Chapter 4. Research to Support the Market Squid Fishery Management Plan

At the core of the Marine Life Management Act (MLMA) is the principle of basing decisions on best available scientific information as well as other information that the Department and Commission possess [FGC §7050(b)(6)]. With this in mind, the MLMA includes, as a broad objective, promotion of marine ecosystem research that will enable better management decisions [FGC §7050(b)(5)]. Within this general policy on science and living marine resources, the MLMA establishes specific policies for the management of marine fisheries. Generally, fishery management decisions are to be based on best available scientific or other relevant information readily available, including what the MLMA calls Essential Fishery Information (EFI).

The MLMA defines EFI, with regard to a marine fishery, as information about fish life history and habitat requirements, the status and trends of fish populations, fishing effort, and catch levels, fishery effects on fish age structure and on other living marine resources and users. The MLMA calls upon the Department to collect EFI for all marine fisheries managed by the State in cooperation with participants in the fishery [FGC §7060(a)(b)]. To foster improvements in the management of individual fisheries, the MLMA requires that fishery management plans include research protocols that identify critical information gaps and the steps that will be taken to close gaps [FGC §7081]. These protocols are to describe the following:

- Past and current monitoring of the fishery;
- EFI, such as age structure of a population and spawning season, and other relevant information; and
- Plans for additional monitoring and research needed to acquire EFI.

In these ways, the MLMA provides an opportunity for fishermen, scientists, fishery managers, conservationists, and others to develop a system for obtaining the information needed to manage our living marine resources.

Although much biological information has been gathered on market squid in the past 30 years, EFI is lacking in many areas for this species. Future research should be directed toward acquiring EFI and involving collaborative efforts of the fishing industry (both commercial and recreational) and qualified university or private fisheries research institutions. In accordance with MLMA, this chapter describes fishery research protocols designed to advance the MSFMP. Additionally, it identifies gaps in the current knowledge of market squid stocks and the fishery and the steps needed to obtain this information for implementation to be successful. This chapter describes a research plan that is designed to incorporate the goals of the MLMA with the objectives for the management of the California market squid fishery.

4.1 Grouping Essential Fishery Information

Besides requiring a description of current and past monitoring of the fishery, the MLMA also requires that research protocols in FMPs include a description of EFI for the fishery. All EFI categories are important or essential; however, resources required to obtain this information will always be finite. Essential fishery information has been categorized below to identify areas that are necessary to management. It is important to emphasize that these groups are not mutually exclusive since one group may include components that fall under another.

4.1.1 Age and Growth Characteristics

Age and growth studies typically measure how long a species lives, the age at which it reproduces, and how fast individuals grow. This information is very important to determine a population's ability to replenish itself, at what rate it might be harvested, and when individuals will reach a harvestable size. Changes in the age structure and growth rate of a population also serve as indicators of the population's health. This information is often essential for stock assessments and models that guide management strategies. Specific EFI includes length/weight ratios, longevity, age/length ratios, age at size at sexual maturity, and age at length at recruitment into the fishery.

4.1.2 Distribution of Stocks

A stock is a population unit that is selected for management purposes. It may be defined based on its ecology, genetics, and/or geographic separation. Discrete stocks of a given species may have very different growth rates, reproductive schedules and capacity, and ecological relationships. Stock distribution refers to where a stock is found and is important in addressing jurisdictional issues. Specific EFI includes the depth and geographic range of a species, the amount of gene flow and genetic structure of the stock, and helps to determine whether stocks are separate or continuous.

4.1.3 Ecological Interactions

This information identifies the interaction of fishes within the environment, habitat, and ecological community. The MLMA recognizes that fisheries are part of a larger system and calls for conserving the health and diversity of marine ecosystems and living marine resources (FGC §7050)]. Fisheries are embedded in a web of ecological relationships that include the effects of oceanographic regimes and human disturbances on physiological, energetic, or behavioral aspects of organisms, relationships with prey and predators, interrelationships among species due to relative density of different populations, and the distribution and quality of habitat that is key to reproduction and recruitment. Estimation of any ecological relationship demands a species-specific, within-habitat approach due to environment and organism cross correlations.

4.1.4 Estimates of Abundance

This information helps to determine how many individuals comprise the population and the number available to the fishery. This information is essential for all predictive modeling of marine resources. Estimates of stock size can be determined through direct (e.g., surveys) or indirect (e.g., examination of the exploitation history) means. Specific EFI includes relative densities of target species, habitat-specific absolute densities, length frequency distributions, relative density estimates of life stages (i.e., eggs, larvae, young-of-the-year, juveniles, or adults), recapture rates of tagged fish, and catch-per-unit-effort information.

4.1.5 Movement Patterns

This information identifies the spatial distribution of fish and their residence time in specific habitats. Many species may exhibit movement patterns that are associated with specific oceanographic conditions. Certain species may aggregate in specific areas for spawning, move in predictable patterns, or move to certain locales that make them especially vulnerable to harvest. Insights into the movement patterns of fish are important to the development of management strategies based on regional catch quotas or marine protected areas. Specific EFI includes the home range, homing ability, seasonal migrations, environmental cues, and spawning grounds of a species.

4.1.6 Recruitment

Recruitment refers to the number of a species that survive to a particular life stage. It is often used to predict the population size in the future. In this context, recruitment refers to both recruitment to the fishery and recruitment to the population. Many species depend on successful recruitment events for replenishment of the stock. Recruitment success can be highly variable because it depends on the proper combination of many factors. As a result, sustainable harvest of the fishery may depend on only a few strong cohorts (born the same year) to provide harvestable stocks until the next successful recruitment event. Resource managers must consider this variable recruitment success when setting harvest levels by allowing sufficient portions of stocks to “escape” harvest and providing spawning biomass for future recruitment successes. Specific EFI includes the duration and distribution of eggs and larvae, size and timing of recruitment events, and annual cohort success. In addition, information on habitat availability and levels of predators and prey items is also important.

4.1.7 Reproductive Characteristics

Understanding key reproductive characteristics allows managers to set appropriate open and closed seasons and protect valuable spawning habitats.
Specific EFI for a species includes the number of eggs released, size at maturity, fertilization and spawning period, geographic spawning area, multiple spawning periods,

and the nature of mating systems. These data describe the reproductive potential of a fish stock and its ability to replenish itself.

4.1.8 Total Mortality

Total mortality of market squid refers to all removals of squid from the biomass and is traditionally separated into natural as well as fishing mortality. Natural and fishing mortality rates comprise the sum of all individuals removed from a population over a fixed time. Fishing mortality is the number of animals that are removed from the population by fishing. Natural mortality refers to all other forms of removal of squid from the population such as predation, starvation, disease or age. Fishing mortality and natural mortality are estimated in setting the current threshold of egg escapement. Mortality figures are essential for stock assessments and models to determine the number or weight (biomass) that may be safely harvested from a population or stock. Specific EFI includes catch data location, amount and sizes of discarded catch, landings by gear type, and survivability of fish that are released.

4.1.9 Market Squid Fishery Social and Economic Factors

The economic stability of coastal communities and quality of life may be affected by changes in activities related to recreational fishing or commercial fishing and processing. These changes may be caused by indirect factors or regulatory changes that directly affect fishing activities. Indirect factors include triggers from consumer or financial markets, such as 1) changes in consumer demand due to the favorable pricing and supply of a substitute item for a fishery product(s), 2) inflation, and, 3) tax changes that affect business investments or activities. These effects may be manifested locally through resultant changes in business output, employment, population, and public service demand. Four factors regarding social and economic information for the market squid fishery (employment, expenditures, market demand and revenue) are discussed below.

4.1.9.1 Employment

Overall, impacts to local community earnings and employment can be gauged using input-output multipliers to project the changes to local personal income and the number of local jobs. This procedure takes the direct change in final demand for an industry product or service in revenue or sales dollars and multiplies this direct change by a total income coefficient to estimate total change in local personal income. Similarly, multiplying the direct change by an employment coefficient will yield an estimate of changes in the number of local jobs.

4.1.9.2 Expenditures

Regulatory changes that directly affect recreational or commercial fishing revenues in local economies have a downstream effect on other economic sectors, which receive and re-spend those revenues. Output multipliers are used to describe the turnover

effect (number of times a dollar is exchanged within a community) and interrelationships between the basic-sector and downstream business sectors in the local economy.

Additionally, changes that directly affect end-user demand for recreational fishing activities or commercial fisheries products may change end-user spending patterns. Depending on the nature of end-user demand for a given service or product, end-users may spend less if the quantity or quality of the service or product is decreased. Conversely, we would expect end-users to spend more if the quantity or quality was improved. These changes in spending patterns may also affect purchases of related or ancillary goods or services provided in the local economy.

Lastly, the costs (usually expenditures) of production of a good, a service, or an activity provide a means to compare the relationship between resources used to benefits derived. Often, this is expressed as the benefits-to-cost comparison. In the case of commercial fishing activities, by monitoring costs of production at various levels of output, we can define production where we have maximum economic benefit (or "profits"). This is important in creating harvest guidelines which foster optimum economic yield and economic efficiency in the fishing fleet. Economic efficiency equates to cost and waste minimizing practices.

4.1.9.3 Market Demand

Changes in the quantity or quality of available fishery-related goods or services affect the individual end-user's demand for those goods or services. How much this demand may be affected depends on individual income, tastes, preferences, and the accessibility to substitute goods or services. The aggregate demand, based on the combined responses of individuals to changes in a good or service, yields an overall demand function for a good or service. This demand function is used to predict the reactions of end-users to changes in the quantity or quality of goods or services, and to estimate the relative value and benefits end-users derive from a good. Consequently, the effects of in-season adjustments to harvest limits can be projected in terms of the anticipated response of the target group of end-users, as well as changes in the corresponding revenue streams.

4.1.9.4 Revenue

This category includes revenue from the sale of local goods or services within the community and those goods or services which are exported out of the community. Revenue information allows resource managers to assess how changes in resources or regulations may affect industry-sector revenues and ultimately, the local community's economic output and vitality. Revenue generated by fishery-dependent activities (e.g., by commercial landings, recreational direct expenditures, or end-user consumption of commercial products) provides basic information for calculating contributions to local economies and a means to compare relative values of goods and services derived from the fishery.

4.2 Past and Ongoing Monitoring of the Commercial Fishery

4.2.1 Sustainable Fishery Control Rules

Fishery control rules determine levels for take and upper limits on take. Information on biomass, reproductive potential and productivity, and age composition, as well as other biological, social, and economic parameters, is necessary to directly and accurately calculate allowable fishing mortality. In some areas, market squid are in a data-rich situation while other areas are data-poor. The result is that some basic EFI is not generally available. These gaps need to be a priority in research.

Although the PFMC adopted the egg escapement method to monitor the market squid fishery setting the egg escapement threshold level at 30%, there are several areas that require further research or refinement including:

- Verify that the current threshold level of egg escapement promotes sustainability of the fishery;
- Information is needed regarding duration of spawning, egg-laying rate, rate of maturation and natural mortality on spawning grounds;
- Fishery-dependent sources of mortality of eggs spawned such as destruction of egg beds by fishing gear should be investigated as they are not quantified in the egg escapement threshold; and
- Egg escapement methodologies need spatial and temporal evaluation of northern and southern fisheries.

4.2.2 Fishery-Dependent Monitoring

4.2.2.1 Past Fishery-Dependent Monitoring

Fishery-dependent data for the commercial market squid fishery have been collected since 1927. Commercial data in the form of landing receipts, which are filled out when the catch is sold to fish businesses or by fishermen selling directly to the public, are the primary source of information on the amount landed, landing location, gear used and value of the catch. Landing receipts to date have provided a general knowledge of when and where fishing activity occurs and amount of squid landed. Logbooks are another useful tool for tracking fishing activity that supplements data gathered from landing receipts. In the case of market squid, logbook information is gathered from fishing vessels and light boats. These records provide a measure of fishing effort and may prove helpful for population modeling.

Additionally, the Department has actively collected fishery-dependent biological data on market squid through a dockside sampling program since October 1998. The typical data collected are species identification, size, weight, sex, age from statoliths, maturity through gonad and mantle tissue collection, and fecundity.

4.2.2.2 Problems with Past and Ongoing Fishery-Dependent Monitoring

Currently, some fishery-dependent data are of limited use. Fishery-dependent monitoring, using landing receipts, does not provide adequate information about fishing location. Fishing blocks used by the Department are 10 nautical miles (nm) by 10 nm representing an area of 100 square nautical miles. The size of the blocks is too large to identify specific fishing locations. Logbooks, which have been in operation since May 2000, will provide a more spatially explicit understanding of fishing activity, which is important for proper fishery management.

Generally, finfish stock fishery-dependent data have performed poorly in predicting stock decline when used alone (National Research Council 2001). However, because squid are pelagic and fishery-independent data are limited, the use of fishery-dependent data are the only source of stock information. Further, squid are short-lived (six-nine months) invertebrates, rather than longer-lived finfish, therefore, using fishery-dependent data presents additional challenges to an already problematic method of predicting abundance.

4.2.3 Fishery-Independent Research

4.2.3.1 Past Fishery-Independent Research`

There have been few fishery-independent studies on market squid. The Department sponsored several research projects beginning in 1998. These studies have provided necessary information on paralarval and market squid distribution when not on the spawning grounds, characterization of spawning habitat, and reproductive potential. Fishery-independent data can: 1) provide measures of the relative abundance, trends, and estimates of the size and age structure of fish stocks which are not affected by fishing practices or management regulations; 2) calibrate trends in fishery-dependent estimates and tune assessment models; and 3) encompass a broad suite of information on the biological community, the physical environment and the ecosystem as a whole, which cannot be obtained directly via fishery-dependent measures.

4.2.3.2 Problems with Past and Ongoing Fishery-Independent Research

Fishery-independent research has, and continues to be, conducted by a few organizations through a diverse set of funding sources. Unfortunately, the bulk of the research suffers from:

- Limited spatial coverage;
- Non-standardized research that prevents comparison with other data sets; and
- High costs.

However, the Department market squid research program was funded primarily through substantial permit fees and has been coordinated for comparability throughout California. Further, the Department has collaborated with agencies, squid fishermen, and universities to conduct the research. This collaborative research approach is effective and should be advanced. A reduction in permit fees to $400 by the Legislature in the 2001-2002 season coincided with a reduction in Department sponsored research.

4.3 Current Knowledge of Essential Fishery Information

Currently, EFI for market squid is limited for management purposes. Additional data would be desirable to assess the biomass of the stock, life history, ecological interactions, and socioeconomics. A description of the data currently available on market squid is outlined below.

4.3.1 Age and Growth Characteristics

The lifespan of market squid has been calculated based on recent research. Preliminary results indicate that market squid harvested are between four and ten months in age with new cohorts entering the fishery at least seven times a year. Length-at-age and length-weight relationships have been calculated, but need to be verified by further age and growth studies. In addition, daily ring deposition on statoliths needs to be validated throughout the lifespan of market squid.

4.3.2 Distribution of Stocks

The distribution of the market squid population is from the southern tip of Baja California, Mexico to southeastern Alaska. It is not known whether the population is made up of one or more stocks.

4.3.3 Ecological Interactions

No statewide coordination exists for studies of ecological interactions of market squid. Consequently, little is known about the region-specific effects of oceanographic regimes and human effects on the physiological, energetic, and behavioral characteristics of market squid, or the species that they interact with as prey, predators, or competitors.

4.3.4 Estimates of Abundance

No defensible estimates of abundance exist for market squid.

4.3.5 Movement Patterns

Paralarval research (Zeidberg and Hamner 2002) provides preliminary information of movement of paralarval squid, including movement offshore within currents and vertical migration.

4.3.6 Recruitment

Paralarval studies (Zeidberg and Hamner 2002) may provide information to predict recruitment into the fishery and identify spawning areas not targeted by the fishery.

4.3.7 Reproductive Characteristics

Some reproductive characteristics of market squid have been identified (Macewicz et al. 2001b). The potential fecundity has been characterized and is utilized in the egg escapement method. While monitoring continues, preliminary data indicate that the rate of eggs spawned prior to harvest varies between seasons. The temperature range for spawning squid has been identified using a remotely operated vehicle (ROV) and is most often in the range of 50 to 57º F. These current fishery-independent data collection methods need to be continued.

4.3.8 Total Mortality

The current rate of natural and fishing mortality for market squid, on either a daily or a monthly basis, is largely unknown. Ageing studies have started to produce better estimates and need to be continued on spatial (throughout its range) and temporal (within and between seasonal) scales.

4.3.9 Social and Economic

Adequate information on employment, expenditures, and revenues for certain basic-sector industries are readily available or can be derived from existing sources. Such sources include the periodic surveys and reports prepared by the Bureau of the Census, the Bureau of Labor and Statistics, the Bureau of Economic Analyses, the USFWS, the Department, and local institutions and academic affiliates. Combined information from these sources allows analyses of impacts or contributions to local economies by commercial fishing activities. However, these sources do not provide adequate information relevant for a thorough analysis of the California market squid fishery.

4.4 Research to Obtain Essential Fishery Information

The Department is currently monitoring the market squid fishery through fishery-dependent programs and fishery-independent research. The fishery-dependent port sampling program allows the Department to determine the characteristics of harvested squid and shifts in the fishery, as well as estimate egg escapement. Another fishery-dependent program is the logbook program, which allows an estimate of fishery effort and provides exact locations of fishing activity. The egg escapement method is based on female squid collected independent of the fishery. Current fishery-independent research is focused on increasing the sample size of female squid to refine the egg escapement model as well as the characterization and location of squid spawning beds.

The following research needs are necessary to fill market squid EFI gaps identified above. The overall goal is to expand our knowledge of market squid. Data-poor management using a MSY proxy should be considered a temporary solution while an accurate method to assess market squid biomass is pursued.

4.4.1 Fishery-Dependent Data Research

Current efforts to collect fishery-dependent data rely heavily on port sampling, landing receipts, and logbook data. Landing receipts and logbooks record fishing effort and allow managers to track fishing trends. Port samples provide valuable environmental and biological information on squid taken in the fishery. When using the egg escapement method (as a proxy for MSY), it is important to be aware of shifts in the fishery that may make this method less effective. These data can be used to detect changes in the fishery including potential shifts (such as a shift to pre-spawning adults), which may have detrimental effects on the population.

4.4.2 Fishery-Independent Data Research

The most important fishery-independent research need is to develop a model to estimate market squid biomass. Since direct population counts cannot be made, it is necessary to develop models or proxies to estimate population parameters (e.g., mortality, fishing pressure).

Currently, market squid fecundity estimates, based on the egg escapement model, are used as a proxy for MSY. However, it is important to improve and enhance these estimates by increasing the sample size of female market squid used in the histological studies upon which the egg escapement model is based. In addition, mantle condition, especially the rate of mantle thinning, will provide insight into the health of squid caught in the fishery. Further, it is necessary to obtain a more complete understanding of squid spawning including the number of times spawning occurs in a lifetime, spawning rate, and the duration of time spent on spawning grounds.

Like other cephalopod species, the age of market squid can be determined by counting growth rings on the statoliths; however, this technique needs to be verified and validated for all stages of market squid development. In addition, current research is aimed at identifying possible differences of growth and/or fecundity rates between squid caught in the northern and southern California fisheries.

A common problem in most fisheries is bycatch. The potential take of both commercially and recreationally important fish species, such as salmon, should be further evaluated. The current port sampling program only monitors the frequency of incidental catch observed at the squid processing facilities. The use of at sea observers should be evaluated to determine if bycatch is an important issue to this fishery by documenting any impacts to commercial and recreationally important fish species such as salmon and rockfish, in addition to marine mammals and seabirds. In addition, squid egg cases can be disturbed during fishing operations. Therefore, it is important to monitor bycatch to determine how squid eggs are being impacted. ROV and visual surveys may provide information on fishery impact to squid egg cases. These data may be applicable to future population models.

Larval squid abundance from California Cooperative Ocean Fisheries Investigations (CalCOFI) cruises from 1978-1998 needs to be analyzed and if possible used as an index of abundance for modeling purposes. Studies on natural mortality rates, dietary requirements, and spawning behavior could also fill in life history gaps. Other identified studies involve examining the distribution and migration of squid, including the determination of squid stock structure using genetic analyses.

Future research also needs to include explorations of spawning areas other than the traditional locations and an examination of egg densities and egg dynamics. Studies on the effects of sound and light disturbance on seabird populations should be continued. The possible interaction of predators (i.e., sea lions) and squid attracted to night-lighting also should be addressed. Furthermore, it is recommended that monies and efforts be invested into archiving data and samples, expanding socioeconomic data collection, and maintaining a database on spawning areas.

4.4.3 Market Squid Fishery Sponsored Research

Collaboration between government researchers and various fishing industries has been promoted in recent years to defray increasing costs of management as well as to increase awareness of the targeted resource. As recognized by the market squid legislation, information on this resource is limited, and the FMP addresses this with a research and monitoring component. As knowledge increases or additional management needs become apparent, the FMP allows for adaptive management to occur. The Department supports and encourages efforts by the squid fishing industry to become involved and address appropriate research questions.

A preliminary meeting in April 2004 between an industry sponsored group of fishermen and processors and Department, NOAA Fisheries and university researchers was held with the goal to identify and prioritize research needs and design a plan for cooperative field research. Some of the proposed projects that industry could participate included:

- Identifying potential spawning areas from anecdotal and existing fishery data;
- Collecting representative samples of the missing age class of virgin female squid;
- Testing the effectiveness of squid light boats at estimating squid abundance using lights for set periods of time (a catch per unit of effort concept); and,
- Testing the effectiveness of light boats and fishing vessels to perform bongo net tows which would augment CalCOFI data with nearshore and additional stations between and outside the CalCOFI stations.

4.4.4 Steps to Monitor the Fishery and Obtain Essential Fishery Information

The Department will need more resources than are currently available in order to begin some of the research needed to address EFI issues. The research objectives should be based on data necessary to model the market squid biomass. The Department is encouraging collaboration with other state and federal agencies, academia, and the user groups to conduct EFI research and address squid management needs. Some of these needs include:

- Further analysis and evaluation of particular components of the egg escapement method for the market squid population off the coast of California. This modeling work should focus on developing a better understanding of squid biology and population-level responses to exploitation strategies;
- Developing an infra-structure to facilitate communication, logistical support, standardization of data collection methods, preliminary analysis, and reporting;
- Addressing the effects of fishing gear (nets, bottom lines and shackles) on squid egg beds;
- Assess relevance of previously collected data, publish for peer review, and use in management decisions;
- Addressing the effects of squid lighting gear on nesting seabird rookeries;
- Assessing the effectiveness of enforcement and adjust as necessary to better manage the resource (i.e., increasing penalties and/or enforcement);
- Obtaining recommendations from advisory committees of the best data collection activities and models for market squid stock assessment; and,
- Initiating educational outreach programs.

4.4.5 Social and Economic Dimensions of the Fishery

The relationship between fishermen and the markets plays a vital role in the survival and sustainability of a fishery (Pomeroy and FitzSimmons 2001). Many squid fishermen have close social and economic ties to local fishing communities. As a result, the economic stability of coastal communities can be greatly impacted by local fisheries. Therefore, comprehensive analyses of the socioeconomic dimensions of the squid fishery should be considered. Due to the instability of the market squid fishery, the socioeconomic components can change frequently; thus, it is important to continually re-examine these conditions.

These recommendations work toward providing needed EFI and bringing the Department closer to an ecosystem-based approach to the management of market squid.