turbidity as well as sedimentation rates and sediment thickness on the bottom (Foster and Schiel, 1985). Industrial wastes may cause similar effects, and also may contain toxic metals and organic compounds that can directly affect the kelp forest ecosystem.

**Giant Kelp**

There is good indirect evidence that sewage from the Los Angeles area, discharged near Palos Verdes, contributed to the decline and eventual loss of giant kelp forests (Meistrell and Montagne, 1983). The decline of kelp forests around the Palos Verdes Peninsula began in the 1940's and 1950's as discharge rates increased. The kelp community did not recover after the El Niño in the late 1950's (Grigg and Kiwala, 1970; Wilson, 1982). Increased turbidity, sludge on the bottom, toxic substances in the discharge such as DDT, and possibly copper and other metals may have all contributed to the decline and lack of recovery. With improvements in the discharge quality in the Los Angeles area and assistance from restoration programs, the *Macrocystis* beds around Palos Verdes improved significantly. Canopies around the peninsula increased to 1.28 $mi^2$ by 1989 (Ecoscan, 1989).

The role of sewage in sea urchin nutrition and persistence of sea urchin populations near outfalls was evaluated by Pearse et al. (1970) and North (1983). Sea urchins can accumulate a wide variety of organic substances from seawater at very low concentrations (Clark, 1969; Pearse et al., 1970). Computations based on measured uptake rates of dissolved free amino acids (DFAA) at concentrations near outfalls by Clark et al. (1972) showed that the purple sea urchin (*Strongylocentrotus purpuratus* ) could meet 50% of the daily maintenance requirement from DFAA alone (Clark, 1969). Pearse et al. (1970) and North (1983) concluded that there was a strong possibility that sea urchins near outfalls were utilizing discharged organics, resulting in persistence of "urchin barrens" devoid of giant kelp. They speculated that sea urchins that would normally perish from lack of food, would persist because of the additional nutrition provided by the DFAA and other organics of sewage origin.

Sewage can also apparently have a positive affect on *Macrocystis*. The Point Loma outfall, near San Diego, discharged approximately 140 million gallons of advanced primary treated sewage daily into the ocean in early 1992. The sewage effluent was discharged in 210 feet of water, approximately 1.4 miles offshore of the Point Loma *Macrocystis* forest. During early February, the outfall pipe broke within the kelp bed and began discharging the sewage directly into the *Macrocystis* bed.

There was initial concern that the turbidity caused by the discharge in the kelp bed would harm nearby young-adult plants that were just reaching the surface in early February. Wastes were discharged directly into the kelp bed for two months, until the outfall pipe was repaired in early April, 1992. During routine aerial surveys of kelp resources in southern California, D. Glantz (pers. comm.) noted that the young adult *Macrocystis* near the outfall break continued to grow and were dark brown in color. *Macrocystis* plants that were some distance from the outfall break (0.5 miles or more away) continued to grow poorly and never took on the dark brown color indicating high tissue nitrogen levels. Presumably, nutrients from the outfall were available for plants near the break and were utilized by these plants for growth. The young adult plants near the break survived and were the most productive part of the Point Loma kelp bed in 1993 (R. McPeak pers. obs.).

The ecological impacts to the Point Loma kelp forest community due to the outfall break was studied by Tegner et. al. 1995b. Although initially there were negative impacts to kelp germination and growth surrounding the area of the sewage break, the kelp forest recovered quickly after the repair of the pipeline. Kelp forest suspension feeders and detritivores showed no significant change in their population due to the sewage leak. Overall the authors believe that the sewage pipeline burst represented a modest disturbance similar to the natural vagaries of kelp recruitment.

Toxic contaminants in urban runoff also have negative impacts to sensitive life stages of giant kelp (Bay et.al. 1996). This study carried out by Southern California Coastal Water Resources Project (SCCWRP) examined the toxicity of dry weather flow from Ballona Creek and three other drains that discharge into Santa Monica Bay. They also conducted toxicity tests using sensitive life stages of red abalone, purple sea urchin, and giant kelp. The invertebrates were found to be more sensitive than the kelp spores with toxic effects produced by dry weather flow of 5.6 % or greater. The study also reported that the constituents causing toxicity in dry weather flow were variable.

There are two major nuclear generating plants that discharge heated water in the vicinity of kelp forests in California: the San Onofre Nuclear Generating Station (SONGS) near Oceanside, and the Diablo Canyon nuclear power plant near San Luis Obispo. Extensive long-term studies have been done at each power plant to determine the effect of discharged heated water on nearby kelp forests.

SONGS consists of three electric power generating units, each using a nuclear reactor equipped with a once-through seawater cooling system that discharges heated effluent into the nearby ocean (Grove, 1993). SONGS Unit 1 began operation in 1968 and was retired from service in November, 1992. It was the smallest of the three units, generating 0.44 million kW. Units 2 and 3 generate 1.1 million kW and use 124 $m^3$/sec of cooling seawater for both units combined. This water, which is 20° F warmer than the intake water, is discharged between 1.14 mi. and 1.58 mi. offshore. The last 0.48 mi. of each discharge pipe contains 63 discharge ports to ensure rapid mixing of the effluent with ambient water. Unit 2 began operation in August, 1983 and Unit 3 in April, 1984.

The California Coastal Commission appointed an independent review committee, the Marine Review Committee (MRC), to monitor and evaluate SONGS impacts on the marine environment. The MRC monitored SONGS from 1975 through 1989. Identifying impacts solely attributable to SONGS was complicated because of the 1982-1984 El Niño that created significant anomalies in natural ocean processes surrounding SONGS (Grove, 1993).

The MRC final report, issued in 1989, identified substantial impacts to the San Onofre kelp bed due to reduced light and increased sedimentation induced by turbidity in the discharge plume (MRC, 1989; Grove, 1993). As a result of the statistically calculated increase in local water column turbidity caused by the diffuser plume, the MRC estimated there would have been 60% more kelp in the San Onofre kelp bed if SONGS were not operating.

A positive impact associated with the discharge plume of SONGS was reported by Jahn et. al. 1998. In their study the researchers hypothesized that the multiport diffuser system which creates the discharge plume should on average provide more inorganic nutrients such as nitrogen to the surrounding ambient surface waters than is normally present. Effects from the plume were investigated by sampling kelp canopy tissues and analyzing them for nitrogen content. The results of their study showed that the San Onofre kelp bed nearest the offshore diffuser consistently had higher than average nitrogen on a percent dry weight basis, and there was an overall pattern of decreasing enrichment with distance from the diffusers.

The effects of large oil spills on beds of *Macrocystis* have been documented twice along the western Pacific coast; once during 1957 when a small tanker, the Tampico, spilled a load of mineral oil in a cove along Baja California; the other during the 1969 offshore well blow-out and spill in the Santa Barbara Channel (Foster and Schiel, 1985). North et al. (1964) studied the Tampico spill and noted that there was massive mortality of invertebrates, including sea urchins, in the cove. Damage to *Macrocystis* was not obvious and within five months of the spill, vegetation in the cove was increasing and juvenile *Macrocystis* began to develop. Presumably, the diesel oil had killed sea urchins that had been maintaining the bottom. Once the urchins were killed, *Macrocystis* and other species of algae began to develop (North et al., 1964). Giant kelp plants that recruited following the loss of sea urchins produced canopy in the cove, approximately 18 months after the spill.

Crude oil from the 1969 Santa Barbara spill polluted a large portion of the mainland coast, and many of the offshore Channel islands (Foster et al., 1971a). Assessment of the effects of the spill was complicated by record storms and rainfall that occurred at the same time as the spill. There was little damage to the *Macrocystis* beds, even though considerable quantities of crude oil fouled the surface canopies (Foster et al., 1971b). The partially weathered crude oil appeared to stay on the surface of the water and did not stick to the fronds of the giant kelp.

Besides the direct effects from oil spills on giant kelp, there are documented negative effects on kelp from substances used in oil spill clean up operations. The surfactant-based oil dispersant, Corexit 9554 has been shown to have acutely toxic negative effects on the early life stages of giant kelp (Singer et.al. 1995).

There are also extensive natural gas and oil seeps that occur near beds of giant kelp near Santa Barbara (Mertz, 1959). These seeps produce continuous oil slicks on the surface of the water and even visible tar mounds on the bottom within kelp beds (Spies and Davis, 1979). The natural seeps appear to cause no visible damage to nearby *Macrocystis* beds, since extensive canopies regularly develop in these beds when oceanographic conditions are good for growth (McPeak, pers. comm.).

### Bull Kelp

Little is known about the effect of domestic and industrial discharge on bull kelp plants. James et. al. (1987) investigated the toxic threshold of 10 species of brown algae gametophytes and young sporophytes to hydrazine, a specialized oxidant. Hydrazine is routinely used to scavenge dissolved oxygen in high–pressure boilers to decrease corrosion. Excess hydrazine may find its way into natural waters when boiler water is discharged into a waste stream.

James et. al. (1987) work showed that bull kelp was the most sensitive to hydrazine. When *Nereocystis* gametophytes were exposed to hydrazine at levels of 0.025 parts per million (ppm), the gametophytes were permanently inhibited and sporophyte production could not occur. In contrast, *Pterygophora californica* was the least sensitive, showing no effect at levels of 0.25 ppm (a magnitude higher than the treatment bull kelp received). Thus, exposure to this compound could have profound effects on the survival of bull kelp.

Hydrazine degrades slowly in seawater (0.15% per hour). Thus high concentrations of this substance might occur in an effluent for several hours. In areas where mixing is minimal and the poorly diluted effluent is not flushed out quickly, the presence of hydrazine could have a serious effect on sensitive seaweed species (James et. al., 1987).

Thermal effects research on seaweeds, invertebrates, and fishes was conducted at the Diablo Canyon power plant onsite marine laboratory by Tera Corporation (1982). In the study, they exposed juvenile *Nereocystis* sporophytes to water temperatures ranging from 10°C to 20°C in the laboratory for a period of 44 days. The results showed that juvenile bull kelp sporophytes cannot endure prolonged exposure to water temperatures of 18°C and above. Also, 25% of those plants held at 15.9°C died after being exposed to this temperature for 36 days. Visual inspection of the plants indicated a reduced capacity for wound–healing in plants at this temperature (Tera Corporation, 1982). Field observation of the effect of increased water temperature on *Nereocystis* was observed in Diablo Cove. During the first year of power plant operation (1985), bull kelp plants that came in contact with the thermal plume (surface to 15 feet depth) experienced premature blade loss (PG&E, 1987). Bull kelp stands continued to exist in those areas where the plume was deflected (such as at Diablo Rock) or in areas where cold water currents prevailed. This occurrence was repeated in 1986 as well and eventually *Macrocystis*, which is more heat tolerant, colonized the areas affected by the plume (PG&E, 1987).

The effects of three petroleum products (diesel fuel, intermediate fuel oil or IFO, and crude oil) were tested on *Nereocystis* plants. Whole plants were exposed for specific time periods and then transferred to the field. Bioassays were performed to measure the effects of petroleum exposure on photosynthetic rate and respiration rate. Diesel treatments had a greater negative effect on net photosynthetic rate than did the IFO treatments. Experimental evidence also verified the susceptibility of *Nereocystis* tissues to the damaging effects of exposure to petroleum. The most severe tissue necrosis was noted in the meristematic zone at the junction of stipe and bulb. Based on these experiments the most damaging effects were from weathered diesel fuel, with the least harmful from weathered crude oil (Antrim et al., 1995).

The abundance and size distributions of subtidal algae, including *Nereocystis*, were measured in Prince William Sound, Alaska one year after the Exxon Valdez oil spill. There were no differences in the total density, biomass or percentage cover of macroalgae between oiled and control sites. However, there were generally smaller plants at oiled sites, suggesting recent recruitment or slower growth there (Dean et al. 1996).

### 3.2.11 Kelp Restoration

#### Giant Kelp

Forests of *Macrocystis* that were once productive off San Diego, Orange, and Los Angeles Counties, began to deteriorate in the 1950s and 1960s. The decline was attributed to several factors including: pollution from domestic and industrial wastes; siltation caused by rainfall; increased sea urchin grazing caused by a reduction in predators; storms; low nutrients and high temperatures caused by El Niño conditions (Wilson and McPeak, 1983; Tarpley and Glantz, 1992).

Kelp restoration was initially undertaken in 1963, off Point Loma, in an effort to reverse the trend of decline. The Scripps Institution of Oceanography and Kelco began a cooperative project to develop techniques to protect and restore forests of *Macrocystis*. The efforts proved successful (North, 1967). Kelp canopies at Point Loma increased from approximately 60 acres to nearly 2,000 acres (North, 1968a). The dramatic recovery at Point Loma was probably the result of several factors, including restoration, changes in water quality, and changes in oceanographic conditions (Wilson and McPeak, 1983). Kelco continued restoration work in San Diego County after 1968, and this work continued through mid–1993.

Kelp restoration off Palos Verdes Peninsula (PVP), Los Angeles County, began in 1967 and continued through 1980. The work was originally started by Dr. W. J. North of the California Institute of Technology. Only two adult *Macrocystis* plants remained in 1967 from a forest that was previously 1,500 acres (North, 1967). The California Department of Fish and Game (CDFG) began parallel restoration work at PVP in 1971 (Wilson et al., 1977, 1979). By 1971, the first naturally expanding kelp forest in twenty years was observed developing off PVP. Nearly 600 acres of kelp had become established off PVP by 1980, when restoration work was discontinued. Aerial surveys in 1989 revealed over 1,100 acres of kelp off PVP (Ecoscan, 1989).

Restoration of *Macrocystis* has also been conducted off Orange County between Newport Beach and Laguna Beach. A total of 18 acres of kelp was planted in this area from 1987 through 1989 by MBC Applied Environmental Services under contract with the CDFG (MBC, 1990). The Orange County Coastkeeper has recently (September 2000) applied for a grant to restore kelp near Reef Point in the Crystal Cove State Park Marine Reserve. They plan to raise kelp in the lab on small tile strips. After six to eight weeks the tile strips will be transferred to the restoration site and attached to the reef with rubber bands. Their goal is to restore one acre of kelp canopy by May 2001.

Kelp restoration was also conducted off Santa Barbara County in areas where *Macrocystis* grows on sandy substrates. These beds were destroyed by storms and warm water/low nutrients associated with the 1982-84 El Niño (Kelco, 1990, 1992; McPeak and Barilotti, 1993). Kelco began developing restoration techniques for this unique sandy habitat following the 1982-84 El Niño. In 1987, under contract with the CDFG, Kelco began work to restore the giant kelp growing on sand near Santa Barbara. Restoration work was supported by the CDFG from 1987 through 1991, and by Texaco in 1992. Best results were obtained offshore of Gaviota, where approximately 3000 plants had been secured to the bottom by mid–1993 (Glantz, pers. comm.).

Kelp restoration methods in California have evolved considerably since the first efforts were initiated in 1963. Restoration work can be divided into five area: (1) grazer control, (2) kelp transplanting, (3) securing plants in soft sediment habitats, (4) competitive seaweed control, and (5) providing substrate (Wilson and McPeak, 1983; McPeak and Barilotti, 1993). Table 3–1 lists restoration techniques that have been used successfully to restore *Macrocystis* in California. The following is a brief description of some of the techniques. For more detailed information see Wilson et al. (1977), Wilson and McPeak (1983), MBC (1990), Glantz (1991, 1992a, 1993), McPeak and Barilotti (1993).

Three species of sea urchins commonly graze and destroy forests of *Macrocystis* and create urchin barrens: *Strongylocentrotus franciscanus*, the red sea urchin, *S. purpuratus*, the purple sea urchin, and *Lytechinus anamesus*, the white seaurchin. Red and purple sea urchins prefer giant kelp to other species of seaweed in southern California (Leighton, 1966, 1971). Five sea urchin control methods have been used to protect or expand existing beds of *Macrocystis*: 1) hammering, 2) suction dredging, 3) quickliming (CaO), 4) feeding sea urchins, and 5) commercial fishing (Wilson and McPeak, 1983; Glantz, 1991, 1992a, b; 1993).

Hammers have been used effectively at Point Loma, especially in areas where sea urchins averaged less than 5/m$^2$ (Wilson and McPeak, 1983). Kelco biologists used hammers to control sea urchins in 125 acres of urchin dominated habitat at south Point Loma in 1981. The work resulted in development of *Macrocystis* throughout the 125 acre area.

### Table 3–1. *Macrocystis* Restoration Techniques Used in California

I. Hard Bottom Substrate

**A. Grazer Control (Sea Urchins)**

- Dredging
- Hammers
- Quicklime
- Commercial Fishing
- Feeding Sea Urchins

**B. Kelp Transplanting**

- Large adults secured to heavy anchor chain
- Large adults secured to rocky substrate by nylon line threaded through the holdfast
- Sub-adults secured to substrate with circlets of inner tube
- Sub-adults attached to a mudstone bottom using rubberbands, stakes, VEXAR, and tie-wraps
- Young plants attached to "stubs" of *Pterygophora* and *Eisenia* using rubberbands

**C. Competitor Control**

- Competitive seaweeds cleared using knife, hacksaw, or scythe

II. Soft Bottom Substrate (Santa Barbara Area)

**A. Kelp Transplanting**

- Attach cultured juvenile plants to mushroom anchors
- Attach natural juvenile plants to mushroom anchors
- Attach adult plants to mesh bags filled with rock

**B. Providing Substrate**

- Use mushroom anchors as substrate for natural kelp recruitment
- Use VEXAR as substrate for natural kelp recruitment

**C. Securing Plants**

- Use rebar staples to secure developing *Macrocystis* in soft sediment

A suction dredge has been used successfully to control purple sea urchins at Point Loma. A 4 inch pump, powered by a 9 HP Dietz Diesel, delivered approximately 700 gallons of seawater per minute. Sea urchins were dislodged with a hand rake and dredged through the 4 inch diameter hose. The technique worked especially well where sea urchins average 30 or more per m$^2$ (Wilson and McPeak, 1983).

Quicklime (CaO) was first used in 1963 to control dense sea urchin concentrations at Point Loma (IMR, 1963). The technique was developed by Dr. Dave Leighton, of the Scripps Institution of Oceanography, and was used through 1979. The CaO was dispersed from the surface in pebblized form until 1976. A diver-directed quickliming device was then developed that allowed dispersion underwater. The use of quicklime was in a large part responsible for successful restoration at Point Loma in the 1960s and 1970s.

A more recent technique that was tested for kelp restoration involved the use of artificial kelp plants constructed of plastic (Vasquez and McPeak 1998). These plastic plants were successful in reducing the density of purple and red sea urchins in sea-urchin-dominated areas by 85 % and 75 %, respectively. The sweeping motion of the blades across the substrate created a whiplash effect which is similar to that reported in natural kelp populations in Chile and southern California. The artificial plants also effectively protected giant kelp transplants that were placed in sea-urchin-dominated areas.

Research has shown that well fed sea urchins move little and allow recruitment and development of *Macrocystis* (Harrold and Reed, 1985). Kelco developed a unique method of sea urchin control in 1991 that involved feeding the grazing sea urchins to stop their destructive movement (Glantz, 1992b). The restoration work was done at a Point Loma site where sea urchin densities often exceeded 100/m$^2$. These urchins were destroying the kelp forest at a rate of 45 ft per month. Chopped kelp was pumped through a diver-directed hose to the grazing sea urchins along a front and in the barrens. Sea urchins in the front that were fed, no longer fed on the attached adult *Macrocystis*, stopped scouring the bottom, and allowed recruitment of juvenile plants to develop along the front as well as in the barrens.

Commercial fishing for red sea urchins has also resulted in protecting or restoring forests of giant kelp in some areas of California. The red sea urchin fishery in California began in 1972. The purple sea urchin fishery first began in 1993 but remains a minor component of total urchin harvest . The affect of sea urchin fishing on the *Macrocystis* community varies considerably, depending upon the numbers and species of the sea urchin population (Wilson and McPeak, 1983). In areas where the sea urchin population is mostly reds, harvesting can result in protecting and increasing the area of kelp. In areas where a mixed urchin population exists (and purples are not harvested), harvesting may result in slowing the destruction of loss of *Macrocystis* (Wilson and McPeak, 1983). In some instances, harvesting reds while leaving purples has resulted in a corresponding increase in purple sea urchins and no protection of the kelp resource.

Many transplanting techniques have been developed over the years to restore kelp to large areas. Only a few to these methods will be discussed here. For more information consult McPeak (1977), Wilson et al. (1977), Wilson and McPeak (1983), MBC (1990), Kelco (1992), and McPeak and Barilotti (1993).

Large adult plants have been secured to anchor chains by lacing nylon through the holdfast, attaching the plant to a buoy, that is tethered to the chain (Wilson and McPeak, 1983). Adult giant kelp has also been tied directly to rocky substrate by lacing nylon line through the holdfast and securing the plant.

Juvenile and sub-adult plants (2-10 fronds) have been transplanted and secured to the substrate using circlets of innertube placed over the holdfast. McPeak (1977) reported transplanting more than 35,000 young *Macrocystis* plants to La Jolla from 1973 through 1976. The young plants were attached to the cut "stubs" of competitive seaweeds *Pterygophora* and *Eisenia*.

A different transplanting technique was developed by Kelco biologists in 1990 for anchoring young adult plants (averaging 6-8 fronds) to mudstone bottom off Point Loma. The technique involved using nails, large rubberbands, tie-wraps, and Vexar to secure the plants. A total of 884 plants were transplanted to a 10 acre area off south Point Loma (McPeak and Barilotti, 1993). There were almost no *Macrocystis* in the area when the transplanting occurred. Excellent recruitment of giant kelp developed throughout the transplant area and in the surrounding areas, resulting in the development of *Macrocystis* canopies throughout south Point Loma.

Kelp beds near Santa Barbara are unique because most of them grow on sand. These beds were virtually destroyed by storms, warm water, and low nutrient conditions associated with the 1982-84 El Niño (McPeak and Barilotti, 1993). Restoration of

*Macrocystis* to these soft sediments requires special techniques. Giant kelp growing on soft substrates usually gets started by recruiting upon polychaete worm tubes of *Chaetopterus variopedatus* and *Eudistylia vancouverensis*. Many plants regularly recruited to these substrates, but few have survived, especially during periods of moderate to heavy water movement. Kelco biologists have found that the best method for restoring beds of *Macrocystis* on soft bottom is to secure naturally developing plants that would otherwise be lost to storms. Two rebar staples, each measuring approximately 18 inches in length, are used to staple each plant in the soft sediment. The stapled plants eventually develop huge holdfasts that are secure and partially buried in the sediment.

Kelp can also be restored or introduced into areas through the use of properly designed artifical reefs. Artificial reefs such as Mission Beach, Topanga, and Pitas Point were designed to provide habitat for kelp. All three reefs have produced kelp canopies. Southern California Edison has completed construction of an extensive experimental reef designed to recruit and sustain kelp canopies off San Mateo Point as part of an agreement to mitigate for canopies lost due to the operation of the San Onofre Nuclear Generating Plant.

**Bull Kelp**

Unlike the extensive restoration work done for giant kelp in southern California, no bull kelp restoration has ever been undertaken in the state. The technology to restore *Nereocystis* beds exists and has been utilized in Washington state for environmental mitigation and habitat improvement (Merrill, 1989; Merrill, 1991).

### 3.2.12 Importance of El Niño Events

The El Niño/Southern Oscillation (ENSO) is a large scale oceanic phenomenon linked to fluctuations in atmospheric pressure over the Pacific and Indian Oceans. Such phenomena may trigger oceanic and meteorologic events of global consequence. The El Niño was originally defined in terms of events off the west coast of South America that were frequently responsible for mass mortalities of marine organisms (Arntz, 1984). Under normal conditions the trade winds tend to deflect the Peru Current away from shore, resulting in considerable upwelling along the coast of Ecuador and Peru. The upwelled water, which can be 4-6° F colder than waters of the Peru Current, is rich in nutrients such as nitrates and phosphates. During the El Niño off South America, the normal current and wind patterns are disrupted, upwelling ceases, and warm nutrient-poor water persists. When the condition strengthens and persists for a year or more, it can have catastrophic effects on the anchoveta population and marine species that depend on these bait fish as food (Norton, et al., 1985).

Strong El Niños, that begin off South America, can eventually influence the climate, resources, and fisheries of California (Norton et al., 1985). A "California El Niño" is characterized by warm sea surface temperatures, a deeper surface mixed layer, a depressed thermocline, nutrient-poor water, greater poleward flow, and an anomalous high sea level (Barber and Chavez, 1983; Dayton and Tegner, 1984; Tegner and Dayton, 1987; North et al., 1993). El Niños impact forests of *Macrocystis* in California in a variety of ways that result in little or no canopy being produced, depending upon the severity of the event. Such impacts also affect kelp forest population dynamics, succession, and competitive interactions among kelp forest kelp species (Tegner et.al. 1997) The impact of the El Niño in California depends on the strength of the event. Mild El Niños, that slowed kelp growth, were felt along the coast of California during 1977-1978 and 1992-1993. Especially strong events impacted kelp resources and stopped commercial kelp harvesting off California in 1941, 1957-1959, and 1982-1984. The 1982-1984 El Niño was the largest ever recorded off South America and California (Rasmusson, 1984). Storms associated with the 1982-1984 El Niño also devastated kelp beds throughout California. The effects of this El Niño on *Macrocystis* in southern California were studied by Gerard (1984), Dayton and Tegner (1984), Zimmerman and Robertson (1985), Dean and Jacobsen (1986), Tegner and Dayton (1987, 1991), and North et al. (1993).

Zimmerman and Robertson (1985) studied a forest of giant kelp at Santa Catalina Island during the 1982-1984 major event. They found that deepened isotherms associated with the El Niño resulted in severe nutrient limitation and very low kelp productivity. Frond growth rates were so low that terminal blades formed before the frond reached the surface, eliminating canopy formation. Frond initiation rates were also extremely low and resulted in significant reductions in mean plant size. Plants growing above 33 ft were more severely affected by the nutrient limitation than plants growing at 66 ft. These results suggested that nutrient pulses associated with internal waves were critical for survival of *Macrocystis* pyrifera in nutritionally marginal habitats in southern California (Zimmerman and Robertson, 1985).

The mean nitrogen content of *Macrocystis* tissues (measured as % dry weight), which typically ranges from 1 to 4% in southern California, can be used as an indicator of the nutritional status (Gerard, 1982a; North et al., 1982). Gerard (1982c) concluded that the critical level representing no nitrogen reserves for growth was a nitrogen content of 1.1% for laminar tissue. Tegner and Dayton (1987) found some spring upwelling at Point Loma during the spring of 1983. *Macrocystis* at Point Loma had nitrogen reserves after the spring upwelling; basal blades averaged 2.7% N and canopy blades averaged about 1.5% N in early July, 1983. By October 1983, basal blades had dropped to between 1.1 to 2% and canopy blades to between 0.8 to 1.0% (Tegner and Dayton, 1987).

The relative growth rates of juvenile *Macrocystis* in southern California were substantially reduced during the 1982–1984 El Niño (Dean and Jacobson, 1986). The lower growth rates were correlated with increased temperature and decreased nitrogen availability. Fertilization of juvenile plants with slow-release nitrogen-phosphorus fertilizer increased the growth rate of juveniles to levels previously observed when the temperature was low and nutrient levels were high (Dean and Jacobson, 1986). The limitation in growth of juvenile giant kelp by levels of available nutrients during the El Niño was in contrast to the usual limitation in growth by irradiance during non-El Niño years. There was a shift in the relative importance of factors controlling growth of juvenile *M. pyrifera* during the El Niño (Dean and Jacobson, 1986).

In conclusion, in terms of kelp forest ecosystem changes, large-scale, low frequency oceanographic phenomena, such as El Niño or La Niña play a very important role in kelp forest successional processes, population dynamics, and competitive interactions with understory kelps (Tegner et. al. 1997). In terms of social-economics, El Niños can drastically reduce the standing crop and canopies of *Macrocystis* in California, resulting in a cessation or reduction of kelp harvesting for many months. Aquaculture, algin, and herring roe-on-kelp industries can all be severely impacted by significant El Niños in California.

## 3.3 Status of the Kelp Population in California

The areal coverage of giant and bull kelp canopies in California changes frequently. Canopies may be extensive one year or one season, only to disappear the next (North et al., 1993). Conditions that affect canopies are quite different in southern

California compared to central California and northern California. In southern California, conditions tend to be more benign resulting in reduced seasonal variability in the kelp forest community and dense canopy throughout the year (Rosenthal et al., 1974). Many southern California forests of giant kelp go through a three to five year cycle of abundance and decline (North, 1971b; Rosenthal et al., 1974). This cycle is usually associated with holdfast deterioration in older plants. Winter swells are larger and more frequent in central and northern California, than in southern California. There is a regular seasonal canopy cycle in central and northern California with maximum canopy in the summer and minimum in the winter (Miller and Geibel, 1973; Gerard, 1976; Foster, 1982; Kimura and Foster, 1984; Reed and Foster, 1982; Barilotti et al., 1985).

Many factors may be responsible for changes in the distribution of canopy, including: sewage pollution (Leighton et al., 1966; Wilson, 1982), El Niños (Jackson, 1977; Tegner and Dayton, 1987, 1991), sea urchin grazing (Leighton et al., 1966; Tegner and Dayton, 1991; Glantz, 1992), sea urchin grazing stimulated by sewage (North, 1974), sea urchin grazing caused by removal of sea urchin predators by man (North, 1974; Tegner and Dayton, 1981), and storms (Dayton and Tegner, 1984; Seymour et al., 1989).

The earliest detailed maps of kelp canopy distribution along the California coast were done in 1911-1912 (Crandall, 1915). The kelp beds were charted from a boat using a sextant and triangulation. Crandall (1915) reported 100.19 $mi^2$ of kelp canopy in California during his 1911-12 survey. Hodder and Mel (1978) suggested that Crandall's early survey may have over–estimated the size of the kelp beds in California, while Neushul (1981) thought that the early mapping was probably accurate because the size of some of the beds reported by Crandall have been repeated.

The California Department of Fish and Game charted and numbered the kelp beds in the nearshore waters of California in 1931 to assist with the management of commercial kelp harvesting. The numbering system has changed over the years and presently there are 74 beds designated in California from the Mexican–United States border to Point Montara, San Mateo County (Figure 2–1a,b,c,). In 1995, 13 additional beds were designated covering the area from Pt. Montara to the Oregon-California border. The official beds are designated in Section 165.5(j) and (k) of Title 14, California Code of Regulations (Appendix 1). These beds are not individual patches but rather geographic areas that are delineated along the coast by true bearings given from landmarks or points. Each kelp bed, therefore, is of a varying length and contains differing amounts of kelp canopy that change with time.

Official kelp beds in southern California, from the Mexico–United States border to Point Arguello in Santa Barbara County, are numbered 1-34 along the mainland (there are no Beds 11-12) and 101-118 around the offshore Channel islands. Beds from Point Arguello to Point Montara, San Mateo County (a point located approximately 20 miles south of San Francisco) are numbered 202-225. Official kelp beds were not delineated for the coastal area north of Point Montara until 1995, presumably because

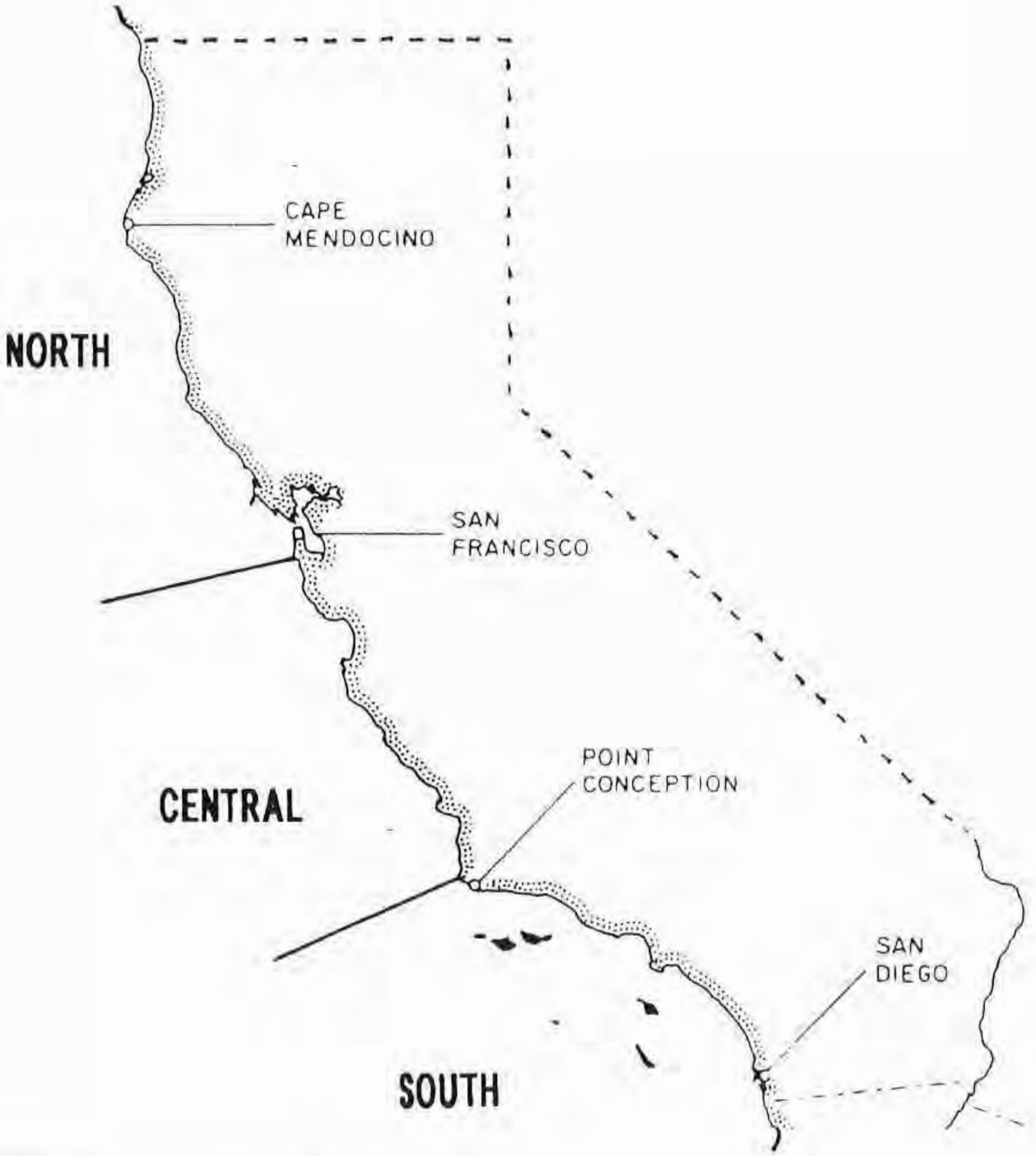


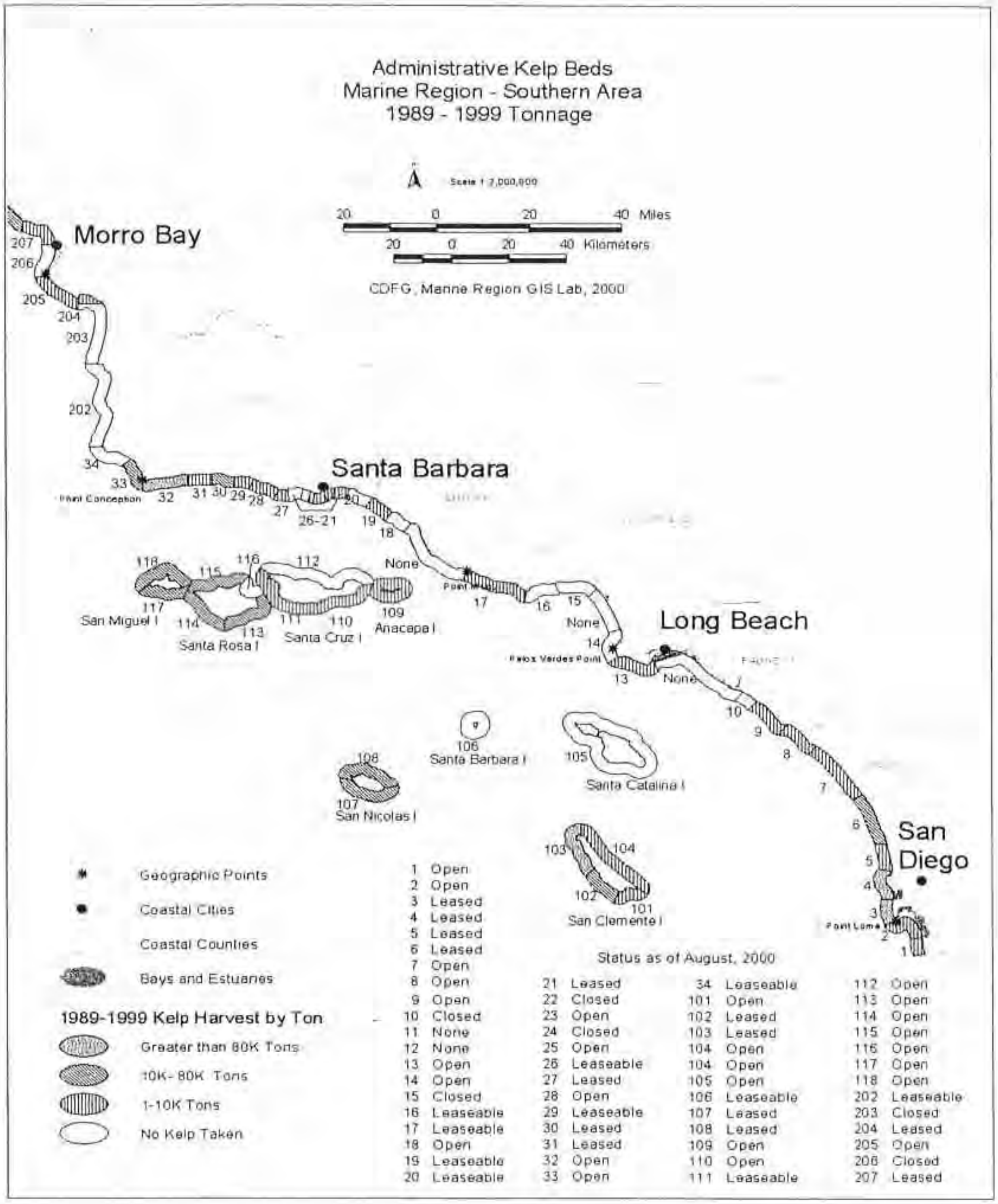
Figure 3-5. Regional division of California.

there was a paucity of giant kelp in the area when official beds were first established in 1917. There are, however, extensive beds of *Nereocystis* that occur from Point San Pedro, San Mateo County to Point Saint George, Del Norte County, which have been numbered 301-312.

Consequently, it is necessary to divide the state into three geographic regions to adequately address the status of the kelp populations in California: northern, central, and southern (Figures 3–5, 3-6a, 3-6b, 3-6c).

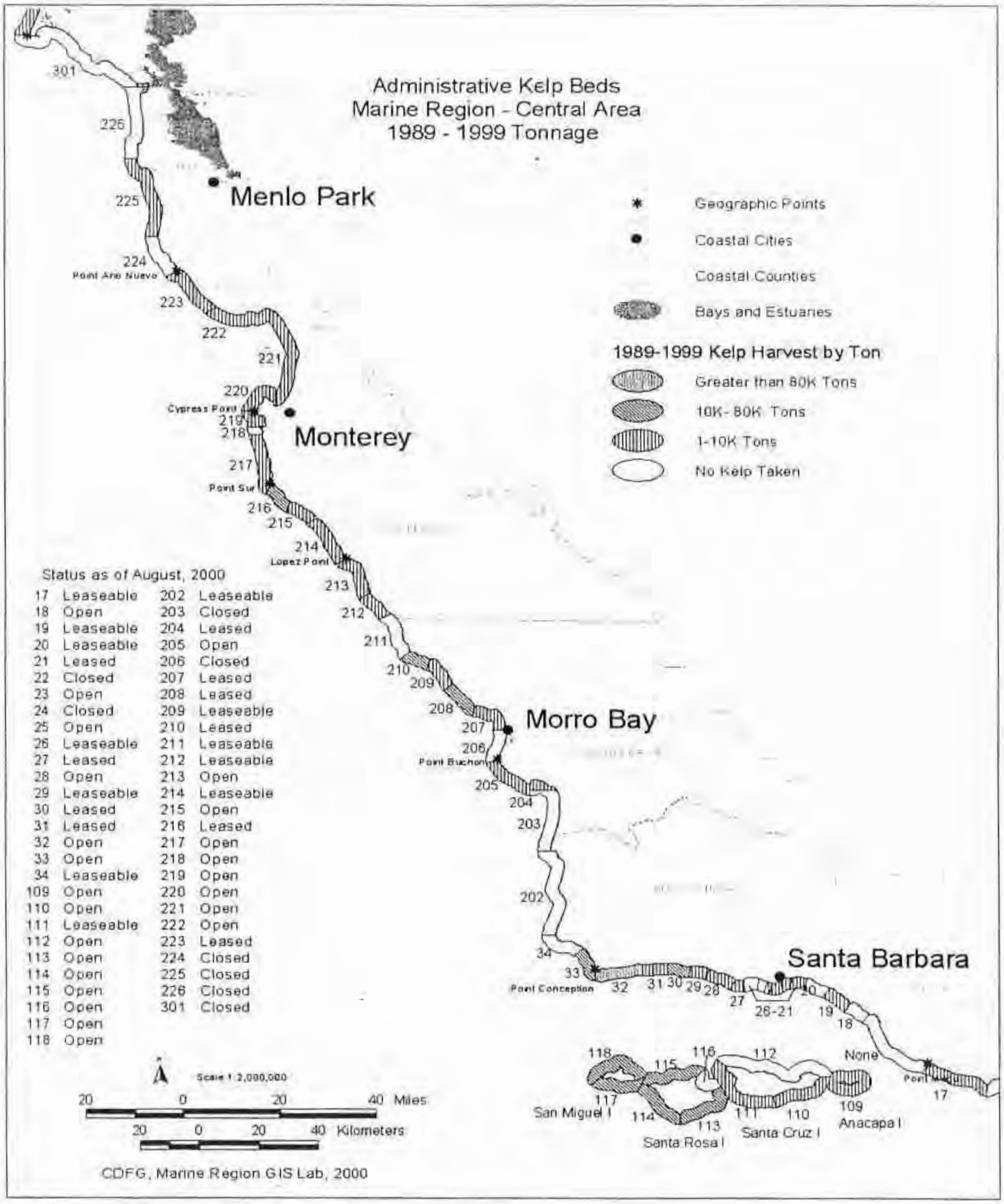
The northern region extends from the California–Oregon border to Point Montara, San Mateo County. This area experiences a high degree of wave energy because of frequent winds and storms. Water temperatures are usually cold and range from about 46°F (8°C) to 59°F (15°C). *Nereocystis* appears to grow well and persist under these cold water and stormy conditions. The central region extends from Point Montara to Point Arquello, Santa Barbara County. This region is also exposed to stormy conditions, especially during winter and spring months. Water temperatures are usually cold and range from about 50°F (10°C) to 59°F (15°C). *Macrocystis* is presently the most abundant species of canopy–forming kelp in the region, however, *Nereocystis* is also abundant along this stretch of coast.

The southern region extends from Point Arquello to the U.S.–Mexican border and includes the offshore islands. The region has a south facing aspect caused by the eastward turn of the coastline at Point Conception. The northern Channel Islands help protect much of the mainland from the northwest swells generated by storms to the north and from northwest winds. Water temperatures range from about 55°F (13°C) to 69°F (21°C) during the year, depending upon the area being sampled. Temperatures are colder to the north around San Miguel Island and warmer to the south around Santa Catalina Island and San Diego. *Macrocystis* is the dominant canopy–forming kelp species in the south coast region. *Nereocystis* does not occur in this region.



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | Open | 21 | Leased | 34 | Leaseable | 112 | Open |
| 2 | Open | 22 | Closed | 101 | Open | 113 | Open |
| 3 | Leased | 23 | Open | 102 | Leased | 114 | Open |
| 4 | Leased | 24 | Closed | 103 | Leased | 115 | Open |
| 5 | Leased | 25 | Open | 104 | Open | 116 | Open |
| 6 | Leased | 26 | Leaseable | 104 | Open | 117 | Open |
| 7 | Open | 27 | Leased | 105 | Open | 118 | Open |
| 8 | Open | 28 | Open | 106 | Leaseable | 202 | Leaseable |
| 9 | Open | 29 | Leaseable | 107 | Leased | 203 | Closed |
| 10 | Closed | 30 | Leased | 108 | Leased | 204 | Leased |
| 11 | None | 31 | Leased | 109 | Open | 205 | Open |
| 12 | None | 32 | Open | 110 | Open | 206 | Closed |
| 13 | Open | 33 | Open | 111 | Leaseable | 207 | Leased |
| 14 | Open | | | | | | |
| 15 | Closed | | | | | | |
| 16 | Leaseable | | | | | | |
| 17 | Leaseable | | | | | | |
| 18 | Open | | | | | | |
| 19 | Leaseable | | | | | | |
| 20 | Leaseable | | | | | | |

Figure 3-6a. Ten year kelp bed usage for beds from California-Mexican border to Morro Bay.



Status as of August, 2000

| | |
|---|---|
| 17 | Leaseable |
| 18 | Open |
| 19 | Leaseable |
| 20 | Leaseable |
| 21 | Leased |
| 22 | Closed |
| 23 | Open |
| 24 | Closed |
| 25 | Open |
| 26 | Leaseable |
| 27 | Leased |
| 28 | Open |
| 29 | Leaseable |
| 30 | Leased |
| 31 | Leased |
| 32 | Open |
| 33 | Open |
| 34 | Leaseable |
| 109 | Open |
| 110 | Open |
| 111 | Leaseable |
| 112 | Open |
| 113 | Open |
| 114 | Open |
| 115 | Open |
| 116 | Open |
| 117 | Open |
| 118 | Open |
| 202 | Leaseable |
| 203 | Closed |
| 204 | Leased |
| 205 | Open |
| 206 | Closed |
| 207 | Leased |
| 208 | Leased |
| 209 | Leaseable |
| 210 | Leased |
| 211 | Leaseable |
| 212 | Leaseable |
| 213 | Open |
| 214 | Leaseable |
| 215 | Open |
| 216 | Leased |
| 217 | Open |
| 218 | Open |
| 219 | Open |
| 220 | Open |
| 221 | Open |
| 222 | Open |
| 223 | Leased |
| 224 | Closed |
| 225 | Closed |
| 226 | Closed |
| 301 | Closed |

CDFG, Marine Region GIS Lab, 2000

Figure 3-6b. Ten year kelp bed usage for beds from Morro Bay to San Francisco Bay.

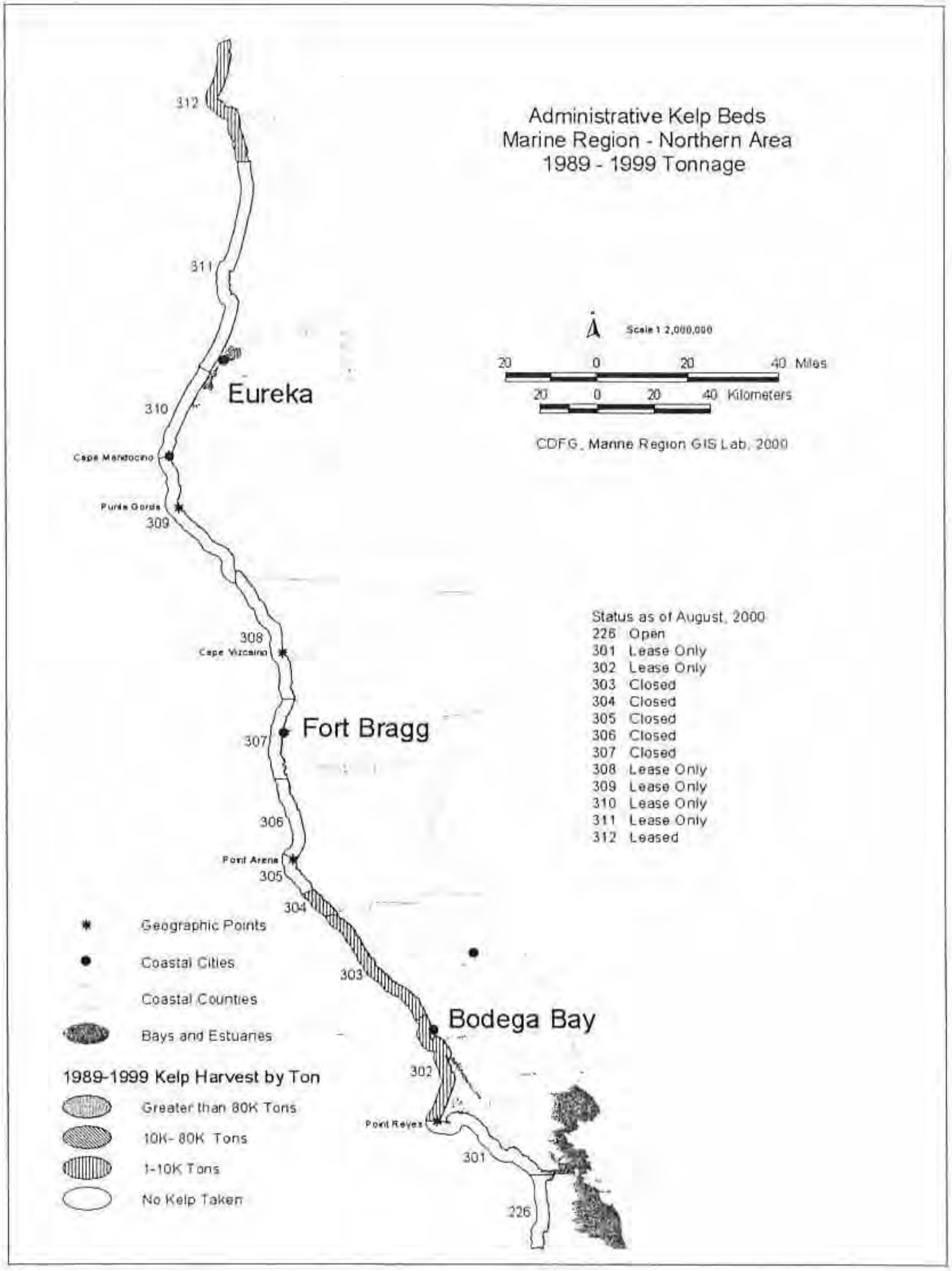


Figure 3-6c. Ten year kelp bed usage for beds from San Francisco Bay to the California-Oregon border.

### 3.3.1 North Coast

The kelp resources of the eastern Pacific coast were first mapped in 1911–1912. The survey extended from the Gulf of Alaska to Cedros Island, Baja California Sur. Since that time little work has been done along the north coast primarily due to the absence of *Macrocystis pyrifera* in this region. Current knowledge of the population levels of *Nereocystis* off the north coast is based on a 1989 survey of the California coast that extended at from Pt. Montara, San Mateo County to Shelter Cove, Humboldt County, a 1999 survey from Pt. Montara to the Oregon border, and information provided by a kelp harvester in Crescent City, California. Table 3-2 contains a summary of recent information.

**Table 3-2. Comparison of historical and current areal levels of *Nereocystis* populations in northern California. Area measured in square statute miles.**

| Year | North coast | Crescent City | Shelter cove | Cape Viscaino | Fort Bragg | Point Arena | Fort Ross |
|---|---|---|---|---|---|---|---|
| 1912 | 6.54[1] | 0.08 | N/D | 0.04 | 0.66 | 2.98 | 0.11 |
| 1989 | 5.71[2] | 0.75[3] | 0.01 | 0.04 | 0.59 | 1.78 | 0.35 |
| 1999 | 3.29 | | | 0.38 | 0.46 | 1.90 | 0.55 |

[1] Survey conducted from Oregon–California border to Point Montara (Department of Agriculture, 1915).

[2] Survey conducted from Shelter Cove to Point Montara (Ecoscan, 1989).

[3] Estimate of *Nereocystis* beds, not included in 1989 totals for north coast (Van Hook, pers. comm.).

Table 3–2 indicates that the bull kelp resource has diminished about 13% between the 1912 survey and the 1989 survey. However, the 1989 survey did not include the area from Shelter Cove to the California/Oregon border. If the estimated areal extent of kelp from Cresent City is added, the north coast resource rises to 6.45 square miles. The 1999 survey, however, indicates about a 42% decline in kelp coverage in the Pt. Montara to Shelter Cover area. Despite the fact that in 1999, anecdotal observations along the Mendocino coast indicated one of the most extensive kelp canopies in the last decade (Kalvass, pers.comm.). One factor in this apparent decline is the fact that the 1999 survey was done after a major storm had already passed through the region and destroyed some of the kelp beds. Additionally, kelp beds are subject to high variability in coverage and density from year to year. And finally, the method used to interpret aerial photographs in 1999 resulted in a more precise representation of kelp beds, implying that the 1989 survey probably overestimated the true extent of the beds ( Wright, pers.comm.).

Comparison of several areas along the north coast illustrates the variability that exists in this region. The fluctuations in *Nereocystis* biomass may be explained by a comment recorded during the 1912 survey. Captain John Olsen of the Point St. George Lighthouse reported that the kelp beds around the lighthouse were much sparser than in previous years. He remarked for several years he had difficulty rowing his boat to the lighthouse because the kelp was so thick (Crandall, 1915). Since year to year fluctuations are common, it is possible that the 1912 survey was conducted during a period of poor recruitment in the Crescent City area.

Barnes and Kalvass (1993) reported that the Fort Bragg area kelp beds appeared to increase in size and density between 1985 and 1988 based on aerial photographic surveys of the area. The *Nereocystis* beds were thought to have reached maximum potential in 1988. The increase was coincident with the removal of over 65 million pounds (27,000 metric tons) of red sea urchins (*S. franciscanus*) from Mendocino and Sonoma Counties by commercial divers, from 1985 to 1988. In 1992, the same beds showed delayed and reduced kelp recruitment and growth. The causes of the poor recruitment in 1992 may have been anomalously elevated nearshore water temperatures in coincident with reduced upwelling (Barnes and Kalvass, 1993). This example illustrates the kind of fluctuations that occur in the recruitment of bull kelp along the north coast and the factors which may play a role in the variability of this resource.

Another factor to consider is the estimate of potential areal coverage as it relates to bull kelp biomass. Ecoscan (1990) gave each bed a planimetric value which represents the sea surface that the canopy covers (Table 3–2). This value can also be thought of as the potential growing area. From their survey, it was determined that the bull kelp beds from Point Montara to Shelter Cove could cover an area of approximately 10 square miles. If the estimation of the available growing space for Crescent City is added the value increases to about 11 square miles. Thus in an optimal growing year, the bull kelp resources could increase about 44% above a typical year's coverage. This would still only represent 15% of the state's total kelp resources.

### 3.3.2 Central Coast

#### Giant Kelp

The kelp forests along the central coast have shifted from having fairly equal amounts of both giant and bull kelp from 1912 to 1967 to mostly *Macrocystis* in 1989. Crandall (1915) charted pure stands of *Macrocystis*, pure stands of *Nereocystis*, and mixed stands of the two species. He reported a total of 17.55 $mi^2$ of canopies in central California (Pt. Arguello to San Francisco): *Macrocystis* - 8.27 $mi^2$; *Nereocystis* - 6.61 $mi^2$; and mixed *Nereocystis* and *Macrocystis* - 2.67 $mi^2$. The 1967 survey by the California Department of Fish and Game charted 16.00 $mi^2$ from Point Arguello, Santa Barbara County to Point Montara, San Mateo County (Beds 202-225). The 1989 survey revealed 28.60 $mi^2$ of canopy along the central coast, a significant increase in kelp area compared to 1967.

The significant increase in kelp coverage in central California may be associated with changes in the abundance and distribution of sea otters (Sec. 3.2.9.1). Van Blaricom (1984) compared canopy distribution data from the early 1900s (when sea otters were essentially absent) with surveys in the 1980s (when sea otters were present). He suggested that *Macrocystis* canopies have increased in central California in recent years while *Nereocystis* has decreased as an indirect result of sea urchin removal by the expanding population of sea otters. Van Blaricom (1984) suggested that bull kelp in central California first colonizes areas where sea otters remove sea urchins because this species of kelp is initially more abundant where sea urchins exist. *Macrocystis* then gradually invades the *Nereocystis*. The canopy of giant kelp reduces light to the bull kelp restricting recruitment of the later species.

There have also been historical changes in the relative abundance of *M. pyrifera* and *N. luetkeana* in central California with sites changing completely or partially from one species to the other and vice versa (Yellin et al., 1977; Van Blaricom, 1984). Severe storms can cause a shift by removing *Macrocystis*, which is replaced by *Nereocystis* (Foster, 1982; Van Blaricom, 1984).

**Bull Kelp**

The distribution of bull kelp along this section of the coast is largely restricted to areas unsuitable for giant kelp (Burge and Schultz, 1973). Thus bull kelp is found skirting the outer edge of *Macrocystis* beds, inshore of the *Macrocystis* beds within the surge zone, or occurs as pure stands in areas of high disturbance such as Año Nuevo and Diablo Cove.

In 1912, the bull kelp beds represented approximately 32% of the kelp available in central California (Crandall, 1915). During the 1967 and 1989 kelp canopy surveys, no differentiation was made between *Macrocystis* and *Nereocystis* beds, therefore, no estimation of the amount of *Nereocystis* present could be made; only changes in relative abundance of kelp canopy were assessed. Our knowledge of what has been happening to the *Nereocystis* population along the central coast comes from long term studies conducted by the Department and Pacific Gas and Electric (PG&E). Together these organizations have documented the changes in *Nereocystis* abundance from 1969 to 1986.

From 1969 to 1977, Pacific Gas and Electric conducted aerial surveys between Point Buchon and Point San Luis (Bed 205). Within this area, *Nereocystis* is the dominant canopy–forming kelp. The survey area was divided into 3 segments: north (Point Buchon to Lion Rock), central (Lion Rock to one–quarter mile south of South Cove), south (southern boundary of central segment to Point San Luis). Within each of the segments, annual changes were variable (Figure 3–7).

For the 9–year period surveyed, the total canopy coverage fluctuated from a low of 0.16 $mi^2$ in 1969 to a high of 2.03 $mi^2$ in 1975. In 1976, the standing crop was approximately half of the previous year and continued to decline to 0.37 $mi^2$ in 1977 (Stephans, 1979). In 1989, the canopy cover equaled 0.64 $mi^2$ for the Point Buchon to Point San Luis area (Ecoscan, 1989).

Co–incidental to the aerial surveys, the Department conducted subtidal and shore–based visual surveys in Diablo Cove from 1970 to 1982 (Gotshall et al., 1986). For the first six years of the baseline study, there was a significant increase in the size and density of the bull kelp beds. By 1975, the beds were so thick the shore census could not be conducted because the overlapping blades and pnuematocysts would have rendered a count useless. The 1975 subtidal survey produced a count of over 400,000 bull kelp sporophytes in the cove. The apparent increase in bull kelp abundance was attributed to the reduction of the sea urchin population by sea otters, which moved into the area in 1973. By 1976, the bull kelp in Diablo Cove began to

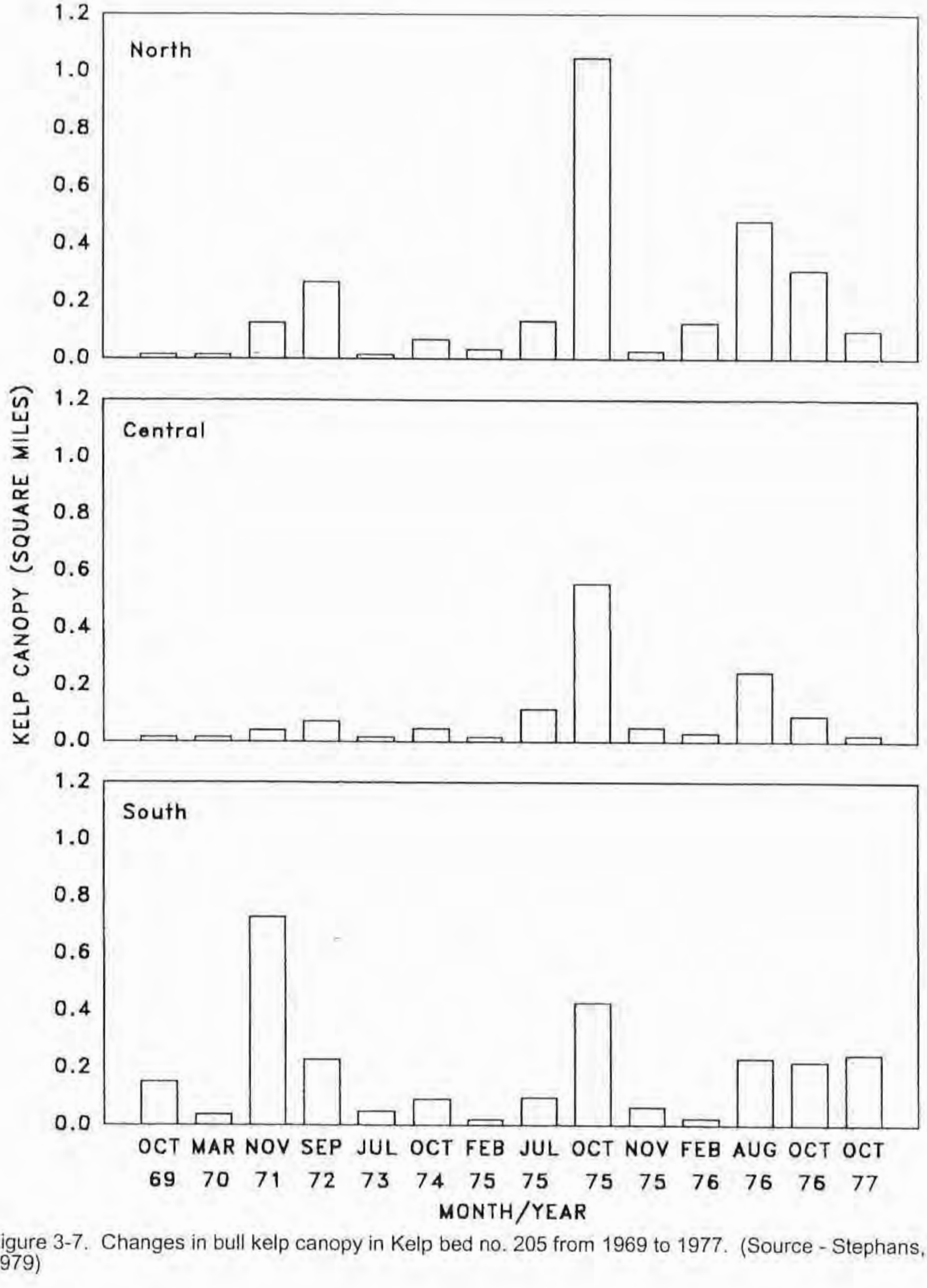


Figure 3-7. Changes in bull kelp canopy in Kelp bed no. 205 from 1969 to 1977. (Source - Stephans, 1979)

decline reaching a low of 1,127 plants in 1982 (Gotshall et al., 1986). The decline was probably due to the increase of the perennials *Laminaria dentigera* and *Pterygophora californica*. The removal of sea urchin grazing pressure allowed these subsurface canopy–forming species to subsequently invade areas once occupied by the annual *Nereocystis*. Once established, *Nereocystis* was unable to compete for space and light (Dayton et. al., 1984). In addition to the competition between *Nereocystis* and the other two brown algae, the coast was experiencing the effects of an El Niño. Thus the increase of water temperatures and decrease in nutrient levels probably aided the decline of the bull kelp at Diablo Cove and other locations (Jackson, 1977).

In 1982, PG&E took over the subtidal and intertidal surveys of Diablo Cove (PG&E, 1987). The shore survey of 1983 produced a count of approximately 10,000 plants in the cove. However, the surface survey for the next three years had counts averaging less than 1,000 plants per year.

The decline in plant numbers in 1985 and 1986 were the result of the increase in water temperature in the cove caused by Diablo Canyon Power Plant. They found that bull kelp sporophytes developed normally until their blades reached the sea surface and contacted the thermal plume. Premature blade loss followed in summer, which led to early degeneration of remaining tissue. This senescence does not normally occur until the late fall and winter (Burge and Schultz, 1973). In areas where the plants were protected from the plume, growth was normal. Despite the early loss of plants in 1985, during the spring of 1986 approximately 50,000 plants reached the sea surface but died back in the areas of thermal plume contact (PG&E, 1987).

### 3.3.3 Southern Coast

Crandall (1915) reported 100.17 $mi^2$ of *Macrocystis* canopy in southern California during the 1911-1912 survey. More recent one–time surveys reveal a 40% to 46% decrease in canopy since Crandall's survey (Table 3–3). The 1967 survey by the California Department of Fish and Game charted 53.86 $mi^2$ of *Macrocystis* in south coast kelp beds: 21.24 $mi^2$ around the Channel islands (Beds 101-118) and 32.62 $mi^2$ along the mainland (Beds 1-34). The 1989 survey of kelp beds along the south coast (Ecoscan, 1989) revealed 39.70 $mi^2$ of kelp; a decrease of 14.16 $mi^2$ or 26% compared to the 1967 survey. Most of this decrease (11.8 $mi^2$ or 22%) occurred in the Santa Barbara area where forests of giant kelp living on soft sediment were destroyed by the 1982-1984 El Niño and associated storms. Most of the beds growing on sand near Santa Barbara had not returned.

**Table 3-3. California coastal kelp resources - kelp canopy area survey (square statute miles).**

| | **1911/1912* survey** | **1967 survey**** | **1989 survey**** | **1999 survey***** |
|---|---|---|---|---|
| **north coast** | 6.54 | N/A | 9.89 | 3.36 |
| **central coast** | 17.55 | 16.00 | 28.60 | 3.02 |
| **south coast** | 100.17 | 53.86 | 39.70 | 11.38 |
| **Total** | 124.26 | 69.86 | 78.19 | 17.76 |

*Crandall, 1915; ** Ecoscan, 1989 *** CDFG, 1999

One of the most detailed studies of the variation in *Macrocystis* canopy coverage was done by North et al. (1993). During a 25–year period from 1967 through 1991, they used infrared aerial photography to study *Macrocystis* canopies along nearly 90 miles of southern California coastline. The aerial photographic surveys were flown several times each year (minimum: 2 flights in 1970; maximum: 35 flights in 1973). Twenty beds (patches) of giant kelp were followed along the Orange and San Diego County coastlines. The areal data reported by North et al: (1993) represented approximately the maximal value measured for each bed during a given year. The 25-year study period included: the wettest year of the century (1978), the largest El Niño (1982-84), a significant La Niña, a period of lower than average water temperatures and high nutrient levels, (1989), and a "200-year" storm (1988). North et al. (1993) noted that about half the beds displayed no canopy for at least one year of the study period.

Ten out of 15 beds in existence during the early 1980s displayed their lowest areas during the 1982-84 El Niño, while 12 of 20 beds in existence at the end of the 1980s displayed either their highest or next-to-highest areas during the 1989 La Niña (North et al., 1993). The large fluctuations in kelp bed sizes in Orange and San Diego Counties during the 1980s probably resulted from the combined effect of water temperature and nutrient availability (North et al., 1993).

The long-term records of canopy coverage among kelp beds of San Diego and Orange Counties indicated some common trends, representing responses to broad scale phenomena such as El Niño/La Niña and major storms. *Macrocystis* canopies were fairly stable from 1967 through 1979 and averaged around 2.3 $\text{mi}^2$ in size. The decade of the 1980s, however, was not stable and was marked by wide fluctuations in canopy coverage. Most of the fluctuations were associated with the 1982-84 El Niño or the 1988-90 La Niña. Canopies dropped to a low of 0.3 $\text{mi}^2$ during 1983-84, while a maximum of 5.8 $\text{mi}^2$ was reached in 1990.

The southern region has historically had the highest levels of kelp canopy when compared to both the central and northern regions (Table 3–3). The abundance of *Macrocystis* is largely due to the favorable environmental conditions: periodic upwelling, the presence of a broad, shallow continental shelf, availability of good bottom substrate, and the protection provided by Point Conception to the north and the Channel Islands to the west which lessens the impact of offshore winds and storms. However, the El Niños of 1982–84, 1992-93 and 1997-98 had a far greater impact on the southern kelp beds than on the central and northern beds.

## 3.4 Socioeconomic Environment

The kelp community along the California coast contributes to human society in both goods and services. Twenty-five fish and invertebrate species are harvested directly from the kelp by commercial and sport fishermen. These nearshore fisheries supply state, national and international markets. In addition, nearly 120,000 tons of kelp have been harvested in the past decade for direct or indirect human consumption. *Ecosystem services* are the conditions and processes through which natural ecosystems, and their component species, sustain and fulfill human life (Daily, 1997). Kelp provides direct services to humans through recreation and tourism. Healthy kelp communities provide indirect services to humans by sustaining the nearshore food-web that makes fisheries products available for exploitation.

### 3.4.1 Commercial Kelp Harvesting Industry

**Giant Kelp**

Giant kelp was first harvested along the California coast during the early 1900's. Scofield (1959) provides a thorough description of the early history of kelp harvesting in California. Many small harvesting companies began operating along the coast from San Diego to Santa Barbara, beginning in 1911. One large company, the Hercules Powder Company, opened in 1916 and operated harvesters from San Diego. The early companies primarily extracted potash and acetone from kelp for use in the manufacture of explosives during World War I (Scofield, 1959; McPeak and Glantz, 1984; Neushul, 1987; Tarpley and Glantz, 1992). Harvesting of giant kelp stopped shortly after the signing of the armistice in November, 1918 and did not resume until the early 1920s.

Giant kelp was again harvested off the California coast beginning in the late 1920's. Philip R. Park, Inc., of San Pedro, began harvesting kelp in 1928 to provide ingredients for livestock and poultry food, while the Kelco Company of San Diego (now ISP Alginates Inc., a Division of International Specialty Products.) began harvesting and processing giant kelp in 1929 for the extraction of algin (Tarpley and Glantz, 1992).

<u>ISP Alginates Inc and the Algin Industry</u>

Kelco Alginates, now known as ISP Alginates, has harvested and processed giant kelp since 1929 and has developed many applications for the unique natural compound, algin, which is found in the cell walls of the plant. Algin is valuable as an efficient thickening, stabilizing, suspending, and gelling agent. It is used in a wide range of food applications including desserts, gels, dairy products, in salad dressings, beer, and in canned foods. It is also important in industrial applications and is used in paper coating and sizing, textile printing, and welding-rod coatings. Algin also has pharmaceutical, cosmetic, and dental applications. The annual sales of algin products manufactured in California in the late 1990's was $40 million.

Initially, ISP Alginates harvested only the kelp beds near San Diego. As production needs increased, or giant kelp productivity decreased due to oceanographic conditions near San Diego, it became necessary for ISP Alginates to harvest distant beds. Currently, ISP Alginates leases 15 kelp beds from Monterey Bay to Imperial Beach, near the U.S.-Mexico border, covering approximately 28.4 square miles. Their harvest accounts for 95% of all kelp harvested in the state. During the past 70 years, ISP Alginates has developed a canopy-harvest strategy based on the economics of the algin business and kelp biology. ISP Alginates maintains a resource assessment division with staff biologists to manage the harvest of the leased and open beds they utilize.

Kelp is a resource whose annual productivity is determined by changes in nutrient levels, water temperature, weather and other geophysical conditions. Storms and expanding urchin populations are two primary reasons why a kelp bed can have high productivity one year and low the next. Seasonally, as water temperatures warm or as nutrient levels change, the canopy sloughs. If storms persist, the canopy is torn from the kelp holdfast and stipes. Therefore, the decision to harvest a particular bed must be made by ISP Alginates on a monthly - or sometimes weekly - basis, after evaluating the productivity of the bed. Unproductive beds are uneconomical to harvest.

ISP Alginates prefers to harvest the beds nearest San Diego harbor, specifically beds 2,3 and 4. (Glantz, pers. comm.). The closeness of these beds makes their harvest most economical. Moreover, these beds - as well as other beds in the Southern California Bight - commonly experience high nitrification associated with a cool upwelling in the summer. With a mild winter, these highly productive beds can grow up to 30 tons of kelp per acre annually and sustain 2 or 3 canopy harvests per year. If ISP Alginates can meet its harvest quota from beds 2, 3 and 4, it may not need to harvest from any other beds. For the same biological and economic reasons, ISP Alginates prefers to purchase kelp harvested from beds along coast of Baja California Sur, Mexico. The Mexican kelp is harvested primarily by Productos del Pacifico, an Ensenada-based company that holds concessions on the kelp beds from the U.S. border to the Sacramento Reef, near El Rosario, Baja California Sur.

Most years, however, there are biological, geographic and economical reasons that require ISP Alginates to harvest beds further from home, either around the southern Channel Islands or along the Central California coast. Consequently, ISP Alginates continues to lease beds which it infrequently uses.

Having kelp beds available for harvest over a wide geographic range allows for utilization of the most mature canopies, allowing younger canopies time to develop (Glantz, pers. comm.). For example, bed 216, south of Monterey, is a large, broadly dispersed, deep-water kelp bed with high productivity during the summer and early fall. The outer canopy can be harvested safely by ISP Alginates's large harvesting vessel while the portion of the bed located in shallower water is never harvested by them. Beds 102 and 103 on the west side of San Clemente Island are highly productive in years with light storm activity and significant upwelling. In high storms or warm water years, it is not economically feasible to harvest any kelp from these beds. Similarly, beds 107 and 108 at San Nicolas Island can be the most productive beds of the entire Bight in a year with calm seas and strong upwellings. Since 1989, these two beds have suffered from two major El Niño events and the development of a large urchin population. Given the current condition of the beds, it is not economically or biologically realistic to harvest these beds and may not be for many years to come. Accordingly, to maintain an efficient and consistent harvesting operation, and to utilize the resource according to its level of productivity, it is necessary to be able to harvest kelp beds in different locations along the California coast (Conner and McPeak, 1982).

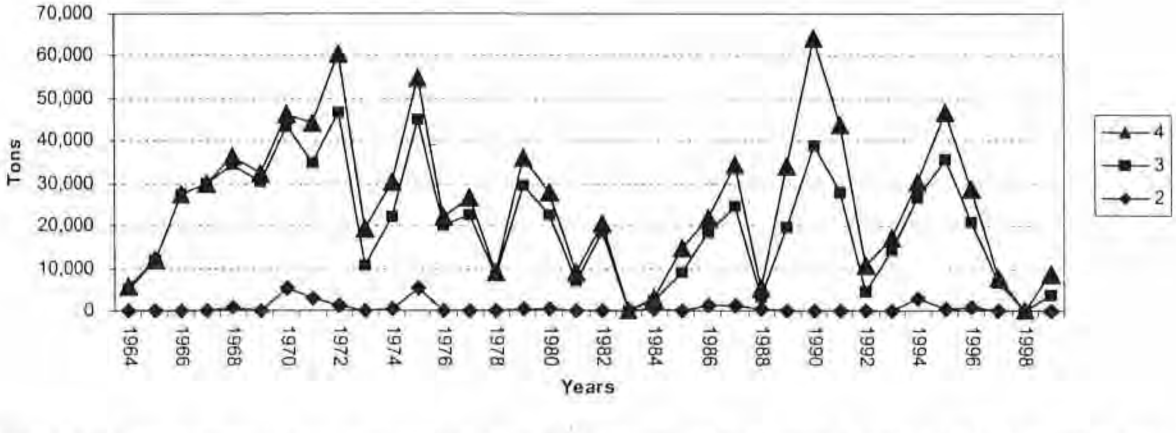


Figure 3-8. Fluctuations in harvest tons for beds 2, 3, and 4. (Data compliments of ISP Alginates Inc., 2000)

The Figure 3-8 shows harvest fluctuations in kelp beds 2-4 that reflect kelp bed productivity. That productivity may be a result of storm events, water temperature, nutrients, grazing or human impact. Beds with low productivity are uneconomical to harvest; thus, from the perspective of this resource use, the harvest appears to be self-regulating.

Beds 30-32, located north of the San Diego and offshore island beds, provided productive kelp canopy for harvest during periods when ISP Alginates experienced low harvest in its preferred beds 2-4 (compare Figure 3-9 to Figure 3-8). From 1974 -1980, beds 30-32 provided high yields, but they were impacted by the 1983-84 El Niño and nearly destroyed by the 1988 '200 year storm.' In addition, the kelp in bed 30 underwent a habitat and general location change. Prior to the storm of 1988, the kelp in bed 30 grew on an offshore sandy substrate. The storm cleared the sand off of a shallower rocky substrate. After a period of 8 years, a new rock-based kelp community developed. Bed 31 never recovered from the El Niño and subsequent storm, possibly because of the difficulty kelp has developing on sandy substrate. Today bed 31 produces no harvestable kelp.

Severe storms and El Niños can have a significant impact on the commercial kelp harvesting operation. The January, 1988 a "200 year storm" virtually destroyed all harvestable kelp canopies in California overnight (McPeak, pers. com). Plants were uprooted, set adrift, and cast ashore during this violent storm. It was several months before processors were able to harvest canopies of giant kelp in southern California. The 1982-1984 El Niño was the strongest on record (Sec. 3.2.12). The El Niño and associated storms devastated the kelp beds. The effects of El Niño on *Macrocystis* are apparent in the harvest records; in 1982, ISP Alginates harvested 75% of its long-term average at Point Loma, but nothing was harvested in 1983, and only 9% in 1984, all at the beginning of the year.

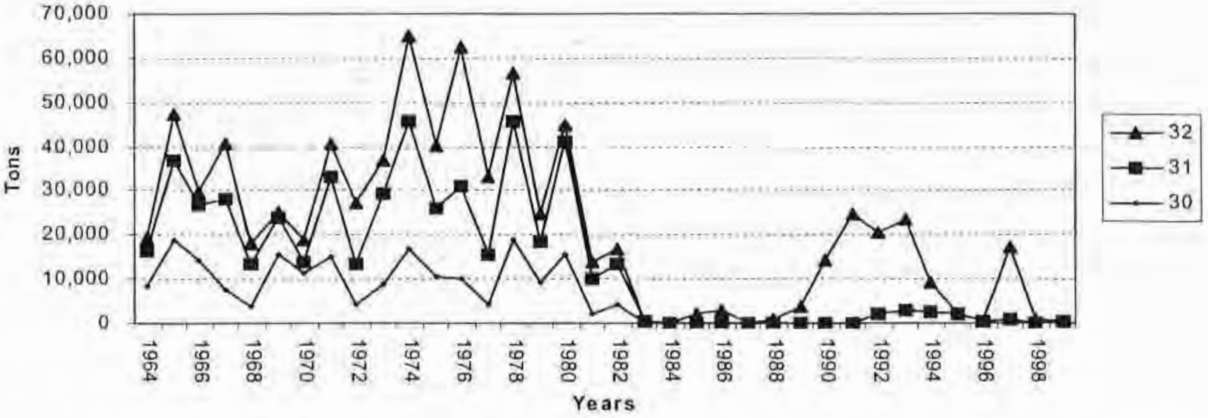


Figure 3-9. Fluctuations in harvest tons for beds 30, 31, and 32. (Data compliments of ISP Alginates Inc., 2000)

The 1998 El Niño caused a greater than 66% drop in ISP Alginates harvest from 1997. Kelp productivity coastwide increased by approximately 30% in 1999. During the El Niño, some of the most productive beds (e.g. beds 3, 4, and 103) fell to zero harvestable kelp canopy. Due to localized cool water upwellings, beds 117 and 114 produced the best yields during this period, although those yields were significantly less than in the previous 2 years. These beds are located on the far western and south-western sides of the Channel Islands. Both bed 114 and 117 are somewhat protected from wind and high swells because of their geographic location. The additional time and expense required to harvest these beds make them a less attractive economic option, but during the 1998 El Niño, they provided the greatest yield.

Beds 3, 4, and 103 are highly productive under normal weather patterns. During the 1998 El Niño, they produced no harvestable kelp. Other beds provided minimal amounts of harvestable canopy at considerable time and cost (Figure 3-10).

During the 1998 El Niño, ISP Alginates harvested 25% of its annual kelp quota from leased beds off the coast of Baja California. As in California, certain beds in Mexico were devastated by the warm El Niño waters and others experienced remarkable growth due to steady upwelling and nitrification. In the 1999 recovery period, California kelp provided 50% of ISP Alginates' harvest requirement and the beds off of Baja provided much of the balance. At times, when fresh *Macrocystis* is unavailable from California or Mexico, expensive dry seaweeds imported from Chile and other parts of the world are used for algin extraction (Glantz, ISP Alginates, pers. comm.).

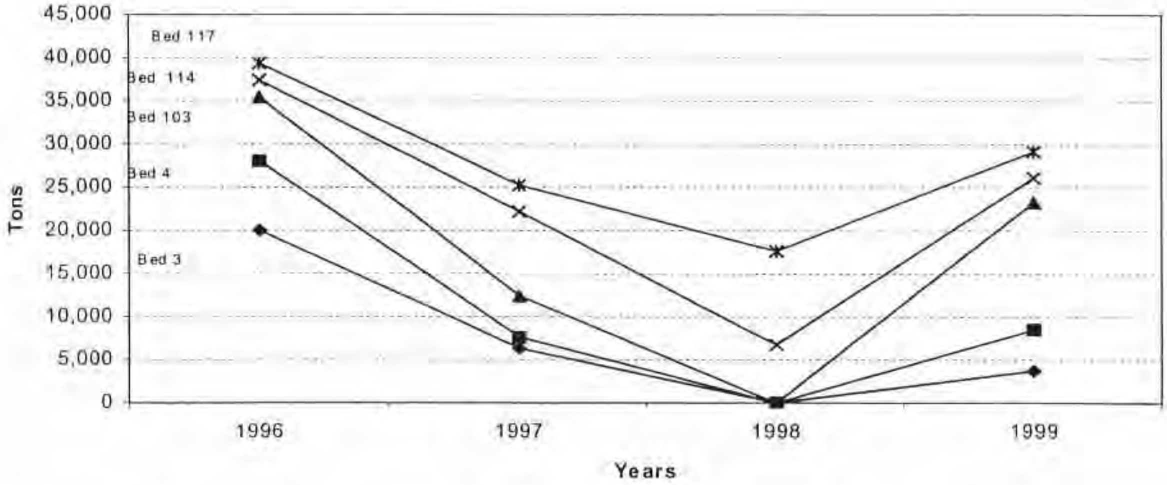


Figure 3-10. Comparison of high yield beds during the 1998 El Niño. ( Data compliments of ISP Alginates Inc., 2000.)

Giant kelp grows exceedingly well during La Niña conditions when ocean temperatures are cool and nutrient levels are high (North, et al., 1993). A significant La Niña occurred in southern California during 1990. Kelp has been maximally harvested in San Diego County since the late 1930s. The kelp harvest in San Diego County in 1990 was the best ever by ISP Alginates, since their operation began in 1929.

Over the past decade, ISP Alginates has reduced its kelp harvest by 50% due to business decisions (Figures 3-11 and 3-12). The international sodium alginate market has become more competitive, with overseas harvesters and producers bringing cheaper labor and manufacturing costs to the market. ISP Alginates now concentrates on processing high quality algin for foods, beverages and pharmaceuticals. Since 1993, the company has changed its production strategy to stabilize and streamline the processing of algin from wet kelp. As a result, ISP Alginates is harvesting less kelp annually. They try to avoid the seasonal influence of kelp productivity by obtaining approximately 6,000 to 7,000 tons per month from whichever Mexican or California beds are most productive.

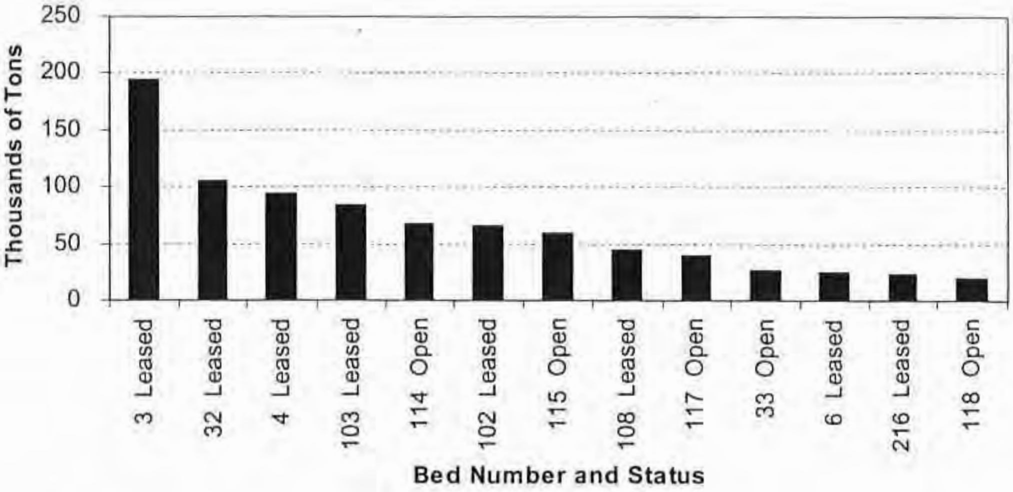


Figure 3-11. High use kelp beds, 1989-1999.

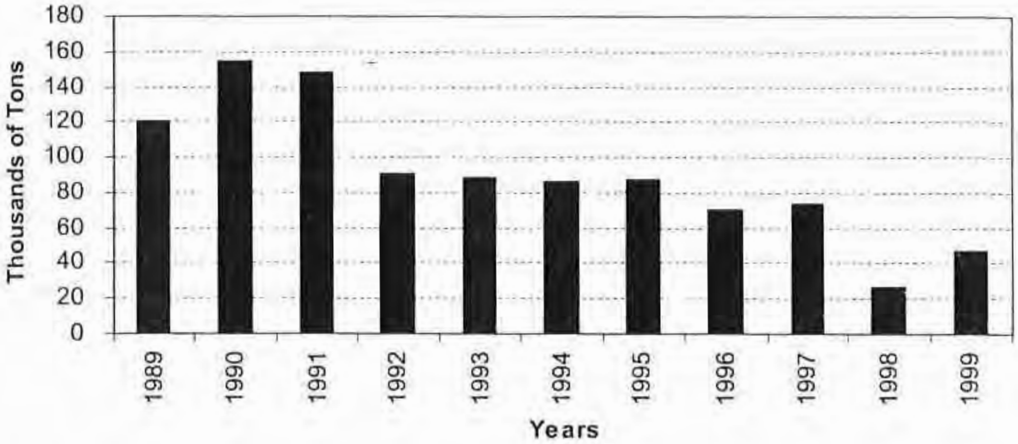


Figure 3-12. Coastwide kelp harvest, 1989-1999.

### ISP Alginates Harvest Techniques

The vessels used for harvesting by ISP Alginates are specially designed and range in length from 140 to 180 feet. The majority of the length of the vessel is taken up by the bin, the area that holds the cut kelp. The harvesters have reciprocating blades (the cutting mechanism) mounted at the base of a conveyer system (drapers) located on the stern of the vessel. The harvester usually arrives at the kelp bed shortly after daylight. The main engines are secured, drapers are lowered into the water to a depth of 3 feet, and a bow propeller is engaged that pushes the harvester stern-first through the kelp bed. Kelp is cut, brought aboard on the drapers, and deposited in the ship's bin. The wheelhouse, from where the captain operates the harvester, is located directly over the drapers and the cutting mechanism. The captain, therefore, has an excellent view of the operation while the harvester moves slowly through the kelp bed at a speed of about 1.5 kts. Modern harvesters carry as much a 600 tons of *Macrocystis* collected during a day of harvesting.

The large harvesters have a draft of about 12 feet and must avoid pinnacles and rock hazards in the kelp beds. The harvesters work in water depths no shallower than about 30 feet. For all practical purposes, these large vessels are only able to harvest about 50% of the canopies within a given kelp bed. The remaining 50% is not harvested.

Giant kelp is especially suitable for mechanical harvesting because: 1) the deep-water habitat allows for use of the large harvesting vessels; 2) photosynthesis, growth, and buoyancy are distributed along the entire length of the plant and, therefore, are not eliminated when the surface portion of the frond is removed; and, 3) surface canopy is regenerated by younger fronds that are growing beneath the surface (Clendenning, 1971).

The Marine Resource Department at ISP Alginates regularly conducts aerial surveys to assess *Macrocystis* resources throughout California. These surveys entail low-level flights over the kelp beds to determine abundance, condition, maturity, and harvestability of the resource. Beds of *Macrocystis* in southern California are usually surveyed once a month; occasionally more often. The central California resource, from Cayucos to Monterey, is usually surveyed about four times a year, since harvestable canopies are virtually nonexistent during the winter and early spring months (Glantz, pers. comm.). Information from the surveys is used by the Harvesting Department to schedule vessels to the most mature canopies, allowing younger canopies time to develop. There are important advantages to harvesting only mature canopies. The older fronds, prior to sloughing and being lost to natural causes, have a higher algin content and provide more biomass per area. The harvesting operation to obtain kelp for algin extraction is a year-round operation when resource is available.

### Mariculture Industry

Giant kelp is also harvested commercially in California to supply mariculture companies with food for rearing abalone. Although each company maintains its unique business objectives, many of them serve the high demand for abalone found in restaurants responding to the coastal tourist trade. There are also state, national and international markets for cultured pearls, abalone meat, shells and, potentially, abalone viscera (for fertilizer, among other products). Abalone aquaculture businesses along the coast range economically from large companies to small hobby operations. As of the end of 1999, the combined abalone farmers account for less than 1.7% of the annual kelp harvest. This figure may increase as the international supply of wild abalone is exhausted and farmed abalone gains market importance.

The Cultured Abalone leases bed 27, north of Santa Barbara. Since 1996, their kelp harvest has increased by approximately 15% annually, in response to a growing abalone market. During the 1998 El Niño, they entered a co-lease with ISP Alginates for bed 208, which is located north of Morro Bay. The Cultured Abalone contracts the harvest of the shallow inshore kelp, and when necessary, Kelco harvests the outer margin, beyond the 6 fathom line of bed 208. The Cultured Abalone harvested approximately 560 tons of kelp in 1999, and they expect to increase their kelp requirement by 15% annually over the next 5 years.

The four abalone growers, Pacific Mariculture, US Abalone, Monterey Abalone, and Pacific Abalone, along with a herring eggs-on-kelp business (Grillo Enterprises) formed the Monterey Bay CO-OP in response to concerns raised over harvesting of kelp along Cannery Row. The issue of kelp harvesting along Cannery Row came to the forefront during the formation of the Ed Ricketts Underwater Park by the City of Monterey. An underwater park that was conceptually developed by a grass roots movement where citizens expressed concern for the environment. The area of the underwater park extends from the Breakwater to Lover's Cove, an area within the boundaries of Bed 220. The CO-OP was developed to deal with kelp-related issues in the Ed Ricketts Underwater Park. The remainder of Bed 220, and Beds 221 and 222 have not had the user conflicts that have occurred within the area of the underwater park.

The two main kelp harvesters in Bed 220 are Monterey Abalone Company and Pacific Abalone. Herring-egg-on-kelp fishing is a seasonal activity that takes place during the winter. Other user groups include scientific collectors for public aquariums and university researchers. US Abalone mainly harvests in Bed 221 and when sea conditions permit, Bed 222. US Abalone on occasion, usually during extended severe winter conditions, also harvests Bed 220. The area of the underwater park is important to US Abalone during extended southernly winter storms when sea conditions make operating out of Santa Cruz Harbor hazardous. The combined kelp needs of the two Monterey abalone growers utilizing Bed 220 is less than 250 tons annually. The estimated needs of US Abalone is 420 tons with an annual increase expected in response to increased demand for abalone pearls, meat, and shells.

A study by Coastal Solutions Group was stimulated by concerns over the possible negative biological effects of kelp harvesting by local aquaculture firms on giant kelp, rockfish, and sea otter populations (Donnellan and Foster 1998). The impacts analysis of the study proved ambiguous because of insufficient data on the long-term spatial and temporal nature of Bed 220. The study did, however, highlight the importance of considering scale in determining harvest impact. The average annual harvest of kelp canopy from Bed 220 over the past decade has been less than 400 tons, but a rough estimate of drift kelp produced from Bed 220 is 200,000 tons per year. The current harvest, therefore, is less than 1% of the estimated drift kelp available from this bed.

Other Bed 220 users, such as divers, kayakers, boaters, and sport fishermen may also have impacts on the kelp bed and kelp dependent fisheries there. In a separate study by Coastal Solutions Group, it was estimated that over 60,000 divers use Bed 220. This study concluded that in large concentration, divers may permanently alter the community structure of this kelp bed.

Bed 220 is an open bed that can be harvested by anyone with a valid kelp harvesting license. In the past decade, ISP Alginates, Pacific Mariculture, and other members of the Monterey Kelp CO-OP, the Monterey Bay Aquarium, scientific researchers, and herring fishermen have all harvested kelp from this bed. Currently it is harvested only by small-scale hand-harvesters.

The Abalone Farm leases beds 204 and 207 near Morro Bay. Over the past 6 years, they have also harvested from several open beds as far south as Santa Monica (bed 17) and as far north as Santa Cruz (bed 222). They harvest an average of 1,800 tons per year using a small, shallow mechanical harvester. Their operation runs at full capacity with 4 million abalone, and they do not anticipate expansion over the next 5 years.

Twenty other kelp harvesters hold current licenses to take kelp from open beds coastwide. Their combined harvest has traditionally been less than 2% of the total annual kelp harvest. Two of the larger harvesters, Sea Farms and Pacific Mariculture, are no longer in business. Consequently, the harvest from these licensees is expected to drop below 1% beginning in 2000.

### Kelp Harvest Techniques for Abalone Aquaculturists

Kelp harvest vessels used by abalone aquaculturists are smaller than those used by ISP Alginates. Many harvesters use modified Navy landing craft, approximately 60 feet in length, to harvest giant kelp. These harvesters are capable of working in relatively shallow water because of their shallow draft. They have the cutting blades mounted on the bow and carry between 15 and 25 tons of kelp. The small harvesters have been used primarily in the Pismo Beach to Point Estero area and near Santa Cruz. One of the harvesters was also used in southern California in 1993 and 1994 when the giant kelp resource was poor in central California.

Kelp is also harvested by hand to supply abalone being cultured in southern California. The Ab Lab, located in Port Hueneme, harvests kelp from small boats (usually less than 30 feet in length) from kelp beds north west of Point Dume and at Santa Cruz Island. Kelp is either cut at the surface, using a knife attached to a pole, or the person harvesting the kelp enters the water directly to cut the surface canopy. The cut fronds are bundled together and pulled aboard the boat by hand.

### Historical Kelp Harvest Information

Kelp harvest fluctuates for reasons that include oceanographic change, weather patterns, water temperature, and nutrient levels. It also changes when the kelp industry's harvest requirements change. The following Tables of total harvest by year and total harvest by bed reflect a combination of both natural and anthropogenic harvest variables.

### Bull Kelp

Until the late 1980s there was little targeted harvest of bull kelp in California, except as a small component of the localized edible seaweed industry. In central California, *Nereocystis* is often in mixed beds with *Macrocystis* and would have been incidentally taken in those operations, but not recorded separately on harvest records. Department records indicate about 19 tons of kelp, probably a mixture of *Macrocystis* and *Nereocystis*, were harvested from what is presently bed 302 off the Bodega Bay, Tomales Bay area between 1993 and 1999. All of this kelp would have been used by local abalone mariculturists. A local Fort Bragg firm, 'Pickles from the Sea' harvested bull kelp under the authority of CCR 165(e)2, which allowed them to take up to 2 tons per year within closed beds 303-307.

The mariculture firm Abalone International in Crescent City, Del Norte County harvests *Nereocystis* for abalone food from their leased bed 312, obtained in 1997. This company has been in operation since 1988, and has been harvesting bull kelp from Point Saint George to Crescent City harbor since that time. In order to follow their own harvesting patterns, and because designated kelp beds did not exist in northern California, the company established 13 unofficial beds in the area in 1988. From 1990-1994, Abalone International and the Department began working together to determine the possible effects of small scale harvesting on *Nereocystis* populations (Kalvass, pers. comm.) (Table 3-4).

Since the operation began, the amount of kelp harvested annually has increased substantially. In the first year about six tons of bull kelp were harvested, even though the kelp was abundant, and in 1996, 132 tons were taken. The initial increases in take were due to additions to the abalone stock held by the company and later due to the feed requirements of abalone growing in size (Van Hook, pers. comm.). While the harvest levels have increased, the actual harvesting operations have become more efficient and effort had remained fairly low (less than 100 hrs per year) through 1994. In 1990, approximately half a ton could be harvested in one hour, while in 1994, 1.2 tons could be harvested in the same time

**Table 3-4. Total annual *Nereocystis* harvest, number of months harvesting occurred, average weight harvested per trip, and annual effort in Crescent City, 1988-1994.**

| Year | Total Weight (tons) | No. of Months Harvest Occurred | Average Weight/Trip (pounds) | Annual Effort (hours) |
|---|---|---|---|---|
| 1988 | 6 | 6 | 500 | 12 |
| 1989 | 8 | N/A | 500 | 16 |
| 1990 | 12.6 | 7 | 622 | 28 |
| 1991 | 33.4 | 11 | 1261 | 53.5 |
| 1992 | 91 | 9 | 3974 | 49 |
| 1993 | 149 | 12 | 4585 | 87.5 |
| 1994 | 101 | 9 | 5315 | 81.3 |

N/A - Information not available

Abalone International's harvest operation consists of one 17–foot Boston Whaler, or 19–foot skiff when available, which they use to transport the kelp from the beds to their facility in the harbor and two people who cut the kelp. The kelp is hand–harvested to a depth of about 2.5 ft below the surface which allows the take of the upper portion of the stipe, the pnuematocyst and all the fronds. Typically harvest takes place when the canopy is at the point of highest tonnage per acre (60 to 80 tons per acre) and the fronds have turned a rich copper brown color. The company rotates harvest among the beds based on the availability of mature (post–sori release) canopy.

Kelp harvesting can occur throughout the year in Crescent City because the coastal topography (broad, flat promontory) of the area creates a storm shadow similar to the one created by Point Conception. Storms from the northwest often damage the exposed beds near Point Saint George but have little effect on the *Nereocystis* beds in the lee of the promontory. Occasionally, storms will track in from the south and then the reverse is true (Van Hook, pers, comm.).

Abalone International's 1997 bid application for the lease of bed 312 required a kelp bed biomass estimate in accordance with CCR 165.5 b(5). They estimated an area of 205 acres of kelp beds in the area between Pt. St. George and Whaler Island within bed 312. Their November 1996 survey yielded a point estimate of 5475 tons (no confidence limits provided) of bull kelp within those 205 acres, at 27 tons per acre. Based on that survey their annual harvest would be limited to 15% of that estimate, equivalent to 821 tons. While their harvest up to that time was only 132 tons (in 1996), or 16% of their allowance, their bid application projected steady harvest increases through 2001 peaking at a 500 ton projected harvest.

### 3.4.2 Commercial Fisheries Harvest

Many commercial fisheries utilize the kelp beds due to the large number of fish and invertebrates that inhabit them (Section 3.2.9). In several instances, harvesting takes place within the kelp beds (i.e. lobster and sheephead trapping) or adjacent to them (i.e. set longlines). In the herring-egg-on-kelp (HEOK) fishery, kelp is harvested, strung on lines, and floated in San Francisco Bay to attract Pacific herring. This fishery is different from the others because it actually uses kelp to attract herring and as part of the harvested product. The following paragraphs give an overview of a few of the fisheries that target kelp forest populations (Table 3–5).

**Table 3-5. Total commercial pounds landed of key species harvested from kelp beds, 1995 to 1999.**

| Species | 1995 | 1996 | 1997 | 1998 | 1999* |
|---|---|---|---|---|---|
| California sheephead | 253,800 | 252,300 | 366,400 | 261,200 | 129,900 |
| Sea Cucumber | 156,800 | 387,900 | 381,200 | 615,800 | 458,800 |
| Wavy Turban Snail | 0 | 700 | 2,400 | 65,600 | 24,300 |
| Red abalone | 65,500 | 62,400 | 33,300 | closed | closed |
| California spiny lobster | 616,400 | 669,500 | 914,200 | 735,700 | 494,000 |
| Rock crab | 935,400 | 1,040,800 | 1,181,200 | 1,231,800 | 788,500 |
| Red sea urchin | 22,259,000 | 20,074,500 | 18,013,900 | 10,550,400 | 14,130,000 |

* Preliminary

**Nearshore Finfishes**

The Nearshore Fisheries Management portion of the MLMA of 1998 defined nearshore finfish species as rockfish (genus *Sebastes)*, California sheephead *(Semicossyphus pulcher*), greenlings (genus *Hexagrammos*), cabezon (*Scorpaenichthys marmoratus*), and other species found primarily in rocky reef or kelp habitat in nearshore waters. Since the early 90's greater emphasis has been placed on identifying individual fish species harvested from this group and avoiding market categories that combine multiple species. The Department has established a dockside sampling program that reinforces the importance of tracking the harvest intensity of this developing fishery. Data for this analysis has been drawn from the sampled and sorted market category for each species and the nominal categories for non-specific catch.

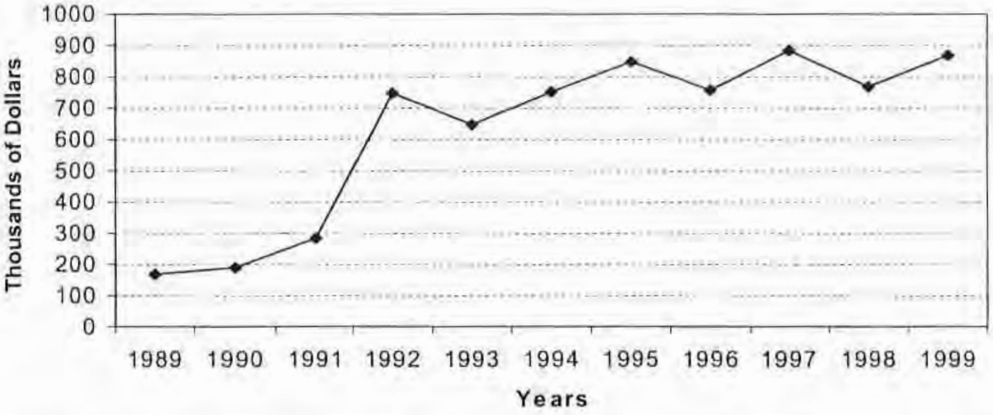


Figure 3-13. Changes in total ex-vessel revenue in the live finfish fishery, 1989-1999.

**Table 3-6. Annual Price Per Pound for kelp-reef related fish, 1989- 1999.**

| | Blue Rockfish | Black Rockfish | Olive Rockfish | Copper Rockfish | Gopher Rockfish | Kelp Rockfish | Black& Yellow | Kelp Greenling | Treefish |
|---|---|---|---|---|---|---|---|---|---|
| 989 | 0.37 | 0.36 | 0.47 | 0.74 | 1.15 | - | 1.30 | 0.41 | - |
| 990 | 0.38 | 0.37 | 0.45 | 0.58 | 1.00 | - | - | 0.54 | - |
| 991 | 0.48 | 0.37 | 0.50 | 0.73 | 0.75 | 0.53 | 0.85 | 1.00 | - |
| 992 | 0.45 | 0.57 | 1.65 | 0.69 | 1.40 | 0.48 | 1.36 | 0.89 | - |
| 993 | 0.58 | 0.43 | 2.00 | 0.72 | 1.45 | 1.02 | 1.54 | 1.42 | - |
| 994 | 0.49 | 0.46 | - | 1.26 | 1.57 | 1.33 | 1.38 | 1.86 | - |
| 995 | 0.51 | 0.50 | 0.31 | 1.17 | 1.88 | 1.05 | 1.72 | 1.62 | - |
| 996 | 0.49 | 0.54 | - | 1.27 | 1.94 | 1.31 | 1.73 | 2.11 | 1.74 |
| 997 | 0.46 | 0.52 | 0.52 | 1.31 | 2.45 | 2.03 | 2.09 | 2.56 | 3.01 |
| 998 | 0.59 | 1.02 | - | 1.54 | 2.35 | 1.62 | 2.24 | 3.05 | 2.33 |
| 999 | 0.79 | 0.90 | 1.20 | 1.42 | 2.54 | 2.81 | 3.30 | 3.47 | |

The principal goal of this nontraditional fishery is to deliver fish live to the consumer in as timely a manner as possible. Trucks or vans equipped with aerated tanks are used to transport fish directly to buyers. This fishery has increased substantially since 1988, and it continues to supply communities with live and premium quality fishes. The impetus of this fishery is the unprecedented and increasing high price paid for live fish (Figure 3-13, Table 3-6) (Pattison, 1999).

**Sea urchin**. One of the most important shellfish fisheries in California is the red sea urchin (*Strongylocentrotus franciscanus*) fishery. The red sea urchin is a keystone herbivore of kelp forest communities throughout the nearshore waters of California (Kato and Schroeter, 1985). As mention in Section 3.2.7.3, sea urchins, as the top grazer of kelp, play a role in its distribution and recruitment within the subtidal environment.

Red sea urchins are harvested by divers who generally use surface supplied air delivered through a hose (hooka gear) instead of self contained underwater breathing apparatus (SCUBA). Hooka gear consists of a low–pressure air compressor which feeds air through a hose to the diver's regulator. The hose is fed out from a reel so the diver has more maneuverability underwater. The urchins are gathered with a rake or hook and placed into large mesh bags which when full are lifted to the surface. Occasionally the bags, hoseline, and even the diver have to be freed from entangling kelp by cutting or breaking away stipes.

The sea urchin fishery is managed by the Department, which uses a combination of size limit, limited entry, and seasons in its efforts to maintain adequate population levels in the State (Kalvass and Hendrix, 1997).

**Rock crab**. The rock crab fishery is made up of three species: the yellow rock crab (*Cancer anthonyi*), the brown rock crab (*C. antennarius*), and the red rock crab (*C. productus*). Approximately 95% of the landings in this fishery come from southern California, although rock crabs inhabit the nearshore waters of the entire state (Parker, 1993).

The three species are commonly found on sand near rocky reefs and within kelp beds around the holdfasts of kelp plants, where they prey on a variety of invertebrates. Rock crabs, along with several species of fish, are considered large predators associated with kelp but the exact nature of the role that crabs play in kelp forest community dynamics is unknown (Foster and Scheil, 1985).

Rock crabs are harvested using baited traps. The traps are set and buoyed either singly or as part of a string (two or more traps tied together). Trap designs and materials vary but most employ single chamber, rectangular traps of 2X4– or 2X2–inch wire mesh. Once set, the traps are left in place for 48 to 96 hours before being checked. A single harvester may use 200 or more traps at one time. Fishermen tend to replace their traps in the same location until fishing in that area diminishes. This creates pathways in the kelp canopy because of the passage of the boats along the same course. The kelp that is cut loose will either fall to the bottom to be eaten by sea urchins and other herbivores, drift out to sea, or become part of the beach litter, or a combination of these events may occur (Larson pers. comm.).

**California Spiny Lobster**. The commercial fishery for California spiny lobster (*Pandulirus interruptus*) is small in total tons landed when compared to sea urchin landings (Table 3–5) but is among the top ten species of highest commercial value. Lobster fishermen received an average of $6.00 per pound for legal size lobster in 1999. The commercial fishery for lobster occurs from Point Conception south to the U.S.–Mexico border and includes islands and banks off southern California.

The range of California spiny lobster is from Monterey Bay south to Manzanillo, Mexico. Spiny lobsters are found primarily from the intertidal zone to 43 fathoms, in mussel beds and rocky areas with crevices, often in kelp beds. They generally hide in crevices and holes during the day and may be found on sandy bottoms at night. *Macrocystis* and other algal species, invertebrates, and small fish are preyed upon by lobster. Like rock crabs, lobster are a part of the kelp forest community but their role is still undefined.

Commercial harvesters may only use traps to take spiny lobster. The Fish and Game Commission regulates the take of lobster and harvesters must obtain a permit from the Commission. Lobster of at least 3.25 inches in carapace length may be taken during the season. The season begins on the first Wednesday in October and ends the first Wednesday after March 15th. All traps must be labeled with the fisherman identification number, the traps must be emptied at least every 96 hrs, weather permitting, and the traps must contain escape ports (Schultz, 1992). The number of traps used by a single fisherman is not restricted and several harvesters have been known to use as many as 500 traps during peak season. Like the crab fishery, lobster harvesters will use the same locations repeatedly until landings fall. Repeated running from trap to trap in the kelp beds causes the canopy to be cut away by the boat's propeller and creates pathways into and throughout the beds. This phenomenon was photographed by North (1969).

**Sea Cucumber.** About 460,000 pounds of sea cucumbers were harvested from California waters in 1999 by commercial divers, representing a 25% decrease from the previous year's total. Most of the catch is taken in southern California waters, with divers almost exclusively harvesting the warty sea cucumber (*Parastichopus parvimensis*) while trawlers primarily take the giant red sea cucumber (*P. californicus*). Divers take their sea cucumbers as far south as San Diego, but most of the catch is taken off the four northern Channel Islands in depths of 6-20 fm. The sea cucumber catch summarized in Table 3-5 is for those taken by divers in habitats more likely to be associated with kelp beds than those taken by trawlers. There are about 102 sea cucumber dive permittees in California out of 130 total cucumber permits (CDFG, 2000).

**Abalone**. There are three species of abalone that were harvested commercially in California prior to 1997: red abalone (*Haliotis rufescens*), pink abalone (*H. corrugata*), and green abalone (*H. fulgens*). In 1997, the area from San Francisco Bay to the California-Mexican border was closed to commercial and recreational harvest of abalone. The Department determined that these species had suffered stock collapse due to overfishing. Prior to 1992, the commercial fishery for black abalone (*H. cracherodii*) was second in pounds landed to red abalone. However, this species suffered significant stock declines due to a condition called "Withering Foot Syndrome" and the fishery was closed in 1992 (Karpov, et. al, in press).

Abalone are found in the intertidal and subtidal zones of California. Their distribution by species is tied to water temperature and depth. Red abalone are distributed throughout the state but are more prominent in the shallow subtidal than the intertidal, and in southern California, are found subtidally near upwelling centers along the coast and at the Channel Islands. The other two species of abalone (pinks and greens) occur south of Point Conception in the subtidal zone (Karpov and Tegner, 1992).

In order to protect northern California stocks from overharvest, abalone north of San Francisco Bay can only be harvested by recreational free divers, diving without the aid of SCUBA. A sport abalone stamp is required to take abalone and in 1998, the first year of this regulation, 32,000 stamps were sold, with 35,000 sold in 1999. Abalone divers are limited to 4 abalone per day and in possession (Karpov, pers. comm).

**California Sheephead**. There has been a small fishery (averaging about 10,000 pounds) for California sheephead (*Semicossyphus pulcher*) since the 1800's. In the last decade, however, sheephead landings have increased dramatically reaching a high of approximately 234,000 pounds in 1993 then falling substantially to 129,900 pounds in 1999. The renewed interest stems from the demand for fresh, live fish to supply Asian seafood restaurants. Commercial fishermen received about $2.64 per pound of live sheephead in 1998.

California sheephead range from the Gulf of California to Monterey, but are rarely found north of Point Conception. This species frequents rocky areas and kelp beds from the surface to 150 feet and deeper; females are usually found in shallower depths than the males. Typical food items are sea urchins, crabs, sand dollars, mussels, abalone and bryozoans (Feder et. al.,1974). While sheephead are most often observed in kelp beds and are known to venture farther from the bottom in the presence of kelp, the exact role that sheephead play, if any, in the kelp forest community is unclear (Feder et. al., 1974).

The live sheephead fishery uses baited wire traps to capture small females. These traps are similar in design as those used by crab harvesters. The basic design is a 3'x2'x1.5', double compartment trap with two entrance funnels. Traps are usually constructed of 2"x2" wire mesh (Palmer–Zwahlen, et. al., 1993). Since sheephead inhabit *Macrocystis* beds, harvesters will set out traps adjacent to and within the kelp beds, along the southern California coast and around the Channel Islands. The activity of setting the traps and checking them causes a small amount of damage to the kelp canopy and may result occasionally in the removal or damage of holdfasts by the movement of the traps during storm surge.

The livefish trap fishery is a limited entry fishery in California south of Point Arguello. Among other limitations, all participants in the fishery are required to purchase a finfish trap permit. Those participants that fish along the mainland may use no more that 50 traps. All traps are required to be marked with the fisherman's identification number. If left in the water overnight, each trap is required to be open and unbaited (CDFG 2000).

**Pacific Herring**. Pacific herring *(Clupea pallasi)* utilize San Francisco Bay as a spawning ground during the winter months (November through March). Pacific herring are demersal spawners, attaching their eggs to intertidal or subtidal vegetation, or any vertical surface free of silt and algal growth (Blaxter and Holliday 1963, Stacy and Hourston 1982, Haegele and Schweigert 1985). These surfaces include pier pilings, rock walls and several species of native vegetation, such as seagrass *(Zostera* sp.) and the red algae (*Gracilaria* sp.)

Commercial harvest of herring eggs on native vegetation began in Tomales Bay in 1965, and in 1966 the Fish and Game Commission accepted sealed bids for the opportunity to take 5 tons of eggs-on-seaweed in San Francisco Bay (Spratt 1981). The eggs-on-seaweed were harvested by divers, with *Gracilaria* and *Laminaria* being preferred by the export market to Japan (Moore and Reilly 1989). During 1985-86 herring spawning season, eggs were harvested using giant kelp, *Macrocystis* sp., which was suspended in the water from a log raft (Moore and Reilly 1989). Since 1989, the commercial harvest of herring eggs on kelp in San Francisco Bay has been restricted to the use of *Macrocystis*, and the herring eggs on kelp (HEOK) fishery (also referred to as the spawn on kelp or roe on kelp fishery) has operated using a fishing method known as the open pound method. Currently, there is no commercial HEOK fishery in Tomales Bay.

In the open pound fishing method, weighted lengths of kelp are suspended from floating rafts (Figures 3-14) or lines in areas where spawning activity is known to occur.

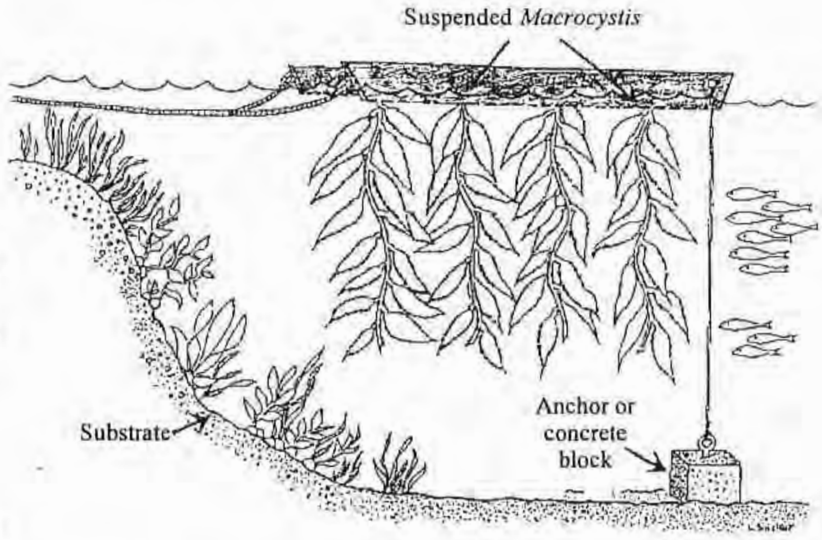


Figure 3-14. Illustration of a typical open pound (Shields et. al., 1985).

The rafts, or pounds, are constructed of metal, wood or plastic and measure approximately 2500 square feet, and approximately 1 ton of kelp is suspended per raft. Kelp is harvested from either Monterey or the Channel Islands (Table 3-7), and the useable portion (Figure 3-15) is trucked to San Francisco and suspended as close to the beginning of a spawning event as possible to insure freshness and quality of product. The rafts are towed to probably spawning locations within the bay and anchored. The kelp and herring roe are harvested once a spawning event has ended.

Participants in the HEOK fishery must possess a herring permit for the limited entry commercial herring fishery in San Francisco Bay, and they must waive their fishing privileges for the gill net fishery to obtain a herring eggs on kelp permit. There has been an average of ten permits issued per season over the past eleven years. The quota for the HEOK fishery is part of the total allowable whole fish quota for San Francisco Bay, and each herring eggs on kelp quota allocation is equivalent to the permittee's individual share in whole fish based on a conversion factor of 0.2237. Current regulations allow permittees to suspend kelp as many times as necessary per season in order to fill their herring eggs on kelp quota. Permittees are limited to two rafts and/or lines per permit.

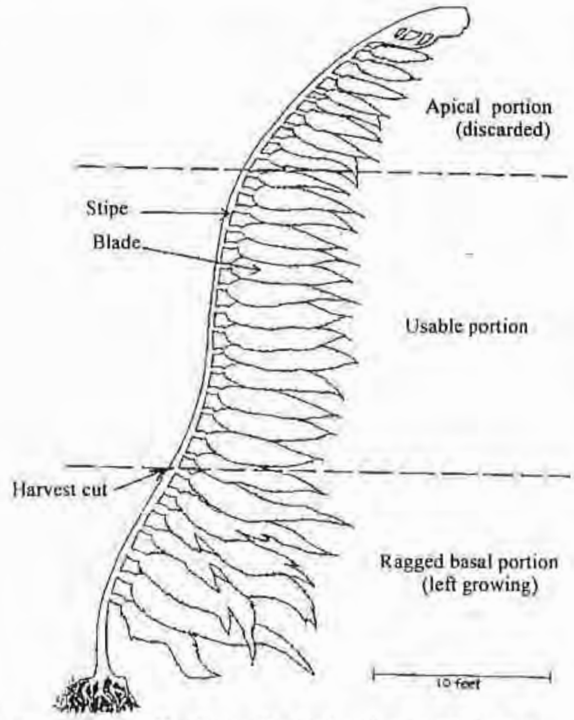


Figure 3-15. Portion of a kelp plant used on a pound.

Quotas for the San Francisco Bay commercial herring fishery are set according to annual biomass estimates of the spawning population, and are limited to a total commercial catch of not more than 20 percent of the spawning biomass from the previous season. As the herring population has fluctuated over the years, so has the total allowable quota. Since 1989, the HEOK quota has ranged from a high of 286 (1996-97) to a low of 35 tons (1993-94) (Table 3- 7). Although the quota has a direct influence on the total landings of HEOK product per season, several environmental factors during the season also affect the success of landing marketable (i.e., 3 or more layers of eggs on each side of the kelp blade) herring eggs on kelp product. For example, temperature and salinity can effect kelp condition. *Macrocystis* grows along the Pacific coast, but is not found growing in San Francisco Bay. The different salinity and temperature characteristics found in the more estuarine water of the bay may cause *Macrocystis* to deteriorate (Lobban et al. 1985). During seasons of heavy rainfall, coordinating kelp suspension and spawning events is crucial and much of the suspended kelp can deteriorate before a marketable product can be successfully harvested. This situation is illustrated in the recorded landings for the 1997-98 season (Table 3.8), when El Niño conditions (heavy rainfall and relatively warm water) resulted in the rapid deterioration of much of the kelp suspended for harvest.

Herring eggs on kelp is a relatively high priced product sold primarily for export to Japan. Product is graded according to the number of layers of eggs on both sides of the kelp blade, and the higher the product grade (i.e., more layers of eggs, even coverage on both sides of the blade) the higher the market price. However, price can fluctuate widely from year to year. For example, the highest product grade of herring eggs on kelp has ranged from $5/pound to $20/pound ($10,000/ton to $40,000/ton). Estimates of price paid to British Columbia producers have declined from a high of $45/pound in the mid-1990's to less than $10/pound in 1999 (Department of Fisheries and Oceans 2000). Price depends upon factors such as: the comparative value of the U.S. dollar and the Japanese yen; the herring catch quotas in Canada, Alaska and the Kamchatka Region of the former Soviet Union; the amount of herring eggs on kelp in cold storage from previous seasons; and the outlook for the Japanese economy.

**Table 3-7. Quotas, landings and number of permits for the herring-eggs-on-kelp fishery in San Francisco Bay, 1989-90 season through 1999-2000 season.**

| Season | Quota (Tons) | Total Landings (Tons) | Percent of Quota Landed | Number of Permits |
|---|---|---|---|---|
| 1989-90 | 110.0 | 107.1 | 97.4 | 8 |
| 1990-91 | 144.0 | 47.0 | 32.6 | 10 |
| 1991-92 | 114.0 | 84.2 | 73.8 | 10 |
| 1992-93 | 84.5 | 47.4 | 56.1 | 10 |
| 1993-94 | 35.1 | 35.0 | 99.7 | 10 |
| 1994-95 | 85.0 | 13.1 | 15.4 | 10 |
| 1995-96 | 106.5 | 106.8 | 100+ | 10 |
| 1996-97 | 286.0 | 185.7 | 64.9 | 11 |
| 1997-98 | 209.0 | 36.4 | 17.4 | 11 |
| 1998-99 | 54.4 | 31.7 | 58.3 | 11 |
| 1999-2000 | 99.2 | 31 | 31.3 | 1 |
| Average (11 yrs.) | 120.7 | 65.9 | 58.8 | 10 |

Table 3-8. Number of herring eggs-on-kelp permits, tons of kelp harvested for the open pound method, tons of eggs-on-kelp harvested, and quota allocation by season in San Francisco Bay.

| Season | No. of Permittees | Estimated Raw Kelp Harvested[1] | Eggs-on-kelp Harvested | Quota |
|---|---|---|---|---|
| 1986-87 | 1 | n/a[2] | n/a[2] | 7.5 |
| 1987-88 | 1 | 17.5 | 19.7 | 20.0 |
| 1988-89 | 5 | 87.5 | 47.1 | 64.0 |
| 1989-90 | 8 | 140 | 107.1 | 110.0 |
| 1990-91 | 10 | 175 | 47 | 144.0 |
| 1991-92 | 10 | 175 | 84.2 | 114.0 |
| 1992-93 | 10 | 175 | 47.4 | 84.5 |
| 1993-94 | 10 | n/a[2] | 35 | 35.1 |
| 1994-95 | 10 | 117.6[3] | 13.1 | 85.0 |
| 1995-96 | 10 | 43.1[3] | 106.8 | 106.5 |
| 1996-97 | 11 | 96[3] | 185.7 | 286 |
| 1997-98 | 11 | 58.8[3] | 36.4 | 209 |
| 1998-99 | 11 | 72.5[3] | 31.7 | 54.4 |
| 1999-2000 | 11 | 123.5[3] | 31 | 99.2 |

[1] Estimated maximum amount of raw kelp harvested by all permittees from Monterey Bay and/or the Channel Islands. The Department estimates that 20% of the total raw kelp used annually in the eggs on kelp fishery is harvested from Monterey Bay.

[2] n/a – Information not available

[3] Prior to the 1993-94 season, eggs on kelp permittees were required to provide invoice information regarding the amount of raw kelp harvested. This regulation was eliminated prior to the 1993-94 season. Raw kelp estimates from 1994 through 2000 were calculated by estimating the number of spawns per season for which each permittee suspended kelp. The amount of kelp used per suspension was calculated by multiplying 0.98 tons (i.e., the capacity for kelp suspended on one raft estimated by Moore and Reilly 1985) by two (i.e., the maximum number of rafts allowed per permittee).

### 3.4.3 Sport Harvest of Kelp

Very little information exists on the amount of kelp harvested for recreational purposes. It is known that several of the coastal native American Indian tribes and some immigrants, especially those from southeast Asian countries, do utilize fresh kelp for food (Kalvass, pers. comm.). The kelp taken is usually drift kelp that has washed up onto the beach. Occasionally, fresh kelp will be harvested from intertidal and shallow subtidal beds at low tide. In addition, kelp is used as an ingredient in at least one form of ceramic art called Sagger firing (Ramos, pers. comm.). Orchardists and gardeners also collect kelp beach wrack for use as compost (Kalvass, pers.comm.)

An estimation, based on a survey of the Department's staff, suggests that less than 25 tons is collected annually by recreational users (Crooke, pers. comm.).

### 3.4.4 Recreational Utilization of Kelp Beds

The kelp beds are utilized not only by commercial interests but by the sportfishing industry as well. As stated in Section 3.2.9, a variety fish and invertebrates inhabit all levels of the kelp beds; some species are true kelp–bed residents and others are occasional visitors. It is this abundance and variety that attract fishermen and sport divers.

The sportfishing industry in California is composed of commercial passenger fishing vessels (CPFV), private boats, and shore anglers. The CPFV's take groups of anglers out on 1/2–day, 3/4–day, full day, and multiday trips. The majority of 1/2– and 3/4–day trips fish within or near the kelp beds except in the summer when California barracuda (*Sphyraena argentea*) and Pacific bonito (*Sarda chiliensis*) are present (Crooke, pers comm.). For the period 1987 to 1989, the number of CPFV's fishing adjacent to the kelp from Orange, Los Angeles, and Santa Barbara Counties averaged 2,225 boats having anywhere from 5 to 50 passengers (CDFG, unpublished data). A partial list of fish species that were taken during these trips includes kelp bass (*Paralabrax clatharus*), cabezon (*Scorpaenicthys marmoratus*); lingcod (*Ophiodon elongatus*), Sheephead (*Semicossyphus pulcher*), blue rockfish (*Sebastes mystinus*), black rockfish (*S. melanops*), and kelp rockfish (*S. atrovirens*).

Data from the Marine Recreational Fisheries Statistics Survey (MRFSS) is broader in scope, taking into account CPFV, private boats, and shore based anglers. This database is composed of fishermen interview data collected between 1987 and 1989. For the period surveyed, on average 24 million fish were landed by about 1.8 million California resident anglers annually when fishing in territorial waters (3 miles or less) was the target location (Witzig et. al., 1992).

In northern California, on average, 72% of the total marine recreational catch during 1987 to 1989 was caught by shore and private/rental boat anglers fishing in inland waters or within 3 miles of shore. Of this, approximately 40% of angling occurred within marine nearshore waters (Witzig et. al., 1992). In 1992 and 1993, the percentage of CPFV fishing activity along the central/northern coast, where fishing activity occurred in the kelp was: Fort Bragg/Bodega Bay – <20%, Halfmoon Bay/San Francisco – 5%, Monterey – 10%, and Morro Bay – 40%. The majority of skiff (private boats/rental boats) activity along the central and northern coast took place adjacent to kelp beds (Wilson-Vandenberg, pers. comm.).

Off of southern California, 63% to 82% of all fishing activity occurred within 3 miles or less of the shore for the same period. All modes were represented equally for this period. Approximately one-half of the angling activity targeted on kelp bed related species (Crooke, pers. comm.).

In addition to sport anglers, there are a large number of sport divers (both free divers and SCUBA divers) who spearfish for many of the species caught by hook and line, as well as, hunt for abalone, rock scallops, and spiny lobster. In addition, there are divers who enjoy nonconsumptive use of the underwater environment through such activities as underwater photography.

No estimate of the number of people who dive in California's ocean waters exists; however, in 1992 approximately 134,287 SCUBA divers participated in chartered boat dive trips. Of this number, 99% visited the Channel Islands and dove in or near the *Macrocystis* beds that surround the islands. The residual dove in nearshore kelp beds from Monterey to San Diego or at the offshore banks (Tanner Bank, Cortez Bank). From these dive trips, a total of 64,847 fish and invertebrates were taken (CDFG unpublished data). The top five species taken were: scallops (*Pecten* spp.; *Hinnites* sp.), 24,942; rockfish (*Sebastes* spp.), 8,527; Sheephead, 3,641; abalone, 8,409; and California spiny lobster, 7,867. All these species are kelp bed residents during all or part of the year (Smith and Carlton, 1975; Miller and Lea, 1972). Although the number of divers who went on commercial dive trips is large, it is probably only one–quarter of the total number of divers who have access to our coastal waters.

Combined telephone and field surveys of sport abalone harvesters in California were used from 1985 to 1989 to estimate total take in northern and central California (Tegner et al. 1992). Estimates of total weight landed averaged 2.028 million pounds (920 MT) from 1986 to 1989 (Karpov et al. In Press).

There are no estimates of the number of people who kayak in California's ocean waters. However, the commercial rental of kayaks is a growing industry with business located near many central and southern California coastal cities. The presence of kelp bed canopy and canopy inhabiting species act as strong attractantors for many recreational kayaking enthusiasts. In addition to enjoying kelp canopy communities, kayakers also rely on the canopy to reduce wave energy and use the canopy as a safe haven.

## 3.5 Regulatory/Management Environment

### 3.5.1 Responsible Agency

The California Department of Fish and Game, within the Resources Agency, is the lead state agency responsible for managing kelp (*Macrocystis pyrifera* and *Nereocystis luetkeana*) and other aquatic plant resources.

### 3.5.2 Management Concepts and Tools

The management strategy for the state's kelp resources has been based largely on a 'reactive, points of concern' approach, similar to many of California's state-managed fisheries (Hilborn and Walters 1992, Kalvass and Hendrix 1997). The Fish and Game code section 6654 gives the Fish and Game Commission authority to close a kelp bed to harvest for up to one year if they determine that damage to the bed is occurring. However, the information necessary for sustained yield management based on formal stock assessment of the state's kelp resources is unavailable and costly to collect. Kelp beds have an intrinsic value as habitat in the nearshore ecosystem as well as having commercial and recreational value as a harvestable resource, therefore the concept of MSY cannot be applied to their management in the traditional sense. Because of these multiple values, kelp management is much more complex than that of most single species.

In 1996, the Fish and Game Commission, with the recommendation of the Department, and in anticipation of increasing interest in large-scale harvest of the northern California bull kelp resource, acted proactively by setting aside beds 303-307 from commercial harvest. In addition the remaining beds in the 300 series were limited to a maximum harvest of 15% of the biomass revealed by a Department approved annual survey conducted by the lessee (CCR 1999).

### 3.5.3 Resource Assessment Methods

#### 3.5.3.1 Monitoring Programs

Commercial kelp landings have been monitored since 1915, four years after kelp harvesting began in California (Tarpley and Glantz, 1992). Monitoring consists of both fishery dependent and independent data collection. Dependent data is in the form of landing records indicating the weight and location of kelp harvested and is required to be maintained by harvesters and submitted to the Department on a monthly basis (CCR 1999). Fishery independent data has originated from 3 sources: the Department and other agencies, the kelp harvesters, and academia. ISP alginates (formerly Kelco) is the primary kelp harvester in California, taking mostly *Macrocystis*. They have been conducting regular resource aerial surveys over the years, but much of their data has been proprietary and unavailable to the public until recently. Department monitoring has been intermittent, relying mostly on occasional aerial photographic monitoring.

The sport fishery is not formally monitored because the take is so small. The Marine Recreational Fisheries Statistics Survey, which collects data on sport caught fish, reported only one incidence of the take of kelp by a recreational fisherman prior to 1995 (Hernandez, pers. comm.).

### 3.5.3.2 Harvest and Landing Records

Harvesters are required by the Commission to keep harvest records and to turn in landing records to the Department. The harvest records must contain information on the category of plant landed (i.e. agar–bearing, edible seaweed, kelp), the number of pounds or tons landed, and the name and address of the person or firm to whom the plants were sold. These records are to be available for inspection by the Department. In addition to harvest records, landing records must be submitted to the Department. The landing record must show the wet weight of all aquatic plants harvested, name of harvester, Department kelp harvester number, date of landing or delivery, Department origin or kelp bed number where plants were harvested, and any other statistical information the Department may require (§165(b)(1) and (2) Title 14, CCR, Appendix 1).

The landing record information is processed to report California annual commercial landings of kelp (Appendix 3). Also, the data is essential for monitoring trends in landings as well as fluctuations in harvest from specific beds.

### 3.5.3.3 Surveys

The Department uses aerial surveys to assess the state's kelp resources. The extent of the giant kelp and bull kelp resource is determined by measurement of the kelp bed's surface canopy on aerial photographs. These numbers are expressed in square miles. The last survey of all the designated beds was done in 1999.