1. GIANT KELP

Overview of Use and Harvest

Kelp is an important food source for humans and animals around the world. In Asia, Europe, and Australia, kelp has historically been used not only as a food source, but also as fertilizer and a component in gunpowder. Algin, a substance found in the cell walls of kelp, is an efficient thickening, stabilizing, suspending, and gelling agent used in a wide range of food and industrial applications. It can be found in various desserts, gels, milk-shake mixes, dairy products, and canned foods. It is also used to emulsify and stabilize salad dressings, to retain moisture and improve the texture of bakery products, to insure smooth consistency and uniform thawing in frozen foods, and to stabilize beer foam. In industrial applications, algin is used for paper and welding-rod coatings, sizing, and textile printing. In pharmaceutical and cosmetic applications, it is used to make tablets, dental impressions, antacid formulations, and facial creams and lotions. Giant kelp, *Macrocystis pyrifera*, is not only an important source of algin in California, it is also harvested and fed to cultured abalone, and used in the herring-roe-on-kelp fishery in San Francisco Bay.

Giant kelp was first harvested along the California coast during the early 1900s. Several harvesting companies operated from San Diego (San Diego County) to Santa Barbara (Santa Barbara County) beginning in 1911. These companies primarily extracted potash and acetone from kelp to use in the manufacture of explosives during World War I.

Kelp harvesting virtually stopped in the early 1920s, after the end of the war. In 1928, Philip R. Park Inc. of San Pedro began harvesting kelp and adding it to livestock and poultry food. In 1929, Kelco Company of San Diego (now ISP Alginates Inc.) began harvesting and processing giant kelp for livestock feed and algin.

Since 1917, kelp harvesting has been managed by the California Department of Fish and Game (DFG) under regulations adopted by the Fish and Game Commission (Commission). Regulations currently allow kelp to be cut no deeper than 4 ft beneath the surface, although the surface canopy can be harvested several times each year without damaging kelp beds. Kelp harvesting licenses are required to take kelp for commercial use. There are 74 designated giant kelp beds which can be leased for up to 20 years; however, no more than 25 sq. mi. or 50% of the total kelp bed area (whichever is greater) can be exclusively leased by any one harvester. In addition to leased beds, there are open beds that can be harvested by anyone with a valid kelp harvesting license. Harvesters pay a royalty of $1.71 to $10.00 per wet ton of kelp harvested.

In 2001, DFG completed an environmental review of giant and bull kelp sport and commercial regulations. As a result of this review, and of public and inter-agency input, a number of amendments were adopted addressing the commercial harvest of kelp. The more substantial amendments include:

- Requiring harvesters to obtain Commission approval of a harvest plan before a mechanical harvester can be used to harvest giant kelp in central and northern California
- Increasing the number of beds closed to harvest

- Closing a portion of a bed in Monterey County which experiences heavy seasonal harvest pressure
- Creating a mechanism for restricting harvest by imposing temporary harvest controls where necessary for resource protection

Giant kelp is one of California's most valuable living marine resources. In 2001, the kelp harvesting industry was valued at more than $30 million annually. Today, giant kelp is harvested from Imperial Beach in San Diego County, near the U.S.-Mexico border, to Santa Cruz (Santa Cruz County). Mexican harvesters in Ensenada provide another source of kelp from beds off Baja California.

The annual harvest has varied from a high of 395,000 tons in 1918 to a low of less than 1,000 tons in 1931 (Figure 1.1, Table 1.1). Such fluctuations are primarily due to climate change and natural growth cycles as well as market supply and demand. During the 10-year period from 1970 to 1979, the harvest averaged nearly 150,000 tons, while from 1980 to 1989 the average harvest was only 66,000 tons. During the 1980s, kelp harvests were devastated by the 1982-1984 El Niño event and accompanying storms, and the 200-year storm that occurred in January 1988. In most areas, giant kelp recovered quickly with the return of cooler, nutrient rich waters. Harvests in California increased to more than 130,000 tons in 1989 and to over 150,000 tons in 1990. During the 1990s, increased competition from Japan for "low end" or less-purified alginate caused ISP Alginates Inc. to reduce harvests by about half. ISP Alginates Inc. anticipates harvesting approximately 50,000 tons of giant kelp annually from California waters over the next several years.

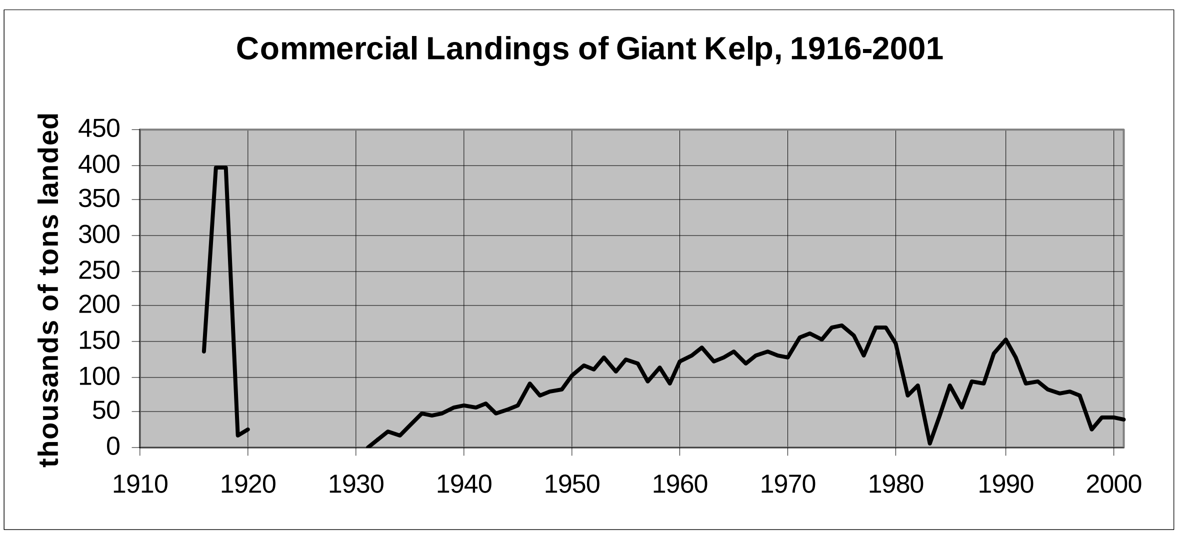

Figure 1.1. Annual commercial landings (tons) of giant kelp from 1916 to 2001. Data source is the Kelp Harvester's Monthly Report (logbook) and data is not available from 1921 to 1930. Kelp landings consist primarily of giant kelp (*Macrocystis pyrifera*).

Kelp harvesters use harvesting methods that best suit their purposes and needs. For example, ISP Alginates Inc. uses specially designed vessels with cutting mechanisms on the stern, and a conveyor system that places the cut kelp into a harvester bin. Blades mounted at the base of the conveyor are lowered 3 ft into the kelp bed while propellers on the bow slowly push the harvester stern-first through the bed. These vessels can collect up to 600 tons of kelp per day. To facilitate its harvesting operations, the company conducts regular aerial surveys from June through November. This survey information is used to direct harvesting vessels to mature areas of kelp canopy that have sufficient density for harvesting. Another kelp harvesting company, The Abalone Farm, harvests kelp to feed cultured abalone using a modified U.S. Navy landing craft with a cutting device and conveyor system mounted on the bow. For the herring roe-on-kelp fishery, however, kelp is hand-harvested from small boats, loaded carefully into bins and transported by truck to San Francisco Bay.

Status of Biological Knowledge

Giant kelp forests occur in the temperate oceans of the Northern and Southern Hemispheres. These forests are especially well developed along the west coast of North America from Punta Abreojos in Baja California, Mexico, to Point Año Nuevo, San Mateo County, California. They create a unique habitat that provides food, shelter, substrate, and nursery areas for nearly 800 species of animals and plants. Many of these animals and some plants are of importance to sport and commercial fisheries.

Typically, giant kelp flourishes in wave-exposed areas of nutrient-rich, cool water ranging from 20 to 120 ft deep. The kelp attaches to rocky areas on the sea floor by means of a root-like structure called a holdfast. Along the protected shoreline of Santa Barbara County, however, giant kelp also grows on sand. Here, it attaches to exposed worm tubes or the remains of old holdfasts. Kelp fronds grow from the holdfast towards the sea surface. A frond is composed of a stem-like stipe which has numerous leaf-like blades springing from it. A gas-filled bladder at the base of each blade, called the pneumatocyst, helps buoy the frond in the water column.

Giant kelp absorbs nutrients from the water through all its surfaces. Under optimal conditions with high nutrient levels and low ocean temperatures (50° to 60° F), fronds can grow up to 2 ft per day. Fronds can reach a length of more than 150 ft, and large plants can have more than 100 fronds. As the fronds mature, die, and break away, young fronds take their place. Although giant kelp plants can live for up to 8 years, individual fronds last for only about 6 to 9 months, and individual blades live only about 4 months.

Giant kelp reproduction involves two very different growth forms, the large canopy-forming sporophyte and the microscopic gametophyte (Figure 1.2). Specialized reproductive blades, located just above the holdfast on an adult sporophyte, release trillions of microscopic spores each year. The spores settle on the bottom and develop into microscopic “male” and “female” gametophyte plants. Fertilization of the female gametophyte produces a small sporophyte. This tiny plant will develop into a canopy-forming adult within 7 to 14 months if it survives competition with other plants, and is not destroyed by undesirable environmental factors or eaten by grazers.

Status of the Beds

The density and abundance of kelp canopy varies by location, year, and season. In central California, natural plant deterioration occurs in late summer and early fall. Canopies virtually disappear during the late fall and winter, when storms cause frond and plant loss. Canopies usually begin forming again in the spring, and by summer are

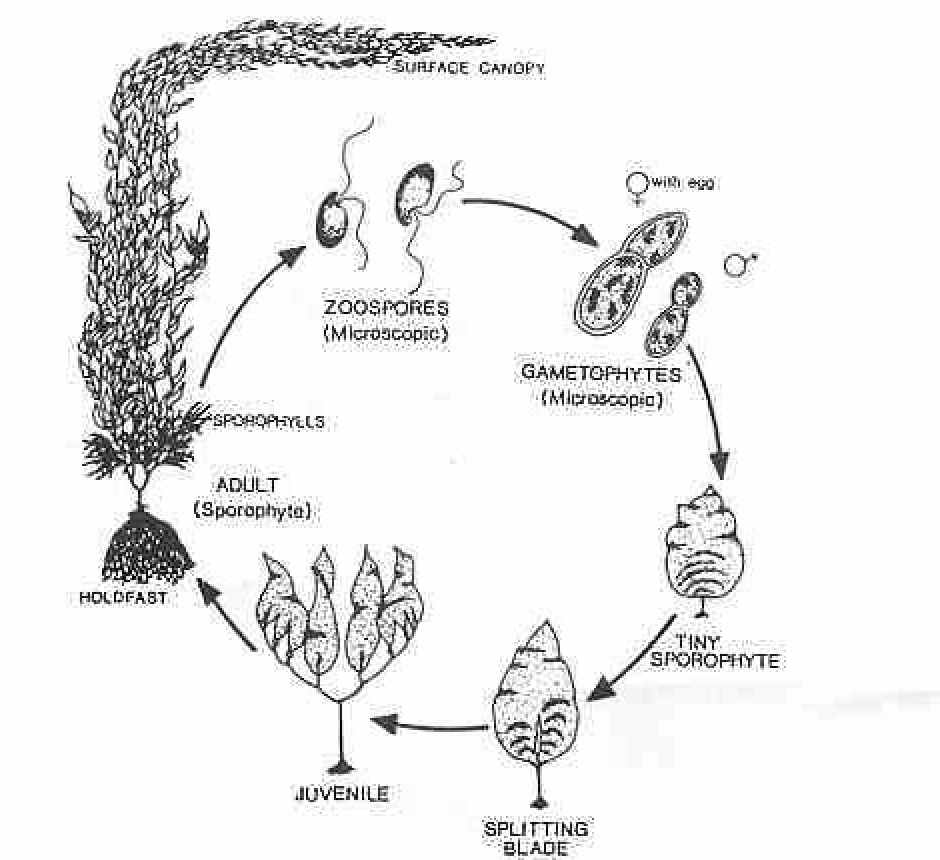

Figure 1.2. The life cycle of giant kelp. Foster, M.S. and D.R. Schiel. 1985. The Ecology of Giant Kelp Forests in California: A Community Profile. Fish and Wildlife Service. U.S. Dept. of the Interior, Biological Report 85(7.2).

quite dense. Off southern California, however, kelp canopies frequently grow throughout the year in the mild weather conditions. Dense canopies can develop during the winter, especially during mild years when storms and large swell events are infrequent.

The health and long-term survival of giant kelp forests is influenced by a variety of factors, including storms and climatic events, grazing, competition, sedimentation, pollution, and disease. These factors can be divided into two different types: naturally occurring, and human-induced. Southern California's giant kelp beds are influenced by both natural and human-induced factors.

Fluctuations in water temperature influence kelp survival in southern California to a great extent. South of Point Arguello (Santa Barbara County), in an area called the Southern California Bight, water temperatures are considerably warmer than for the rest of the State. The warmer water temperatures in this area tend to negatively affect kelp survival. Human influences on giant kelp also tend to be greater in southern California due to the concentration of the State's population within this region, and associated pollution and coastal development.

During the last 30 years, the size, distribution, and location of the kelp canopy throughout California has fluctuated considerably. An aerial survey conducted in 1967 showed a total of 70 sq. mi. of kelp canopy from around Point Montara (San Mateo

County) to the U.S.-Mexico border, with 53.9 sq. mi. of the total in southern California (Figure 1.3). In southern California, 33 sq. mi. occurred along the mainland coast and 20.9 sq. mi. occurred around the Channel Islands. A survey conducted in 1989 reported 40.7 sq. mi. of kelp canopy along the entire California coast. Of this, 17.5 sq. mi. were recorded for southern California. The Channel Islands accounted for 9.8 sq. mi., while the mainland coast of southern California totaled 7.7 sq. mi. During the most recent statewide kelp forest survey conducted in 1999, a total of 17.8 sq. mi. of giant kelp canopy was charted along the California coast, with 11.4 sq. mi. off southern California, including the offshore islands. The 1999 survey showed only 3.7 sq. mi. of giant kelp canopy along the mainland coast of southern California, and 7.7 sq. mi. off the Channel Islands.

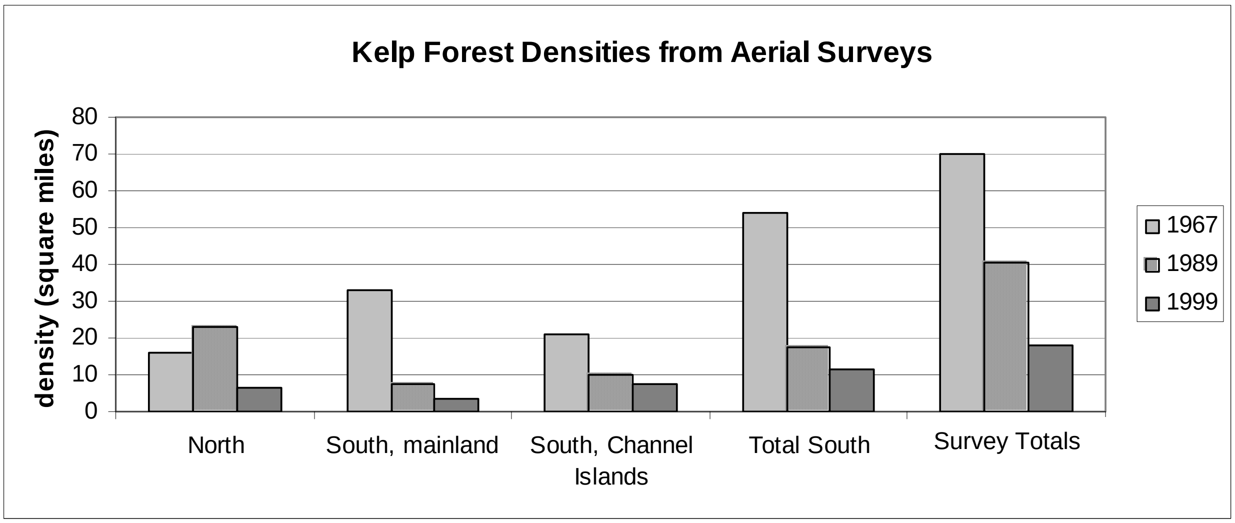

Figure 1.3. Kelp forest densities from aerial surveys completed in 1967, 1989, and 1999. South refers to areas south of Point Arguello, and north refers to areas north of Point Arguello.

The methodology used to conduct photographic aerial surveys is subject to a high degree of error. During these surveys, infrared film is used to highlight temperature differences between the kelp canopy at the water's surface and the background water temperature. Kelp immediately below the surface is invisible using this method. Results from these surveys may also vary due to wind waves and local currents. The degree of error in aerial kelp surveys could be greatly reduced by conducting surveys more frequently, and by using new technology such as digital multi-spectral imaging.

This being said, it is still evident that kelp forests are declining, particularly in southern California. The decline can be at least partly explained by the warming trend over the past 20 years and the frequency of severe El Niño events. However, the warming trend cannot explain differences in kelp canopy distribution between the Channel Islands and the mainland coast in southern California, since both areas are likely to experience the same oceanographic conditions in a given year. This suggests that the change in the relative abundance of kelp in these two areas may be due to factors other than warming trends.

During the 1980s and 1990s, many major oceanographic events affected kelp beds, including an El Niño event from 1982 through 1984, a devastating storm within that same period, and a large swell event in 1988. Excessive wave action from storms and surge can break kelp fronds and dislodge entire plants. Dislodged plants can also become entangled with other, nearby plants, pulling them from the substrate. Two more El Niño events occurred from 1992 through 1994 and from 1997 through 1998, with the 1992-1994 El Niño event followed by severe storms. The most recent El Niño event, from 1997 through 1998, was the warmest of the three.

The warm water and storms associated with the El Niño events destroyed plants, inhibited kelp growth, and resulted in minimal canopy development throughout southern California. During the 18-year period from 1981 to 1998, sea surface temperatures exceeded the previous 60-year mean in all but a single year (1988). In 1967, there were approximately 18 sq. mi. of kelp canopy near Santa Barbara, compared to only 6 sq. mi. in 1989. When last checked in 2000, the giant kelp forests that had been anchored in sand substrate near Santa Barbara had not returned.

Fishes such as opaleye and halfmoon regularly graze upon kelp. These fish can damage kelp forests when present in large numbers, especially when conditions are unfavorable for kelp growth. Invertebrates such as sea urchins, amphipods, isopods, and crabs also graze on kelp and may cause damage. The removal of the southern sea otter from southern California eliminated a major predator on sea urchins, and changed the balance of predator-prey relationships in the kelp bed community.

In addition, intensive fishing for some of the remaining sea urchin predators, such as California sheephead and California spiny lobster, and fishing for sea urchin competitors such as abalone has significantly altered the sea urchin population dynamics in kelp forests. Sea urchin populations increased exponentially in some areas and overgrazed the kelp, creating areas referred to as “urchin barrens.”

Human activities may also influence the health and distribution of kelp beds. Human-caused disturbances include pollution, sedimentation, wastewater discharge and thermal (warm-water) discharge. Sedimentation of the rocky bottom can retard kelp growth and even bury young plants, preventing development and reproduction. Pollution can affect kelp forests in a variety of ways. Industrial and domestic wastewater discharges carry toxins such as pesticides and heavy metals, which can accumulate in nearshore sediments. Chemicals such as these alter the physical and chemical environment near the discharge site, and may decrease the growth and survival of kelp forests. Thermal discharges from power plants can have localized effects on kelp forests. Wastewater and thermal discharges can increase turbidity and redistribute sediments into nearby kelp forests, affecting kelp growth and survival. A variety of pathogens are known to affect kelp, but their broad impacts on kelp forests have not been studied. While tumors, galls, and lesions have been observed on kelp, only occasionally have they caused severe damage.

Short- and long-term declines and, in one case, the complete disappearance of a kelp bed in southern California have been associated with human activity. An extensive kelp bed, known as Horseshoe Kelp Bed, existed off the coast of what is now Los Angeles Harbor prior to the 1920s. The bed reportedly measured a quarter-mile to a half-mile wide, and two miles long. A DFG Information Bulletin reported interviews with “old-time fishermen” who recalled that the kelp bed began to decline during the 1920s and 1930s. During this time period, the main channel and West Basin of Los Angeles Harbor was widened, and an entire island (Deadman's Island) was removed by dredging. Some fishermen recalled that the White's Point Sewer Outfall, which began discharging in 1934, was associated with the disappearance of the last remnants of this bed. The Horseshoe Kelp Bed grew in water 80 to 90 ft deep. While kelp still commonly grows at this depth off the Channel Islands, kelp does not grow at this depth along the southern California mainland coast today. Several years of decline in kelp beds near Salt Creek in Orange County and Barn Kelp Bed near Las Pulgas Canyon (off Camp Pendleton Marine Base) in San Diego County were associated with extensive grading of land around drainages adjacent to those beds.

The most thoroughly documented decline of giant kelp beds from human-induced causes was associated with the San Onofre Nuclear Generating Station in northern San Diego County. The discharge of heated and turbid cooling water caused the loss of approximately 150 acres of kelp. This single event was the only instance where damage to California kelp beds was documented well enough for mitigation to be required as compensation for the loss.

In the 1950s and 1960s, once-productive kelp forests off Point Loma and La Jolla (San Diego County) and along the Palos Verdes Peninsula (Los Angeles County) began to deteriorate. This, too, was attributed to biological and physical factors related primarily to human activities. Currently, there are several areas where the status of kelp is of concern, including the entire coastline of Santa Barbara and Ventura Counties, the Malibu coast in Los Angeles County, portions of the Palos Verdes Peninsula, the coast between Newport and Laguna Beach in Orange County, and San Onofre, south Carlsbad and La Jolla in San Diego County. Other kelp losses have undoubtedly occurred as a direct result of human activities along the southern California coastline, but the lack of strong baseline data prevents resource agencies from proving damages and seeking compensation. The development of a computerized Geographic Information System (GIS) that links known discharge and coastal development sites to aerial photographs of kelp canopies may provide effective tools to document and analyze such damage.

Kelp Restoration

In 1963, the Scripps Institution of Oceanography and Kelco Company began to develop techniques to protect and restore kelp forests off San Diego. Sea urchin control was achieved by crushing or spreading lime on urchins, and transplanting kelp. Later experimentation between 1991 and 1992 involved feeding urchins along a front to discourage feeding on attached plants, and increasing urchin reproduction so that commercial harvesting could be encouraged. These methods appear to have succeeded in restoring kelp beds off San Diego. However, there are indications that the urchin fronts will redevelop when these labor-intensive efforts cease. This drawback calls into question the long-term benefits of any one-time restoration effort, as well as the economic feasibility of such an effort as a long-term solution covering a broad area.

Between 1967 and 1980, kelp restoration was conducted along the Palos Verdes Peninsula by the Institute of Marine Resources and the DFG. This work combined sea urchin control and kelp transplanting, with the objective of establishing several small stands of kelp that would provide seed stock for new and expanding beds. In 1974, the first naturally expanding kelp stand in 20 years was observed off the Palos Verdes Peninsula. By 1980, when restoration work was discontinued, the stand had developed into a kelp bed covering nearly 600 acres. In 1989, aerial surveys found over 1,100 acres of kelp off the Palos Verdes Peninsula. Two subsequent El Niño events have severely decreased the size of these beds, however.

Kelp restoration work has also been conducted in storm-damaged areas off Santa Barbara and Orange Counties. Shortly after the 1982-1984 El Niño event, Kelco Company began developing techniques for restoring kelp beds in Santa Barbara County. In 1987, under contract with DFG, Kelco Company began anchoring giant kelp in the sandy habitat near Santa Barbara. Several kelp forest nuclei were established; however, sea urchin grazing and unfavorable water conditions impeded progress. By the early 1990s, this restoration attempt had failed.

Loss of Orange County kelp forests from Newport Harbor south to San Mateo Point was caused by urchin grazing, by heavy rainfall and siltation in 1980, and by the 1982-1984 El Niño event. Under contract with DFG, the MBC Applied Environmental Sciences Company established kelp forest nuclei from Laguna Beach north to Newport Harbor. Despite transplanting adult and juvenile giant kelp and keeping sea urchin populations under control, the beds north of Laguna Beach never recovered. The kelp forests south of Laguna Beach, however, recovered naturally after a few years.

In 1992, the DFG Artificial Reef Program built a ten-acre reef, around 3 ft in height, outside the harbor entrance channel to Mission Bay (San Diego County). The reef was constructed of broken slabs of concrete from nearby roadway demolition. By 1993 a kelp bed had become established on the reef without human assistance. This bed has persisted at least through the spring of 2000.

During the fall of 1999, the Southern California Edison Company built a 22-acre experimental reef off the City of San Clemente (Orange County) to mitigate damage that the San Onofre Nuclear Power Station had inflicted on local kelp beds. The experiment has had tremendous success as of spring 2003, with thick kelp canopies covering all of the experimental modules. The reef will be expanded to a minimum of 150 acres after the 5-year experimental phase is completed. It appears that the creation of new reef substrate may be a valuable mechanism for kelp bed expansion throughout southern California.

Management Considerations

For the purpose of management, the kelp beds off California represent more than just a single species of interest; they represent an important nearshore ecosystem. Giant kelp forests provide essential habitat for a diverse assemblage of marine fishes and invertebrates, and their loss would reduce the populations of many marine species. Kelp forests are not only important to sport fishermen, commercial fishermen, and kelp harvesters; they are also important to recreational divers, photographers, and tourists who value them for aesthetic reasons.

During the latter half of the twentieth century, California kelp forests (especially in the south) have been subjected to increasing environmental stress. Warm water El Niño events apply naturally caused stress. Other environmental stress is clearly the result of human activity. Human-caused environmental stress is brought about by pollution and sedimentation from power plants, sewage discharge, and coastal development practices. While the causes of decline are complex and masked by seasonal fluctuations, it is generally agreed that there is now much less kelp along the southern California coast than there was when DFG first began conducting surveys in the early 1900s.

At least three areas of management offer some hope for reversing this trend of decline:

- Large numbers of sea urchins can damage kelp forests. DFG may consider applying more stringent limits on the take of sea urchin predators, such as California sheephead and California spiny lobster. The southern sea otter may eventually return to its southern California habitat, but whether this will, or should be allowed, to happen is highly controversial.
- Coast-wide photographic flights should be conducted at least annually (preferably quarterly or biannually, during canopy maximum and minimum). The causes for the apparent declines in kelp beds, particularly in southern California, cannot be thoroughly analyzed or understood without a better time series of data. Once gathered, the data should be incorporated into a statewide GIS. A similar database should be instituted for coastal development. This information should be available through the California Coastal Commission, since all coastal development requires a permit from the Commission. Once established, the GIS should be frequently reviewed for evidence of kelp bed damage tied to onshore activities.
- Provide additional substrate (constructed reefs) over widespread areas for establishment of new kelp beds. These may also serve as sources of giant kelp spores for re-establishment of former, natural kelp communities.

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Further Reading

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Table 1.1. Commercial landings (tons) of giant kelp, 1916-2001

Year	Tons	Year	Tons	Year	Tons	Year	Tons	Year	Tons
1916	134,537	**1933**	21,622	**1950**	100,602	**1967**	131,495	**1984**	46,479
1917	394,974	**1934**	15,880	**1951**	114,760	**1968**	134,853	**1985**	87,300
1918	395,098	**1935**	30,602	**1952**	110,158	**1969**	131,239	**1986**	56,832
1919	16,673	**1936**	49,317	**1953**	126,649	**1970**	127,039	**1987**	93,264
1920	25,464	**1937**	43,954	**1954**	106,215	**1971**	155,559	**1988**	90,615
1921	------	**1938**	47,697	**1955**	124,063	**1972**	162,511	**1989**	132,761
1922	------	**1939**	56,736	**1956**	117,815	**1973**	153,080	**1990**	151,439
1923	------	**1940**	59,004	**1957**	94,207	**1974**	170,181	**1991**	127,505
1924	------	**1941**	55,717	**1958**	114,062	**1975**	171,597	**1992**	91,247
1925	------	**1942**	61,898	**1959**	89,599	**1976**	158,371	**1993**	92,940
1926	------	**1943**	47,958	**1960**	120,300	**1977**	130,597	**1994**	81,006
1927	------	**1944**	53,030	**1961**	129,256	**1978**	169,029	**1995**	77,753
1928	------	**1945**	59,181	**1962**	140,233	**1979**	171,020	**1996**	78,461
1929	------	**1946**	91,069	**1963**	121,032	**1980**	147,636	**1997**	73,165
1930	------	**1947**	74,237	**1964**	127,254	**1981**	73,064	**1998**	25,313
1931	260	**1948**	78,641	**1965**	135,129	**1982**	86,503	**1999**	42,211
1932	10,315	**1949**	83,346	**1966**	119,464	**1983**	5,271	**2000**	41,943
								2001	40,116

------ Landings data not available from 1921 to 1930.
1. Data source: Kelp Harvester's Monthly Report (logbook).
2. Kelp landings consist primarily of giant kelp (*Macrocystis pyrifera*).