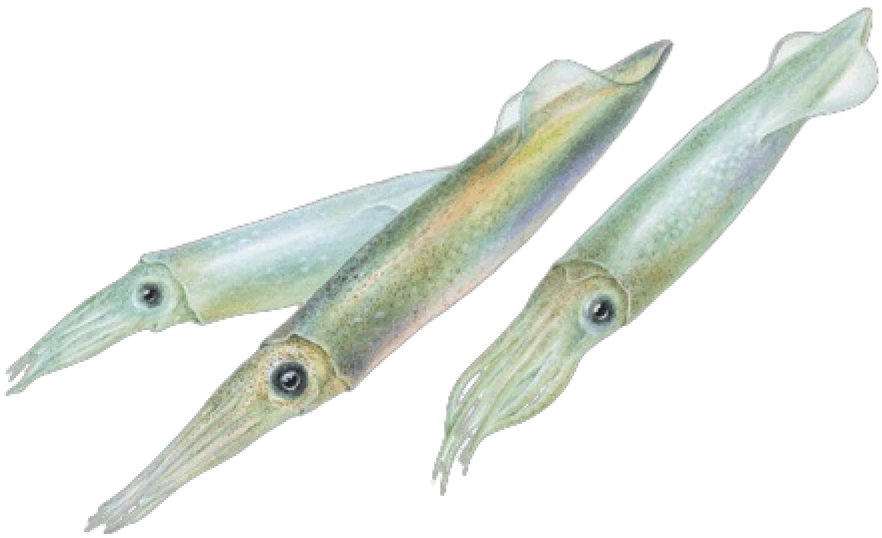
Monterey Bay Aquarium
Seafood Watch

Environmental sustainability assessment of wild-caught California market squid from California caught using purse seines



Species: California market squid *(Doryteuthis [Loligo] opalescens)*

Location: California

Gear: Purse seines

Type: Wild Caught

Author: Seafood Watch

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Assessed using Seafood Watch Fisheries Standard v4

Table of Contents

About Seafood Watch

Monterey Bay Aquarium's Seafood Watch program evaluates the environmental sustainability of wild-caught and farmed seafood commonly found in the United States marketplace. Seafood Watch defines sustainable seafood as originating from sources, whether wild-caught or farmed, which can maintain or increase production in the long-term without jeopardizing the structure or function of affected ecosystems. The program's goals are to raise awareness of important ocean conservation issues and empower seafood consumers and businesses to make choices for healthy oceans.

Seafood Watch's science-based ratings are available at www.SeafoodWatch.org. Each rating is supported by a Seafood Watch assessment, in which the fishery or aquaculture operation is evaluated using the Seafood Watch standard.

Seafood Watch standards are built on our guiding principles, which outline the necessary environmental sustainability elements for fisheries and aquaculture operations. The guiding principles differ across standards, reflecting the different impacts of fisheries and aquaculture.

- Seafood rated Best Choice comes from sources that operate in a manner that's consistent with our guiding principles. The seafood is caught or farmed in ways that cause little or no harm to other wildlife or the environment.

- Seafood rated Good Alternative comes from sources that align with most of our guiding principles. However, one issue needs substantial improvement, or there's significant uncertainty about the impacts on wildlife or the environment.

- Seafood rated Avoid comes from sources that don't align with our guiding principles. The seafood is caught or farmed in ways that have a high risk of causing harm to wildlife or the environment. There's a critical conservation concern or many issues need substantial improvement.

Each assessment follows an eight-step process, which prioritizes rigor, impartiality, transparency and accessibility. They are conducted by Seafood Watch scientists, in collaboration with scientific, government, industry and conservation experts and are open for public comment prior to publication. Conditions in wild capture fisheries and aquaculture operations can change over time; as such assessments and ratings are updated regularly to reflect current practice.

More information on Seafood Watch guiding principles, standards, assessments and ratings are available at www.SeafoodWatch.org.

Guiding Principles

Seafood Watch defines sustainable seafood as originating from sources, whether fished[1] or farmed, that can maintain or increase production in the long term without jeopardizing the structure or function of affected ecosystems.

The following guiding principles illustrate the qualities that fisheries must possess to be considered sustainable by the Seafood Watch program (these are explained further in the Seafood Watch Standard for Fisheries):

- Follow the principles of ecosystem-based fisheries management.
- Ensure all affected stocks are healthy and abundant.
- Fish all affected stocks at sustainable levels.
- Minimize bycatch.
- Have no more than a negligible impact on any threatened, endangered, or protected species.
- Managed to sustain the long-term productivity of all affected species.
- Avoid negative impacts on the structure, function, or associated biota of aquatic habitats where fishing occurs.
- Maintain the trophic role of all aquatic life.
- Do not result in harmful ecological changes such as reduction of dependent predator populations, trophic cascades, or phase shifts.
- Ensure that any enhancement activities and fishing activities on enhanced stocks do not negatively affect the diversity, abundance, productivity, or genetic integrity of wild stocks.

These guiding principles are operationalized in the four criteria in this standard.Each criterion includes:

- Factors to evaluate and score
- Guidelines for integrating these factors to produce a numerical score and rating

Once a rating has been assigned to each criterion, Seafood Watch develops an overall recommendation. Criteria ratings and the overall recommendation are color coded to correspond to the categories on the Seafood Watch pocket guides and online guide:

Best Choice/Green: Buy first; they're well managed and caught or farmed responsibly.

Good Alternative/Yellow: Buy, but be aware there are concerns with how they're caught, farmed or managed.

Avoid/Red: Take a pass on these for now; they’re caught or farmed in ways that harm other marine life or the environment.

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[1] “Fish” is used throughout this document to refer to finfish, shellfish and other invertebrates

Summary

This report provides recommendations for the U.S. domestic fishery for market squid (*Doryteuthis opalescens*, formerly *Loligo opalescens*). Market squid ranges from southeastern Alaska, United States to Baja California, Mexico. The fishery for market squid occurs along the U.S. West Coast, where it is concentrated primarily in southern and central California. This report assesses and provides a recommendation for the purse seine market squid fishery in California.

Criterion 1
No formal stock assessment or traditional biological reference points exist, so total biomass and a sustainable biomass level are unknown. There is no evidence of overfishing, and paralarval and juvenile abundance sampling suggests resilience to fishing pressure. An egg escapement model is used for a proxy biological and fishing mortality reference point and to evaluate the effects of fishing mortality on the stock's spawning potential. Data-limited assessments suggest positive, healthy trends in juvenile and paralarval stocks, raising little concern about stock status. Total fishing mortality is unknown, though the egg escapement level is monitored throughout each fishing season.

Criterion 2
Bycatch is minimal and primarily comprises other coastal pelagic species such as anchovy, sardine, and mackerel. The northern subpopulation of Pacific sardine is overfished, but the market squid fishery makes minimal contributions to sardine catch. Some protected species such as marine mammals are occasionally captured, but the majority are released alive, and the market squid fishery is classified as Category III by the National Oceanic and Atmospheric Administration (NOAA) under the Marine Mammal Protection Act (MMPA). Seal bombs, which are used as a deterrent for marine mammal predation during fishing, may have negative impacts on marine mammals, but research that shows direct links between seal bomb use in squid fisheries and marine mammal population impacts is lacking.

Criterion 3
The market squid fishery is managed through the Market Squid Fishery Management Plan (MSFMP), which is implemented by the California Department of Fish and Wildlife (CDFW). Market squid management also comes from the federal-level Coastal Pelagic Species (CPS) Fishery Management Plan (FMP), though responsibility for these aspects of management is also given to the state of California by the Pacific Fishery Management Council (PFMC). The MSFMP and other state legislation include a number of fishery control rules: a seasonal catch limit of 118,000 short tons; time and area closures to provide uninterrupted squid spawning; gear restrictions on attracting lights; a restricted access, permit-based program for entry into and participation in the fishery; and a threshold proportional egg escapement level of 30% for stock sustainability.

Management makes use of an informal proxy reference point because formal biological reference points do not exist, given the short lifespan and fluid abundance of market squid. This approach involves unknowns that leave room for uncertainty in how well the stock is managed. Abundance data for juvenile and paralarval squid are collected annually through trawl surveys, but adult abundance data are lacking. Proportional egg escapement levels are monitored through CDFW's port sampling program, and incidental catch, weight of squid landings, and sex and size data for landed squid are monitored through electronic ticket reporting. Management can adapt based on egg escapement and catch levels, but for egg

escapement, this can only be done after, not during, a fishing season. The egg escapement model is re-examined annually, and further models for squid abundance, although used in other squid fisheries, have not been created for market squid.

Port sampling and logbooks are used to monitor the fishery. The catch limit has been exceeded twice since its introduction, exhibiting a potential weakness in the enforcement of this control rule, but landings have routinely been below the catch limit since 2013. Permit numbers are approaching target capacity, and there is no evidence of substantial illegal fishing for squid. But, barracuda and Chinook salmon, two species for which purse seine capture is illegal, are observed in a small number of sampled nets each season. A pilot observer program from 2004 to 2008 found minimal bycatch in the fishery, and little bycatch beyond other CPS species is found through the logbook and sampling programs, but a more thorough confirmation that bycatch remains low could be useful.

Criterion 4
Purse seines in the fishery are used in the water column above spawning aggregations, and in order to avoid bottom contact, fishers do not hang their nets as low as some other fisheries, though this is only done voluntarily. But, squid spawn in shallow, nearshore waters on muddy and sandy bottom substrate, and bottom contact by purse seines does occur. At least 10.1% of sampled nets from 2010 to 2020 contained egg capsules that had been laid on bottom substrate, but the impacts of squid purse seine gear on the benthic habitat remain unknown. Market squid is an important prey species for fish, marine mammals, seabirds, and other squid species, and it is an important predator of krill and mesozooplankton, playing a central role in the food web of the California Current ecosystem (CCE). Management measures provide some protections for squid spawning habitats through reserves and protected areas, and gear restrictions are in place for seabird protection. It is not certain that these measures adequately protect the role that market squid plays in the food web.

Final Seafood Recommendations

SPECIES | FISHERY	C 1 TARGET SPECIES	C 2 OTHER SPECIES	C 3 MANAGEMENT	C 4 HABITAT	OVERALL	VOLUME (MT) YEAR
California market squid | Eastern Central Pacific | Purse seines | United States | California	3.318	5.000	3.000	3.000	**Best Choice (3.496)**	57,020 (MT) 2021

Source: CDFW market squid landing receipt data: https://wildlife.ca.gov/Conservation/Marine/Pelagic/Market-Squid-Landing (CDFW 2022). Landings data are for the 2021-2022 (April 1-March 31) fishing season.

Summary

Market squid from California is rated a Best Choice. The population appears healthy, the fishery has minimal bycatch, and the gear produces little environmental impact. The total stock size is unknown, but data-limited assessments suggest that fishing pressure has had little impact on the population. A pilot observer program found there to be minimal bycatch, though this program was completed over a decade ago. Net sampling confirms that bycatch remains minimal. Management is scored as moderately effective, because more precautionary approaches could be used in setting the catch limit, adjusting fishing pressure during low biomass years, and responding in a timely manner to signs that the stock is not healthy. Market squid is an important prey species and a predator of krill and mesozooplankton in the California Current ecosystem, and a more ecosystem-based approach could better protect these roles. An ongoing review of the management plan for market squid is expected to review relevant information that may help address this concern.

Scoring Guide

Scores range from zero to five where zero indicates very poor performance and five indicates the fishing operations have no significant impact.

Final Score = geometric mean of the four Scores (Criterion 1, Criterion 2, Criterion 3, Criterion 4).

Best Choice/Green = Final Score >3.2, and no Red Criteria, and no Critical scores

Good Alternative/Yellow = Final score >2.2-3.2, and neither Harvest Strategy (Factor 3.1) nor Bycatch Management Strategy (Factor 3.2) are Very High Concern2, and no more than one Red Criterion, and no Critical scores

Avoid/Red = Final Score ≤2.2, or either Harvest Strategy (Factor 3.1) or Bycatch Management Strategy (Factor 3.2) is Very High Concern or two or more Red Criteria, or one or more Critical scores.

[2] Because effective management is an essential component of sustainable fisheries, Seafood Watch issues an Avoid recommendation for any fishery scored as a Very High Concern for either factor under Management (Criterion 3).

Introduction

Scope of the analysis and ensuing recommendation

This report assesses the California market squid (*Doryteuthis opalescens*, formerly *Loligo opalescens*) commercial fishery using purse seines. Market squid inhabits a range from southeastern Alaska, United States to Bahia Asunción in Baja California, Mexico (Recksiek and Frey 1978). The market squid fishery occurs on the U.S. West Coast, primarily in California, with occasional catches in Oregon and Washington (PFMC 2022). The fishery is California's largest by volume, representing an important part of the state's coastal economy. Market squid is landed using round haul gear, including purse seines, drum seines, and lampara nets (CDFW 2021). The primary gear type used by squid fishers is purse seines, which will be used to refer to all squid round haul gear in this report.

Species Overview

Market squid is a short-lived species (6–9 months) (Butler et al. 1999) that has been an important commercial fishery species in the state since the mid- to late 1800s (Vojkovich 1998). Figure 1 shows the known range of market squid. The purse seine fishery currently operates in two primary areas: central California (near Monterey Bay, where the fishery originated) and southern California (near the Channel Islands) (CDFW 2021). In central California, spawning occurs from April to October, and in southern California, from October to April/May, creating year-round fishing opportunities (Zeidberg et al. 2011)(CDFW 2021). Although there has been some past uncertainty whether the population consists of one or multiple stocks, market squid is managed as a single stock (CDFG 2005). This stock turns over annually, because market squid is a semelparous, terminal spawner {Macewicz et al. 2004}.

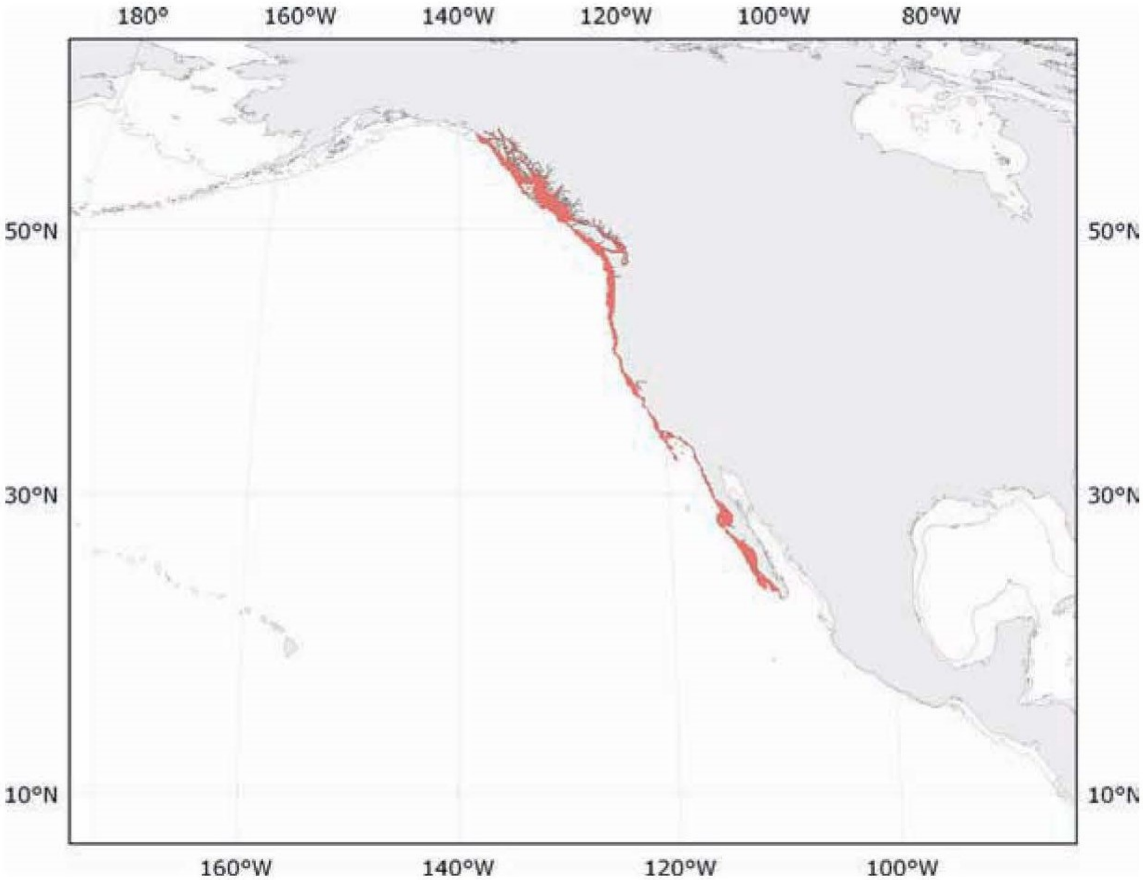

Fig. 92 ***Doryteuthis (Amerigo) opalescens***

Known distribution

Figure 1. Known range of market squid. Figure from {Jereb et al. 2010}.

Market squid plays an important role in the California Current ecosystem (CCE). The species serves as a prey item for bony and cartilaginous fish, marine mammals, seabirds, and jumbo squid (Szoboszlai et al. 2015). Researchers recently created a California Current Predator Diet Database, which includes 51 predators of market squid (Szoboszlai et al. 2015). Market squid is typically considered a lower-energy species and an alternative prey species, though it is still found among the top prey items in the diets of predators such as sea lion and common murre (McClatchie et al. 2016)(Hilborn et al. 2017)(Warzybok et al. 2018). Market squid has been identified as one of the most common prey items for a number of predators in the Monterey Bay, including curlfin turbot and Pacific sanddab (Figure 2) (Morejohn et al. 1978). Market squid also plays an important role as a mid-trophic species, predating on mesozooplankton and krill (Ish et al. 2004)(CDFW 2021).

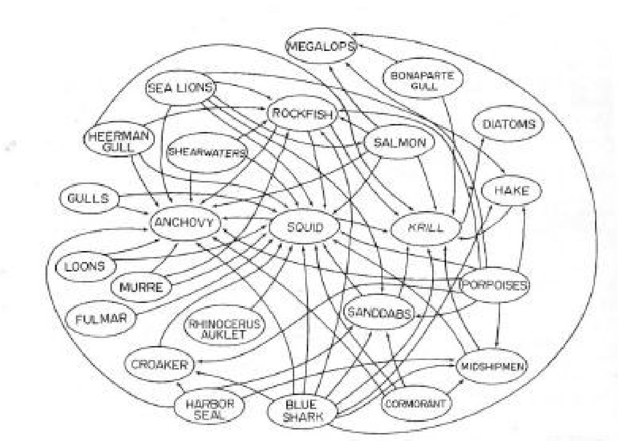

Figure 2. Food web for market squid and abundant or commercially important other species in the CCE. Figure from (Morejohn et al. 1978).

Market squid also exhibits highly variable productivity and abundance, largely influenced by climatic conditions from the El Niño Southern Oscillation (ENSO) (Van Noord 2020). During warmer El Niño periods, squid is thought to move to deeper depths for spawning {Van Noord and Dorval. 2017}, and the population may contract. Market squid may also move farther north toward Canada and Alaska during these warmer periods (Reiss et al. 2004)(Chasco et al. 2022). In contrast, cooler La Niña periods have been associated with higher paralarval abundance and potential population expansion (Van Noord and Dorval 2017). The exact dynamics of these populations and potential area shifts are not known. As a result, traditional evaluations of market squid stock status and abundance are not possible, making biological reference points for the stock unavailable. Instead, a proxy biological reference point is used, based on an egg escapement model (CDFG 2005). This informal reference point is set to ensure that at least 30% proportional egg escapement occurs in female squid captured by fishers (see Criterion 1 for more details).

Production Statistics

Before 1998, the fishery was open access, but increased market demand and consequent fishing pressure in the 1980s and 1990s led to a moratorium on fishing permits (CDFG 2005). In 2001, management of the fishery was transferred from the California Legislature to the California Fish and Game Commission. The Commission manages the fishery via the Market Squid Fishery Management Plan (MSFMP), which has set an annual limit on landings of 118,000 short tons since 2004 (CDFG 2005). Much of the market for this species comes from Asian buyers (Porzio and Brady 2006), and both Asian and European demand for market squid have increased in recent decades (CDFW 2021). Most market squid landed in California is subsequently frozen and exported to international markets (CDFW 2021).

Landings of market squid have generally increased since 1980, when demand and production began to increase, with the value of landings also showing an increasing trend (Figure 3) (CDFW 2021). Landings in the 2014–15 fishing season were projected to reach the catch limit for the fifth season in a row, but purse seiners voluntarily stopped fishing before the end of the season, so total catch remained under the limit (Porzio 2015). Landings are not consistent from season to season, which is largely influenced by ENSO patterns (Chasco et al. 2022). Market squid contributed 64% of the total fishing tonnage and 30% of the total ex-vessel value for all species landed in California in 2014 (Porzio 2015). Squid was the highest volume species landed in California for all but four years from 1997 to 2020 (CDFW 2021). In the past two fishing seasons (2020–21 and 2021–22), landings were 20,768 short tons and 62,869 short tons, respectively (CDFW 2022). In 2021, market squid landings composed 66% of all fishery landings across California ports (Marine Resources Committee 2022). Although the fishery originated in Monterey, landings in the 1990s to 2000s were concentrated in southern California (Figure 4). But in the early 2010s, squid landings began increasing farther north (Ralston et al. 2018), with squid captured north of San Francisco Bay at the Port of Humboldt Bay (Eureka) for the first time in 2014 (Porzio 2015).

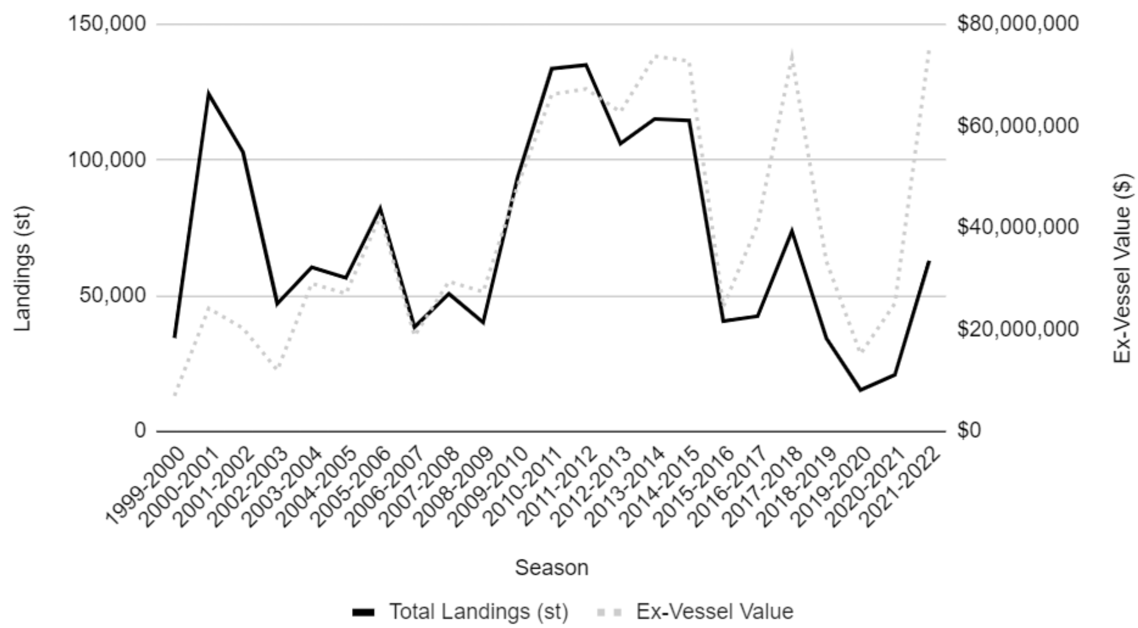

Figure 3. Squid landings and ex-vessel value amounts from 1990 to 2021. Data from (CDFW 2022).

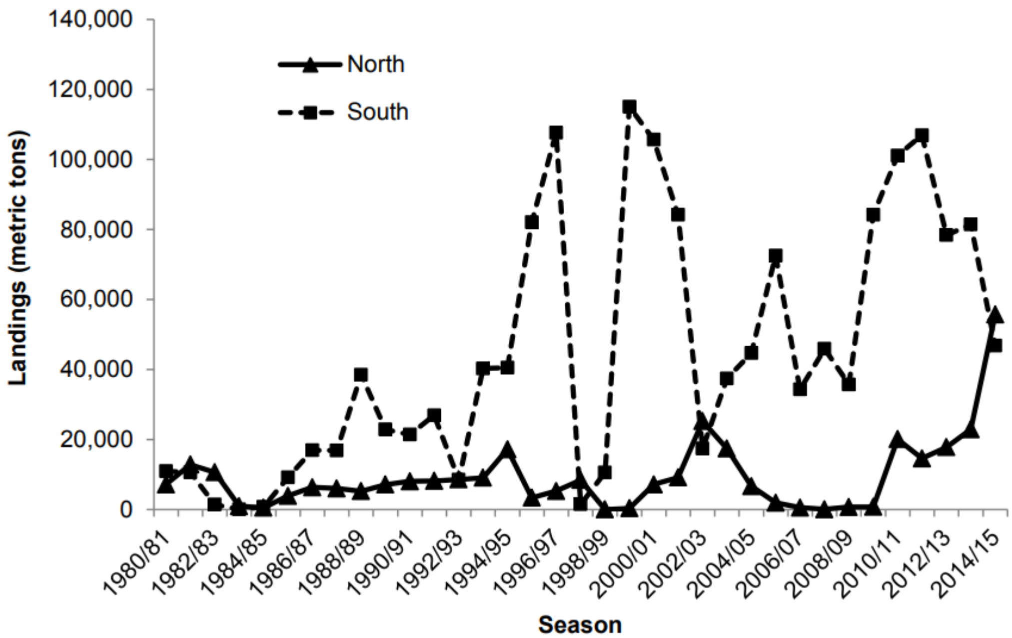

Figure 4. Landings of market squid in northern and southern port areas from 1980 to 2015. Figure from (PFMC 2019).

Importance to the US/North American market.

The value of market squid, on average, has increased since 2000, and the species has routinely brought in more revenue than all other California Coastal Pelagic Species (CPS) finfish combined since 2000 (Figure 5) (PFMC 2019). In 2021, over $78 million worth of frozen market squid and over $3 million worth of dried, salted, and brined market squid were exported to foreign markets (NOAA Fisheries 2022b). The majority of this squid (>80%) was exported to China (NOAA Fisheries 2022b); some of it is then re-imported into the United States after processing. Domestically, market squid is an important bait source for recreational fishers (NOAA Fisheries 2022a).

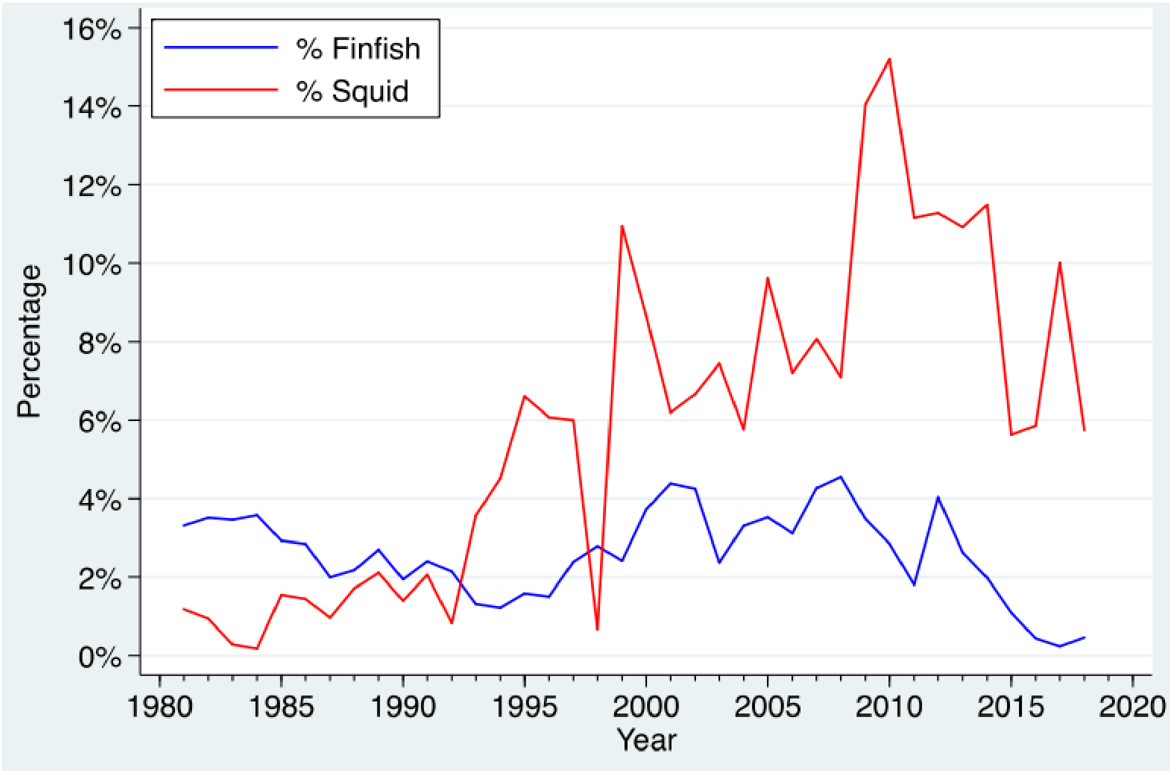

Figure 5. Ex-vessel revenue from market squid and CPS finfish (Pacific sardine, Pacific mackerel, jack mackerel, anchovy) landed on the U.S. West Coast from 1981 to 2017, as a percentage of total ex-vessel revenue for the coast. Figure from (PFMC 2019).

Common and market names.

Market squid has previously been referenced in the literature as *Loligo opalescens*, before the name change to *Doryteuthis opalescens*. Common names for market squid include California market squid, squid, and calamari (FDA 2021).

Primary product forms

Squid is sold both fresh and frozen in the form of rings (sliced squid), tubes (mantle), tentacles, and whole (FishChoice 2020). Squid is often consumed as calamari, whole steaks, or stuffed (Sea Fare Group 2011). Squid provides protein and important nutrients such as iron, selenium, and vitamin B_{12} (Kidadl 2021).

Assessment

This section assesses the sustainability of the fishery(s) relative to the Seafood Watch Standard for Fisheries, available at www.seafoodwatch.org. The specific standard used is referenced on the title page of all Seafood Watch assessments.

Criterion 1: Impacts on the species under assessment

This criterion evaluates the impact of fishing mortality on the species, given its current abundance. When abundance is unknown, abundance is scored based on the species' inherent vulnerability, which is calculated using a Productivity-Susceptibility Analysis. The final Criterion 1 score is determined by taking the geometric mean of the abundance and fishing mortality scores. The Criterion 1 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Rating is Critical if Factor 1.3 (Fishing Mortality) is Critical.

Guiding principles

- *Ensure all affected stocks are healthy and abundant.*
- *Fish all affected stocks at sustainable level*

Criterion 1 Summary

CALIFORNIA MARKET SQUID			
REGION / METHOD	**ABUNDANCE**	**FISHING MORTALITY**	**SCORE**
Eastern Central Pacific | Purse seines | United States | California	3.670: Low Concern	3.000: Moderate Concern	Green (3.318)

Criterion 1 Assessments

SCORING GUIDELINES

Factor 1.1 - Abundance
Goal: Stock abundance and size structure of native species is maintained at a level that does not impair recruitment or productivity.

- *5 (Very Low Concern) — Strong evidence exists that the population is above an appropriate target abundance level (given the species' ecological role), or near virgin biomass.*
- *3.67 (Low Concern) — Population may be below target abundance level, but is at least 75% of the target level, OR data-limited assessments suggest population is healthy and species is not highly vulnerable.*
- *2.33 (Moderate Concern) — Population is not overfished but may be below 75% of the target*

abundance level, OR abundance is unknown and the species is not highly vulnerable.

- *1 (High Concern) — Population is considered overfished/depleted, a species of concern, threatened or endangered, OR abundance is unknown and species is highly vulnerable.*

Factor 1.2 - Fishing Mortality

Goal: Fishing mortality is appropriate for current state of the stock.

- *5 (Low Concern) — Probable (>50%) that fishing mortality from all sources is at or below a sustainable level, given the species ecological role, OR fishery does not target species and fishing mortality is low enough to not adversely affect its population.*
- *3 (Moderate Concern) — Fishing mortality is fluctuating around sustainable levels, OR fishing mortality relative to a sustainable level is uncertain.*
- *1 (High Concern) — Probable that fishing mortality from all source is above a sustainable level.*

California market squid

Factor 1.1 - Abundance

Eastern Central Pacific | Purse seines | United States | California

Low Concern

Because of market squid's short lifespan, responsiveness to environmental conditions, and high population plasticity, its stock abundance is unknown, population dynamics are difficult to understand, and a formal stock assessment has never been conducted (CDFG 2005)(Maxwell et al. 2005)(Zeidberg et al. 2006)(Ralston et al. 2018)(CDFW 2021). Data-limited assessments of the population suggest that it is resilient to high fishing pressure and has low vulnerability, and there is no evidence that the population is overfished (Dorval et al. 2013)(Van Noord and Dorval 2017)(Ralston et al. 2018)(NOAA Fisheries 2022a)(Patrick et al. 2009). One informal proxy biological reference point exists and is applied through an egg escapement model (CDFG 2005)(Dorval et al. 2013). This reference point has been in place since 2005 and is periodically re-examined by the California Department of Fish and Wildlife (CDFG 2005)(Maxwell et al. 2005). Because the results of data-limited assessments have low uncertainty and suggest that the stock is healthy, this factor is scored a low concern.

Justification:

Market squid has a life expectancy of 6–9 months (Butler et al. 1999)(Jackson and Domeier 2003) and is a semelparous species, with death occurring after spawning events (Butler et al. 2001). This means that the stock turns over annually, with abundance depending on the success of and survival from the previous year's spawning efforts {Macewicz et al. 2004}(Maxwell et al. 2005). The fishery in California targets mature spawning squid, and the stock's health is best maintained when fishers capture squid after they have spawned (NOAA Fisheries 2022a). Dorval et al. (2013) found that less than 5% of the sampled catch during most quarters from 1999 to 2006 was made up of immature squid. But, when fishers target aggregations of squid during spawning, they do capture female squid that have not released all of their eggs (Dorval et al. 2013).

Though there are two primary spawning areas and seasons, the stock is managed as a single interbreeding population. Genetic evidence suggests that there is only one population of market squid, but that this population may consist of microcohorts with overlapping recruitment periods, allowing for year-round spawning (Cheng et al. 2020). These microcohorts differ genetically over time and space and have been observed in other *Loliginid* species (Cheng et al. 2020). Abundance patterns within microcohorts have not been studied, so they are currently unknown, though managers were awarded funding in June 2022 to further study market squid, including research into its genomics (Marine Resources Committee 2022).

Data-limited abundance assessments have been used to examine paralarval abundance and juvenile abundance of market squid in the California Current ecosystem (CCE) (Van Noord and Dorval 2017)(Ralston et al. 2018). Abundance models using survey data from NOAA exhibit increases in paralarval and juvenile squid density in the CCE since 2004 (Wells et al. 2017)(Ralston et al. 2018)(Chasco et al. 2022), alongside and in spite of high fishing pressure during the same period. One analysis found that environmental conditions had much more influence on population fluctuations than fishing pressure (Van Noord and Dorval 2017). Another assessment using RREAS trawl data found that the numbers of prerecruit squid captured in trawls correlated with subsequent adult squid landings (Ralston et al. 2018). Results from this research also showed that prerecruit abundance from 1990 to 2014 was generally steady or slightly increased (Ralston et al. 2018). Another assessment using net sampling data found no measurable impact from the squid fishery on the average size (via mantle length and mass) or sex ratio from 2000 to 2013 (Protasio et al. 2014).

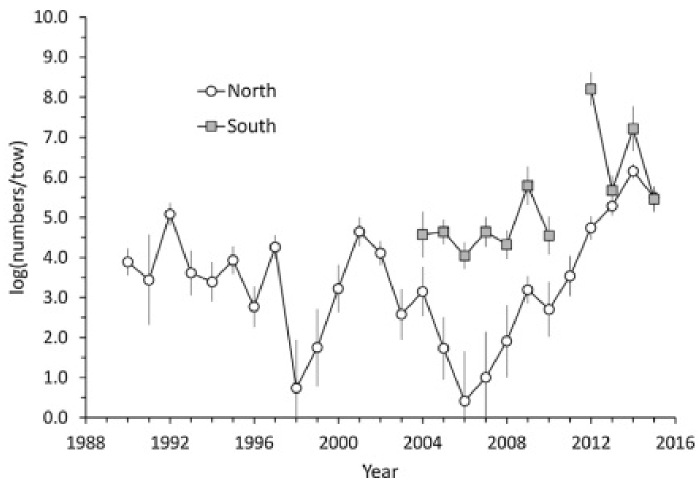

Figure 6. Annual changes (±1.0 standard error) in market squid larval abundance in midwater trawl surveys, 1990–2014. Figure from (Ralston et al. 2018).

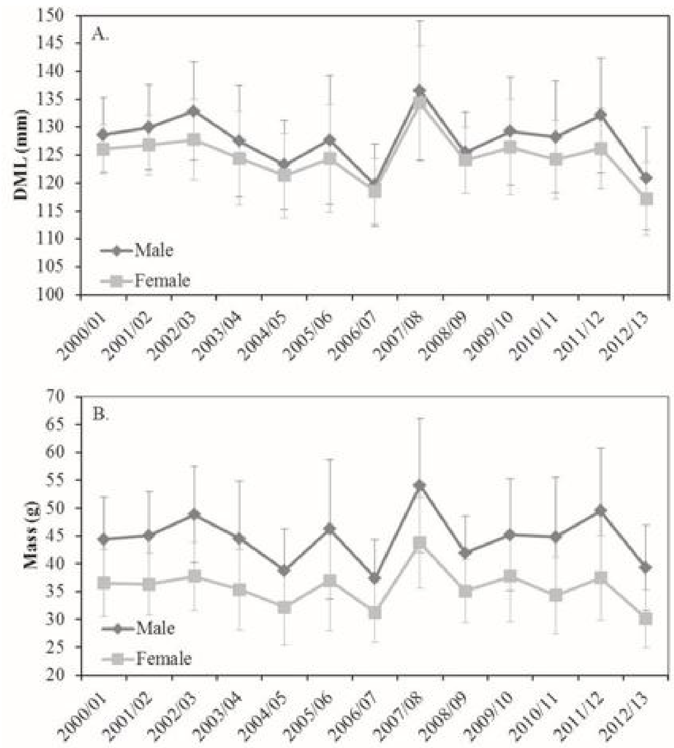

Figure 7. (A) Mean (±SD) dorsal mantle length (DML), and (B) mass for male and female California market squid across all regions by commercial fishing season. Figure from (Protasio et al. 2014).

Managers use an egg escapement model developed by Maxwell et al. (2005) for proxy biological reference points and to evaluate squid population dynamics (CDFG 2005). Successful recruitment is dependent on egg survival during the previous spawning season, so a threshold of initial egg deposition should be met to maintain the stock (Zeidberg et al. 2011). Although cephalopods are generally resilient (Ralston et al. 2018), Zeidberg et al. (2011) note that egg failure for multiple seasons in a row would create concern for the stock. The escapement model uses a 30% threshold: at least 30% proportional egg escapement should occur during the fishing season (CDFG 2005). If at least 30% of egg cases are released by females before their capture in the fishery, the population will be large enough during the following fishing season to continue supporting the fishery without negative population impacts. The last formally published research using egg escapement data is from a 2013 study that used catch data from 1999 to 2006 {Dorval et al 2013}. This study found that, in most quarters, proportional egg escapement in three primary California port areas was, on average, above 30%, but during some quarters, egg escapement was as low as 8%. The data for this assessment did not come from the entire market squid fishery, so the estimates are not fishery-wide. Published research on re-examining the egg escapement model has not been produced since this 2013 paper, though CDFW and NOAA are currently reviewing the model and do so each year (CDFW 2021). In 2021, CDFW provided publicly available egg escapement measurements (see Figure 8 in Factor 1.2) that indicated that annual mean egg escapement was above 0.30 for all but one fishing season from 2014 to 2020. The COVID-19 pandemic affected managers' ability to measure egg escapement in the 2020–21 and 2021–22 fishing seasons (CDFW 2021).

Factor 1.2 - Fishing Mortality

Eastern Central Pacific | Purse seines | United States | California

Moderate Concern

Similar to abundance, there is no formal measurement of fishing mortality for market squid. Managers have used the egg escapement model to determine an acceptable biological catch (ABC) level that allows for continued population health—this is the fishing mortality level at which at least 30% egg escapement occurs (Maxwell et al. 2005)(Dorval et al. 2013)(CDFW 2021)(PFMC 2022). But, this is an informal reference point; because there are no formal biological reference points in place, mortality relative to the abundance of the stock remains uncertain (Dorval et al. 2013) (CDFW 2021). Because fishing mortality is unknown, this factor receives a score of moderate concern.

Justification:

Escapement models are popular among squid fisheries because of the species' population fluctuations and the lack of abundance data (Arkhipkin et al. 2015). Other fisheries have adopted an escapement threshold of 40% (Beddington et al. 1990)(Basson et al. 1996)(Agnew et al. 1998), while the market squid level of 30% is based on data for haddock, a species with a different life history than squid (CDFW 2021). The egg escapement model for California market squid accounts for catch fecundity versus total potential fecundity, leading to a recommended level of at least 30% proportional egg escapement, to maintain population health. This means that, across the fishing season, captured female squid should have the chance to deposit at least 30% of their egg capsules before being captured by the fishery. The model sets a proxy F_{MSY} (as well as an overfishing limit and ABC) as the level at which this threshold of escapement occurs (Maxwell et al. 2005)(Dorval et al. 2013)(CDFW 2021). This method requires only an indirect measure of fishing mortality, through the measurement of proportional egg escapement.

The acceptable level of egg escapement undergoes periodic review, incorporating new measurements and data, but it has not changed since its introduction (PFMC 2019). CDFW takes samples of landed squid throughout each season to calculate egg escapement (CDFG 2005). The most recent publication on egg escapement in the market squid fishery confirmed that escapement levels were, on average, at least 30% across each fishing season from 1996 to 2013, but these data did not cover the entire squid fishery (Dorval et al. 2013). Laboratory procedures for the egg escapement method create a time lag in applying the model to the fishery (McDaniel et al. 2015), which could delay critical management actions. But, since 2015, new updates to lab procedures have started to decrease the time needed for this process (PFMC 2019). The most recent proportional egg escapement numbers from CDFW show that escapement was above 0.30 in all but one fishing season (in which escapement was just 0.006 below the threshold) from the 2014–15 season to the 2019–20 season (Figure 8). Escapement during this time did not fall below 0.30 for two years in a row, so management action was not needed to protect the health of the stock or to lower fishing pressure.

Fishing Season	Number of Samples	Proportion of Vessel Landings Sampled	Mean Proportional Egg Escapement
2014 - 2015	106	0.029	0.402
2015 - 2016	95	0.063	0.409
2016 - 2017	102	0.039	0.294
2017 - 2018	194	0.050	0.366
2018 - 2019	130	0.060	0.359
2019 - 2020	43	0.028	0.468
2020 - 2021	*	*	*
2021 - 2022	*	*	*

Figure 8. Summary of statewide market squid proportional egg escapement from the 2014–15 to 2019–20 fishing seasons. Figure from (CDFW 2021).

Two existing productivity-susceptibility analyses for market squid suggest that the species is resilient to fishing pressure, with low vulnerability (to fishing) scores of 1.4 and 1.33 (Patrick et al. 2009)(Swasey et al. 2016). There is no evidence that overfishing is occurring or has occurred in the market squid fishery, but there is uncertainty about the quantified impact and the sum of fishing mortality relative to the total stock abundance. Hatfield and des Clers (1998) noted that absolute egg production (how many total eggs are deposited and spawned successfully) is more important for stock health than proportional egg escapement from fishery landings (Hatfiled & des Claires 1998). Current management methods do not include a measurement of absolute egg production. Furthermore, fishery closures are set by a landing tonnage limit across the entire fishery (118,000 short tons), rather than using the egg escapement indicator during the fishing season as a means of closing the fishery. If proportional egg escapement were to drop below 30% for two years in a row, the fishery may become actively managed rather than simply monitored, but this does not indicate that there would be a definite fishery closure to allow for population recovery (PFMC 2019). This increases uncertainty around the impacts of the fishery on stock health and abundance.

Criterion 2: Impacts on Other Species

All main retained and bycatch species in the fishery are evaluated under Criterion 2. Seafood Watch defines bycatch as all fisheries-related mortality or injury to species other than the retained catch. Examples include discards, endangered or threatened species catch, and ghost fishing. Species are evaluated using the same guidelines as in Criterion 1. When information on other species caught in the fishery is unavailable, the fishery's potential impacts on other species is scored according to the Unknown Bycatch Matrices, which are based on a synthesis of peer-reviewed literature and expert opinion on the bycatch impacts of each gear type. The fishery is also scored for the amount of non-retained catch (discards) and bait use relative to the retained catch. To determine the final Criterion 2 score, the score for the lowest scoring retained/bycatch species is multiplied by the discard/bait score. The Criterion 2 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Rating is Critical if Factor 2.3 (Fishing Mortality) is Crtitical

Guiding principles

- *Ensure all affected stocks are healthy and abundant.*
- *Fish all affected stocks at sustainable level.*
- *Minimize bycatch.*

Criterion 2 Summary

Criterion 2 score(s) overview

This table(s) provides an overview of the Criterion 2 subscore, discards+bait modifier, and final Criterion 2 score for each fishery. A separate table is provided for each species/stock that we want an overall rating for.

CALIFORNIA MARKET SQUID			
REGION / METHOD	**SUB SCORE**	**DISCARD RATE/LANDINGS**	**SCORE**
Eastern Central Pacific | Purse seines | United States | California	5.000	1.000: < 100%	Green (5.000)

Criterion 2 main assessed species/stocks table(s)

This table(s) provides a list of all species/stocks included in this assessment for each 'fishery' (as defined by a region/method combination). The text following this table(s) provides an explanation of the reasons the listed species were selected for inclusion in the assessment.

EASTERN CENTRAL PACIFIC | PURSE SEINES | UNITED STATES | CALIFORNIA			
SUB SCORE: 5.000	DISCARD RATE: 1.000	**SCORE: 5.000**	
SPECIES	**ABUNDANCE**	**FISHING MORTALITY**	**SCORE**
California market squid	3.670: Low Concern	3.000: Moderate Concern	Green (3.318)

The market squid fishery has minimal bycatch (CDFG 2005)(CDFW 2021), but some species are incidentally caught in the fishery's purse seine nets. Primary bycatch species are other coastal pelagic species (CPS), namely northern anchovy, jack mackerel, Pacific mackerel, and Pacific sardine (CDFW 2021)(PFMC 2022). These species tend to be landed with squid because CPS fishes often form mixed schools (PFMC 2022). Landings receipts from the 2013–14 to 2020–21 fishing seasons show that landings, in weight, of these species made up well below 5% of each season's total catch (PFMC 2019)(PFMC 2022), so no bycatch species are considered main species in this fishery.

Pacific sardine's northern subpopulation is classified as overfished, and the commercial sardine fishery is closed, so there is no current F_{MSY}. An ABC does exist, and squid fishery landings of sardine from 2017 to 2020 were between 0.4% and 3.0% of this threshold (see Appendix B) (Kuriyama et al. 2022)(PFMC 2022).

There is no bycatch observer program for the market squid fishery, though there has been a mandatory logbook reporting system in place since 2000 (Zeidberg et al. 2006). A pilot observer program was run from 2004 to 2008 and exhibited minimal incidental catch and discards in the fishery (Figure 9) (PFMC 2019). This program noted the amounts and species types in fishery discards—discard weights were negligible compared to total landings, and incidentally caught species made up well under 5% of total landings (PFMC 2019). The program also noted small bycatch numbers during the period for marine mammals (California sea lion, harbor seal, common dolphin), sharks (blue shark, thresher shark), and seabirds (unidentified gulls). All were released alive, except one dolphin and one gull (PFMC 2019). NOAA classifies the California market squid fishery as a Category III Fishery (fishery contributes <1% of

PBR for incidentally captured marine mammals or total fishing mortality is <10% of PBR) (CDFW 2021). Within this classification, NOAA does note that the fishery has interactions resulting in mortality or serious injury with the California sea lion, long-beaked and short-beaked common dolphins, and Risso's dolphin (NOAA Fisheries 2022c). Each of these species has healthy local stocks, with total fishing mortality below 10% of PBR.

Target species - Squid					
Species	Target Catch	Incidental Catch	Bycatch Returned		
			Alive	Dead	Unknown
Squid	1274 mt		28 mt	350 lbs	2 mt
Anchovy		100 lbs	120 lbs		
Jack Mackerel		2 mt	18 lbs	2 lbs	
Pacific Mackerel		20 mt	20 mt	180 lbs	1 lb
Sardine		12 mt	13 mt	1077 lbs	3 lbs
Spanish Mackerel		20 lbs			
Bat Ray			53		1
Bat Star			1		
Blue Shark			2		
Common Mola			1		
Pelagic Stingray			60		
Pacific Butterfish		19			1
Sunstar		30	4		
Squid Eggs					505 lbs
Lobster			3		
Brittle Star				3000	
Unid. Batfish				2 lbs	
Unid. Crab		1	1		93
Unid. Croaker		3	2	16 lbs	
Unid. Flatfish		1	1	6	2
Unid. Jellyfish		4			
Unid. Mackerel		2 lbs	102 lbs		
Unid. Octopus		1			
Unid. Rockfish		1	1	4	
Unid. Ray			4		1
Unid. Sanddab		4	3		4
Unid. Seastar		1			
Unid. Seaslug					21
Unid. Scorpionfish		1			
Unid. Surfperch				3	
Unid. Skate		3		1	
Unid. Smelt		49			
Unid. Stingray		9	17		
Unid. Shark					1
Thresher Shark		1			
CA Sea Lion			98		
Harbor Seal			3		
Common Dolphin				1	
Unid. Gull			16	1	

Figure 9. Preliminary catch summary from vessels targeting market squid from NMFS–SWR coastal pelagic species pilot observer program, 2004–08. Table from (PFMC 2019).

Some concerns have been raised around the use of seal bombs in the fishery. These devices detonate underwater and are meant to be used to scare away and deter pinnipeds attempting to feed on aggregated squid while the nets are being deployed (Simonis et al. 2020). Researchers have noted concerns about potential physical, auditory, and behavioral impacts from seal bombs on both pinnipeds and cetaceans (Myrick et al. 1990, cited by Simonis et al. 2020)(Wiggins et al. 2019)(Simonis et al. 2020); however, because bombs deployed by fishers have not been found to harm marine mammals directly and are legal as a deterrent method, they do not create additional bycatch in the fishery. Impacts from seal bombs are still being explored and are not yet fully understood, but it is thought that more research is needed because of the potential harm from these devices. NOAA also notes that, in observed marine mammal interactions in 2020, the fishery produced no mortalities (NOAA 2021).

From 2016 to 2020, a small percentage of sampled landings contained species for which purse seine capture is illegal: barracuda, salmon, and white seabass (CDFW 2021), though this created little cause for concern with respect to the amounts of these species that were landed. But, quantification of the number or weight of each of these landed species would help ensure that the fishery has no impact on their populations, because these landings are currently only reported as the percent of sampled nets with the presence of each species (see Appendix C). These "listed" species that are landed are reported by CDFW to their Law Enforcement Division.

The market squid fishery is rated a low concern for its impacts on other capture species, because no other species compose 5% or more of the total catch, and it is unlikely that the fishery has an impact on populations of species of concern.

Criterion 2 Assessment

SCORING GUIDELINES

Factor 2.1 - Abundance
(same as Factor 1.1 above)

Factor 2.2 - Fishing Mortality
(same as Factor 1.2 above)

Factor 2.3 - Modifying Factor: Discards and Bait Use
Goal: Fishery optimizes the utilization of marine and freshwater resources by minimizing post-harvest loss. For fisheries that use bait, bait is used efficiently.

Scoring Guidelines: The discard rate is the sum of all dead discards (i.e. non-retained catch) plus bait use divided by the total retained catch.

Ratio of bait + discards/landings	Factor 2.3 score
<100%	1
>=100	0.75

Factor 2.3 - Discard Rate/Landings

Eastern Central Pacific | Purse seines | United States | California

< 100%

The fishery does not use bait, and the pilot observer program showed discards to be minimal (PFMC 2019).

Criterion 3: Management Effectiveness

Five factors are evaluated in Criterion 3: Management Strategy and Implementation, Bycatch Strategy, Scientific Research/Monitoring, Enforcement of Regulations, and Inclusion of Stakeholders. Each is scored as either 'highly effective', 'moderately effective', 'ineffective,' or 'critical'. The final Criterion 3 score is determined as follows:

- *5 (Very Low Concern) — Meets the standards of 'highly effective' for all five factors considered.*
- *4 (Low Concern) — Meets the standards of 'highly effective' for 'management strategy and implementation' and at least 'moderately effective' for all other factors.*
- *3 (Moderate Concern) — Meets the standards for at least 'moderately effective' for all five factors.*
- *2 (High Concern) — At a minimum, meets standards for 'moderately effective' for Management Strategy and Implementation and Bycatch Strategy, but at least one other factor is rated 'ineffective.'*
- *1 (Very High Concern) — Management Strategy and Implementation and/or Bycatch Management are 'ineffective.'*
- *0 (Critical) — Management Strategy and Implementation is 'critical'.*

The Criterion 3 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Rating is Critical if Management Strategy and Implementation is Critical.

Guiding principle

- The fishery is managed to sustain the long-term productivity of all impacted species.

Five factors are evaluated in Criterion 3: Management Strategy and Implementation, Bycatch Strategy, Scientific Research/Monitoring, Enforcement of Regulations, and Inclusion of Stakeholders. Each is scored as either 'highly effective', 'moderately effective', 'ineffective,' or 'critical'. The final Criterion 3 score is determined as follows:

Criterion 3 Summary

FISHERY	MANAGEMENT STRATEGY	BYCATCH STRATEGY	DATA COLLECTION AND ANALYSIS	ENFORCEMENT	INCLUSION	SCORE
Eastern Central Pacific | Purse seines | United States | California	Moderately Effective	Highly effective	Moderately Effective	Moderately Effective	Highly effective	**Yellow (3.000)**

Criterion 3 Assessment

<u>SCORING GUIDELINES</u>

Factor 3.1 - Management Strategy and Implementation
Considerations: What type of management measures are in place? Are there appropriate management goals, and is there evidence that management goals are being met? Do manages follow scientific advice? To achieve a highly effective rating, there must be appropriately defined management goals, precautionary policies that are based on scientific advice, and evidence that the measures in place have been successful at maintaining/rebuilding species.

Factor 3.2 - Bycatch Strategy
Considerations: What type of management strategy/measures are in place to reduce the impacts of the fishery on bycatch species and when applicable, to minimize ghost fishing? How successful are these management measures? To achieve a Highly Effective rating, the fishery must have no or low bycatch, or if there are bycatch or ghost fishing concerns, there must be effective measures in place to minimize impacts.

Factor 3.3 - Scientific Research and Monitoring
Considerations: How much and what types of data are collected to evaluate the fishery's impact on the species? Is there adequate monitoring of bycatch? To achieve a Highly Effective rating, regular, robust population assessments must be conducted for target or retained species, and an adequate bycatch data collection program must be in place to ensure bycatch management goals are met.

Factor 3.4 - Enforcement of Management Regulations
Considerations: Do fishermen comply with regulations, and how is this monitored? To achieve a Highly Effective rating, there must be regular enforcement of regulations and verification of compliance.

Factor 3.5 - Stakeholder Inclusion
Considerations: Are stakeholders involved/included in the decision-making process? Stakeholders are individuals/groups/organizations that have an interest in the fishery or that may be affected by the management of the fishery (e.g., fishermen, conservation groups, etc.). A Highly Effective rating is given if the management process is transparent, if high participation by all stakeholders is encouraged, and if there a mechanism to effectively address user conflicts.

Factor 3.1 - Management Strategy And Implementation

Eastern Central Pacific | Purse seines | United States | California

Moderately Effective

The market squid management strategy includes several control measures: an annual catch limit of 118,000 short tons, a restricted access program with required permits for commercial fishing, spatial closures through protected areas, and weekend closures for uninterrupted spawning (CDFG 2005). Managers also use an egg escapement model to monitor relative fishing pressure. Adaptive management is a requirement for the fishery under California's Marine Life Management Act (MLMA)—the squid fishery allows for adaptations in response to consistently low egg escapement, high catch volume, or amendments to the MSFMP (CDFW 2021).

Catch trends and trends in squid size and sex ratios are monitored via CDFW's port sampling program, but trends in catch relative to effort are not directly proportional to abundance trends (Dorval et al. 2013). Size and sex ratios have remained largely steady, suggesting that the fishery has not negatively affected these (Protasio et al. 2014). But, management does not and cannot know true abundance or trends in abundance based on currently available models and data, as a consequence of the short lifespan and natural population fluctuations of market squid. Therefore, official reference points are unavailable for the stock. A proxy reference point has been developed and is in use via the egg escapement model; this reference point has been in use since 2005. Other squid fisheries have established more robust stock assessments and reference points using different methods than those employed in the market squid fishery (Kidokoro et al. 2003) (Yamashita and Kaga 2013)(Hendrickson 2017).

There is no evidence that the stock is overfished, but because no formal biological reference points exist, some uncertainty is brought into assessing and managing the health of the stock. Variability in stock abundance and productivity due to environmental factors is not considered in the adaptability of the application of the egg escapement model, the annual catch limit, or time closures—these are static rather than adaptive measures. Egg escapement is measured during each fishing season to give a measure of relative abundance, but because there is no absolute abundance or biomass estimate, management does not account for seasons with lower initial biomass. An annual catch limit was developed using a method recommended by NOAA but was ultimately set at a less conservative level than is usually recommended. The catch limit is monitored via landings reports during the season, and the fishery will close accordingly if the limit is met. Because little is known about the stock abundance, there is no biomass threshold below which fishing should not occur. Current harvest control rules could be more precautionary in nature because they do not adapt to environmentally-driven biomass fluctuations and would benefit from quicker reactions to stock changes; therefore, management strategy is given a moderately effective score.

Justification:

The fishery will close early if the catch limit is reached during a season, which includes a public announcement of the closure from CDFW (NOAA Fisheries 2022c). If the proportional egg escapement goal of at least 30%—based on in-season sampling of captured female squid—is not met for two seasons in a row, the fishery can move from being monitored to being actively managed under the CPS FMP (PFMC 2022). Actively managed fisheries are subject to annual harvest limits that are based on biomass estimates (CDFG 2005). It is not clear how this active management would take shape, given the difficulties in estimating biomass for market squid. The fishery is already actively managed under the MSFMP and is subject to a seasonal harvest limit via the 118,000 short tons catch limit.

The CPS FMP notes that actively managed fisheries are subject to more conservative harvest control rules than fisheries managed using maximum sustainable yield (MSY) approaches (PFMC 2021). This FMP sets certain requirements for the squid fishery, most of which are implemented through the MSFMP. The CPS FMP requires all CPS fisheries to have an established MSY, ABC, optimum yield, and annual catch limit. But, the FMP allows an exception for market squid: the species is exempt from an annual catch limit and can use a proxy MSY because of its short lifespan and fluctuating biomass (CDFW 2021). The CPS FMP also outlines management tasks and procedures for changes in how the fishery is managed.

One commonly used strategy for developing a catch limit is to base the total allowable catch on the average historical catch from a period with no clear biomass declines (Restrepo et al. 1998). In theory, this limit should not exceed 50%–75% of that average catch level, unless there is a scientific reason to believe that the stock is above B_{MSY} (Restrepo and Powers 1999). The market squid catch limit was developed based on a proxy MSY, using several consecutive years of historically high catch without a decline in landings in the following years (CDFG 2005). This proxy MSY method partly follows NOAA guidance for data-poor species (Restrepo et al. 1998). Proxy MSY values were developed based on 3-, 5-, and 10-year catch averages. The average of landings from 1999 to 2002 (the 3-year average)—about 118,000 short tons—was set as the annual catch limit (CDFG 2005). Landings before 1999 were, on average, lower than 118,000 short tons. By setting the catch limit as the average catch from three years of historically high catch data, managers chose the least conservative MSY, largely because there were no signs of stock decline following these three seasons.

The proxy MSY method for market squid deviates from NOAA guidance in setting the catch limit relative to the calculated average catch. This limit inherently exceeds 75% of the average catch of the species (the ceiling provided in NOAA's methodology), because it is set as 100% of that average. Although the stock is thought to be healthy and there have been no signs of declining stock productivity (based on landings data), this limit does exceed the recommended level for this approach, and B_{MSY} is unknown, bringing some uncertainty into the ability of this catch limit to prevent stock declines. Managers note that the multiplier of 1.0 relative to the historical catch average was used because of squid's short lifespan: a shorter-lived species requires a less precautionary optimum yield multiplier (CDFW 2021). There is evidence to suggest that the squid population rebounds quickly because of the species' short lifespan (Zeidberg et al. 2006), but the choice of a 1.0 multiplier rather than a more conservative 0.75 multiplier is not fully explained by this fact.

Previous research has cautioned managers against failing to incorporate climate-induced productivity changes to their management plans in this ecosystem, because the California sardine fishery previously collapsed due to this failure (Patrick et al. 2009). Although squid harvest control rules, such as the catch limit and the egg escapement method, allow managers to adjust fishing pressure, these adjustments are not made for natural fluctuations in market squid biomass. Because biomass cannot be directly measured, the catch limit and egg escapement threshold remain constant from year to year, even in years when environmental conditions are thought to create population contractions (i.e., El Nino years). This also means that managers do not have a minimum biomass target, which would set a population abundance threshold below which fishing should not occur. As noted above, if proportional egg escapement is below the 30% threshold for two years in a row, the fishery can become actively managed under the CPS FMP, whereas it is currently monitored only at the federal level (CDFG 2005)(PFMC 2022). But, there is no guaranteed mechanism in place that would more quickly adjust fishing pressure based on low egg escapement estimates during a fishing season. Proportional egg escapement is also different from true spawning success, so is not a direct indicator of the following season's stock health. In this respect, the egg escapement model can only be used to evaluate impacts on the spawning potential of the squid stock (CDFW 2021). Managers note that the model is not meant to be used as a real-time management tool (CDFW 2021). Therefore, precautionary policies may not be as strong as they should be for a highly effective management system.

Fishing intensity is also controlled through time and area closures. No fishing is allowed from noon on Friday to noon on Sunday, giving squid a period of uninterrupted [by fishing] spawning each week (CDFG 2005). No round haul net fishing is allowed in California's state ecological reserves (CDFG 2005). California's MPA network also provides protections for essential market squid spawning grounds. South Coast no-take MPAs protect at least 14.6% of available spawning grounds (Van Diggelen 2017). Northern Channel Island MPAs provide additional protection from fishing. Bathymetry modeling suggests that 13% of known squid spawning grounds are found within MPAs (CDFW 2021). But the exact contribution of MPAs to squid spawning success is unknown (Van Diggelen 2017).

Finally, the potential existence of microcohorts within the population (see Factor 1.1) suggests that management may need to shift its approach in order to preserve genetic diversity (Cheng et al. 2020). Genetic diversity within a population is important for overall stock health and resilience (Lynch 2016). Currently, the fishery is managed based on the assumption of a single population, but if microcohorts are present within this population, it would be better managed in a way that minimizes concentrated fishing pressure over finite space and time, so that no cohorts become depleted. Genomic research is being funded as part of the FMP review and may improve understanding in this area (Marine Resources Committee 2022).

Factor 3.2 - Bycatch Strategy

Eastern Central Pacific | Purse seines | United States | California

Highly effective

The market squid fishery's total landings include <5% bycatch species (PFMC 2022). Species of concern are rarely captured, so the fishery does not pose a threat to these populations; however, quantification of these species' landings would further solidify this assertion. In 2011, the fishery was moved from a Category II to a Category III fishery for marine mammal impacts, where it has stayed since (NOAA Fisheries 2022c). But, better monitoring of the use of seal bombs would help ensure that they are used correctly in deterring marine mammal predation, because it is illegal to use them to corral squid into nets and they pose a risk to the welfare of individual marine mammals. Pacific sardine, an overfished species, has a rebuilding plan in place that puts limits on incidental landings of sardine in other CPS fisheries, including market squid (PFMC 2020). The squid fishery's incidental catch of sardine is well below this limit (see Appendix B). Chinook salmon, which is classified as "Threatened" under the Endangered Species Act, was found in small percentages of sampled nets from 2016 to 2020 (see Appendix C), but the squid fishery is not a significant contributor to Chinook salmon mortality (CDFW 2021). Fishers avoid mixed CPS schools when possible, because mixed landings increase the sorting time (PFMC 2020). Bycatch is thought to primarily occur when fishing is done in shallow waters over rocky habitats, which are typically avoided by fishers because they can damage round haul net gear (CDFW 2021), but there are not laws that these areas must be avoided or that mixed CPS schools must be avoided. Gear modifications for the use of attracting lights may help reduce seabird interactions in the fishery. Lights are restricted to a maximum output of 30,000 watts and must be shielded above the horizontal line of sight (CDFG 2005). Lights must be directed downward, or those not directed downward may be used if they are fully underwater (CDFG 2005). The lower edges of light shields must run parallel to the deck of the fishing vessel that they are used on (CDFG 2005). There are also area restrictions on the use of attracting lights, including their prohibition in the Gulf of the Farallones (CDFG 2005). These restrictions and modifications were put in place because of the risk that attracting lights posed to nesting seabirds. Finally, larger species that are incidentally caught in squid purse seine nets can be released alive while the nets are still in the water, via at-sea grate sorting (PFMC 2019). Because bycatch rates are low and the fishery does not have an impact on the stocks of bycatch species, the market squid bycatch strategy is rated highly effective.

Factor 3.3 - Scientific Data Collection and Analysis

Eastern Central Pacific | Purse seines | United States | California

Moderately Effective

Formal stock assessments are not used for market squid because adult abundance data are not collected. But, both fishery-dependent and -independent data are still collected, to monitor the health of the stock. CDFW collects dorsal mantle length, mass, and sex data from sampled fishing nets (Protasio et al. 2014). These data are used to examine trends in squid size and sex ratios over time. Egg escapement levels are also monitored throughout the fishing season (CDFG 2005). Monitoring the egg escapement levels ensures that the fished squid stock is given enough opportunity to replenish the stock for the following season.

Fishery-independent data are collected through ongoing surveys, which provide CDFW with both juvenile and paralarval abundance data. The California Wetfish Producers Association produces squid research and monitoring in cooperation with CDFW and the National Marine Fisheries Service (NMFS) (CWPA 2013). CWPA comprises fishers and processors of coastal pelagic species in

California who collect paralarval, zooplankton, and abiotic data. NOAA's Rockfish Recruitment and Ecosystem Assessment Survey (RREAS) and Juvenile Salmon and Ocean Ecosystem Survey (JSOES) collect data that can be used to monitor trends in young squid abundance. The California Cooperative Oceanic Fisheries Investigations (CalCOFI) performs quarterly offshore cruises that also collect paralarval squid data, complementing the nearshore data collected by CWPA (CWPA 2022). Although juvenile and paralarval abundance do not directly correlate with adult abundance, these data have helped lead to data-limited assessments of the health of the squid stock (Ralston et al. 2018)(Thompson et al. 2019)(Chasco et al. 2022).

The resulting data-limited assessments and catch numbers suggest that the stock is healthy and not negatively affected by fishing pressure; however, the true stock size, full geographic range, and exact biomass patterns remain unknown. No bycatch observer program exists, but there is a mandatory logbook program in place, and incidental catch is not a concern in this fishery. Incidental catch is also monitored through the port sampling program, but formal observer data have not been collected since 2008. Recent research projects have created models and suggestions for improved understanding of squid abundance and management, using collected fishery and stock data (Dorval et al. 2013)(Ralston et al. 2018)(Cheng et al. 2020)(Succa et al. 2022), but these have not yet been adopted. In the absence of recurring formal stock assessments or population models, or more recent bycatch observer data, but with other health and abundance data still collected and monitored, scientific data collection and analysis is scored moderately effective.

Justification:
Adult stock assessments have never been part of the management process for market squid; however, a number of publications have come out of juvenile and paralarval squid data collected during surveys. RREAS runs annually and collects trawl-based data used for stock assessments and early life history for rockfish and other species along the coast of central California (SWFSC 2022). JSOES also runs annually, collecting primarily salmon data for managers in the Northern California Current ecosystem (NWFSC 2022). Although JSOES occurs north of most of the range of market squid, data from recent surveys were used in two different publications to exhibit a northward movement of market squid, possibly as a result of climate change (Thompson et al. 2019)(Chasco et al. 2022). One of these publications also used RREAS trawl data to examine juvenile squid abundance in central California (Thompson et al. 2019).

Another recent publication used RREAS data not only to examine juvenile abundance, but also to examine the relationship between juvenile abundance and adult catch by creating a predictive model for the fishery (Ralston et al. 2018). CDFW was involved in this analysis. RREAS data have also been used to examine juvenile squid abundance data in other publications across the 2010s (McClatchie et al. 2016)(Warzybok et al. 2018). Finally, the California Wetfish Producers Association (CWPA) has performed annual paralarval sampling and other data collection in cooperation with the NMFS and CDFW since 2004 (CWPA 2013). The goal of this research is to maintain the viability of the market squid fishery while improving understanding of population dynamics and environmental impacts (CWPA 2021). Publications using CWPA survey data are created periodically and available on CWPA's website.

CDFW manages the squid fishery logbook and sampling programs, which provide catch and squid health data. Logbooks have been required since 2000 and are used to monitor catch per unit effort (CPUE) (CDFG 2005). Although CPUE is not a direct measure of squid stock abundance, the monitoring of CPUE trends still provides managers with a way to increase understanding of stock health. The net sampling program is used to monitor bycatch and squid health indicators. Changes in the sex ratio, squid mass, and squid mantle length may indicate changes in the health of the stock, thus highlighting the importance of this monitoring. Net sampling also is used for egg escapement measurements. Proportional egg escapement is monitored to ensure that it does not fall below 30% for two consecutive years. The last formally published research using this data is from a 2013 study that used catch data from 1999 to 2006 (Dorval et al. 2013), but CDFW reviews the egg escapement model annually and has provided publicly available egg escapement data for the 2014–15 through 2019–20 fishing seasons.

An observer-based bycatch monitoring program is not in place, though logbooks and net sampling collect some data on retained species. Net sampling does not collect data on at-sea interactions with larger, nonretained species. A pilot observer program was run from 2004 to 2008 to monitor bycatch in the fishery. The program observed minimal occurrences of bycatch, with most non-CPS species released alive (PFMC 2022). Furthermore, some NOAA marine mammal observations have taken place in the past two decades, and nonlethal interactions with California sea lion, long-beaked common dolphin, Risso's dolphin, and California short-beaked common dolphin occurred in 2020 (NOAA Fisheries 2022c). The use of seal bombs and their interactions with marine mammals are not consistently monitored or observed.

Factor 3.4 - Enforcement of and Compliance with Management Regulations

Eastern Central Pacific | Purse seines | United States | California

Moderately Effective

Through the MSFMP, CDFW uses logbooks and a port sampling program to monitor the fishery (CDFG 2005). A seasonal catch limit is in place that prompts a fishery closure, and permits are required to participate in this limited-entry fishery. Since the catch limit was established in 2004, it has been surpassed twice, despite monitoring of catch tonnage throughout the season to avoid this (CDFW 2021)(CDFW 2022). The permitting program has been in place since 2000, and there is no current evidence of substantial illegal fishing. But, barracuda and Chinook salmon, which are both illegal to capture with purse seine nets, were found in a small percentage of sampled squid nets from 2016–20 and 2017–20, respectively (see Appendix C) (CDFW 2021). Also, the egg escapement threshold was not met in the 2016–17 fishing season—though the mean proportional escapement level was just 0.006 short of the 0.30 threshold (CDFW 2021)—and management is only required to take action if this level is not met for two consecutive fishing seasons, which has not happened. Enforcement and compliance are rated moderately effective, because the catch limit has been surpassed in the past and some catch of illegal species recurs.

Justification:

The MSFMP set in place several layers of permitting and regulations for the market squid fishery.

Squid attraction lights are capped at 30,000 watts, and light boats require a permit for participation (CDFG 2005). Commercial fishing vessels also require permits, which are either transferable or nontransferable. Permit fees apply, ranging from $600 to $3,000 (CDFW 2021). Fishery capacity goals also exist: CDFW set these as 55 vessel permits, 18 brail permits, and 34 light boat permits for the market squid fishery. At the start of the 2022–23 season, 71 vessel permits, 46 brail permits, and 31 light boat permits had been issued (CDFW 2021). These numbers indicate that the fishery capacity goals are not currently being met, but it is clear that the fishery is moving toward reaching these goals. In 2018, there were 73 vessel permits, 45 brail permits, and 33 light boat permits (PFMC 2019); when the capacity goals were created, there were 165 vessels and 40 light boats in the fishery (OPC 2019). Commercial vessels that incidentally capture market squid do not require squid permits, but there are limits on the amount of squid they can land: either 2 tons per trip or 10% of the total fish volume (CDFW 2021). Vessels fishing for squid for use as live bait also do not require a permit, regardless of the amount of squid captured (CDFG 2005)(Porzio 2013). But, the bait fishery has been subject to electronic reporting requirements for its landings since 2019 (CDFW 2021).

The first market squid commercial catch limit was set in 2001 at 125,000 short tons (CDFW 2021). During the four seasons when this limit was set, it was not surpassed. In 2004, managers calculated a new catch limit of 118,000 short tons, based on a 3-year average from recurring high landing numbers. This catch limit was surpassed in the 2010–11 and 2011–12 seasons, and it was approached but not surpassed for three consecutive seasons after 2011–12 (CDFW 2021). Although CDFW is meant to close the fishery when the limit is reached, this did not happen for two seasons in a row. The limit has not been surpassed since 2012, but since the 2015–16 season, landings have stayed well under the 118,000 short ton limit, creating no need for management to consider closing the fishery. During the last high-volume season (2014–15), when landings had reached 97.2% of the catch limit, seine fishers voluntarily stopped fishing, thus preventing the need for management intervention (Porzio 2015). During seasons when the catch limit had been surpassed, paper landing receipts were submitted by mail, but this process has since moved to electronic tickets, thus allowing for reporting nearly in real time and a lower likelihood that the limit will be surpassed again (pers. comm., K. Grady 2023).

The port sampling program helps managers to monitor egg escapement. The program results in improved knowledge about squid age, squid sex ratios, female squid fecundity, and incidentally caught species (CDFG 2005). The port sampling program also collects egg cases found within nets, providing further information about fishing impacts on spawning success and fishing gear interactions with the spawning habitat. This sampling program found that mean egg escapement was 0.294 in 2016–17, just short of the required threshold, but the following year, the escapement level returned to above 0.30. The port sampling and logbook programs provide a means to monitor capture of nonsquid species as well. In 2016 to 2020, data from the sampling program found barracuda in a small percentage (2%–4%) of sampled nets each year (see Appendix C) (CDFW 2021). Although these instances are not common enough to raise concerns for managers, it is important to note that capture of barracuda with purse seine nets is unlawful in California (California Fish and Game Code 2013). Chinook salmon was found in a small percentage (2%–6%) of sampled nets from 2017 to 2020 (see Appendix C). Though these instances were similarly rare enough to not create management concerns, coastal California Chinook salmon is listed as

“Threatened” under the Endangered Species Act (NOAA Fisheries 2022d), and the capture of salmon with purse seines is unlawful in California (California Fish and Game Code 2021). The presence of barracuda and Chinook salmon in sampled nets suggests that management methods are able to identify these occurrences, but they may be lacking in preventing them.

Factor 3.5 - Stakeholder Inclusion

Eastern Central Pacific | Purse seines | United States | California

Highly effective

The MSFMP was created using a thorough stakeholder inclusion process. Under the MLMA of California, the development of fishery management plans must include significant stakeholder involvement (CDFG 2005). In this regard, the California Department of Fish and Game created two advisory committees that comprised fishers, scientists, and environmentalists, giving relevant parties a seat at the table. Numerous public meetings, hearings, and comment periods were also integrated into the development of the MSFMP (CDFG 2005). CDFW’s website has feedback surveys posted on it, to be used when regulations may change. Furthermore, the process for implementing changes to the MSFMP and enforcing fishery changes via the MSFMP (e.g., closures if the catch limit is reached) is transparent. Today, the California Wetfish Producers Association, a nonprofit established in 2004 by wetfish industry workers/owners, communicates with squid fishery managers and has members that sit on the PFMC’s CPS advisory subpanel (CDFW 2021). CWPA also has an ongoing cooperative research program with NOAA’s Southwest Fisheries Science Center and CDFW, in which the three groups work together to collect data that help maintain the sustainability of the California market squid industry (CWPA 2021). CDFW’s current FMP review process began with interviews with 35 stakeholders across the fishing, processing, conservation, science, and regulatory sectors (Marine Resources Committee 2022). The anticipated Squid Fishery Advisory Committee will also contain a variety of stakeholders and will consider the needs of fishers, including small-scale fishers, alongside conservation needs. Stakeholder inclusion is rated highly effective because of the thorough inclusion of and participation from stakeholders in the development, application, and current review and updates of management plans.

Criterion 4: Impacts on the Habitat and Ecosystem

This Criterion assesses the impact of the fishery on seafloor habitats, and increases that base score if there are measures in place to mitigate any impacts. The fishery's overall impact on the ecosystem and food web and the use of ecosystem-based fisheries management (EBFM) principles is also evaluated. Ecosystem Based Fisheries Management aims to consider the interconnections among species and all natural and human stressors on the environment. The final score is the geometric mean of the impact of fishing gear on habitat score (factor 4.1 + factor 4.2) and the Ecosystem Based Fishery Management score. The Criterion 4 rating is determined as follows:

- ***Score >3.2=Green or Low Concern***
- ***Score >2.2 and ≤3.2=Yellow or Moderate Concern***
- ***Score ≤2.2 = Red or High Concern***

Guiding principles

- Avoid negative impacts on the structure, function or associated biota of marine habitats where fishing occurs.
- Maintain the trophic role of all aquatic life.
- Do not result in harmful ecological changes such as reduction of dependent predator populations, trophic cascades, or phase shifts.
- Ensure that any enhancement activities and fishing activities on enhanced stocks do not negatively affect the diversity, abundance, productivity, or genetic integrity of wild stocks.
- Follow the principles of ecosystem-based fisheries management.

Rating cannot be Critical for Criterion 4.

Criterion 4 Summary

FISHERY	FISHING GEAR ON THE SUBSTRATE	MITIGATION OF GEAR IMPACTS	ECOSYSTEM-BASED FISHERIES MGMT	FORAGE SPECIES?	SCORE
Eastern Central Pacific | Purse seines | United States | California	Score: 3	Score: 0	Moderate Concern	No	**Yellow (3.000)**

Criterion 4 Assessment

SCORING GUIDELINES

Factor 4.1 - Physical Impact of Fishing Gear on the Habitat/Substrate
Goal: The fishery does not adversely impact the physical structure of the ocean habitat, seafloor or associated biological communities.

- *5 - Fishing gear does not contact the bottom*
- *4 - Vertical line gear*
- *3 - Gears that contacts the bottom, but is not dragged along the bottom (e.g. gillnet, bottom longline, trap) and is not fished on sensitive habitats. Or bottom seine on resilient mud/sand habitats. Or midwater trawl that is known to contact bottom occasionally. Or purse seine known*

to commonly contact the bottom.*

- *2 - Bottom dragging gears (dredge, trawl) fished on resilient mud/sand habitats. Or gillnet, trap, or bottom longline fished on sensitive boulder or coral reef habitat. Or bottom seine except on mud/sand. Or there is known trampling of coral reef habitat.*
- *1 - Hydraulic clam dredge. Or dredge or trawl gear fished on moderately sensitive habitats (e.g., cobble or boulder)*
- *0 - Dredge or trawl fished on biogenic habitat, (e.g., deep-sea corals, eelgrass and maerl)*
  Note: When multiple habitat types are commonly encountered, and/or the habitat classification is uncertain, the score will be based on the most sensitive, plausible habitat type.

Factor 4.2 - Modifying Factor: Mitigation of Gear Impacts
Goal: Damage to the seafloor is mitigated through protection of sensitive or vulnerable seafloor habitats, and limits on the spatial footprint of fishing on fishing effort.

- *+1 —>50% of the habitat is protected from fishing with the gear type. Or fishing intensity is very low/limited and for trawled fisheries, expansion of fishery's footprint is prohibited. Or gear is specifically modified to reduce damage to seafloor and modifications have been shown to be effective at reducing damage. Or there is an effective combination of 'moderate' mitigation measures.*
- *+0.5 —At least 20% of all representative habitats are protected from fishing with the gear type and for trawl fisheries, expansion of the fishery's footprint is prohibited. Or gear modification measures or other measures are in place to limit fishing effort, fishing intensity, and spatial footprint of damage caused from fishing that are expected to be effective.*
- *0 —No effective measures are in place to limit gear impacts on habitats or not applicable because gear used is benign and received a score of 5 in factor 4.1*

Factor 4.3 - Ecosystem-Based Fisheries Management
Goal: All stocks are maintained at levels that allow them to fulfill their ecological role and to maintain a functioning ecosystem and food web. Fishing activities should not seriously reduce ecosystem services provided by any retained species or result in harmful changes such as trophic cascades, phase shifts or reduction of genetic diversity. Even non-native species should be considered with respect to ecosystem impacts. If a fishery is managed in order to eradicate a non-native, the potential impacts of that strategy on native species in the ecosystem should be considered and rated below.

- *5 — Policies that have been shown to be effective are in place to protect species' ecological roles and ecosystem functioning (e.g. catch limits that ensure species' abundance is maintained at sufficient levels to provide food to predators) and effective spatial management is used to protect spawning and foraging areas, and prevent localized depletion. Or it has been scientifically demonstrated that fishing practices do not have negative ecological effects.*
- *4 — Policies are in place to protect species' ecological roles and ecosystem functioning but have not proven to be effective and at least some spatial management is used.*
- *3 — Policies are not in place to protect species' ecological roles and ecosystem functioning but detrimental food web impacts are not likely or policies in place may not be sufficient to protect species' ecological roles and ecosystem functioning.*
- *2 — Policies are not in place to protect species' ecological roles and ecosystem functioning and the likelihood of detrimental food impacts are likely (e.g. trophic cascades, alternate stable states,*

etc.), but conclusive scientific evidence is not available for this fishery.

- *1 — Scientifically demonstrated trophic cascades, alternate stable states or other detrimental food web impact are resulting from this fishery.*

Factor 4.1 - Physical Impact of Fishing Gear on the Habitat/Substrate

Eastern Central Pacific | Purse seines | United States | California

Score: 3

The market squid fishery focuses on capturing spawning squid aggregations above the sandy and muddy substrate where egg capsules are attached. Fishers primarily use purse seine gear to capture squid that are attracted to lights employed by vessels. Although the use of chain lead lines was once standard practice, most commercial seiners have transitioned to using nonchain, weighted lines, with some using riblines (pers. comm., K. Grady 2023). Though purse seine gear is aimed at use higher in the water column, above the seafloor, there is evidence that occasional contact with the seafloor does occur. Squid egg cases were found in 26.2% of sampled fishers' nets from 2010 to 2020 (CDFW 2021). Egg cases may end up in nets as a result of post-capture release by female squid or bottom contact by nets (CDFW 2021), because squid lay eggs on sandy, benthic substrate (Zeidberg et al. 2011). Netted egg cases in these samples were tested for age, and 43.5% were found to be released pre-capture (denoted as eggs older than one day), thus indicating seafloor interactions (CDFW 2021). From this, researchers gleaned that at least 10.1% of these sampled landings interacted with egg beds on the seafloor (CDFW 2021). This creates cause for concern around bottom contact from squid purse seines. The initial stages of the MSFMP review process have also brought up concerns with egg cases increasingly seen in nets (alongside occasional coral and crustaceans), suggesting bottom contact (Marine Resources Committee 2022). The demonstrated bottom contact that market squid purse seines make with the seafloor warrants a score of 3.

Justification:

The MSFMP notes concerns about the possibility of seine nets scraping the seafloor and the lack of a quantified impact of this fishery's gear on bottom habitat (CDFG 2005). This impact remains unquantified today (PFMC 2022). Appendix D of the CPS FMP notes the potential for squid fishing to affect the seafloor, but the Plan also notes that damage from nets is not thought to be extensive (PFMC 1998). Still, managers lack extensive scientific data to confirm this belief. Appendix C of the Pacific coast groundfish FMP also notes that squid nets in contact with the seafloor may affect essential fish habitat (PFMC 2019b). Squid purse seine nets tend to hang higher than purse seines used in other fisheries, helping to avoid seafloor contact (CDFG 2005). Fishers also attempt to hang their nets shallower in the water column than those in other fisheries, because fishers are aware of potential consequences from seafloor contact for the replenishment of squid stock (CDFW 2021). But these actions are voluntary, with no official regulations in place around how deep nets can be hung. Within the squid fishery, the primary concern with bottom contact is the risk to egg capsules. Squid attach their egg capsules to sandy and muddy substrate and will lay new egg capsules at the base of existing, already attached capsules (Zeidberg et al. 2011). By targeting spawning aggregations, fishers risk interacting with females who are actively laying eggs, which could disrupt both new and existing egg capsules if contact with bottom substrate occurs (Young et al. 2011). Therefore, many fishers recognize the importance of avoiding these interactions.

Though the fishery uses attracting lights to bring squid closer to the surface, accidental bottom contact does still occur, because the fishery operates in shallow nearshore waters. This is exhibited by recent research showing that at least 10.1% of sampled nets from 2010 to 2020 contained eggs from the seafloor (CDFW 2021). The percentage of sampled nets containing egg cases increased from 2016 to 2020 (see Appendix C), but because this 10.1% figure comes from unpublished CDFW data, it is not clear if there is a pattern in seafloor interactions (e.g., if the occurrence of older egg capsules likely to be from the seafloor also increased during the study period). In its latest squid status report, CDFW notes the possibility of expanding research in this area, which could lead to management around seafloor and attached egg capsule interactions (CDFW 2021).

Purse seines are generally regarded as having minimal to no impacts on benthic habitat, although this view often assumes that this open-water gear type has no bottom contact (MSC 2022). Unlike with other gear types (e.g., bottom trawls), if bottom contact does occur with purse seines, it typically does not include prolonged dragging motions, so damages are minimized. But, the extent of possible damage from squid purse seines has not been examined or quantified, so it cannot be assumed that no damage is occurring.

Factor 4.2 - Modifying Factor: Mitigation of Gear Impacts

Eastern Central Pacific | Purse seines | United States | California

Score: 0

Although fishers make efforts to avoid bottom habitat by not hanging their nets as deep as those in other fisheries and by attracting squid to the surface with lights, there are no official gear modifications in place for mitigating damage to the seafloor. Gear modifications do exist, but these are targeted toward protecting seabirds and other nontarget species, rather than protecting habitats. But, some squid habitat is protected through California's marine reserves system. No-take MPAs are estimated to protect at least 14.6% of squid spawning grounds in southern California (Van Diggelen 2017); however, an estimate does not exist for northern California. Other reserves also contribute to protections for squid spawning habitats. But, the full extent of these reserves' contributions to protecting all squid representative habitats is not known, so it cannot be said that they definitively protect at least 50% of these habitats, which would be required for bonus points to be awarded for this factor. The lack of formal mitigation tactics with respect to seafloor contact and the lack of evidence that at least 50% of representative habitats are protected result in no bonus points for Factor 4.2.

Justification:

Shifting to riblines and/or other gear modifications to reduce seafloor impacts is being considered as part of the FMP review process, but no formal changes have been made in this regard (Marine Resources Committee 2022). Currently, most fishers are thought to make an effort to avoid bottom contact, but this assumption is predicated on the voluntary efforts of fishers, and no regulations state that fishers must avoid contact with the seafloor.

California has a strong network of MPAs and state ecological reserves that help protect squid spawning areas and individuals. An MPA network implemented on California's southern coast in 2012 is thought to protect a minimum of 14.6% of the area's available spawning grounds for market squid, making these areas an important contributor to the preservation of essential fishery habitat (Van Diggelen 2017). Northern marine reserves such as Point Lobos and Asilomar State Marine Reserves, established through the Marine Life Protection Act, also protect squid and other species' habitat from fisheries (CDFW 2021). Bathymetry modeling estimates that roughly 13% of known squid spawning grounds across all of California lie within MPAs that do not allow fishing (CDFW 2021). The exact percentage of representative squid habitat protected by MPAs and reserves is not known. Because of market squid's expansive range, it does not have specifically designated harvest replenishment areas (CDFG 2005). Weekend squid fishery closures provide spawning habitat protections from squid purse seines, but these closures last only 48 hours weekly and do not extend to all fisheries that may interact with the environment on California's coast; thus, these closures do not guarantee full protection of squid habitat.

Factor 4.3 - Ecosystem-based Fisheries Management

Eastern Central Pacific | Purse seines | United States | California

Moderate Concern

Market squid is an important prey species for dozens of CCE predators, including fish, seabirds, and marine mammals. Although market squid is not always a primary prey choice, it nonetheless is an important component of this ecosystem, and the squid fishery recognizes the need to balance its needs with those of dependent predators. Recent research suggests that squid predators do not seem to be in direct competition with the fishery (Hilborn et al. 2017). In RREAS surveys from 2004 to 2014, squid landings increased alongside observed increases in juvenile squid abundance (McClatchie et al. 2016), suggesting that there is stock resilience to fishing pressure. But, the linkages between market squid and so many predators in the CCE make detrimental food web impacts a possibility, especially given the volatility of squid abundance to environmental conditions.

The California Fish and Game Commission has a forage species policy in place that applies to market squid. This policy stipulates that management goals should 1) be precautionary, and 2) incorporate essential fishery information for ecosystem-based fisheries management (California Fish and Game Commission 2023). The MSFMP is required to make ecological considerations under the MLMA, and these exist in the form of area closures and other fishery control rules. Area closures through the no-take MPA system and state ecological reserves serve as harvest replenishment areas for squid and other species (CDFG 2005), and management has not designated any additional, squid-specific harvest replenishment areas because of these existing protected areas. Additional gear and fishing restrictions also serve to protect seabird populations (CDFG 2005). Ecological considerations within the MSFMP only address seabirds and are more focused on seabird–fishery interactions than prey availability for seabirds, though the MSFMP does acknowledge the importance of squid as a prey species. The fishery uses temporal management through its weekend closures, allowing for uninterrupted squid spawning throughout the fishing range and season.

The current management system's spatial and temporal closures seem effective, because squid juvenile and paralarval abundance have not dropped following years of high fishing pressure. But, the possibility of detrimental food web impacts such as trophic cascades (given the important role squid plays in the CCE), results in a moderate concern score.

Justification:
Market squid is linked in the CCE to commercially important predators such as Chinook and coho salmon, Pacific bonito, swordfish, and halibut (Fields 1965)(Morejohn et al. 1978)(PFMC 2022). Marine mammals (such as the California sea lion and Risso's dolphin) and seabirds (such as the common murre and sooty shearwater) also feed on market squid (Morejohn et al. 1978)(Lowry and Carretta 1999)(Szoboszlai et al. 2015)(Warzybok et al. 2018). Market squid is one of several key prey species that are central to the food web in coastal waters such as Monterey Bay (Morejohn et al. 1978), leaving room for concern if they were removed from the ecosystem. Ralston et al. (2018) note that, because squid is one of the most common prey species in the CCE, overfishing of the stock could lead to ecosystem destabilization. Often, predators that consume large numbers of squid also heavily consume northern anchovy (Morejohn et al. 1978)(Szoboszlai et al. 2015)(McClatchie et al. 2016)(Warzybok et al. 2018). The northern anchovy stock exhibited declines in the early 2000s and mid-2010s (Zeidberg et al. 2006)(McClatchie et al. 2016)(Bittenbender 2019), but the population has since increased (PFMC 2022). If anchovy or other common forage species were to decline, market squid may be increasingly relied upon by predators, as suggested by a recent study of the diets of California sea lion (McClatchie et al. 2016). Squid also plays an important role as a predator of krill and mesozooplankton in the CCE.

Currently, there is no evidence that fishing pressure is creating detrimental impacts on stock abundance, and therefore on prey availability. Juvenile and paralarval abundance surveys show recent increases in squid (McClatchie et al. 2016)(Ralston et al. 2018), although patterns in adult abundance remain more uncertain. Detrimental food web impacts have not been seen so far in the history of the fishery, and research suggests that predators of market squid are not exhibiting competition with squid removal by fisheries (Hilborn et al. 2017). Thus, detrimental food web impacts from the squid fishery are not thought to be likely, but remain a possibility in the CCE. In addition, Risso's dolphin, unlike some other squid predators, is thought to have a diet that relies primarily on market squid. Although the Commission's forage species policy notes that management goals should "progressively incorporate" information including effects on dependent predators (California Fish and Game Commission 2023), it is not clear if potential food web impacts on species such as Risso's dolphin have been fully incorporated into the FMP.

California's MLMA requires managers to include ecosystem considerations in their strategies, and these considerations are addressed in the MSFMP. The MSFMP notes the presence of both temporal and spatial closures to support squid spawning efforts and dependent predators. California's MPA network, including 12 MPAs around the northern Channel Islands, overlaps with previous squid fishing areas, providing relief for the stock in these locations (CDFG 2005). California's state ecological reserves include some squid spawning sites, and round haul net fishing is prohibited in these reserves (CDFG 2005). Though these protected areas were not created specifically for market squid, they do serve as important squid harvest replenishment areas and essential habitat protective areas. It is thought that a minimum of 14.6% of southern market squid spawning grounds are protected by south coast MPAs (Van Diggelen 2017). CDFW unpublished data also suggest that 13% of the known squid habitat across California is protected by MPAs (CDFW 2021). Market squid also has a range beyond where it is fished, which makes it likely that there are other areas where uninterrupted spawning can occur (CDFG 2005).

Ecological considerations in the MSFMP focus on area closures to benefit spawning squid and local seabird populations. Weekend closures are used in combination with MPAs and state reserves to protect spawning habitat and to allow squid to spawn without fishery interruptions (CDFG 2005). Area closures also extend to other species: no squid attracting lights are allowed in the Gulf of the Farallones National Marine Sanctuary, which protects nesting and foraging seabirds in that area (CDFG 2005). The fishery has also implemented gear restrictions on attracting lights, also for the benefit of seabirds that may interact with squid fishing and light vessels. Other specific ecological considerations or control rules for prey availability to predators of squid do not exist, and the impact of oceanographic conditions, though noted by the forage species policy as information that should be incorporated into management plans, is not currently used in setting control rules for the fishery.

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Scientific review does not constitute an endorsement of the Seafood Watch® program, or its seafood recommendations, on the part of the reviewing scientists. Seafood Watch® is solely responsible for the conclusions reached in this report.

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References

Agnew, D. J., R. Baranowski, J. R. Beddington, S. ddes Clers, and C. P. Nolan. 1998. Approaches to assessing stocks of Loligo gahi around the Falkland Islands. Fisheries Research 35(3):155-169.

Arkhipkin, A. I., P. G. K. Rodhouse, G. J. Pierce, W. Sauer, M. Sakai, L. Allcock, J. Arguelles, J. R. Bower, G. Castillo, L. Ceriola, C. Chen, X. Chen, M. Diaz-Santana, N. Downey, A. F. González, J. G. Amores, C. P. Green, A. Guerra, L. C. Hendrickson, C. Ibáñez, K. Ito, P. Jereb, Y. Kato, O. N. Katugin, M. Kawano, H. Kidokoro, V. V. Kulik, M. R. Lipinski, B. Liu, L. Mariátegui, W. Marin, A. Media, K. Miki, K. Miyahara, N. Moltschaniwskyj, H. Moustahfid, J. Nabhitabhata, N. Nanjo, C. M. Nigmatullin, T. Ohtani, G. Pacl, J. A. A. Perez, U. Piatkowski, P. Saikliang, C. A. Salinas-Zavala, M. Steer, Y. Tian, Y. Ueta, D. Vijai, T. Wakabayashi, T. Yamaguchi, C. Yamashiro, N. Yamashita, and L. D. Zeidberg. 2015. World squid fisheries. Reviews in Fisheries Science and Aquaculture 23:92-252.

Basson, M., J. R. Beddington, J. A. Crombie, S. J. Holden, L. V. Purchase, and G. A. Tingley. 1996. Assessment and management techniques for migratory annual squid stocks: the Illex argentinus fishery in the Southwest Atlantic as an example. Fisheries Research 28(1):3-27.

Beddington, J. R., A. A. Rosenberg, J. A. Crombie, and G. P. Kirkwood. 1990. Stock assessment and the provision of management advice for the short fin squid fishery in Falkland Islands waters. Fisheries Research 8(4):351-365.

Bittenbender, S. 2019. After ruling in anchovy case, future stock assessment method under debate. Seafood Source, Portland, Maine. Available: https://www.seafoodsource.com/news/environment-sustainability/after-ruling-in-anchovy-case-future-stock-assessment-method-under-debate.

Butler, J. J. Wagner, & A. Henry. 2001. Age and growth of Loligo opalescens. Pacific Fishery Management Council Squid Stock Assessment Review. Pacific Fishery Management Council, Portland, OR.

Butler, J., D. Fuller, and M. Yaremko. 1999. Age and growth of market squid (Loligo Opalescens) off California during 1998. CalCOFI Rep. 40:1-5.

California Department of Fish and Wildlife (CDFW). 2021. Market squid enhanced status report. CDFW.

California Department of Fish and Wildlife. 2022. California commercial market squid landing receipt data. California Department of Fish and Wildlife, Monterey, California. Available: https://wildlife.ca.gov/Conservation/Marine/Pelagic/Market-Squid-Landing.

California Fish and Game Code Part 3. Commercial Fishing Chapter 3. Nets Article 2. Nets for Particular Varieties of Fish. 2013. Code of California, section 8623.

California Fish and Game Code Part 3. Commercial Fishing Chapter 3. Nets Article 7. Round Haul Nets. 2021. Code of California, section 8756.

California Fish and Game Commission. 2023. Fisheries Policies.

https://fgc.ca.gov/About/Policies/Fisheries.

California Wetfish Producers Association (CWPA). 2013. Squid research project. California Wetfish Producers Association, Buellton, California. Available: https://californiawetfish.org/squid-research.

California Wetfish Producers Association (CWPA). 2021. Market squid paralarval research update, 2020-21. California Wetfish Producers Association, Buellton, California.

CDFW (2005). Market Squid Fishery Management Plan. California Department of Fish and Game.

Chasco, B. E., M. E. Hunsicker, K. C. Jacobson, O. T. Welch, C. A. Morgan, B. A. Muhling, and J. A. Harding. 2022. Evidence of temperature-driven shifts in market squid Doryteuthis opalescens densities and distribution in the California current ecosystem. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 14:e10190.

Cheng, S. H., M. Gold, N. Rodriguez, and P. H. Barber. 2020. GenomeǀVide SNPs reveal complex fine scale population structure in the California market squid fishery (Doryteuthis opalescens). Conservation Genetics 22: 97-110.

CWPA. 2022. Squid Research Project. California Wetfish Producers Association, Buellton, California.

Dorval, E., P.R. Crone, and J.D. McDaniel. (2013). Variability of egg escapement, fishing mortality and spawning population in the market squid fishery in the California Current Ecosystem. Marine and Freshwater Research. 64:80-90.

Fields, W. G. 1965. The structure and development, food relations, reproduction, and life history of the squid, Loligo opalscens Berry. California Department of Fish and Game, Fish Bulletin 131:1-108.

FishChoice. 2020. California market squid. FishChoice Seafood Buying Guides. FishChoice, Fort Collins, Colorado. Available: https://fishchoice.com/buying-guide/california-market-squid.

Food and Drug Administration (FDA). 2021. FDA Seafood List Updates for 2020. Food and Drug Administration, Silver Spring, MD. Available: https://www.fda.gov/food/seafood-guidance-documents-regulatory-information/fda-seafood-list-updates-2020/.

Hendrickson, L.C. 2017. Longfin inshore squid (Doryteuthis (Amerigo) pealeii) stock assessment update for 2017. National Marine Fisheries Service, Woods Hole, Massachusetts.

Hilborn, R., R. O. Amoroso, E. Bogazzi, O. P. Jensen, A. M. Parma, C. Szuwalski, and C. J. Walters. 2017. When does fishing forage species affect their predators? Fisheries Research 191:211-221.

Ish, T., E. J. Dick, P. V. Switzer, & M. Mangel. 2004. Environment, krill and squid in the Monterey Bay: from fisheries to life histories and back again. Deep Sea Research II 51:849-862.

Jackson, G. D., and M. L. Domeier (2003). The effects of an extraordinary El Niño event on the size and growth of the squid Loligo opalescens off Southern California. Marine Biology 142:925-935.

Kidadl. 2021. 45 Squid nutrition facts: Protein-rich diet for you and your kids! Available: https://kidadl.com/facts/45-squid-nutrition-facts-protein-rich-diet-for-you-and-your-kids.

Kidokoro, H., K. Mori, T. Goto, and T. Kinoshita. 2003. Stock assessment and management method for the Japanese common squid in Japan. Suisankanri Danwakaiho, 30:18-35.

Kuriyama, P. T., K. T. Hill, & P. Zwolinski. 2020. Update Assessment of the Pacific Sardine Resource in 2022 for U.S. Management in 2022-2023. NOAA Southwest Fisheries Science Center, La Jolla, CA.

Lowry, M. S. and J. V. Carretta (1999). Market squid (Loligo opalescens) in the diet of California sea lions (Zalophus californianus) in southern California (1981-1995). CalCOFI Reports 40:196-207.

Macewicz, B. J., J. R. Hunter, N. C. H. Lo, and E. L. LaCasella. (2004). Fecundity, egg deposition, and mortality of market squid (Loligo opalescens). Fish. Bull. 102:306-327.

Marine Resources Committee. 2022. California Fish and Game Commission Marine Resources Committee Meeting Binder. California Fish and Game Commission, Santa Rosa, California.

Marine Stewardship Council (MSC). 2022. Purse seine. Marine Stewardship Council, London, United Kingdom. Available: https://www.msc.org/what-we-are-doing/our-approach/fishing-methods-and-gear-types/purse-seine.

Maxwell, M. R., L D. Jacobson, and R. J. Conser. 2005. Eggs-per-recruit model for management of the California market squid (Loligo opalescens) fishery. Canadian Journal of Fisheries and Aquatic Sciences 62(7):1640-1650.

McClatchie, S., J. Field, A. R. Thompson, T. Gerrodette, M. Lowry, P. C. Fiedler, W. Watson, K. M. Nieto, and R. D. Vetter. 2016. Food limitation of sea lion pups and the decline of forage off central and southern California. Royal Society Open Science 3(3).

McDaniel, J.M., E. Dorval, J. Taylor, and D. Porizo. (2015). Optimizing biological parameterization in the egg escapement model of the market squid, (Doryteuthis opalescens), population off California. NOAA Technical Memorandum NMFS. NOAA-TM-NMFS-SWFSC-551, La Jolla, California.

Morejohn, V. G. (1978). The importance of Loligo opalescens in the food web of marine vertebrates in Monterey Bay, California. Department of Fish and Game Fish Bulletin 169:67-98.

Myrick, A.C., E. R. Cassano, and C. W. Oliver. 1990. Potential for physical injury, other than hearing damage, to dolphins from seal bombs used in the yellowfin tuna purse-seine fishery: results from open-water tests. Cambridge University Press, Cambridge.

National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2022. Fisheries Foreign Trade Data [online database]. National Oceanic and Atmospheric Administration, Silver Spring, Maryland. Available:

https://www.fisheries.noaa.gov/foss/f?p=215:2:7347232813177::NO:::.

National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2022a. Species directory: California market squid. National Oceanic and Atmospheric Administration, Silver Spring, MD. Available: https://www.fisheries.noaa.gov/species/california-market-squid.

National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2022c. California squid purse seine fishery - MMPA list of fisheries. Available: https://www.fisheries.noaa.gov/national/marine-mammal-protection/california-squid-purse-seine-fishery-mmpa-list-fisheries.

National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2022d. Chinook salmon (protected). NOAA Species Directory. Available: https://www.fisheries.noaa.gov/species/chinook-salmon-protected#:~:text=About%20the%20Species&text=Two%20species%20of%20chinook%20salmon,Fisheries'%20Species%20in%20the%20Spotlight.

National Oceanic and Atmospheric Administration (NOAA). 2021. List of fisheries for 2021. Federal Register 50:229(14 January 2021):3028-3053.

NWFSC. 2022. Zooplankton Data - Juvenile Salmon & Ocean Ecosystem Survey. NOAA National Centers for Environmental Information.

Ocean Protection Council (OPC). 2019. Draft marine species report: market squid. Ocean Protection Council, Sacramento, California.

Pacific Fisheries Management Council (PFCMC). 2022. Status of the Pacific coast coastal pelagic species fishery and recommended acceptable biological catches: stock assessment and fishery evaluation (SAFE) 2021 (draft March 2022). PFMC 1-96.

Pacific Fisheries Management Council (PFMC). 1998. Appendix D Description and identification of essential fish habitat for the coastal pelagic species fishery management plan. Pacific Fishery Management Council Portland, Oregon.

Pacific Fisheries Management Council (PFMC). 2019. Status of the Pacific coast coastal pelagic species fishery and recommended acceptable biological catches: Stock assessment and fishery evaluation (SAFE) 2018. Pacific Fisheries Management Council 1-102.

Pacific Fisheries Management Council (PFMC). 2019b. Pacific Coast Groundfish Fishery Management Plan for the California, Oregon, and Washington groundfish fishery, Appendix C part 2. PFMC 1-30.

Pacific Fishery Management Council (PFMC). 2020. Pacific sardine rebuilding plan: preliminary environmental analysis. Pacific Fishery Management Council, Portland, Oregon.

Pacific Fishery Management Council (PFMC). 2021. Coastal pelagic species fishery management plan as amended through amendment 18. Pacific Fishery Management Council Portland, Oregon.

Patrick, W. S., P. Spencer, O. Ormseth, J. Cope, J. Field, D. Kobayashi, T. Gedamke, E. Cortés, K. Bigelow, W. Overholtz, J. Link, & P. Lawson. 2009. Use of Productivity and Susceptibility Indices to Determine Stock Vulnerability, with Example Applications to Six U.S. Fisheries. NOAA Technical Memorandum NMFS-F/SPO-101, Washington, D.C.

PFMC (1998). Appendix D: Description and identification of essential fish habitat for the coastal pelagic species fishery management plan. Available at http://www.westcoast.fisheries.noaa.gov/publications/habitat/essential_fish_habitat/coastal_pelagic_appendix_d.pdf

Porzio, D. 2013. Review of selected California fisheries for 2012: Coastal pelagic finfish, market squid, herring, groundfish, highly migratory species, white seabass, Pacific halibut, red sea urchin, and sea cucumber. CalCOFI Rep. 54:12-36.

Porzio, D. 2015. Review of selected California fisheries for 2014: Coastal pelagic finfish, market squid, groundfish, Pacific herring, dungeness crab, ocean salmon, true smelts, hagfish, and deep water ROV surveys of MPAs and surrounding nearshore habitat. CalCOFI Rep. 56:1-30.

Porzio, D. and B. Brady (2006). Status of the fisheries report: market squid. California Department of Fish and Game: 1-11.

Protasio, C.Q., A.M. Holder, and B.C. Brady (2014). Changes in biological characteristics of the California market squid (Doryteuthis opalescens) from the California commercial fishery from 2000-01 to 2012-13. California Fish and Game. 100:276-288.

Ralston, S., E. Dorval, L. Ryley, K.M. Sakuma, J.C. Field. (2018). Predicting market squid (Doryteuthis opalescens) landings from pre-recruit abundance. Fisheries Research 199:12-18.

Recksiek, C.W., and Frey, H. W. 1978. Biological, oceanographic, and acoustic aspects of the market squid, Loligo opalescens Berry. Fish Bulletin 169:1-144.

Reiss, C. S., et al. (2004). Investigating environmental effects on population dynamics of Loligo opalescens in the Southern California Bight. CalCOFI Rep. 45:87-97

Restrepo, V. R. and J. E. Powers. 1999. Precautionary control rules in US fisheries management: specification and performance. ICES Journal of Marine Science 56:846-852.

Restrepo, V. R., G. G. Thompson, P. M. Mace, W. L. Gabriel, L. L. Low, A. D. MacCall, R. D. Methot, J. E. Powers, B. L. Taylor, P. R. Wade, and J. F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA, Technical Memorandum NMFS-F/SPO-31, Silver Spring, Maryland.

Sea Fare Group (2011). Quantification and market analysis of the top 30 seafood species/categories consumed in the U.S. Prepared by Sea Fare Group for Monterey Aquarium Seafood Watch®, March 15, 2011.

Seafood Watch 2020. Seafood Watch Standard for Fisheries version 4. Available: https://www.seafoodwatch.org/globalassets/sfw/pdf/standards/fisheries/seafood-watch-fisheries-standard-version-f4.pdf.

Seafood Watch 2020a. Fisheries and Aquaculture Standards Review Highlights of Final Revisions (2019-2020 cycle). March 2020. Accessed 2/10/23 from https://www.seafoodwatch.org/globalassets/sfw/pdf/standards-revision-reference/2020-standards-revision/scope/seafood-watch-2019-2020-standards-review-highlights-final-revisions.pdf

Simonis, A. E., K. A. Forney, S. Rankin, J. Ryan, Y. Zhang, A. DeVogelaere, J. Joseph, T. Margolina, A. Krumpel, and S. Baumann-Pickering. 2020. Seal bomb noise as a potential threat to Monterey Bay harbor porpoise. Frontiers in Marine Science 7(142):1-9.

Suca, J. J., J. A. Santora, J. C. Field, K. A. Curtis, B. A. Muhling, M. A. Cimino, E. L. Hazen, & S. J. Bograd. 2022. Temperature and upwelling dynamics drive market squid (Doryteuthis opalescens) distribution and abundance in the California Current. ICES Journal of Marine Science 79:2489-2509.

Swasey, J., E. Zollett, & E. Wilson. 2016. Productivity and Susceptibility Analysis for Selected California Fisheries. MRAG Americas Report to California Ocean Science Trust and CDFW US2212.

SWFSC. 2022. Rockfish Recruitment and Ecosystem Assessment Survey. NOAA National Centers for Environmental Information.

Szoboszlai, A. I., J. A. Thayer, S. A. Wood, W. J. Sydeman, and L. E. Koehn. 2015. Forage species in predator diets: Synthesis of data from the California Current. Ecological Informatics 29(1):45-56.

Thompson, A. R., I. D. Schroeder, S. J. Bograd, E. L. Hazen, M. G. Jacox, A. Leising, B. K. Wells, J. L. Fisher, K. C. Jacobson, S. M. Zeman, E. P. Bjorkstedt, R. R. Roberston, M. Kahru, R. Goericke, C. E. Peabody, T. R. Baumgartner, B. E. Lavaniegos, L. E. Miranda, E. Gomez-Ocampo, J. Gomez-Valdes, T. D. Auth, E. A. Daly, C. A. Morgan, B. J. Burke, J. C. Field, K. M. Sakuma, E. D. Weber, W. Watson, J. M. Porquez, J. Dolliver, D. E. Lyons, R. A. Orben, J. E. Zamon, P. Warzybok, J. Jahncke, J. A. Santora, S. A. Thompson, B. Hoover, W. Sydeman, and S. R. Melin. 2019. State of the California Current 2018-19: A Novel Anchovy Regime and a New Marine Heat Wave? California Cooperative Oceanic Fisheries Investigations Reports Volume 60.

United States Geological Survey (USGS). 2016. Why is genetic diversity important? USGS Climate Adaptation Science Centers, Reston, Virginia. Available: https://www.usgs.gov/news/why-genetic-diversity-important/.

Van Diggelen, A. (2017). State of the California south coast supplemental report: Market squid. CDFW, Monterey, CA.

Van Noord, J. E. 2020. Dynamic spawning patterns in the California market squid (*Doryteuthis opalescens*) inferred through paralarval observation in the Southern California Bight, 2012–2019. Marine

Ecology 41(4).

Van Noord, J.E. and E. Dorval. (2017). Oceanographic influences on the distribution and relative abundance of market squid paralarvae (Doryteuthis opalescens) off the Southern and Central California coast. Marine Ecology 38:e12433.

Vojkovich, M. (1998). The California fishery for market squid (Loligo opalescens). Calif. Coop. Oceanic Fish. Invest. Rep. 39:55-60.

Warzybok, P., J. A. Santora, D. G. Ainley, R. W. Bradley, J. C. Field, P. J. Capitolo, R. D. Carle, M. Elliott, J. N. Beck, G. J. McChesney, M. M. Hester, and K. Jahncke. 2018. Prey switching and consumption by seabirds in the central California Current upwelling ecosystem: Implications for forage fish management. Journal of Mar. Sys. 185:25-39.

Wells, B.K., I. D. Schroeder, S. J. Bograd, E. T. Hazen, M. G. Jacox, A. Leising, N. Mantua, J. A. Santora, J. Fisher, W. T. Peterson, E. Bjorkstedt, R. R. Robertson, F. P. Chavez, R. Goericke, R. Kudela, C. Anderson, B. E. Lavaniegos, J. Gomez-Valdes, R. D. Brodeur, E. A. Daly, C. A. Morgan, T. D. Auth, J. C. Field, K. Sakuma, S. McClatchie, A. R. Thompson, E. D. Weber, W. Watson, R. M. Suryan, J. Parrish, J. Dolliver, S. Loredo, J. M. Porquez, J. E. Zamon, S. R. Schneider, R. T. Golightly, P. Warzybok, R. Bradley, J. Jahncke, W. Sydeman, S. R. Melin, J. A. Hilderbrand, A. J. Debich, and B. Thayre. (2017). State of the California current 2016-2017: Still anything but "normal" in the north. CalCOFI Rep., Vol. 58.

Wiggins, S. M., A. Krumpel, L. M. Dorman, J. A. Hildebrand, and S. Baumann-Pickering. 2019. Seal bomb sound source characterization. MPL, Technical Memorandum 633, La Jolla, California.

Yamashita, N. and T. Kaga. 2013. Stock assessment and evaluation for winter spawning stock of Japanese common squid (fiscal year 2012). Fishery Agency and Fisheries Research Agency of Japan, 571-604.

Young, M. A., R. G. Kvitek, P. J. Iampietro, C. D. Garza, R. Maillet, and R. T. Hanlon. (2011). Seafloor mapping and landscape ecology analyses used to monitor variations in spawning site preference and benthic egg mop abundance for the California market squid (Doryteuthis opalescens). Journal of Experimental Marine Biology and Ecology 407:226-233.

Zeidberg, L. D., et al. (2006). The fishery for California market squid, Loligo opalescens (Cephalopoda: Myopsida), from 1981 through 2003. Fish. Bull. 104(1):46–59.

Zeidberg, L. D., et al. (2011). Estimation of spawning habitats of market squid (Doryteuthis opalescens) from field surveys of eggs off Central and Southern California. Marine Ecology 33(3):1-11.

Appendix A: MSFMP Review

CDFW is currently reviewing the MSFMP, a process that is expected to produce management recommendations in summer 2024 (Marine Resources Committee 2022). This work is part of a larger effort by CDFW to review and update the MSFMP through the development of a Squid Fishery Advisory Committee (SFAC), stakeholder interviews, and new assessment tools (Marine Resources Committee 2022).

Through this process, CDFW is working to incorporate climate impacts on abundance shifts into market squid management, but this work is ongoing and not currently incorporated into abundance estimation efforts or management strategies (Marine Resources Committee 2022). The ongoing MSFMP review will also address several other management strategy issues, including seasonal stock variability, a review of available monitoring data, and considering the application of the egg escapement model to inform climate resilience in the fishery (Marine Resources Committee 2022). This review and data synthesis process began in 2022 with stakeholder interviews, allowing for the identification of key scientific knowledge gaps, interests and issues in current fishery management, and ideas on maintaining the future sustainability of the fishery (Marine Resources Committee 2022). Once the SFAC is assembled, the group will advise CDFW on various management options. The Department will then provide any recommendations for consideration by California's Marine Resources Committee in 2024. One potential recommendation is to adapt harvest control rules to be more climate-responsive, as informed by long-term monitoring data (Marine Resources Committee 2022). During the initial interview stages of the FMP review, concerns have been brought up around topics discussed in this report, such as the impact of seine nets on spawning habitat for market squid. CDFW plans to review the available information in this area and consider gear adjustments based on findings. The FMP review is primarily a review of current literature and does not guarantee that additional research will be performed in addressing the above concerns. Because this process is ongoing, its potential outcomes are not used for scoring in this report. To learn more about CDFW's review process, visit: https://s3-us-west-2.amazonaws.com/sfw-images/reportsresources/28012/references/MRC_MeetingBinder_2022_07_14.pdf.

Appendix B: Pacific Sardine Landings

Landings and limits for Pacific sardine from 2017–18 to 2020–21, with the final column showing the percent of Pacific sardine allowable biological catch (ABC) represented as bycatch in the squid fishery. Although bycatch does occur in the squid fishery, amounts are minimal and compose less than 3 percent of the total ABC. Data acquired from NOAA and PFMC (Kuriyama et al. 2022)(PFMC 2022).

Year	OFL	ABC	Northern Subpopulation Landings	Squid Bycatch Landings	Percent of ABC
2017–18	16,957	15,497	372	152	0.98
2018–19	11,324	9,436	651	111	1.18
2019–20	5,816	4,514	705	115	2.55
2020–21	5,525	4,288	852	111	2.59

Appendix C: Bycatch Occurrence in the Squid Fishery

Common Name	Scientific Name	2016	2017	2018	2019	2020
Finfish						
Northern anchovy	*Engraulis mordax*	9.47	13.30	26.70	25.00	31.33
California barracuda	*Sphyraena argentea*	4.21	2.21	2.00	2.78	2.41
Giant sea bass (juvenile)	*Stereolepsis gigas*			0.67	1.85	
Blacksmith	*Chromis punctipinnis*	1.05	0.55	1.33		
Pacific bonito	*Sarda lineolata*	3.16	1.10		2.78	2.41
Butterfish	*Peprilus simillimus*	7.37	8.84	9.33	16.67	16.87
Longspine combfish	*Zaniolepsis latipinnis*					2.41
White croaker	*Genyonemus lineatus*	3.16	2.76	2.67	5.56	6.02
Wolf eel	*Anarrhichthys ocellatus*					1.20
Unspecified flatfish			7.73	16.00	17.59	14.46
Starry flounder	*Platichthys stellatus*	1.05			1.85	
California flying fish	*Cheilopogon pinnatibarbatus californicus*	1.05	1.66	0.67	0.93	
Sarcastic fringehead	*Neoclinus blanchardi*			0.67	0.93	2.41
Halfmoon	*Medialuna californiensis*	1.05				2.41
California halibut	*Paralichthys californicus*		2.21	5.33	7.41	4.82
Pacific halibut	*Hippoglossus stenolepsis*					1.20
Pacific herring	*Clupea pallasii*		0.55	5.33	1.85	
Red-eye round herring	*Etrumeus teres*	1.05	1.10		11.11	1.20
Jacksmelt	*Atherinopsis californiensis*	9.47	14.36	10.67	18.52	37.35
Kelp bass	*Paralabrax clathratus*		0.55	0.67	1.85	1.20
Kelpfishes						1.20
Lingcod	*Ophiodon elongatus*			0.67		1.20
California lizardfish	*Synodus lucioceps*	2.11	2.21	1.33		
Unspecified mackerel	*Scomber/Trachurus*			1.33		
Jack mackerel	*Trachurus symmetricus*	24.21	24.86	20.67	47.22	33.73
Pacific (chub) mackerel	*Scomber japonicus*	31.58	45.30	44.67	52.78	48.19
Unspecified midshipman	*Porichthys* spp.			0.67	2.78	
Plainfin midshipman	*Porichthys notatus*	1.05	3.31	1.33	3.70	14.46
Ocean sunfish	*Mola mola*					3.61
Ocean whitefish	*Caulolatilus princeps*	2.11	1.10	1.33		
Unspecified rockfish	*Sebastes* spp.			0.67	2.78	1.20
Black rockfish	*Sebastes melanops*					1.20
Blue rockfish	*Sebastes mystinus*			1.33		
Bocaccio rockfish	*Sebastes paucispinis*		1.10	3.33	0.93	3.61
Sablefish	*Anoplopoma fimbria*	1.05	0.55	0.67		1.20
Unspecified salmon	*Oncorhynchus* spp.			1.33		
Chinook salmon	*Oncorhynchus tshawytscha*		0.55	2.67	1.85	6.02
Coho salmon	*Oncorhynchus kisutch*		2.76			
Unspecified sanddab	*Citharichthys* spp.	1.05	1.10	3.33	6.48	1.20
Longfin sanddab	*Citharichthys xanthostigma*		1.66	2.00	0.93	1.20
Pacific sanddab	*Citharichthys sordidus*	5.26	6.08	10.00	11.11	27.71

Speckled sanddab	*Citharichthys stigmaeus*	3.16	1.10	2.00	4.63	3.61
Pacific sardine	*Sardinops sagax*	30.53	31.49	33.33	74.07	71.08
Unspecified scallop			0.55			1.20
California scorpionfish	*Scorpaena guttata*	5.26	3.31	4.00	9.26	9.64
Unspecified sculpin	*Cottidae* spp.			0.67	0.93	2.41
Yellowchin sculpin	*Icelinus quadriseriatus*			1.33		
Staghorn sculpin	*Leptocottus armatus*			2.00		1.20
American shad	*Alosa sapidissima*					1.20
Night smelt	*Spirinchus starksi*					3.61
C-O sole	*Pleuronichthys coenosus*					1.20
Curlfin sole	*Pleuronichthys decurrens*	4.21	1.10	2.00	1.85	
Fantail sole	*Xystreurys liolepsis*	1.05	1.10	1.33	0.93	
English sole	*Pleuronectes vetulus*	1.05	2.21		4.63	6.02
Petrale sole	*Eopsetta jordani*		0.55			1.20
Rex sole	*Glyptocephalus zachirus*			0.67		1.20
Sand sole	*Psettichthys melanostictus*		1.10	2.67	1.85	1.20
Unspecified surfperch	*Embiotocidae*	1.05		3.33		
Pink surfperch	*Zalembius rosaceus*		0.55	0.67		1.20
Shiner surfperch	*Cymatogaster aggregata*				0.93	1.20
White surfperch	*Phanerodon furcatus*					1.20
Topsmelt	*Atherinops affinis*	1.05	0.55	4.00	1.85	4.82
Tonguefish	*Cynoglossidae*	1.05	1.10			
Unspecified turbot	*Pleuronectidae*		0.55		1.85	
Diamond turbot	*Hypsopsetta guttulata*	3.16	0.55	2.67	1.85	
Hornyhead turbot	*Pleuronichthys verticalis*	1.05	3.87	2.67	3.70	9.64
Spotted turbot	*Pleuronichthys ritteri*				0.93	1.20
Elasmobranchs						
Bat ray	*Myliobatis californica*	9.47	8.29	10.00	3.70	
Pacific electric ray	*Tetronarce californica*	3.16	3.87	2.67	8.33	1.33
Common thresher shark	*Alopias vulpinus*	1.05				
Shark eggs						1.20
Horn shark	*Heterodontus francisci*		0.55		6.48	
Shortfin mako shark	*Isurus oxyrinchus*	2.11				
Big skate	*Raja binoculata*	4.21	0.55	2.00	2.78	6.02
California skate	*Raja inornata*		0.55		2.78	1.20
Longnosed skate	*Beringraja rhina*		0.55	0.67	1.85	1.20
Unspecified skate	*Rajidae*			1.33		1.20
Invertebrates						
Unspecified anemones	*Anthozoa*	2.11	1.10			3.61
Unspecified clam						1.20
Rosy razor clam	*Solecurtus strigilatus*					1.20
Unspecified crab				0.67	6.48	12.05
Brown box crab	*Lopholithodes foraminatus*		0.55		1.85	
Crab claws		1.05		2.00	2.78	2.41
Decorator crab	*Oregonia gracilis*				0.93	2.41
Dungeness crab	*Metacarcinus magister*	2.11	3.31	5.33	5.56	9.64
Hermit crab	*Pagarus* spp.	1.05				1.20
Pelagic red crab	*Pleuroncodes planipes*	15.80	7.73	4.00	3.70	
Red rock crab	*Cancer productus*		0.55	1.33	5.56	3.61

Unspecified rock crab	*Cancer* spp.				0.93	2.41
Crab shells		1.05	1.10	2.67	8.33	15.66
Shore crab	*Pachygrapsus crassipes*					1.20
Slender crab	*Metacarcinus gracilis*	2.11		0.67		
Unspecified swimming crab		6.32	1.66	2.00	12.04	7.23
Unspecified jellyfish	*Hydrozoa*	6.32	18.80	26.00	35.19	49.40
California spiny lobster	*Panulirus interruptus*	2.11	0.55	2.00	1.85	6.02
Unspecified mussel	*Mytilus* spp.			2.00	6.48	1.20
Unspecified octopus	*Octopus* spp.		2.21	0.67	2.78	2.41
Spot prawn	*Pandalus platyceros*	1.05			0.93	1.20
Pyrosome	*Pyrosoma atlanticum*		4.42	7.33	27.78	31.33
Salps			0.55	5.33	6.48	3.61
Sand dollar	*Dendraster excentricus*			1.33	0.93	1.20
Unspecified sea cucumber			0.55	1.33	1.85	3.61
Warty sea cucumber	*Parastichopus parvimensis*	1.05				
Unspecified sea hare	*Aplysia* spp.		1.66	1.33		1.20
Unspecified sea star	*Asteroidea*		1.66	2.67		2.41
Unspecified shrimp	*Crustacea*	1.05	0.55		0.93	
Black-spotted bay shrimp	*Crangon nigromaculata*	3.16	0.55			
Mantis shrimp	*Hemisquilla ensigera*					1.20
Target shrimp	*Sicyonia penicillata*	6.32	11.60	6.00	3.70	7.23
Unspecified snail			0.55	0.67		2.41
Tegula snail	*Tegula* spp.				1.85	
Sponges	*Porifera*		3.31			
Squid egg cases		16.80	11.00	24.70	31.48	45.78
Tunicates	*Urichordata*		0.55	1.33		1.20
Marine Plants						
Marine algae	*Phycophyta*	1.05	1.10	4.00	21.30	13.25
Eelgrass	*Zostera* spp.	1.05	4.42	11.33	3.70	2.41
Unspecified kelp	*Laminariales*	16.80	49.20	46.70	60.19	73.49
Bull kelp	*Nereocystis luetkeana*	4.21		2.00	1.85	2.41
Feather boa kelp	*Egragia menziesii*		0.55	8.00	7.41	6.02
Giant kelp	*Macrocystis pyrifera*	1.05	1.10	14.00	11.11	4.82
Surfgrass	*Phyllospadix* spp.	4.21	7.18	25.30	35.19	57.83

Appendix D: Forage Species Determination

Version 4 of the Seafood Watch Standard for Fisheries (Seafood Watch 2020) updated requirements around "forage species," thus (Seafood Watch 2020a):

- Criterion 1: Acknowledges the high level of uncertainty associated with static reference points and lowers the score where B > B_{MSY} for forage species (relative to nonforage species). Specifically, static reference points with stationary parameters, such as unfished biomass and B_0, are not considered to meet this requirement for forage species, because of those species' dynamic productivity that shifts in response to environmental conditions.
- Criterion 3: Requires adaptive and flexible management to account for environmentally driven biomass and fluctuating populations (not just for forage species).
- Criterion 4: Requires a greater understanding of forage species' roles in the ecosystem to get a moderate concern score or better. Addition of a critical score when there is evidence of fisheries affecting the ecosystem (e.g., trophic cascades).

According to the glossary for the Version 4 of the Seafood Watch Standard for Fisheries (Seafood Watch 2020):

"Forage species play an important role in food webs because they 1) exhibit high connectance to other organisms in the ecosystem, and 2) a large amount of energy is channeled through those species. Forage species typically exhibit highly variable productivity, such that there may be high uncertainty in their reference points, making it difficult to evaluate their stock status. The drivers of this variability in productivity may be environmental forcing and/or other factors. As a result of their importance in food webs, these stocks require management that is tailored to their specific life histories and ecological roles. Species that generally qualify as forage species include sandeels, sandlances, herrings, menhaden, pilchards, sardines, sprats, anchovies, krill, lanternfish, smelts, capelin, mackerels, silversides, sand smelts, and Norway pout (adapted from MSC Fisheries Standard V2.01, p. 14). Other species or stocks may qualify if they meet the definition above."

To determine whether a species within a particular ecosystem is defined as a "forage species," it must fulfill both criteria in the glossary term: 1) exhibits high connectance, and 2) serves as a channel for a large amount of energy. To identify their potential key role, a forthcoming white paper commissioned by Seafood Watch computed three indices using data and food webs applied to existing static ecosystem models. The connectance index and the Supportive Role to Fishery ecosystems (SURF) index were calculated from mass-balanced models and an energy index from energy-balanced models. Excerpts from that study are presented below. The supporting data are available upon request.

The California Current

The model area as considered in the food web model for the complete California Current system developed by Koehn et al. (2016) included both the northern and southern upwelling system, ranging from the northern tip of Vancouver Island (British Columbia, Canada) to Punta Eugenia (Baja California, Mexico) and the 2,000 m isobath offshore (Figure 1). The total model area was 302,000 km^2. The area included most of the habitats of commercially important forage fish that overlapped with predators' habitats; e.g., sardine occurs offshore in the southern part of the system (Zwolinski et al., 2012), anchovy and herring mainly occur inshore and/or in the northern part (Koehn et al., 2016). In addition, the model area included both important seabird breeding colonies in the north (near the northern part of Vancouver Island) and pinniped breeding colonies in the south (on the Baja Peninsula). For more details, see Koehn et al. (2016). Koehn et al. (2016) developed the model to assess the general functioning of the entire California Current as one ecosystem for an unspecified time period.

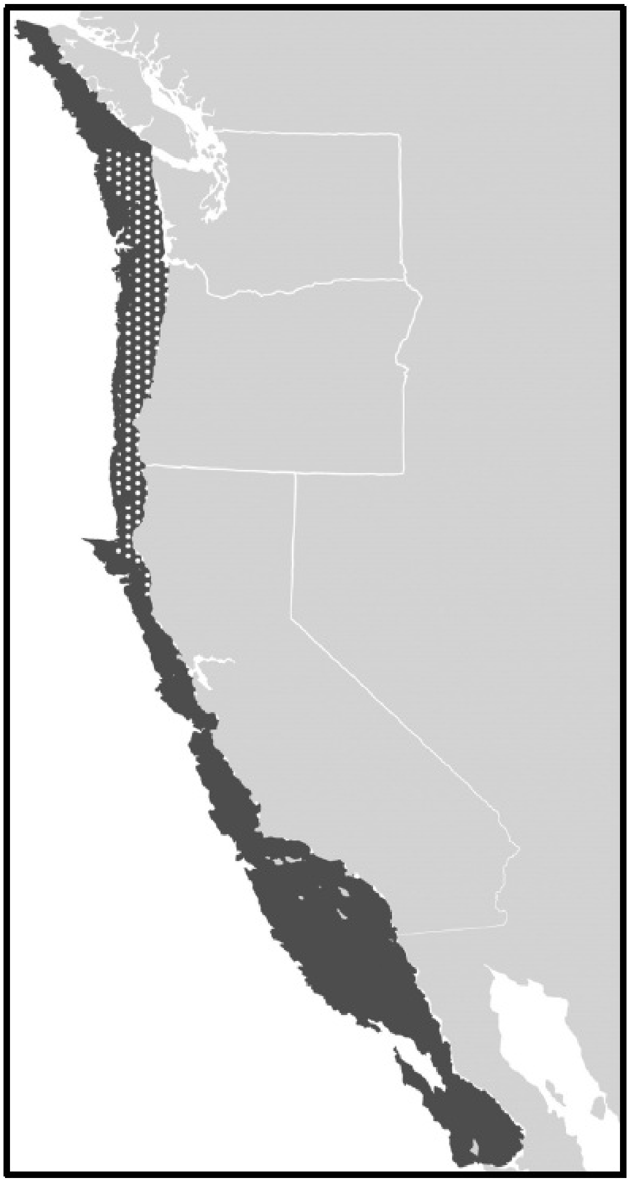

Figure 10. The model area of the complete California Current ecosystem as considered in the food web model by Koehn et al. (2016) in dark grey extending from Vancouver Island (Canada) in the north to Punta Eugenia in Baja California (Mexico) in the south. (White dots show the area covered by two older Ecopath models by Field (2004) and Ruzicka et al. (2007). Image copied from {Koehn et al. 2016}.

Results

None of the small pelagic species considered meet the criteria to be considered a forage species for the purposes of a Seafood Watch assessment.

Ecosystem Model	Model Group Name	Scientific name	Connectance	SURF	Energy
California Current	Pacific sardine	*Sardinops sagax*	KEY		
	Northern anchovy	*Engraulis mordax*	KEY		
	Pacific mackerel	*Scomber japonicus*	KEY		
	Market squid	*Doryteuthis opalescens*	KEY		