

1. CALIFORNIA MARKET SQUID

Review of the Fishery

One of the state's most valuable fisheries, the California market squid, *Loligo opalescens*, was first exploited commercially in Monterey Bay in the 1860s by Asian and European immigrants. They established successful fishing communities, many that still exist today, with multiple generations participating in the fisheries of their ancestors. Market squid has become the largest and most valuable California commercial fishery by volume with 54,200 tons (49,200 metric tons) landed in 2006. Fishing revenue from the 2006 commercial harvest of market squid was about \$27 million (ex-vessel 2006 dollars). The contribution to total business output, for the State, from this 2006 commercial harvest is estimated to be \$52 million. Likewise, total employment and wages from market squid is estimated to be the equivalent of 924 jobs and \$24 million, respectively.

Market squid is an important international commodity with the majority of the export product being frozen and shipped to China, Japan, and Europe for human consumption. In 2006, 46 percent of the catch landed was exported for a value of \$28.8 million. Domestically, market squid is canned or used fresh for human consumption, and is increasingly used live and frozen as bait by recreational fishermen.

When the fishery first developed in 1863, Chinese fishermen rowed small boats, called sampans, in the shallow waters of the bay at night using lighting techniques such as torches and wire baskets with burning pitchwood hung over the sides of their boats to attract spawning aggregations of market squid to their nets. They dried their catch and sold it for export to Asian countries as a food staple and as fertilizer. At the turn of the twentieth century, immigrating fishermen from Europe brought their methods from the old world and quickly adapted them to California waters. Italian fishermen from Sicily introduced the lampara net to Monterey which increased competition between the Chinese and Italian fishermen and led to the growth of market squid as a major product from Monterey Bay.

Purse seine fishermen from Yugoslavia and Italy settled the Santa Barbara and San Pedro areas to fish market squid and sardines. Lights and brail nets were used almost exclusively in southern California until the late 1970s. These boats were smaller and required smaller crews than the purse seine or lampara vessels. However, there was a shift in gear for the southern fleet, from brail to purse seine around 1977. Smaller brail vessels could not compete with the larger seine vessels that could easily meet increasing demands. An expansion of the southern California market squid fishery began in 1961 with a dramatic rise in landings in the Santa Barbara area ports.

Two distinct fisheries have emerged north and south of Point Conception due to the timing of peak spawning periods in each region. Historically, the fishery north of Point Conception, mainly around Monterey Bay, has operated from April through

September, while the southern fishery has been most active from October through March. However, spawning and fishing activities can occur in both areas throughout the duration of the fishing season, which runs from April 1 to March 31 of the following year.

The most common practice in today's fishery is to use two vessels and a skiff to capture market squid. As the majority of fishing takes place at night, light boats with high wattage bulbs are used to attract and concentrate market squid near the surface. A seine vessel then deploys a skiff that encircles an aggregation of market squid with round haul gear (Figure 1.1). The seine vessel then pumps the market squid onboard. A smaller volume of market squid may be taken by the light boats using brail gear, which is a large scoop net. From 1996 to 2006, approximately 95 percent of the vessels used either purse (69 percent) or drum (26 percent) seine nets, and 5 percent used brail nets.



Figure 1.1. Fishing operations: a) A light boat attracting market squid; b) a purse seine vessel with skiff deployed.

The market squid fishery is strongly affected by environmental and atmospheric conditions of the California current. California market squid are extremely sensitive to the warm water trends of El Niño, with overall catches decreasing, but then rebounding in cooler La Niña phases which bring increased upwelling. El Niño conditions hamper the southern fishery and market squid landings are minimal during these events, while landings in the northern fishery often increase, then decrease for several years after. During these warm water events with nutrient poor water, landings can disappear entirely in some areas.

Due to an increase in market demand, the commercial market squid fishery grew to an average annual catch of 10,000 tons (9,080 metric tons) by 1980. A significant expansion of fishing activity in southern California during the 1980s and 1990s was driven by a rapid expansion of the international export market, which helped the California market squid fishery emerge as one of the largest and most

important in the state (Figure 1.2). Since 1985, the southern California fishery has dominated statewide landings and expanded its fishing areas, particularly in the Channel Islands and along the coast. In 1993, market squid became the largest California commercial fishery by volume with 47,100 tons (42,770 metric tons) landed, and by 1996 it had become the most valuable fishery resource valued at \$33.3 million. Commercial landings of market squid in California increased almost 400 percent from the 1990/1991 season to the 1997/1998 season.

California market squid landings fluctuate as a consequence of demand that results from the volatile overseas markets and from the success of other international squid fisheries. During times of high resource abundance, demand may be the limiting factor in determining the amount of market squid landed. Local dealers often place daily trip limits on vessels, such as 30-tons (27-metric tons), as supply can sometimes exceed the demand. Market demand, resource availability, and the quality of the product all affect the price paid to fishermen. When resource volume is low, the markets pay a higher price per ton. During some months of the 1997/1998 El Niño when market squid was scarce, prices averaged \$320 per ton. When resource volume is high the price is driven down, as in the year 2000 when prices averaged \$257 per ton. A few prices were recorded as low as \$100 per ton to some vessels bringing in full loads. Significantly higher prices are paid for market squid taken by brail gear, and for market squid purchased in lower volumes by smaller local dealers. Since 2005, prices have remained around \$499 per ton due to the strong international demand for California market squid because of the collapse of other squid fisheries.

During the slower months in the northern fishery, many participating vessels will return to other ports in Oregon and Alaska to fish for sardines and salmon. Both the northern and southern fleets also participate in other coastal pelagic finfish fisheries targeting Pacific sardine, *Sardinops sagax*; Pacific mackerel, *Scomber japonicus*; and northern anchovy, *Engraulis mordax*.

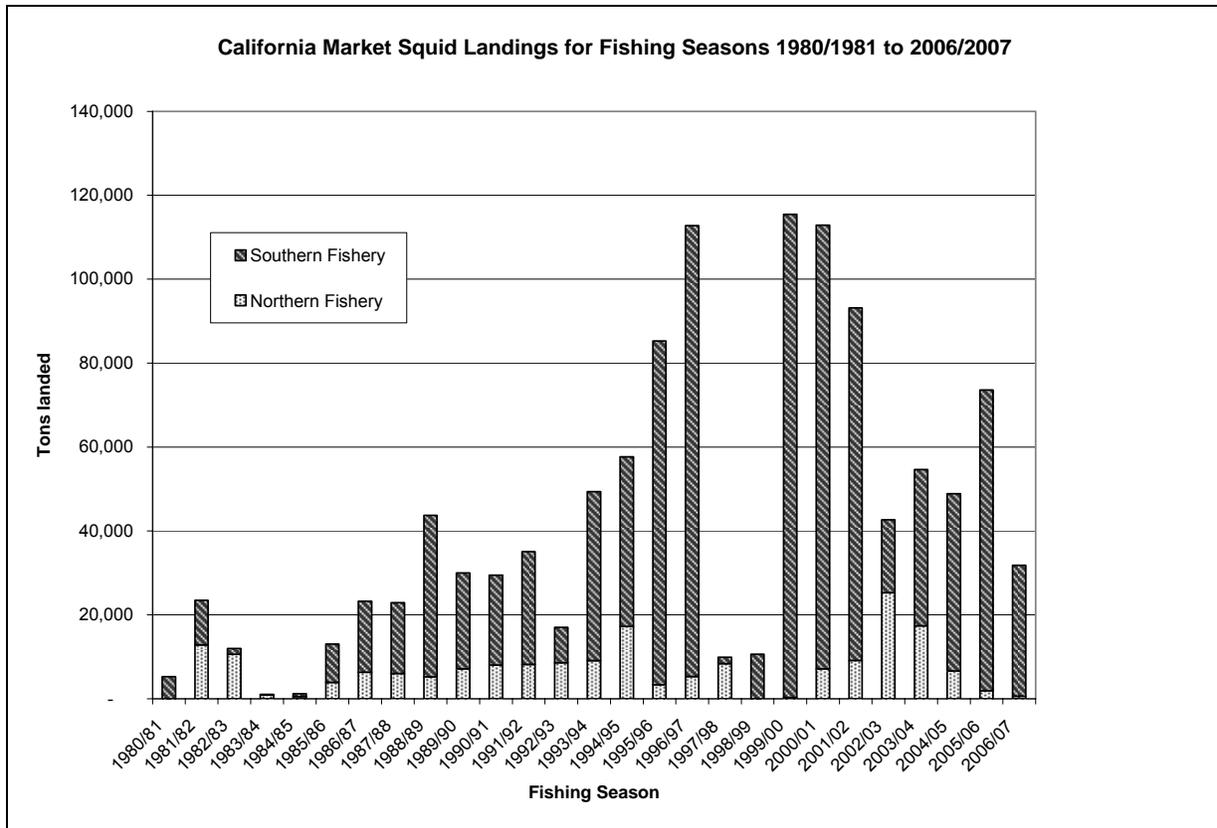


Figure 1.2. Market squid landings for northern and southern fisheries by fishing permit season (April 1 - March 31), from the 1980/1981 season to the 2006/2007 season.

Although substantial growth in the market squid fishery was concentrated in the Southern California Bight, questions were raised about the fisheries overall ecological and socioeconomic sustainability. Prior to 1997, regulations had been piecemeal and limited to Monterey Bay, with limits on the use of lights, the prohibition of round haul gear, and weekend closures that were imposed in 1983 to allow market squid a consecutive two-day period of non-interrupted spawning. As one of the West Coast's last open access fisheries in the late 1990s, the market squid fishery attracted fishermen facing declines in other fisheries. They were met with a willingness of the local markets to utilize their vessels in order to fill increasing demands for product. However, they faced opposition from local fishermen that felt their livelihoods might be jeopardized due to the over-expansion of the fishery.

The rapid increase in harvest and number of new vessels entering the fishery, especially from other states, prompted industry sponsored legislation in 1997, with Monterey Bay fishermen asking for a limited entry fishery. Beginning on April 1, 1998 new legislation placed a moratorium on the number of fishing vessels participating in the fishery, and a \$2,500 annual permit fee was imposed for three years in order to fund resource assessment for conservation and management of the market squid

resource. Interim measures also included mandatory biological port sampling, logbooks from light boats and round haul vessels, and an extension of the weekend closure to southern California. For the first market squid fishing season under the moratorium (1998/1999), 243 market squid vessel permits and 53 light boat permits were issued (Table 1.1).

Both shielding requirements and wattage restrictions for market squid-attracting lights were imposed in response to concerns raised in 1999 by the National Park Service that the abundance of vessels lighting for market squid may be responsible for the apparent increase in nest abandonment and chick predation among seabirds nesting at the Channel Islands. The Fish and Game Commission (FGC) placed a statewide wattage restriction on light boats and round haul vessels to 30,000 watts, and required these vessels to shield their lights to reduce impacts. Even with these restrictions, the landings increased to a record high in 2000 of 118,800 tons (107,870 metric tons), with an ex-vessel value of \$36 million.

Table 1.1. The number of market squid permits sold since legislation was enacted to maintain the fishery at sustainable levels. A moratorium on the number of permits was enacted in 1998 and a restricted access program was enacted in 2005.

Season	Market Squid Vessel Permit	Market Squid Light Boat Permit	Transferable Market Squid Vessel Permit	Transferable and upgrade Market Squid Brail Permit	Non-transferable Market Squid Vessel Permit	Experimental Non-transferable Market Squid Vessel Permit	Total
1998/99	243	53					296
1999/00	219	52					271
2000/01	204	50					254
2001/02	197	44					241
2002/03	185	41					226
2003/04	176	39					215
2004/05	167	44					211
2005/06	-	64	77	14	14	1	170
2006/07	-	64	76	14	12	3	169

In 2004, the Market Squid Fishery Management Plan (MSFMP) was adopted by the FGC, and went into effect March 28, 2005. Goals of the MSFMP were developed to ensure sustainable long-term conservation of the resource, and to provide a management framework that would be responsive to environmental and socioeconomic changes. The four components of management include: 1) fishery control rules including a seasonal catch limit, various spatial and temporal constraints, and continued fishery-dependent monitoring programs utilizing logbooks

and biological port sampling; 2) a restricted access program based on historical participation in the fishery was established to produce a moderately productive and specialized fleet of round-haul and light vessels; 3) an area closure to the use of lights to protect seabirds at the Farallon Islands; and 4) administrative items that allow the Director to establish an advisory committee composed of scientific, environmental and industry representatives. The 2005/2006 fishing season marked the inaugural year of implementation of the MSFMP.

Status of Biological Knowledge

The California market squid ranges from as far north as southeastern Alaska and as far south as Bahía Asunción Baja California, Mexico. It is a nearshore species that is found within 200 miles (322 kilometers) of shore. Although they are generally considered pelagic, market squid are found over the continental shelf from the surface to depths of 2,300 feet (700 meters). Adult market squid move into deeper water during the day, but return to surface waters at night within the upper 295 feet (90 meters) of the water column to feed. Adults and juveniles are most abundant at temperatures between 50 to 61° F (10 to 16° C). Market squid occupy the middle trophic level as active predators of copepods, euphausiids, and fish, and are a principal forage species preyed on by many fishes, birds and marine mammals.

The California market squid is a small mollusk with eight arms and two longer feeding tentacles, and an internal shell called a pen. Fishery-dependent samples indicate that market squid can grow to 7.9-inches (20-centimeters) in mantle length (ML) and can weigh up to 5-ounces (144-grams). Males are generally larger than females with longer and more robust arms and tentacles. Sex ratios are sometimes dominated by males or females but tend to be 1:1. The life cycle of market squid has four stages: eggs, hatchlings (paralarvae), juveniles, and adults. It is a short-lived species with a lifespan of 6 to 9 months. Adult market squid are semelparous (spawning only once) and spawn at the end of their lifespan. Although they are terminal spawners, market squid may spawn repeatedly over the last weeks of their lives.

When adults reach maturity, they move into shallow waters to spawn, usually over sandy habitat. In some areas, spawning may occur throughout the year. In Monterey, mass spawning events start around April and coincide with the upwelling season when water temperatures reach approximately 57° F (14° C). In southern California, spawning begins around November when there is less stratification of the water column and more mixing due to winter storms and colder air temperatures. While spawning, males grab the females and hold them in a vertical position while using a specially modified hectocotylized left ventral arm to transfer a bundle of spermatophores (sperm packets) into the female's mantle cavity near the oviduct. The female usually lays her eggs on sandy substrate, at depths of 49 to 164 feet (15 to 50 meters) in Monterey Bay and 66 to 295 feet (20 to 90 meters) in the Southern California Bight.

Eggs are laid within elongated finger-like capsules containing up to 300 eggs suspended in a gelatinous matrix that may protect against predation. The capsules are made up of many layers of protein and contain bacteria that may serve as an antibiotic to prevent fungal infection. Each female produces 20 to 30 egg capsules which she inserts into the sand with a sticky substance to anchor them in place allowing them to aerate in the surge. Groups of capsules are placed in masses creating clusters or “flowers” that can extend into vast egg beds covering more than 1,076 square feet (100 square meters) (Figure 1.3). Observations in Monterey Bay indicate that the rate of egg laying is slow, so egg beds may be built up over many days instead of in rapid spawning events occurring over one or two nights. The eggs are preyed on predominately by bat stars, brittle stars, sea urchins and rays; fish do not appear to eat them. Incubation time varies and is dependent on temperature. Eggs take between 3 to 5 weeks to hatch at average water temperatures of 52 to 57°F (11 to 14° C). Warmer water temperature shortens the incubation time.



Figure 1.3. Cluster or “flower” of market squid egg capsules on sandy substrate.

Paralarvae hatch from the eggs resembling miniature adults (0.08- to 0.12-inches; 2- to 3-millimeters) ML and immediately begin swimming. They rapidly learn to hunt, eating copepods, krill, and other plankton in the first months of their lives. They perform a daily vertical migration in the water column from 98 feet (30 meters) depth during the day, up to 49 feet (15 meters) depth where they are found in greatest abundance at night. The daily migration and the zone created by tidal and nearshore currents often entrain the paralarvae within 1.9 miles (3 kilometers) of shore. At around two months, market squid reach 0.6-inches (15-millimeters) ML and are strong enough to swim in groups. These juveniles form large groups that hunt with tentacular strikes resembling the adults. Their sexual organs mature between 4 to 8 months and they are then considered adults.

Biological data collected through port sampling efforts include length, weight, sex, maturity, and age. Maturity is determined by the presence or absence of eggs and spermatophores. The age of market squid can be estimated by counting daily

ring deposition on statoliths (Figure 1.4). Statoliths are calcareous structures secreted by the squid similar to the bony otoliths in fish. Since the fishery targets spawning market squid, statoliths collected should represent individuals approaching the end of their life span. Studies indicate the average age of harvested market squid is 188 days.

From 1999 to 2007, an overall decline in market squid length and weight has been observed with the exception of the 2005/2006 season in southern California (Figure 1.5, weight not shown). This has management implications for the resource since the fecundity of females increases with length, and the reproductive output of the population might be affected.

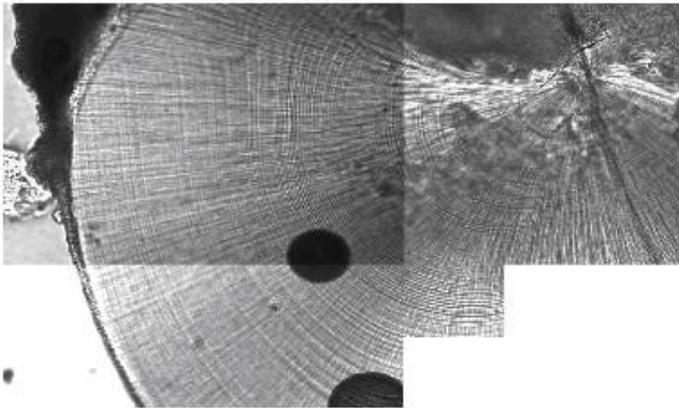


Figure 1.4. Multiple pictures overlaid of a cross-sectioned statolith showing daily ring deposition.

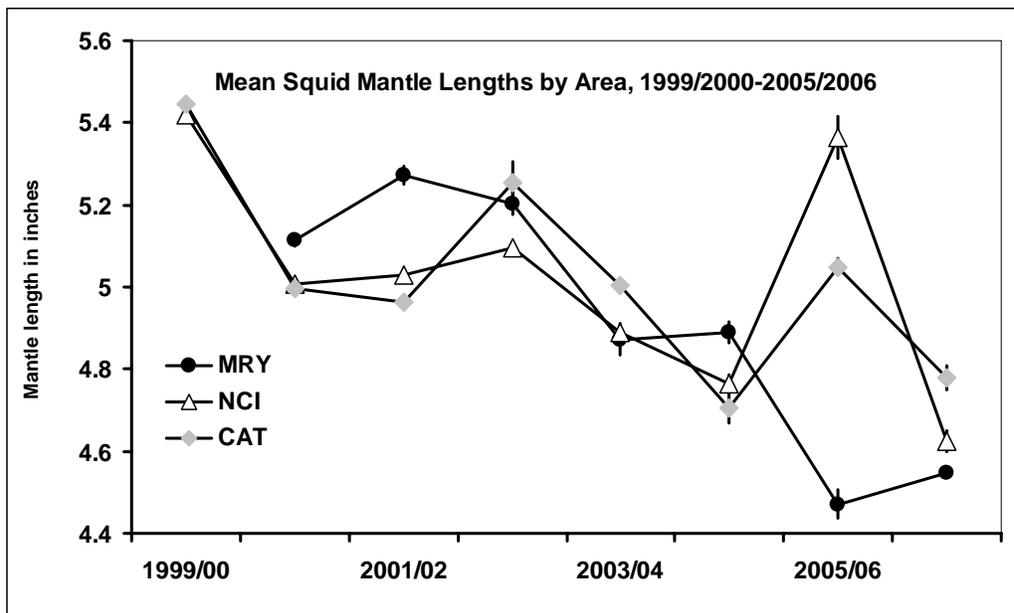


Figure 1.5. Mean squid dorsal mantle length by fishing season for fishery-dependent samples taken from Monterey (MRY), the northern Channel Islands (N CI), and Catalina Island (CAT).

Status of the Population

The status of the population is not fully understood because there is no reliable estimate of market squid biomass. However, evidence from studies on paralarvae, egg beds, behavior, genetics, and catch data suggest biomass is large, and at times, may constitute the largest population of any single marketable species in California's coastal environment. Since the California fleet targets spawning adults in limited geographic areas, it is not known if reduced landings indicate only a decline in availability to the fishery, or if overall stock size is diminished, since market squid have been commonly documented at greater depths not accessible to the fishery. Other spawning aggregations of market squid are also occasionally found as far north as British Columbia, and in the early 1980s, a short-term fishery developed along the coast of Oregon.

Historically, the market squid resource was considered by some to be underutilized. There are, however, few reliable estimates of the utilization of the market squid resource by other species. Although it is known that the resource supply can exceed demand, in some years the demand has exceeded the catch. The fluctuations in supply coincide with the environmental conditions. Because market squid are a short-lived and highly fecund species, it seems to be able to recover from dramatic decreases in the population from environmental fluctuations in a short period of time. However, other fishery-independent estimates of abundance are needed before the true status of the population can be determined.

The number of market squid stocks or subpopulations along the Pacific Coast is unknown at this time; and genetic analyses have had limited success in distinguishing stocks within a fishery. No significant differences were observed between the southern California and Monterey populations, suggesting that there are not two distinct stocks between the two fisheries.

Studies indicate that market squid endure very high natural mortality rates, and the adult population is composed almost entirely of new recruits made up of multiple cohorts. Even in the absence of fishing, the entire stock replaces itself semi-annually, so the stock is entirely dependent on successful spawning from each generation coupled with good survival of recruits to adulthood. Preliminary data indicate that the rate of eggs spawned prior to harvest varies between seasons. Because market squid are short lived, populations have been more effectively correlated with local oceanographic conditions than have pelagic fish species with longer life spans. Results indicate densities of paralarvae in February are correlated to catch-per-unit-effort (CPUE) of landings for the following November in southern California. Because market landings are driven by demand, it is difficult to use landing and vessel data to estimate an accurate CPUE or biomass.

Management Considerations

Since the implementation of the MSFMP, further issues affecting the management of this monitored species have been raised. The realized lifetime fecundity is a critical life history trait. Because the market squid fishery takes place above the spawning grounds, it is critical that management allows for an adequate number of eggs to be spawned prior to harvest. Allowing enough market squid to spawn before capture helps to ensure production for the next generation.

Biological sampling carried out by CDFG is designed to estimate the percentage of the population allowed to spawn before being captured by the fishery. The Pacific Fishery Management Council adopted the egg escapement method and an egg escapement threshold level of 30 percent as a proxy for maximum sustainable yield (MSY), since there is no reliable measure of annual recruitment success or biomass stock estimates beyond information obtained from the fishery. Fishery-dependent data presents difficulties in management of market squid because they are terminal spawners with short life spans, and fishing activity generally occurs only on spawning aggregations in shallow water. Use of egg escapement in determining if the stock is subject to overfishing, in lieu of a biomass estimate, should be considered a temporary solution while other fishery-independent methods are pursued to assess biomass and to collect essential fishery information. It is imperative to gather information on the extent and distribution of spawning grounds along the Pacific Coast, especially in deep water and areas north of central California not traditionally targeted by fishing vessels. Further information on fecundity, egg survival, impacts of different types of fishing gear on spawning grounds, and paralarvae density estimates is also needed from different spawning habitats and oceanographic conditions associated with the entire geographic range of the market squid population.

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Suggested Reading

California Department of Fish and Game. 2005 Final Market Squid Fishery Management Plan, March 28, 2005. State of California Resource Agency, Department of Fish and Game Marine Region. 525 p.

Forsythe, J., N. Kangas, and R. Hanlon. 2004. Does the California market squid (*Loligo opalescens*) spawn naturally during the day or night? A note on the successful use of ROV's to obtain basic fisheries biology data. Fishery Bulletin 102:389-392.

- Ish, T., E. Dick, P. Switzer, and M. Mangel. 2004. Environment, krill and squid in the Monterey Bay: from fisheries to life histories and back again. Elsevier, Deep-Sea Research II 51:849-862.
- Pomeroy, C. and M. FitzSimmons. 2001. Socio-economic organization of the California market squid fishery: assessment for optimal resource management. California Sea Grant. 9 p.
- Reiss, C., M. Maxwell, J. Hunter, and A. Henry. 2004. Investigating environmental effects on population dynamics of *Loligo opalescens* in the southern California Bight. Calif. Coop. Oceanic Fish. Invest. Rep. 45:87-97.
- Vojkovich, M. 1998. The California fishery for market squid (*Loligo opalescens*). Calif. Coop. Oceanic Fish. Invest. Rep. 39:55-60.
- Zeidberg, L., W. Hamner, N. Nezlin, and A. Henry. 2006. The fishery for California market squid (*Loligo opalescens*) (Cephalopoda:Myopsida), from 1981 through 2003. Fishery Bulletin 104:46-59.