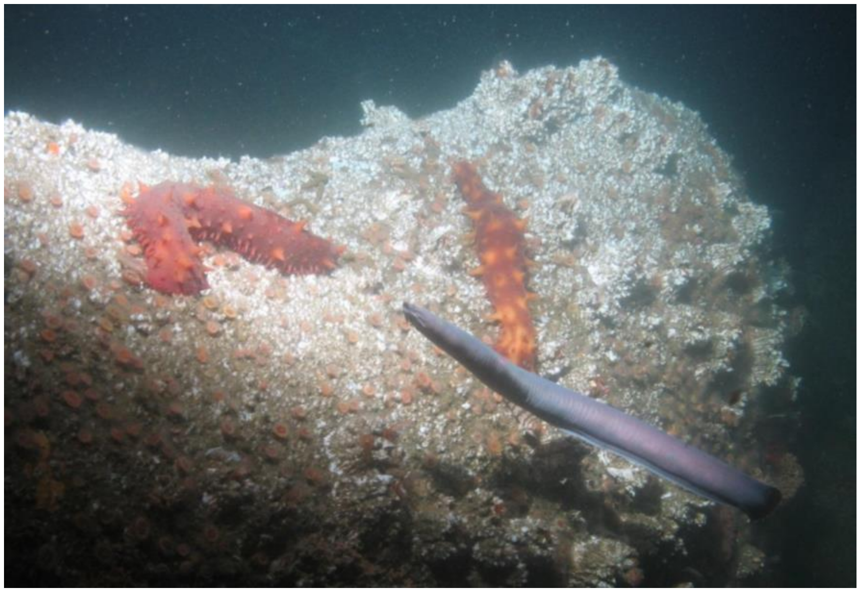
Pacific Hagfish, *Eptatretus stoutii*
Enhanced Status Report



Pacific Hagfish, *Eptatretus stoutii*. (Photo Credit: CDFW/MARE).

California Department of Fish and Wildlife
Marine Region

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Enhanced Status Reports

The Marine Life Management Act (MLMA) is California's primary fisheries law. It requires the California Department of Fish and Wildlife (Department) to regularly report to the California Fish and Game Commission (Commission) on the status of fisheries managed by the state. The 2018 Master Plan for Fisheries expanded on this general requirement by providing an outline for Enhanced Status Reports (ESRs) that is based on the MLMA's required contents for Fishery Management Plans (FMPs). The goal of ESRs is to provide an overview of the species, fishery, current management and monitoring efforts, and future management needs, and provide transparency around data and information that is unavailable or unknown. ESRs can help to guide Department efforts and focus future partnerships and research efforts to address information gaps and needs to more directly inform management. It is also anticipated that some ESRs will be foundations for future FMPs by providing background information and focusing analyses and stakeholder discussions on the most relevant issues.

Note that in order to describe management measures in clear terms, ESRs contain summaries of regulatory and statutory language. To ensure full compliance with all applicable laws and regulations, please refer directly to the relevant sections of the Fish and Game Code and/or Title 14 of the California Code of Regulations.

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List of Acronyms

CCR	California Code of Regulations
CPP	Count Per Pound
CPUE	Catch Per Unit Effort
EFI	Essential Fishery Information
ESR	Enhanced Status Report
F	Fishing Mortality
FGC	Fish and Game Code
FMP	Fishery Management Plan
MLMA	Marine Life Management Act
MLPA	Marine Life Protection Act
MPA	Marine Protected Area
NOAA	National Oceanic and Atmospheric Administration
SST	Sea Surface Temperature
TL	Total Length

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Fishery-at-a-Glance: Pacific Hagfish

Scientific Name: *Eptatretus stoutii*

Range: Hagfish are distributed coast-wide from southern Alaska to central Baja California, Mexico.

Habitat: Hagfish live on the sea floor in soft bottom (mud) habitat and are found at depths of 30 to 2,400 feet (9 to 732 meters).

Size (length and weight): Hagfish are long and skinny, achieving lengths up to 20 inches (508 millimeters) or more. Depending upon sex, weight may exceed 8 ounces (230 grams). Individual fish weight-at-length is highly variable.

Life span: Hagfish are slow growing. Their maximum age is unknown, but evidence suggests that Hagfish can live to be 25 to 50 years old.

Reproduction: There is no specific spawning season and female Hagfish may have viable eggs at any time. Hagfish mature at 7 to 12 years of age and have low fecundity, with females producing up to 30 eggs at a time. It is unknown how often Hagfish spawn.

Prey: Hagfish are primarily scavengers of carrion, but also prey on small benthic invertebrates.

Predators: Spiny Dogfish, Harbor Seals, Harbor Porpoises, and Elephant Seals prey on Hagfish.

Fishery: Fishermen deploy baited traps to attract Hagfish. After many years of very low landings, landings increased in 2007 due to increased demand. In 2018, 43 fishermen landed 2.12 million pounds statewide.

Area fished: Hagfish fishing is allowed in all depths within state and federal waters off California except in marine protected areas.

Fishing season: Hagfish can be taken year-round.

Fishing gear: Hagfish are taken with baited traps attached to weighted groundlines, usually with floats on each end. Traps must have holes of a certain diameter to allow small Hagfish to escape.

Market(s): Landed Hagfish are exported live for human food in South Korea.

Current stock status: The status of the Hagfish stock is unknown currently. However, available information suggests that Hagfish are relatively long lived and have low fecundity, making them likely susceptible to fishery depletion.

Management: The open-access Hagfish fishery is managed via restrictions on the amount and type of gear allowed. The fishery has no reporting requirement, other than a fish ticket (formerly landing receipt). There is no minimum size limit, landing quota, or seasonal closure. There are no daily, seasonal, or annual catch limits. The fishery is assessed by dockside sampling using a mean count-per-pound metric, and samples are taken for life history studies. During the past 8 years this metric has been highly variable and has shown no trend.

1. The Species

1.1. Natural History

1.1.1. Species Description

Pacific Hagfish (Hagfish) (*Eptatretus stoutii*) are a member of the Myxinidae (Hagfishes) family. Hagfish are cartilaginous fish that lack eyes, jaws, scales, and paired fins (Figures 1-1, 1-2). Hagfish have eye spots, a single nostril, and a mouth that contains two parallel rows of pointed, keratinous teeth. These teeth are secured to rasping dental plates. The oral/nasal cavity is surrounded by eight barbels. Lacking an operculum, Hagfish have from 11 to 13 gill pores or slits (Worthington 1905). They are brown in color and may have dark mottling. Members of the Hagfish family also have mucous producing “slime” glands along each side of the fish’s body. When agitated, Hagfish will produce a protein-based mucous that, when mixed with water, produces a thick, viscous slime. This characteristic is the reason Hagfish are called “slime eels”.

Figure 1-1. Dorsal view of a Pacific Hagfish. Notice the eye spots (Photo Credit: Andrew Clark, University of California, Irvine).

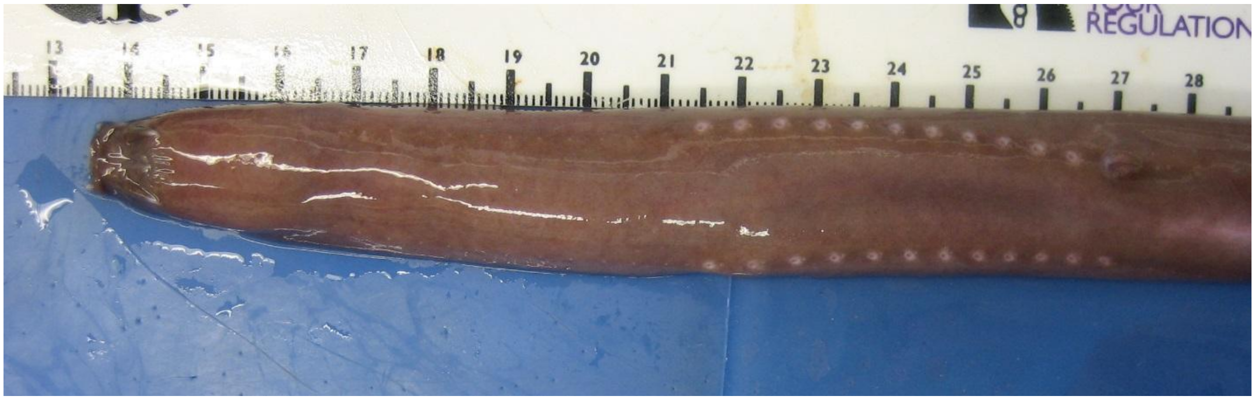

Figure 1-2. Ventral view of a Pacific Hagfish. Notice this individual has 11 gill pores on one side and 12 on the other (Photo Credit: Andrew Clark, University of California, Irvine).

Hagfish are osmoconformers, meaning that a Hagfish’s blood osmolality is isosmotic with the environment (Hastey 2011). Because Hagfish are unable to regulate sodium and chloride ions, they are sensitive to changes in salinity, especially decreases.

Considered scavengers and benthic predators, Hagfish will feed upon carrion or live invertebrates. They identify food sources through their excellent sense of smell and touch. Hagfish will protract/retract their plates until the food source is secured and consumption begins by entering an existing hole or making one by using their dental plates. The Hagfish will then enter its food item, if possible, consuming it from the inside. Hagfish were once thought of as parasites due to this behavior.

A related species, the Black Hagfish (*Eptatretus deani*), occurs in deeper waters than Pacific Hagfish although their distributions overlap. Landings are sometimes mixed, but those of Black Hagfish are rare. Black Hagfish are found over soft mud habitat at depths from 1,560 to 3,500 feet (ft) (476 to 732 meters (m)) (Miller and Lea 1972). Black Hagfish are uniform purple/black in color. Gill pores are closer to the head than in Pacific Hagfish

1.1.2. Range, Distribution, and Movement

Hagfish are distributed coast-wide from southern Alaska to central Baja California, Mexico. Preferring deep, soft mud habitat, Hagfish are found at depths of 30 to 2,400 ft (9 to 732 m) (Miller and Lea 1972) but are more common in depths less than 1,200 ft (366 m) (Love 1996). In California they are usually caught in depths less than 1,800 ft (549 m).

Knowledge about Hagfish movement is limited. Based on fishing activity as reported via voluntary logbooks, Hagfish may exhibit limited migration, and respond to the presence of food. The introduction of food sources, such as from fishing discards, may result in a localized increase of Hagfish (Martini 1998).

Changes in oceanic conditions or habitat may force Hagfish to migrate to more favorable depths or locations. Hagfish are sensitive to salinity decreases, significant increases in water temperature, or substrate alterations (Hastey 2011).

1.1.3. Reproduction, Fecundity, and Spawning Season

As protogynous hermaphrodites, Pacific Hagfish exhibit relatively unique reproductive characteristics among fish species. As protogynous hermaphrodites, all fish initially develop female oocytes, but hermaphroditism can occur as a temporary “juvenile” event (Gorbman 1990). Females begin gonadal maturation before males. Laboratory research has shown that female differentiation occurs gradually in early life stages until reaching 8 inches (in) (203 millimeters (mm)) Total Length (TL). Eggs begin developing after 8 in (203 mm) TL, and females are sexually identifiable at this size. Male Hagfish show a temporary version of juvenile hermaphroditism (Gorbman 1990). The anterior section of the testis develops through stages of oogenesis for Hagfish less than 8 in (203 mm).

For fish larger than 8 in (203 mm), the testes begin development of testicular follicles resulting in the production of spermatocytes. During testicular development, the part of the gonad that underwent oogenesis begins to degrade (Gorbman 1990). Males are sexually identifiable internally without magnification at 11 in (279 mm) TL.

Fecundity is low with females going through cycles of spawning maturity. Viable female Hagfish will contain eggs of various stages of maturity. Immature female Hagfish can produce up to 200 eggs however, at peak maturity, the number of eggs that reach maturity is significantly lower. Reid (1990) found an average of 23 mature eggs per female, while Fleury (2016) estimated as few as 20. In 4 years (yr) of sampling, Barss (1993) found females to average up to 28 eggs per spawn cycle with only one set of eggs maturing at a time. The number of eggs a female will carry to term may be dependent upon length with longer females carrying a greater number of mature eggs (Nakamura 1991).

There is no specific spawning season and female Hagfish may have viable eggs at any time. Once mature, the female will carry eggs of various stages, including spent eggs, year-round as observed in Department sampling efforts. While viable eggs have been observed more frequently in Department-sampled Hagfish during fall and winter months, Hagfish most likely spawn throughout the year. The peak of the spawn may be during the summer (Barss 1993).

Sex ratio may be skewed toward female or male; however, a sex ratio approaching or near 1:1 is expected prior to spawning. Nakamura (1991) found that males were more prominent throughout the year based on quarterly sampling, but the number of males and females were closest during the summer. Other studies found that females were more dominant in the population. Reid (1990), after sampling all four seasons, found a male: female ratio of 1.0:1.5. In 2018, the sampled sex ratio favored males over females with a ratio of 1.0:1.30 (CDFW Hagfish Sample Data 2018).

1.1.4. Natural Mortality

Determining the natural mortality (M) of marine species is important for understanding the health and productivity of their stocks. Natural mortality results from all causes of death not attributable to fishing such as old age, disease, predation or environmental stress. Natural mortality is generally expressed as a rate that indicates the percentage of the population dying in a year. Fish with high natural mortality rates must replace themselves more often and thus tend to be more productive. Natural mortality along with fishing mortality result in the total mortality operating on the fish stock.

Natural mortality has not been directly estimated for Hagfish. However, it is thought to be very low based on empirically derived life history relationships that link maximum age to natural mortality rate for many fish species. Nakamura (1994) suggested that a maximum age of more than 50 years was possible, making natural mortality less than 0.1 using Hoenig's (1983) method

1.1.5. Individual Growth

Individual growth of marine species can be quite variable, not only among different groups of species but also within the same species. Growth is often very rapid in young fish and invertebrates but slows as adults approach their maximum size. The von Bertalanffy Growth Model is most often used in fisheries management, but other growth functions may also be appropriate.

Hagfish growth has proved difficult to characterize as a result of difficulties with determining age-at-length since, as a cartilaginous fish, they lack any of the bony structures that are typically used to estimate age. Nakamura (1994) attempted an age and growth study, both by analyzing limited mark-recapture data and by evaluating growth rates observed in Hagfish reared in the laboratory. The resulting data showed a wide range of possible age-length relationships and additionally documented fish that experienced zero or even negative growth in both natural and laboratory settings. Growth models were constructed using three categories of observation data; laboratory-reared fish excluding negative growth observations (Lab +), wild fish excluding the negative/zero observations (Wild +), and wild fish including negative/zero observations (Wild +/-). Although negative growth is a phenomenon that occurs in other cartilaginous fishes (e.g. Lamprey), it may also be exacerbated by handling, tag, and/or lab stress and was consequently excluded in two of the models. The laboratory-reared fish grew significantly more slowly than those observed in the wild, creating a likely unrealistic characterization of Hagfish growth. Including or excluding negative growth observations had a large consequence on the resulting age-length relationship in the wild population data, which is an uncertainty that should be taken into consideration when characterizing Hagfish growth in future work. The three age-length relationships are provided in Figure 1-3.

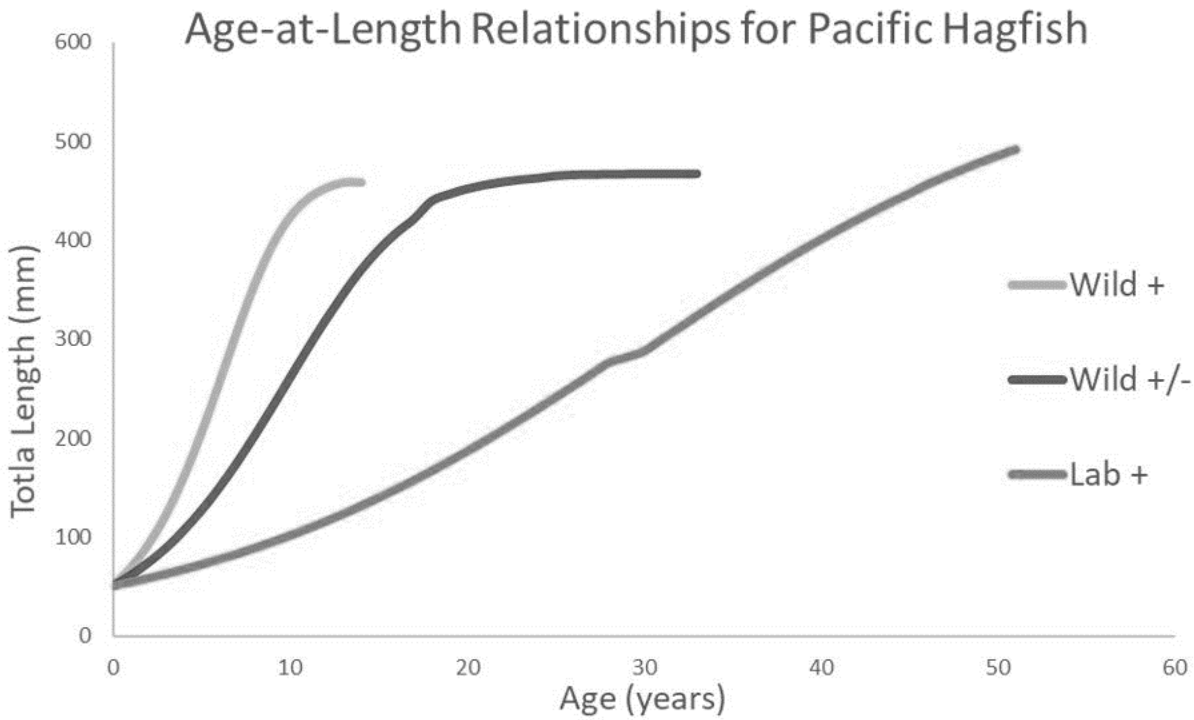

Figure 1-3. Age-at-length relationships for Pacific Hagfish captured off the central California coast using three datasets: Wild + - includes mark-recapture data with only positive growth observations, Wild +/- uses mark-recapture data that includes negative/zero growth observations, and Lab + uses only fish held captive in laboratory conditions (Reproduced from Nakamura 1994).

1.1.6. Size and Age at Maturity

Research indicates that Hagfish begin sexual differentiation around 8 in (203 mm) and are mature at 12.8 in (338.0 mm). Nakamura (1994) estimated that female Hagfish off California mature around 12.8 in (325.0 mm) TL when they are between 7 and 8 yr old. Based on Department sample data, Tanaka and Crane (2014) found that female Hagfish were mature at 13.3 in (338.0 mm).

Barss (1993) found that male Hagfish off Oregon and Washington were 50% mature at 13.8 in (351.0 mm) and 100% mature at 16.5 in (419.0 mm). Females were 50% mature at 16.5 in (419.0 mm) and 100% mature at 20 in (508 mm). This same study found the smallest mature male was 10.2 in (259.0 mm) and the smallest female was 11.8 in (300.0 mm)

1.2. Population Status and Dynamics

Current and historical stock status is unknown. There is limited knowledge of Hagfish life history with which to model the population dynamics for this species. However, available information suggests that Hagfish are relatively long lived and have low fecundity, making them likely susceptible to fishery depletion. While there is a catch record for this species, there is unfortunately no standardized measure of associated fishing effort, precluding the development of an index of relative abundance. Currently, staff are working on applying data-limited methods to Hagfish data to elucidate population status.

1.2.1. Abundance Estimates

Nakamura (1991) estimated population abundance off the central coast of California using a series of tagging surveys. During this study, more than 5,000 Hagfish were caught, tagged, and released, and 39 were recaptured. Based on this, the estimated density of Hagfish was 1.15 million per square mile (mi^2) (2.59 square kilometers (km^2)). Other studies observing Black Hagfish, saw average densities of 840,000 per mi^2 (2,175,590 km^2) off the coast of California, with maximum densities ranging up to 1.5 million per mi^2 (3,884,982 km^2), but considered these estimates low due to burrowing Hagfish, which could not be sampled by trawl gear (Wakefield 1990). Observations of Hagfishes (*Eptatretus* spp.) off Oregon's coast also show that they are more active at night, causing lower abundances to be observed during the day due to burrowing behavior (Hart et al. 2010).

1.2.2. Age Structure of the Population

Age information is limited due to the lack of reliable aging structures such as otoliths or other bony structures in Hagfish. However, Nakamura's (1994) work gives estimated age at length. Nakamura results suggest that a 7.1 in (180.0 mm) long Hagfish is 4 to 8 yr old, and a 17.7 in (450.0 mm) long Hagfish is 15 to 25 yr old. Applying Nakamura's estimate to Department sample data from 2015 to 2018 (2015 is the effective year of the 0.56 in (14.0 mm minimum trap hole diameter regulation), the fishery retains minimal female Hagfish under 12.8 in to 13.3 in (325.0 to 338.0 mm) or 7 to 8 yr of age. Based on Department sampling, 96 to 98% of sampled Hagfish are longer than 13.3 in (338.0 mm). Due to the minimum trap hole diameter, the number of potentially available Hagfish under 8 yr is unknown. Since the fishery retains nearly 100% of Hagfish captured, 81 to 87% of retained Hagfish could be 8 to 15 yr of age. The percentage of older, larger fish showed a declining trend, but rebounded in 2018. In 2015, 12.4% of sampled females were 17.7 in (450.0 mm) (15+ yr) or longer. This percentage decreased in 2016 and decreased again in 2017 to 3.9%. Sampled female percentage rebounded to 16.8% in 2018.

1.3. Habitat

Hagfish prefer deep water (between 30 to 2,400 ft (9 to 732 m)), soft bottom (mud) habitat, which is the predominant marine habitat type off California. Still, Hagfish can be found over mixed substrate (mud, sand, gravel) or in areas with larger boulder formations (Cailliet et al. 1991) (Figure 1-4). Hagfish are sensitive to salinity decreases, significant increases in water temperature, or substrate alterations (Hastey 2011). A significant increase in temperature or prolonged decrease in salinity can have lethal effects (Martini 1998).

Figure 1-4. Hagfish in their natural habitat (Photo Credit: http://ocean.si.edu/ocean-photos/pacific-hagfish, NOAA).

1.4. Ecosystem Role

As scavengers, Hagfish play a significant ecosystem role by assisting in the rapid recycling of nutrients in deep water, soft bottom, benthic habitat. Hagfish are also benthic predators of invertebrates, particularly polychaete worms (Johnson 1994).

In addition, at increased densities, Hagfish facilitate benthic turnover through burrowing. Martini (1998) suggested several adaptations to a burrowing lifestyle:

- smooth skin with elongate body shape
- degenerative eyes
- reduction of the lateral line system
- gill ventilation by a velar pump system
- low basal metabolic rate

1.4.1. Associated Species

Fishermen are not allowed to land incidentally caught finfish, and logbooks are not required for reporting catch, so there is little information on associated species. Limited information on observed associated species is based upon observation trips aboard Hagfish vessels and Department studies. There are known species that inhabit deep, soft-bottom habitat, including: Pacific Sanddab (*Citharichthys sordidus*), Sablefish (*Anoplopoma fimbria*), Spotted Cusk Eel (*Chilara taylori*), Octopus (*Octopus* (spp.), Dungeness Crab (*Metacarcinus magister)*, and Shrimp (species unknown). Other species likely to co-occur with Hagfish on deep, soft-bottom habitat include: Spiny Dogfish (*Squalus acanthias*), Dover Sole (*Microstomus pacificus*), English Sole (*Pleuronectes vetulus*), Big Skate (*Raja binoculata*), California Skate (*Raja inornata*), California Tonguefish (*Symphurus atricauda*), Spotted Ratfish (*Hydrolagus colliei*), Petrale Sole (*Eopsetta jordani*), and benthic invertebrates, such as polychaetes, sea stars, and crustaceans.

1.4.2. Predator-prey Interactions

Despite having a slime-producing mechanism for defense, Hagfish are preyed upon at all life stages. In California waters, Hagfish face predation from Spiny Dogfish, Harbor Seals (*Phoca vitulina*) Harbor Porpoises (*Phocoena phocoena*), and Elephant Seals (*Mirounga angustirostris*) (Martini 1998). A scat analysis of Harbor Seals showed that Hagfish occurred as a prey item 27.5% of the time on an annual basis (Hanson 1993). Hagfish eggs are preyed upon by some invertebrates (Martini 1998). Deep-water fishes such as Sablefish are also known to eat Hagfish.

Hagfish are primarily scavengers and have been observed feeding on the muscles and viscera of large fishes such as cod, Spiny Dogfish, Sablefish, Lingcod (*Ophiodon elongatus*), perches, flounders, and salmon (*Onchorhynchus* spp.) (Hart 1973). In areas subject to extensive fishing pressure, Hagfish may feed on fishing discards (Martini 1998). Hagfish are also benthic predators of cephalopods, polychaetes, sergestid shrimp, euphausiids, and small fishes (Johnson 1994). Johnson (1994) also found that many of the Hagfish sampled had empty stomachs and inferred that Hagfish spend little time searching for food. Being burrowers, Hagfish most likely lie in wait for a scent trail to follow.

A significant, long-term reduction in Hagfish density could have the effect of a buildup of carrion falls or a disruption in nutrient recycling. It is unknown what potential ecosystem effects could occur due to a reduction of Hagfish density (Martini 1998).

1.5. Effects of Changing Oceanic Conditions

Hagfish are sensitive to significant temperature changes and are susceptible to thermal stress. Thermal stress through heating influences biochemical reactions and can double or triple the metabolic rate of Hagfish for every 10 degrees Celsius (˚C) (50 degrees Fahrenheit (°F)) increase and may disrupt the osmotic balance of Hagfish (Hastey 2011). As an osmoconformer, any disruption to osmotic balance leads to additional stress. Prolonged or significant oceanic temperature changes due to events such as El Niño or La Niña may have a temperature affect as deep as 300 m (984 ft) (Norton and McLain 1994). However, due to the greater depths that Hagfish inhabit, the effect of changes to temperature at depth may not be significant enough to force Hagfish migration (J. Norton personal communication). The potential stress to Hagfish caused by increased temperature is apparent after the fish are caught and are subject to ambient Sea Surface Temperature (SST) during transit to the buyer and after being placed in dockside receivers. During significant warm water months, some buyers will stop all market orders, particularly in southern California, due to loss associated with the stress of increased water temperature. Landing trends do not reflect the market-imposed limits placed on southern California vessels. Some Hagfish exporters can keep their fish alive using water chillers, but at greater expense.

2. The Fishery

2.1. Location of the Fishery

Within California, Pacific Hagfish have been fished over soft bottom in waters from 180 to 1200 ft (55 to 366 m) but are more commonly targeted in water depths ranging from 180 to 600 ft (55 to 183 m). Hagfish are landed statewide, from Eureka (Humboldt County) to Oceanside (San Diego County). There are a greater number of landings off central California due to a larger number of participants, but pounds of fish per landing are smaller by comparison. Fewer, but larger landings occur off the north coast.

2.2. Fishing Effort

2.2.1. Number of Vessels and Participants Over Time

When the fishery began in 1982, four vessels participated. Due to demand, the number of participants quickly increased and by 1990, a total of 56 vessels participated in the fishery. However, the market collapsed shortly thereafter, resulting in a decline in the number of participants and very little fishing effort until 2005 (Figure 2-1).

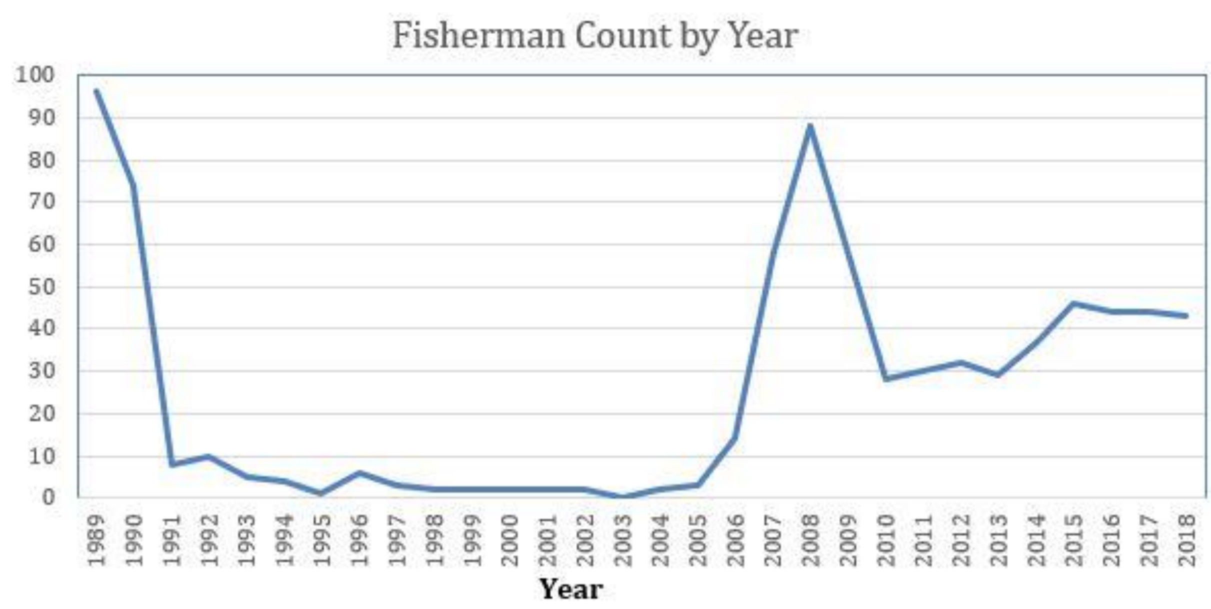

Figure 2-1. Hagfish fishermen count by year. Note the closure of the commercial salmon fishery during 2008 to 2009 (CDFW Commercial Fisheries Information System 2018 and Marine Landings Data System 2019).

Fishing effort rebounded significantly beginning in 2007 due to renewed interest in California-caught Hagfish. In 2008, effort increased due to interest from displaced fishermen, either from fisheries that had seasonal reductions, emergency closures, or those seeking additional income (Figure 2-1). The Hagfish fishery is open access, and fishermen tend to enter and leave the fishery depending on market volatility or involvement in other fisheries. Since the resurgence of the fishery in 2005, fishing effort, (mostly market driven) has increased to a relatively consistent level in recent years. In 2018, 35 vessels, operated by 43 fishermen, participated in the Hagfish fishery. This contributed to a statewide landing total of 2.12 million pounds (lb) (965,024 kilograms (kg)), valued at $1.81 million (CDFW Marine Landings Data System, 2019). The 10 yr average (2009-2018) of participating fishermen who made at least one landing is 39,594 lb (17,960 kg) (range: 27,416 to 48,352 lb (12,436 to 21,932 kg)).

Fishing effort is dictated by market order, which is dependent upon Korean import demand. Hagfish are stored dockside for several days prior to shipping. Fishermen are often told when to deliver to allow time for stored fish to purge their gut contents prior to packing. During Dungeness Crab or Chinook Salmon (*Oncorhynchus tshawytscha*) seasons, fishermen may not take part in the Hagfish fishery for several months in order to participate in these more profitable fisheries. Typically, Hagfish vessels are operated by one captain and one or two deckhands, but a few fishermen work independently.

2.2.2. Type, Amount, and Selectivity of Gear

When the California fishery began in 1982, fishermen were free to utilize any trap type with no restrictions on trap capacity, escapement opening, or total trap number. The only general regulations applicable for traps used for Hagfish were the use of a destruct device, regular trap servicing, and marking the float with the fisherman's license number.

Hagfish are harvested using 5-gallon buckets or Korean traps and in 2016, barrel traps were included as another authorized gear type (Figure 2-2). All traps are attached to weighted groundlines (Figure 2-3), usually with floats on each end. Based on fisherman preference, groundlines may be any length, but 1,000 ft (305 m) or longer is common. In 2015, the Department implemented new regulations that required all holes, except for the entrance, to be at least 0.56 in (14 mm) in diameter. Holes of 0.56 in (14 mm) or greater have shown to minimize trap retention of immature Hagfish (Tanaka and Crane 2014). Tanaka and Crane's (2014) study showed that increasing trap hole diameter from 0.50 to 0.56 in (12 to 14 mm) resulted in a 10.5% reduction of immature fish retained by the trap. Traps with smaller hole diameters retained Hagfish of all lengths, including a greater number of smaller fish (Figure 2-4). For more information on gear types, see section 3.1.2.1.3.

Figure 2-2. Five gallon bucket Hagfish trap, cylindrical Korean trap, and barrel trap (Photo Credit: Travis Tanaka, CDFW).

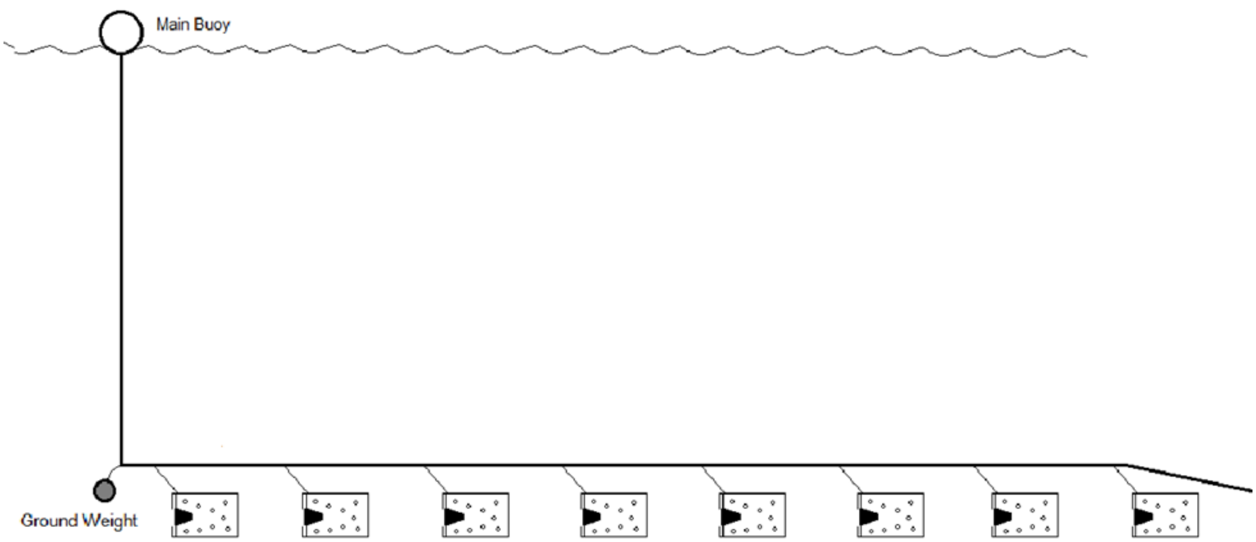

Figure 2-3. Graphic of a groundline equipped with Hagfish bucket traps (Illustration Credit: Ashok Sadrozinski, CDFW).

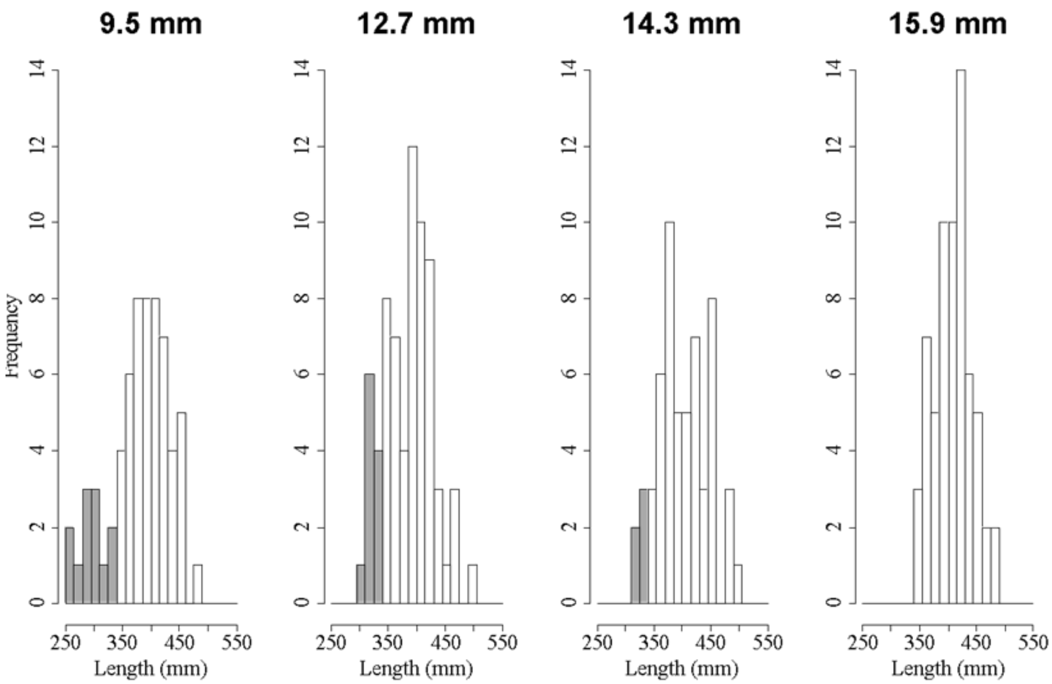

Figure 2-4. Sample length frequency relative to trap hole diameter (Reproduced from Tanaka and Crane 2014).

2.3. Landings in the Recreational and Commercial Sectors

2.3.1. Recreational

There is currently no recreational fishery for Hagfish.

2.3.2. Commercial

The Hagfish fishery in California began in response to demand from South Korean buyers. Minor landings occurred from 1982 to 1984. In late 1987, Korean processors solicited California fishermen, mostly from San Francisco and Monterey, to target Hagfish. These fishermen began fishing the following year. In 1988, eight vessels landed 690,000.0 lb (312,978.5 kg). Between 1988 and 1991, effort and landings peaked at 4.9 million lb (2.22 million kg), caught by 56 vessels (Figure 2-5). Korean interest in California-caught Hagfish decreased during the 1990 season, leading to a market driven collapse in 1991. Several fishermen and receivers who participated in the early fishery claim that Korean importers left the fishery to avoid paying their debts, but there is not documentation of this. Between 1991 and 2006, annual landings ranged from near zero to 406,000.0 lb (184,158.4 kg) with an average of 82,000.0 lb (37,194.5 kg).

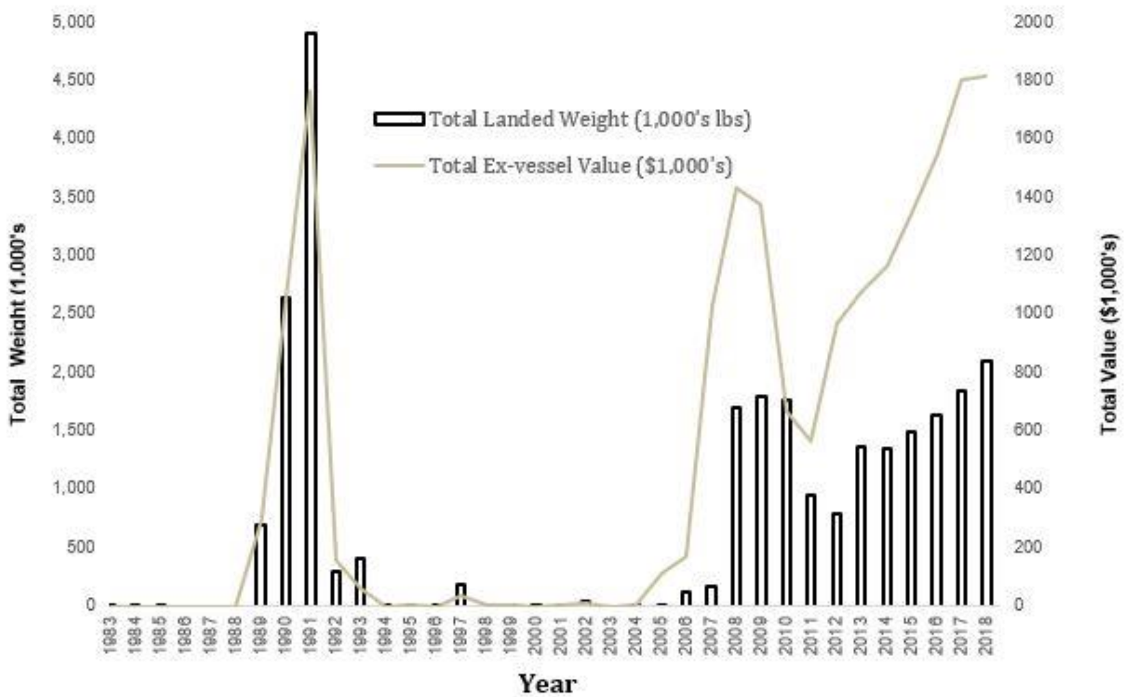

Figure 2-5. Total annual landing weight of Hagfish and value by year (CDFW Commercial Fisheries Information System 2018 and Marine Landings Data System 2019).

Due to renewed interest in California-caught Hagfish, fishing effort and landings rebounded significantly beginning in 2007 with total landings reaching 1.69 million lb (766,570.5 kg), valued at $1.03 million (CDFW CFIS). Fishermen, especially those who did not have other fishery options, began targeting Hagfish to satisfy Korean demand.

Annual landings reflect fluctuations in Korean demand, with seasonal declines occurring during the late spring followed by significant increases in demand. In 2018, the fishery supported 43 fishermen who landed 2.12 million lb (965,024 kg) statewide.

2.4. Social and Economic Factors Related to the Fishery

The California Hagfish fishery began as a result of foreign fishery depletion. In 1983, Korean “eel skin” leather products gained popularity and the fishing effort increased in the waters off Korea and Japan to accommodate the need for Hagfish skins. In South Korea, from 1983 to 1985, 400 vessels contributed to landing totals up to 6 million lb (2,721,552 kg) per year. Between 1986 and 1987, there were approximately 600 vessels and 35 Korean processors in the South Korean port of Pusan. Due to severe fishery depletion, Korean processors began to look for outside sources of Hagfish, and this spurred the development of the California Hagfish fishery in 1989 (Kato 1990).

Being an export-only fishery, fishermen and fish receivers are affected by changes in South Korea’s economy, policies, and customs. From 1988 to 1992, the average ex-vessel price was $0.37 per lb ($0.81 per kg) to satisfy the need for “eel skin” leather goods. California fish receivers sold locally caught Hagfish to Korean importers. However, Korean interest in California-caught Hagfish decreased in the 1990 season, leading to a market driven collapse in 1991. Demand declined during the early 1990s due to skin quality defects (unexplained holes) found on California-caught Hagfish causing Korean importers to seek other sources for Hagfish (Melvin and Osborn 1992).

After robust landings for several years, most Hagfish fishing in California ceased after 1992. Landings were made at a minor level until 2006 when South Korean demand for California-caught Hagfish once again increased. Korean buyers also helped build interest by offering trap components or equipment to those who would sell Hagfish to them. Between 2008 and 2018, the total average annual landing value was $1.25 million with an average price per lb of $1.03 ($2.27 per kg). In 2018, the average price per lb was $0.95 ($2.09 per kg).

In addition to the ex-vessel price, exporters must also factor in the fees and costs to ship live Hagfish overseas. According to one Hagfish exporter, the cost to ship one box is approximately $60. This includes the costs of packaging, labor, and airfreight. This does not include the costs to store and maintain Hagfish prior to shipment. (C. Thomsson pers. comm.).

During the peak fishery of 1990, 24 fish receivers purchased California-caught Hagfish. Based on Department records, 11 of those receivers were backed or owned by Korean interests. Of the 24 receivers, only two have remained in business. In 2016, nine fish receivers purchased Hagfish. By 2018, 17 fish receivers purchased Hagfish, but not all receivers export. Several purchasing dealers sell the landed catch to other exporters. Market conditions continue to support these fish receivers, even during periods of poor fishing or demand collapse. Two of the 17 receivers are fishermen who catch, pack, and export their own catch.

Hagfish fishermen face their own economic constraints. In addition to costs associated with maintaining a vessel and fishing gear, fishermen have costs and the burden of acquiring/storing bait, especially during bait shortage or a management closure of the bait species and paying crew during periods of irregular fishing activity due to weather or market changes. Depending on the type of trap used (bucket or barrel) the quantity of bait varies and is based on fisherman preference. Bait (sardines) is currently $0.40 per lb ($0.88 per kg) (2018 price). Some fishermen can acquire fish carcasses. Bucket fishermen may use up to 800.0 lb (362.9 kg) of bait per set. Barrel fishermen from the same port may use up to 400.0 lb (181.4 kg) per set. During periods of bait shortage, fishermen fish fewer days to maximize soak time on their traps and to minimize bait purchased per fishing week (H. Juarez pers. comm.). Some barrel fishermen use up to

125.0 lb (56.7 kg) of bait per set, but utilize bait containers to extend bait life and to limit consumption by small fish and invertebrates (C. Thompson pers. comm.)

The Hagfish fishery has provided a needed boost for fishery-based economies of several fishing communities. Displaced fishermen rely on Hagfish as a source of income during fishery closures or between fishing seasons for other targeted species. For example, the City of Morro Bay cited the Hagfish fisheries role in “contributing to the diversity of species, scale of operation, and export market opportunities” (Lisa Wise Consulting 2015). During the period examined by Wise Consulting, Hagfish contributed over $2.4 million to the Morro Bay area from 2006 to 2014. Even though Hagfish are exported, Morro Bay fish receivers must employ staff, usually local fishermen, to care for the retained Hagfish prior to shipment. Money is spent on packaging materials, dock rental, and transportation. Fish receivers and exports pay taxes/fees for exportation and landing taxes on Hagfish purchased from fishermen. In 2018, Hagfish landings significantly contributed to the fishing economies of eight California port complexes (Table 2-1). Of the eight port complexes, Eureka, Bodega Bay, and Morro Bay complexes contributed to 70% of state-wide landings.

Table 2-1. 2018 Pounds and total value by port complex (CDFW Marine Landings Data System, 2019).

Port complex	Pounds landed	Total value (U.S dollars)
Eureka	645,067	459,798
Fort Bragg	258,069	202,356
Bodega Bay	432,545	324,409
Monterey	128,699	119,403
Morro Bay	413,811	443,943
Santa Barbara	64,314	70,755
Los Angeles	115,316	115,933
San Diego	69,672	76,733

Based on Department marine landing records, as of 2018 most participating fishermen in the Hagfish fishery were those without special permits, either vessel or individual. In 2018, of the 43 participating fishermen, 27 did not hold additional permits to other fisheries. The remaining fished Hagfish while in between seasons or in the case of salmon, closure of their fishery. Of the 35 vessels used in the 2018 season, 17 did not have any vessel-based permits. Sixteen participating vessels were permitted as salmon or Dungeness Crab vessels and two were permitted for participation in the squid fishery. Due to the variability or lack of other fishing opportunities, in any given month participation was approximately 20 fishermen.

3. Management

3.1. Past and Current Management Measures

The Hagfish fishery began with no regulations or management oversight. A series of regulations were enacted in Fish and Game Code (Table 3-1) after the market-induced collapse in 1991. Additional management measures were enacted ten years after the last amendment to Hagfish regulations in Fish and Game Code.

Table 3-1. Additions or amendments to Hagfish fishing statutes and regulations in California by year.

Year	Fish and Game Code or Title 14	Addition or amendment	Result
1995	FGC	Addition §9001.6	Established a Finfish Trap Permit; no popups for buoy lines; destruct device that conforms to current devices adopted by the Commission required for finfish traps.
1996	FGC	Amendment §9001.6	Allowed take of Hagfish in Korean and bucket traps; when in possession of Korean or bucket traps, no finfish other than Hagfish shall be taken or possessed.
1997	FGC	Amendment §9001.6	Established dimensions of Korean and bucket traps; establishes 2003 as sunset year.
1998	FGC	Amendment §9001.6	Established trap limits of 500 for Korean traps and 200 for bucket traps.
2001	FGC	Amendment §9001.6	Established requirement of General Trap Permit for take of Hagfish; extend sunset year to 2006.
2004	FGC	Amendment §9001.6	Clean up of Section 9001.6.
2014	Title 14	Addition §180.6	Required a minimum hole diameter of 0.56 in (14 mm) for all holes except the entrance.
2015	Title 14	Amendment §180.6	Allowed for take of Hagfish in 40 gallon (151.4 liter) barrel traps; If barrel traps are used, may be attached to no more than three ground lines.
2016	Title 14	Amendment §180.6	Replaced 40 gallon (151.4 liter) requirement with maximum allowable dimensions (40 in long x 25 in outside (1016 mm long x 635 mm outside) diameter).

3.1.1. Overview and Rationale for the Current Management Framework

The Hagfish fishery is an open access, state-managed commercial fishery. The fishery was initially managed through legislation with management measures found in Section 9001.6 of the Fish and Game Code (FGC). However, beginning in 2014, the Commission implemented regulatory measures, located in Title 14 of the California

Code of Regulations (CCR). Statutes and regulations relevant to the Hagfish fishery are summarized in Table 3-1. The fishery began with minor landings occurring during the period 1982 to 1984, with significant landings from 1988 to 1992. However, legislation to manage the fishery was not enacted until 1995.

The fishery is managed via restrictions on the amount and type of gear allowed. The rationale behind these early regulations that limited the number of traps each participant may deploy was to help prevent overfishing and limit gear abandonment. Additional regulations enacted in 2014 require that all trap holes be at least 0.56 in (14.0 mm) in diameter to minimize trap retention of immature Hagfish (Tanaka and Crane 2014). The authorization of barrel traps for Hagfish take gives fishermen an option that reduces loss due to crowding, minimizes gear conflicts, and, depending on the number of fishermen that switch to barrels, would limit the number of traps in contact with the bottom. There is no reporting requirement, other than a fish ticket, for this fishery. Currently, there is no minimum size limit, landing quota, or seasonal closure. Hagfish fishing is allowed in all depths within state and federal waters off California except in Marine Protected Areas (MPAs). There are no daily, seasonal, or annual catch limits.

3.1.1.1. Criteria to Identify When Fisheries Are Overfished or Subject to Overfishing, and Measures to Rebuild

MLMA defines "overfishing" as a rate or level of take that the best available scientific information, and other relevant information, indicates is not sustainable or that jeopardizes the capacity of a marine fishery to produce the maximum sustainable yield on a continuing basis.

The Department has not yet established any biological reference points or other criteria which could be used to classify the Hagfish fishery as overfished or to determine when overfishing occurs. However, the Department monitors the average Count Per Pound (CPP) in the catch, which is a proxy for the average size of Hagfish landed by the fishery (see Section 4). The time series of CPP data is intended as a means of detecting truncation of the underlying population size structure, which can be indicative of a decline in population abundance. A sustained increase in CPP would indicate that the average fish size in the population was reduced and would consequently trigger a more thorough investigation of other possible indicators of stock status. Department staff are currently developing a method for determining a CPP threshold which approximates an overfishing limit, but no specific management action is prescribed if such a threshold is surpassed.

3.1.1.2. Past and Current Stakeholder Involvement

Department staff have working relationships with some Hagfish fishermen, buyers, and processors, primarily in central and northern California. This facilitates valuable exchanges of information, an understanding of the market-related factors driving the fishery, and an opportunity to sample landed Hagfish for life history information. In the recent past, Department staff have worked on an ad-hoc basis with fishermen to develop and implement regulations for a minimum hole diameter in Hagfish traps, which became effective in 2015. Department staff also worked with fishermen to develop and implement the use of barrel traps in the fishery, which were not permitted prior to 2015; this included onboard observations during the experimental phase of gear testing.

3.1.2. Target Species

3.1.2.1. Limitations on Fishing for Target Species

3.1.2.1.1. Catch

There are no limits on the amount of Hagfish that can be landed. The Hagfish fishery is currently a single species fishery. Black Hagfish is a related species present and available in deeper waters but are not currently desirable in the export market and thus not targeted by the California fishing fleet. Fishermen are prohibited from retaining other species of finfish when targeting Hagfish or in possession of Hagfish.

3.1.2.1.2. Effort

The Hagfish fishery is open access. Fishermen are required to obtain a General Trap Permit to participate in the fishery. Although the Hagfish fishery is open access, fishing capacity per vessel is limited through trap limits (see Section *3.1.2.1.3*).

3.1.2.1.3. Gear

Under the authorization of FGC and CCR Title 14, Hagfish may be taken in bucket, Korean, or barrel traps. No other method of take is allowed. Following the fishery of 1988 to 1991, Korean and 5-gallon (18.9 liter) bucket traps were the only methods authorized. Korean traps are approximately 21 in (533 mm) long with a diameter of 5 in (127 mm). Fishermen can fish 500 Korean or 200 5-gallon (18.9 liter) bucket traps, but not both.

After receiving a petition for an experimental gear permit to use 40-gallon (151.4 liter) barrel traps in 2014, the Department evaluated this potential gear with the cooperation of commercial fishermen. Barrel traps, which are larger, improve the landing condition of captured Hagfish and may result in less dead loss due to crowding. Subsequently, in

2015 the Department recommended to the Commission that 40-gallon (151.4 liter) barrel traps be approved as a method of take for Hagfish, with a maximum of 25 traps per vessel. In a later rulemaking, the volumetric requirement of 40-gallon (151.4 liter) was replaced with a maximum dimensional requirement. This allowed flexibility in selecting barrels for trap construction.

Regardless of the trap fished, all Hagfish traps are fished in a string on weighted groundlines (Figure 2-3). Fishing on a groundline is efficient and reduces the amount of gear compared to fishing traps with individual vertical lines and floats. Fishermen using barrel traps may spread out their barrels over no more than three groundlines. There is no groundline requirement for bucket or Korean traps. Commercial trap fishermen must service their gear every 96 hours (hr).

Hagfish traps have multiple holes drilled in the trap. This allows water flow and can act as a means of escapement for small Hagfish. After a Department study (Tanaka and Crane 2014) showed a direct relationship between escapement of small Hagfish and trap hole diameter, the Commission adopted a regulation for a minimum hole diameter of 0.56 in (14.0 mm), except for the trap entrance. It is possible to circumvent this added protection by what is known as short soaking the traps. Small Hagfish are known to leave traps once the bait is completely consumed. Pulling traps before this occurs will not allow small Hagfish to escape.

3.1.2.1.4. Time

The Hagfish fishery is open year-round.

3.1.2.1.5. Sex

There are no restrictions on the take of Hagfish by sex; it is impossible to determine Hagfish sex externally.

3.1.2.1.6. Size

Hagfish are often sold live and are difficult to measure. Consequently, there is no minimum legal size for Hagfish since it would be difficult if not impossible to implement and enforce. As an alternative, the Commission established a minimum hole diameter of 0.56 in (14.0 mm) for Hagfish traps which reduces the number of small Hagfish retained (Tanaka and Crane 2014). To some extent, the market also influences the size of Hagfish targeted and retained by the fishery. During the eel-skin fishery of 1988 to 1991, the industry preferred Hagfish 14.2 in (361.0 mm) or longer (Tanaka and Crane 2014). Since the fishery has switched to landing in live condition for human consumption, weight is more important than length and live Hagfish are difficult to measure. The export market will use Hagfish of all sizes, but potential buyers could decline shipments with large numbers of immature Hagfish.

3.1.2.1.7. Area

There are no specific area restrictions for the Hagfish fishery, other than those discussed below.

3.1.2.1.8. Marine Protected Areas

Pursuant to the mandates of the Marine Life Protection Act (Marine Life Protection Act) (FGC §2850), the Department redesigned and expanded a network of regional MPAs in state waters from 2004 to 2012. The resulting network increased total MPA coverage from 2.7% to 16.1% of state waters. Along with the MPAs created in 2002 for waters surrounding the Santa Barbara Channel Islands, California now has a statewide scientific based ecologically connected network of 124 MPAs. The MPAs contain a wide variety of habitats and depth ranges.

Even though the use of MPAs as a fishery management tool was not one of the primary goals of the MLPA, they function as one for the following reasons:

1. They serve as adaptive spatial closures to fishing if the species of interest is within their boundaries and is prohibited from harvest. Under the MLPA, the Department has the authority to evaluate the effectiveness of the closure, possibly resulting in changes in allowance for extractive practices.

2. They function as comparisons to fished areas for relative abundance and length or age/frequency of the targeted species.

3. They serve as ecosystem indicators for species associated with the target species, either as prey, predator, or competitor.

4. Many of the MPAs served to displace fishing effort when they were implemented.

Although the network of MPAs was not designed specifically to protect populations of Hagfish, some MPAs have significant amounts of soft bottom in depths exceeding 318 ft (100 m), which Hagfish prefer. Within state waters along the California mainland and island coasts there are 669.9 mi^2 (1,735.0 km^2) of soft bottom habitat in depths of 318 to 9,840 ft (100 to 3,000 m) (Table 3-2). The state's network of MPAs shelter 139.6 mi^2 (361.6 km^2) or 20.83% of available soft bottom habitat between 318 and 9,840 ft (100 and 3,000 m) (Table 3-3). While a significant proportion of Hagfish habitat, as well as the fishery, occurs outside state waters, the network of protected soft bottom habitat within state waters may have direct benefits by protecting a segment of the population that could contribute to rebuilding the populations around the MPAs should fishery depletion occur.

Table 3-2. Total square miles of soft bottom habitat in depths of 100 to 3,000 m within State waters off California (California Seafloor and Coastal Mapping Project 2017).

Depth (meters)	North Coast	North-Central Coast	Central Coast	South Coast	Total
100 to 200	62.8	5.5	73.3	158.4	300.0
201 to 3,000	7.7	0.0	127.9	234.3	369.9
Total	70.5	5.5	201.2	392.7	669.9

Table 3-3. Total square miles of soft bottom habitat in depths of 100 to 3,000 m within California MPAs by region (California Seafloor and Coastal Mapping Project 2017).

Depth (meters)	North Coast	North-Central Coast	Central Coast	South Coast	Total
100 to 200	10.2	3.8	17.0	41.2	72.2
201 to 3,000	2.2	0.0	26.7	38.5	67.4
Total	12.4	3.8	43.7	79.7	139.6

3.1.2.2. Description of and Rationale for Any Restricted Access Approach

There is currently no restricted access program for Hagfish. The fishery is open access, and anyone with a General Trap Permit can participate in the fishery.

3.1.3. Bycatch

3.1.3.1. Amount and Type of Bycatch (Including Discards)

The Fish and Game Code (FGC §90.5) defines bycatch as “fish or other marine life that are taken in a fishery, but which are not the target of the fishery.” Bycatch includes “discards,” defined as “fish that are taken in a fishery but are not retained because they are of an undesirable species, size, sex, or quality, or because they are required by law not to be retained” (FGC §91). The term “Bycatch” may include fish that, while not the target species, and are desirable and are thus retained as incidental catch and does not always indicate a negative impact.

Information regarding bycatch in this fishery is minimal. There is no method in place to monitor bycatch routinely in the Hagfish fishery. Retention of finfish bycatch is prohibited, so these species are discarded at sea. Based on Department observations, the Hagfish trap fishery is a relatively “clean” fishery with little to no bycatch.

The Department conducted two studies on Hagfish trapping. Over four days of trapping, using 96 5-gallon (18.9 liter) bucket traps, 7,595 (1,818 lb) (824.6 kg) Hagfish were caught, and one live octopus and one live Pacific Sanddab were observed as bycatch (Tanaka and Crane 2014). In the second study, barrel traps were evaluated through onboard observation and fishermen logbooks. Department observers documented the entire contents of 74 barrel traps with no observed bycatch (Tanaka 2015). In addition, voluntary fishermen logbooks reported no bycatch on trips without Department observers on board. Related to the barrel trap study, the Department sought to test the rate of dead loss in bucket traps (Tanaka 2015) by setting two strings of 20 baited bucket traps. Prior to setting the traps, video of a baited bucket trap was taken to verify that the area held Hagfish. The footage revealed that Pacific Sanddabs, Sablefish and Dungeness Crabs showed interest in the trap, but none entered. Upon retrieval, one live octopus and one live juvenile Sablefish were the only observed bycatch. A total of 2,781 Hagfish were released alive and 68 were dead after an overnight soak.

The Hagfish fishery is a deep-water trap fishery, thus there are no interactions with birds and small marine mammals such as otters. There are no documented instances of entanglement with large marine mammals. The likelihood of entanglement is reduced by the fact that Hagfish traps are fished on a single groundline, as opposed to single traps attached to individual buoys. National Oceanic and Atmospheric Administration (NOAA) Fisheries-Office of Protected Resources classifies California Hagfish trap fishery as Category III with no known marine mammal interactions (NOAA Fisheries 2016).

To be proactive in reducing the chance of entanglement, the Commission approved the Department’s request to authorize barrel trap gear with no more than three groundlines for Hagfish take in 2015. There are no regulations for the number of groundlines for bucket or Korean trap gear.

3.1.3.2. Assessment of Sustainability and Measures to Reduce Unacceptable Levels of Bycatch

As described above, the Hagfish trap fishery is relatively clean with minimal bycatch of other species. Immature Hagfish are the only significant bycatch in the Hagfish trap fishery. The use of 0.56 in (14.0 mm) holes is the only restriction in place to minimize trap retention of small Hagfish. Prior to the 0.56 in (14.0 mm) requirement, California fishermen were using hole diameters from 0.38 to 0.56 in (10.0 to 14.0 mm). By requiring a 0.56 in (14.0 mm) minimum hole diameter, the potential for retention of immature Hagfish (Figure 3-1) is reduced as shown in Tanaka and Crane (2014). The study showed 0.56 in (14.0 mm) diameter holes provide a trade-off between minimizing retention of immature Hagfish and maintaining the viability of the fishery. In the figure below, maturity was compared to results from Gorbman and Dickhoff (1978) and Barss (1993).

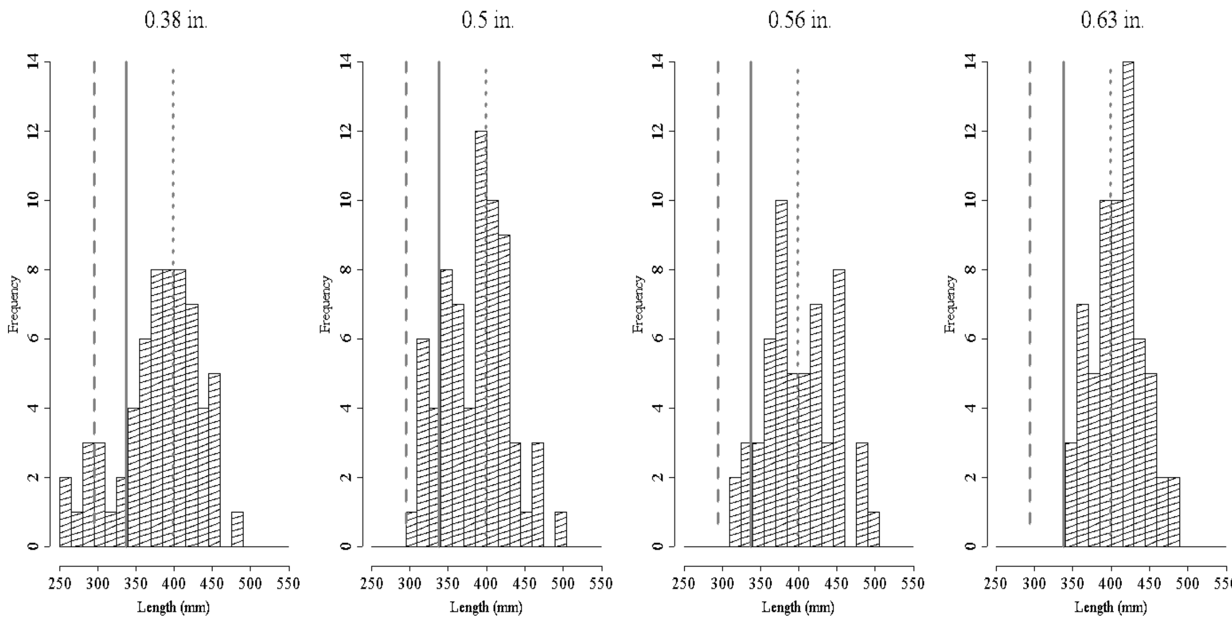

Figure 3-1. Trap retention of immature Hagfish is related to trap hole diameter, as studied by Tanaka and Crane (2014) Sampled female Hagfish results (solid line) from Tanaka and Crane (2014) as compared to Reid (1990) (dashed line) and Gorbman and Dickhoff (1978) (dotted line). First observed maturity, for the purposes of this study is considered Condition 2 as described by Barss (1993).

3.1.3.2.1. Discard Mortality

There is no discard mortality estimate for this fishery, except for dead-loss due to crowding. Typically, all live Hagfish are retained regardless of length. Sorting of live Hagfish at sea is labor intensive and not practical. Some fishermen do report doing minimal sorting, with smaller, live Hagfish getting released overboard. There is no information on the survival of these Hagfish upon release.

Over the course of dockside sampling, fishermen have reported dead loss due to crowding in bucket traps. Fishermen report that when there are dead Hagfish, usually the entire bucket is dead due to crowding. This dead loss is discarded at sea. To estimate dead loss, the Department conducted its own dead loss study. A total of 61 dead Hagfish and 2,781 live Hagfish (2.1%) were counted for 32 traps (Tanaka, unpublished Cruise report 2014). No dead loss was reported while evaluating barrel traps.

Commercial trap fishermen must service their gear every 96 hr. Regular servicing lessens mortality of captured species and reduces the potential for lost gear due to traps filling with mud or sand. All traps must have a destruct device to prevent “ghost fishing” and to release captured fish should the trap become lost.

Pursuant to a regulation effective in 2014, all holes, except for the entrance must be at least 0.56 in (14.0 mm) or greater in diameter. When fished on longer soaks and the correct amount of bait for the trap used, 0.56 in (14.0 mm) holes allow for escapement of smaller, immature Hagfish, thus reducing discards as well as minimizing discard mortality.

The Hagfish trap fishery has no documentation of impacts to threatened, endangered, or overfished species. Department sampling, both onboard and dockside, has not documented the retention of any such species. Federally, the Hagfish trap fishery is considered a Category III with no documented interactions with marine mammals. Category III fisheries have a remote likelihood of or no known interactions with marine mammals.

3.1.4. Habitat

3.1.4.1. Description of Threats

The Hagfish trap fishery has minimal impact to the seafloor. Hagfish are targeted over deep water, soft mud bottom habitat. Traps, lines, and anchors are deployed and retrieved by lowering to and lifting from the seafloor. This method and gear have less overall contact when compared to gears that drag.

Hagfish habitat may be subject to trawling from groundfish fisheries. Benthic trawls, including those that are considered “light touch” can temporarily disturb, but not significantly alter, soft bottom habitat (Wick T, Tanaka T, Pradham N, Enriquez L. pers. comm.).

3.1.4.2. Measures to Minimize Any Adverse Effects on Habitat Caused by Fishing

In addition to improving the landing condition of captured Hagfish, barrel traps potentially have less effect on the substrate than bucket traps due to fewer traps deployed and less line/weights to fish this gear. Fishermen that choose barrel traps are required to use three ground lines or less for their 25 traps. Based on Department interviews, fisherman use three to five ground lines to fish 200 bucket traps (Tanaka, pers. comm.).

3.2. Requirements for Person or Vessel Permits and Reasonable Fees

The Hagfish fishery is open access and participation does not require any fishery-specific permits. Participants do need a commercial fishing license, vessel registration, and a general trap permit. The fees associated with each of these are shown in Table 3-4. Additionally, Hagfish receivers also require a license; the type of license depends on the activities of that business (Table 3-4).

Table 3-4. List of commercial license and permit fees related to the Hagfish fishery 1 April 2019 to 31 March 2020. Note that fees associated with fish business licensing are based on a calendar year, January to December. (CDFW License and Revenue Branch 2019).

Commercial License	Permit Fee (US dollars)	Description
Resident Commercial Fishing License	$145.75	Required for any resident 16 yr or older who uses or operates or assists in using or operating any boat, aircraft, net, trap, line, or other appliance to take fish for commercial purposes, or who contributes materially to the activities on board a commercial fishing vessel.
Nonresident Commercial Fishing License	$431.00	Required for any nonresident 16 yr or older who uses or operates or assists in using or operating any boat, aircraft, net, trap, line, or other appliance to take fish for commercial purposes, or who contributes materially to the activities on board a commercial fishing vessel.
Commercial Boat Registration (Resident)	$379.00	Required for any resident owner or operator for any vessel operated in public waters in connection with fishing operations for profit in this state; or which, for profit, permits persons to sport fish.
Commercial Boat Registration (Nonresident)	$1,122.00	Required for any nonresident owner or operator for any vessel operated in public waters in connection with fishing operations for profit in this state; or which, for profit, permits persons to sport fish.
Trap Permit	$54.08	Required for any person who uses traps to take finfish, mollusks, or crustaceans for profit except Spiny Lobster and Dungeness Crab, as defined in FGC §9001. Dungeness Crab can only be taken on vessels with a valid Dungeness Crab vessel permit. Commercial fishermen can only take Spiny Lobster under the authority of a Spiny lobster operator permit. Spot Prawn can only be taken on vessels with a valid Spot Prawn Trap Vessel Permit.
Fish Receiver's License	$824.00	Any person who purchases or receives fish for commercial purposes from a commercial fisherman not licensed as a fish receiver must obtain a Fish Receiver's License.

Some of the costs associated with management of the fishery by the Department are borne by the fishermen, fish receivers, and processors. In addition to licensing fees, fish businesses in California must pay a landing fee for all fish purchased. The landing fee rate is set in FGC §8051. The rate for Hagfish is $0.0067. In 2018, California fish businesses collectively paid $14,254 in landing fees for Hagfish.

4. Monitoring and Essential Fishery Information

4.1. Description of Relevant Essential Fishery Information

FGC §93 defines Essential Fishery Information (EFI) as “information about fish life history and habitat requirements; the status and trends of fish populations, fishing effort, and catch levels; fishery effects on age structure and on other marine living resources and users, and any other information related to the biology of a fish species or to taking in the fishery that is necessary to permit fisheries to be managed according to the requirements of this code”. Some Hagfish life history parameters have not been determined (see Section 5), age and growth, reproductive potential, movement and migration, and natural mortality. Since Hagfish are impossible to measure in live condition, the Department uses CPP to evaluate the average size of the fish in the landing. All other practical life history parameters that are feasible to determine are done in the lab, including individual fish length, weight, sex, and spawning status. Other EFI parameters are examined through long-term monitoring of the fishery, as discussed in Section 4.2.

4.2. Past and Ongoing Monitoring of the Fishery

4.2.1. Fishery-dependent Data Collection

The Department’s (Marine Region) Northern and Central California Finfish Research and Management Project monitor the Hagfish fishery through use of fish tickets (formerly landing receipts) and opportunistic dockside sampling. Fishery-dependent collection of Hagfish data began in 2008 with samples taken from Monterey area vessels. Other than tracking landings, the Department did not collect fishery-dependent data from the 1988 to 1991 Hagfish fishery. Logbooks are not required for this fishery. The Department has received limited voluntary logbook data from a small number of fishermen.

The record of any fish taken (species and weight) under a commercial fishing license are submitted to the Department electronically via E-Tix. Other information submitted includes the date of fish purchase, fisherman information (name, license number), vessel name and number, species, weight, price, block location of catch and gear type. In many fisheries, landing records are the primary means of monitoring, and particularly for those fisheries like Hagfish that have no catch quota or closed seasons. When coupled with sample data and a comprehensive understanding of the dynamics of the fishery, landing records could be reasonable indicators of the status of the fishery. While not often used, condition and use of fish categories are available. Fish businesses making the purchase must provide the business name and license number. Both the fisherman and business receiving the fish must sign the document signifying that the information provided is true and correct. Upon submission to the Department, fish ticket information is available to staff within 24 hrs. If errors are suspected, staff will contact the fish business to verify the information on the fish ticket. The fish business must correct the mistake through their E-Tix account and resubmit to the Department.

In addition to landing totals, the Hagfish fishery is monitored opportunistically dockside by full-time staff or volunteers as schedules and office location allow. Not all ports of landing are sampled. Basic sampling protocol is as follows:

1. Using a 5-gallon (18.9 liter) bucket, a sample of fish is taken, preferably mixing the fish in the container while scooping because larger Hagfish typically force the smaller Hagfish to the surface. Water can drain, and slime or other debris is removed.

2. The bucket and fish are weighed.

3. Fish are counted into a separate container, allowing the sampler to continue to sample the tote.

4. The remaining slime and bucket are weighed, which becomes the tare weight for the bucket sample.

5. The CPP is calculated by dividing the counted number of Hagfish by the weight.

A lower CPP indicates a larger average size of Hagfish and vice versa. The export market prefers a minimum CPP of 3.60 to 4.00 (Tanaka and Crane 2014); in this size range, most Hagfish are mature. However, recent market sampling and discussions with Hagfish buyers indicate that the desired CPP is only a target.

Department staff may opportunistically take a sample of fish to process as a fresh laboratory sample as time permits. Freezing Hagfish for later processing is not practical and not useful for sample purposes. Sex and spawning status are difficult to determine in thawed Hagfish because often the gonads are in poor condition due to freezing. Lab samples are processed for individual fish length, weight, sex, and spawning status as described by Barss (1993) (Table 4-1). While spawn status is recorded for both sexes, female condition status is the most important.

Table 4-1. Female Hagfish spawning status criteria (Barss 1993).

Stage	Condition	Criteria
1	Immature	All round eggs
2	Maturing, but not mature	Some oblong eggs; >1 and <5.0 mm (0.04 to 0.2 in) in length; no empty ovarian capsules present
3	Mature, ova developing	Oblong eggs >5.0 mm (0.2 in) without hooks present
4	Mature, developed	Large eggs ≥20.0 mm (0.79 in) with hooks present
5	Mature, spent	Large, empty ovarian capsules present

Average CPP and laboratory data are used to document and track the status of the fishery. It is important to note that average CPP may depend upon fishery practices, such as short soaking traps or using excessive bait. Both would result in increased retention of smaller Hagfish. Shorter soak time does not allow enough time for smaller Hagfish to escape, especially if the bait is not exhausted. Using excessive bait promotes retention because the fish do not have a reason to try to escape. These fishing practices would result in an increase in CPP (smaller Hagfish). Department studies indicate that Hagfish 13.3 in (338.0 mm) or shorter are immature (Tanaka and Crane 2014). Hagfish of this length, depending upon weight, translate to a CPP greater than six. If the CPP suggests that fishermen are taking significant numbers of immature Hagfish or market demand changes to wanting smaller fish, additional management measures may be necessary. Some fishermen commented that fishing depth may influence how many small Hagfish are trapped. Nakamura (1991) found that the average length decreased from 15.7 in (398.0 mm) at 300 ft (91 m) to 12.2 in (310.0 mm) at 900 ft (274 m).

A summary of Department Hagfish sampling data since 2008 shows relatively high variability in average CPP, both among ports and within a port among years (Figure 4-1). An increasing trend indicates a decreasing average size of Hagfish, however there is no established threshold that could trigger management action. After the 0.56 in (14.0 mm) minimum hole diameter requirement went into effect in 2014, average CPP was generally lower in the Morro Bay and Eureka areas. However, the longest continuous database from Eureka shows no consistent trend over a 10 yr span. Fishermen in Eureka reported that they were using 0.56 in (14.0 mm) diameter holes prior to the regulation change.

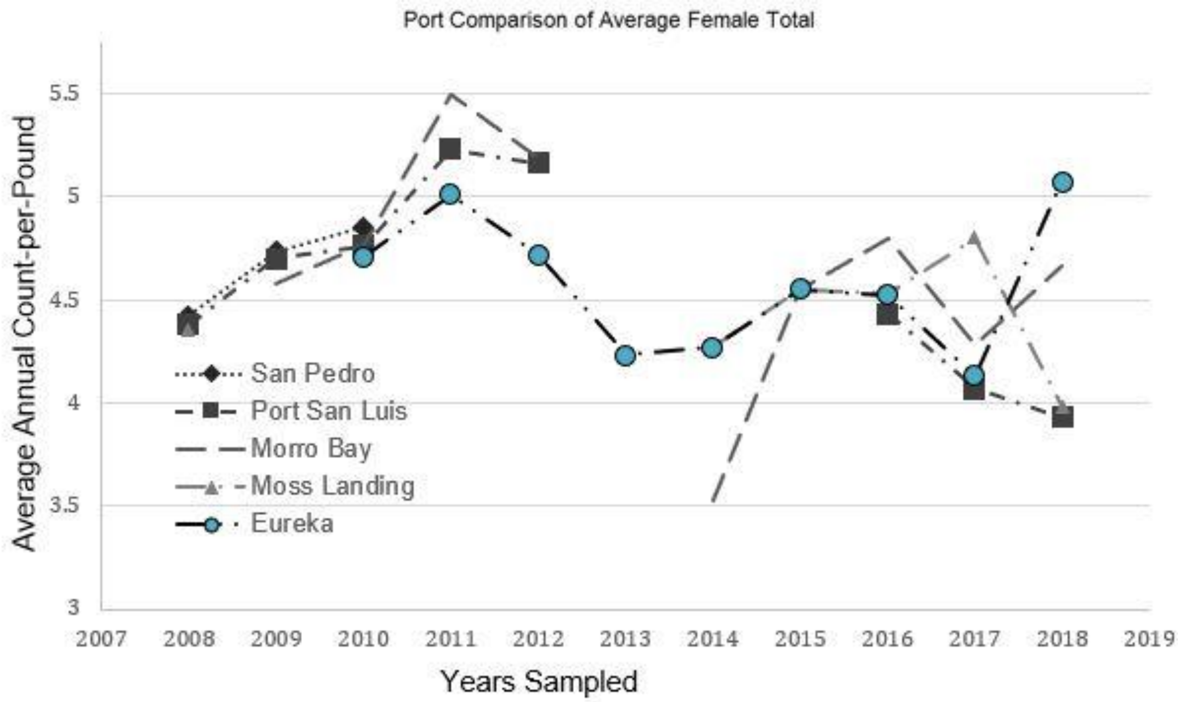

Figure 4-1. Average annual CPP by port area. In 2014, the requirement for a 0.56 in (14.0 mm) minimum hole diameter became effective (CDFW Hagfish Sample Data 2008-2018).

Like the CPP data, the annual average female Hagfish TL has varied both within and among ports. This is particularly true in San Pedro and Morro Bay, but with a slight increasing trend (Figure 4-2). Reasons for this change could be related to the mandatory hole diameter regulation and longer soak times on gear. Sampled average lengths in Eureka were consistent and then increased in 2016 and 2017 but decreased in 2018. Fishing practice in Eureka has not changed; the reason for the change in length is unknown.

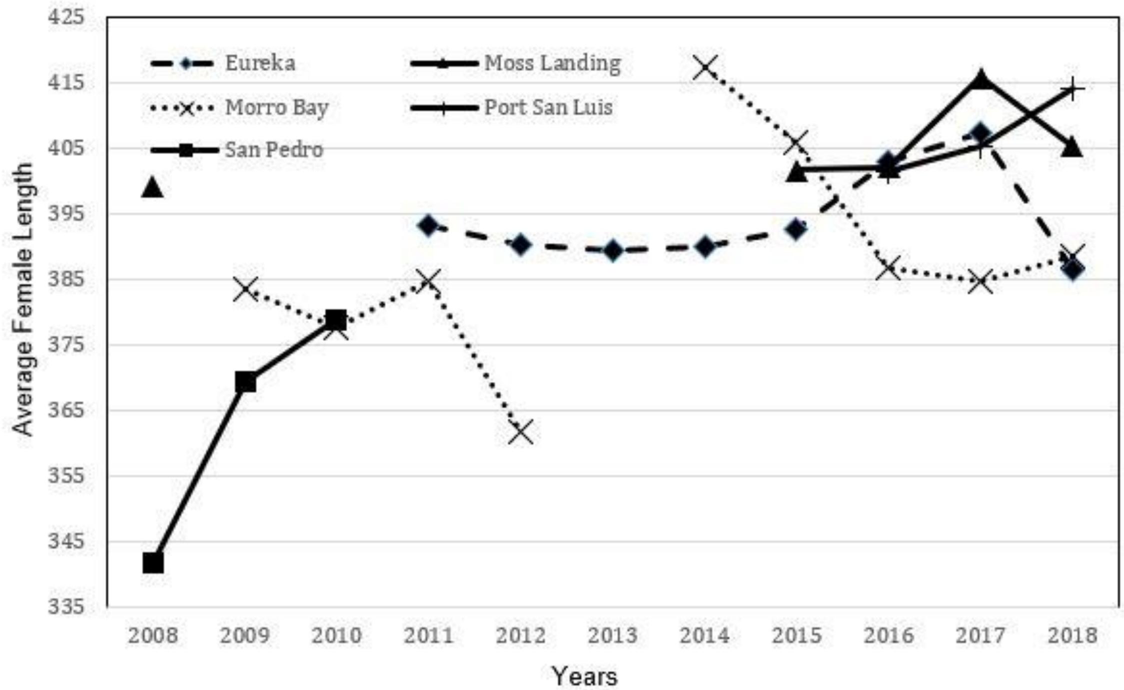

Figure 4-2. Average annual female Hagfish total length by port area based on Department sampling (CDFW Hagfish Sample Data 2008-2018).

4.2.2. Fishery-independent Data Collection

There is no on-going fishery-independent monitoring of this fishery, but fishery-independent studies have been conducted to answer specific research questions. In March 2013, Department staff conducted a fishery independent study to test the influence of trap hole diameter on the average size of retained Hagfish. As part of the survey design, fishermen were interviewed to determine what hole diameters, number of traps, preferred bait, and typical soak duration were used by the fleet. Staff tested four-hole diameters ranging from 0.38 to 0.63 in (10.0 to 16.0 mm). Bait type and amount were standardized. Retained fish were evaluated using the count per kg method (kg instead of lb) and a sample was retained for laboratory analysis to document length, weight, sex ratio, and spawning maturity per hole diameter. This study found that increasing hole diameter resulted in reduced catch with the benefit of decreased retention of immature females and retention of larger fish (Figure 4-3) (Tanaka and Crane 2014). Minimal bycatch was observed.

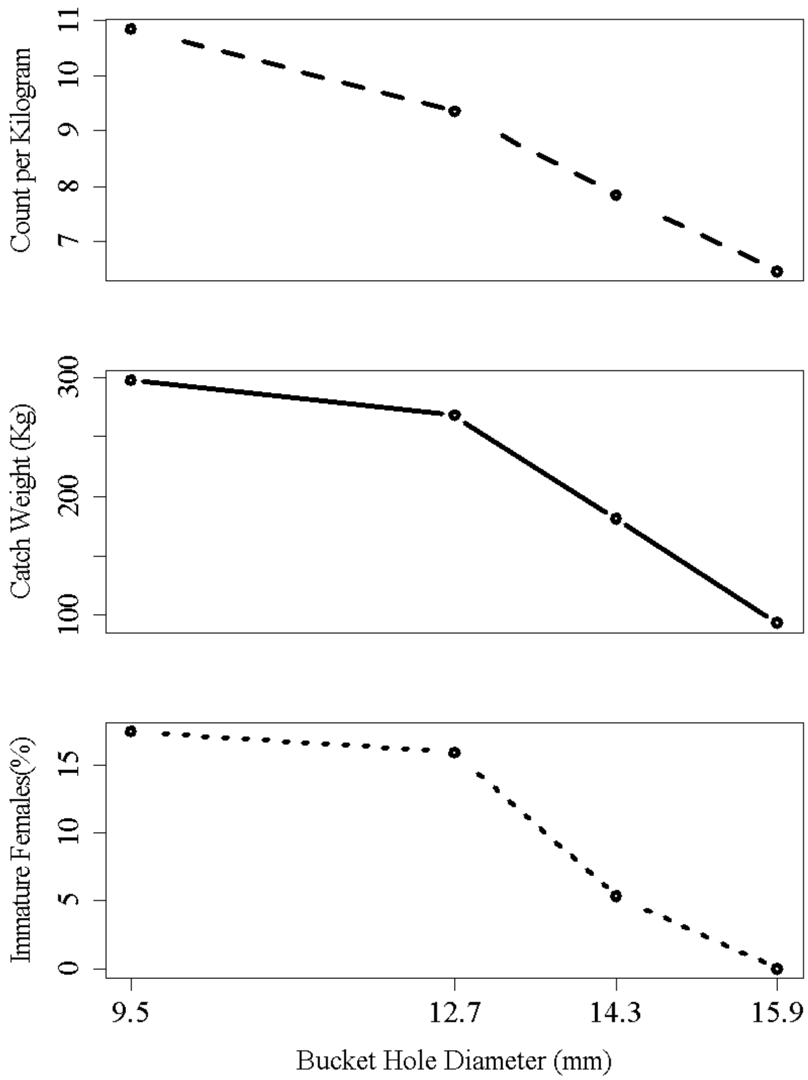

Figure 4-3. Results from a trap hole diameter study suggests holes 14.3 mm (0.56 in) in diameter are a compromise between retained catch and escape of immature female Hagfish (Reproduced from Tanaka and Crane 2014).

As a follow-up to this study, and to answer questions regarding the rate of dead loss in bucket traps, Department staff deployed and retrieved two strings of 20 traps after an overnight (>24 hr) soak. Traps were baited using quantities like those in the commercial fishery (Tanaka, unpublished Cruise Report). One live octopus and one live juvenile Sablefish were the only observed bycatch. A total of 2,781 Hagfish were released alive and 68 were dead. Most of the dead loss came from a single trap that was filled.

5. Future Management Needs and Directions

5.1. Identification of Information Gaps

Considered a data poor species, many Hagfish life history parameters have not been determined, age and growth, reproductive potential, movement and migration, and natural mortality (Table 5-1).

Table 5-1. Informational needs for Hagfish and their priority for management.

Type of information	Priority for management	How essential fishery information would support future management
Population age structure	High	Key component to recruitment estimate
Number of spawning waves and seasonal maturity	High	Used to determine temporal trends and changes in spawning patterns and sex ratio. Could be compared to effort periods in the fishery and potential impacts
Age and growth	High	Information is required to estimate recruitment, mortality, and year class distribution.
Stock distribution	Medium	Could be used to track distribution shifts due to environmental changes

These and others are discussed below.

5.2. Research and Monitoring

5.2.1. Potential Strategies to Fill Information Gaps

EFI is gathered by the Department from a variety of sources, including voluntary logbooks, fish tickets, onboard observations, dockside sampling, and laboratory work. The MLMA states that EFI is important and required for sustainable fisheries management. While the Department monitors the Hagfish fishery through landings and dockside sampling, many EFI are lacking, most notably the subjects discussed below (listed in order of priority). Some of these topics would be well suited to graduate students independently conducting research for their theses or dissertations. Others would be better suited for collaborative research with fishermen and the Department. Some EFI parameters have been previously studied, but further research is still needed.

5.2.1.1. Stock Distribution

It is unknown if the population (by sex and size class) is distributed by depth, has sub-populations, or is generally a mixed population across all strata. A standardized trap study stratified by habitat and depth in unfished areas could provide enough data to address the question of distribution on a broad scale.

5.2.1.2. Stock Composition

Stock composition collectively refers to the length frequency distribution, abundance, and sex ratio of a stock. Data about stock composition, especially by depth strata, would be important in the event of any management action needed due to an issue in the fishery. Length frequency is typically used to determine growth rate. However, length frequency from commercial catch will not reflect the length frequency of the unfished population due to the selectivity of the fishing gear, which is unlikely to retain small individuals. An extensive trap survey using trap gear with no escapement holes is required to sample the entire available size range of a population. The catch should be representative of the size frequency of the population above the size of 100% selectivity, and therefore still provides information on the composition of most of the stock.

Based on Department sampling data, the percentage of older, larger female Hagfish may be declining in the catch. In 2015, 12.4% of sampled females were 17.7 in (450.0 mm) (15+ yr) or longer. This percentage decreased in 2016. In 2017, samples had 3.9% of females 17.7 in (450.0 mm) or longer. 2018 sample data showed an increase in mature females (16.8%) which could indicate a fishery shift to new areas not previously fished or recovered from fishing activity.

5.2.1.3. Recruitment

Larval recruitment and relative abundance data could indicate future availability of the fishery. However, very little is known about Hagfish spawning and larval recruitment. The Department does limited monitoring of recruitment into the fishery by documenting the presence of immature Hagfish in the catch through dockside sampling. However, the market prefers larger Hagfish and gear restrictions are in place to reduce the take of immature fish.

Hagfish have a low fecundity rate and it is unknown how often a female will go through a spawn cycle. It is also unknown how the densities of Hagfish impact their ability to reproduce. A specialized trap survey, like protocols used by Nakamura (1991) could be used to collect data on immature Hagfish smaller than 13.3 in (338.0 mm). Nakamura’s survey captured immature fish, but not those that could be less than 1 yr old. Traps would need small diameter holes to retain Hagfish of all lengths. Sampling would occur across several isobaths to target multiple segments of the population should Hagfish segregate seasonally by sex or length. This trapping would have to occur several times a year in the same location to document changes in length composition, sex ratio, and spawning maturity.

5.2.1.4. Reproduction

More work is required to determine the periodicity of spawn cycles and maturation. By determining the seasonality of spawn, if any, could be used to correlate fishery closures to minimize take during the spawn season. Estimating sex ratio by season could also determine spawning periodicity. Nakamura (1991) suggested that a sex approaching 1 could indicate spawning activity.

Increased seasonal sampling and documenting the sex ratio could help identify seasonal shifts in spawning. The increased presence of spent females would indicate the end of the spawn cycle.

5.2.1.5. Indices of Abundance

A continuous time series of catch data for Hagfish is available, but a reliable measure of effort is needed to calculate a Catch Per Unit Effort (CPUE) based index of abundance with those data. Although logbooks containing effort information do exist for this fishery, they are currently voluntary, incomplete, and not representative of the activities of the fleet. In order to use CPUE as an index of abundance, it would be necessary to collect consistent logbook data that included appropriate measures of effort such as trap type, number of traps deployed, and total soak time. Fishermen using logbooks could report this information, thus the Department could make logbooks mandatory to capture this information.

5.2.1.6. Age and Growth

Nakamura (1994) conducted a Hagfish age and growth study utilizing fish marked and recaptured off San Luis Obispo County. Hagfish were also captured and held in an aquarium for comparison. Growth rates and age were estimated using positive growth (observed increase in length), negative growth (fish shrunk), and zero growth (no growth change). To better refine estimates, Nakamura (1994) suggested more work on Hagfish age and growth. Suggestions included work on population length-frequency distributions using a more sophisticated mathematical approach and exploring the possible use of statoliths to age Hagfish. Statoliths are hard, crystalline receptors in a sack-like structure and are used to maintain equilibrium. They are also found in gastropods and other invertebrates.

5.2.1.7. Target and Limit Development

Currently CPP is monitored, but there are no targets, limits, or other thresholds to help managers interpret CPP or link the CPP to the current health of the stock. If these reference points were developed it might be possible to use CPP to determine when management changes are necessary. A simulation model is currently in development which will provide insight into the relationship between observed CPP data obtained through sampling and the underlying Spawning Potential Ratio of the population. Results from the modeling effort should assist managers in defining target and limit reference values for CPP and will also provide a measure of uncertainty associated with using CPP data as a population metric.

5.2.1.8. Movement Patterns

Hagfish do not exhibit long-range migration patterns but are known to move small distances. Based on logbook data, fishermen will fish an area until the area becomes unproductive and then move to new grounds, ultimately returning to the original area after significant time has passed. Areas previously depleted due to fishing tend to repopulate over time if left unfished. Understanding movement patterns would help managers understand fishing impacts and the benefits of unfished areas, such as MPAs. Tagging studies, especially in MPAs with soft bottom habitat, would be helpful in determining the rate of movement or replenishment of a fished area.

5.2.1.9. Mortality

Determining natural mortality of Hagfish in the environment is problematic, mostly due to the scope of work required. One method of estimating natural mortality is doing a tag-recapture study. Nakamura (1991) tagged and recaptured Hagfish as part of a population/biomass survey. Nakamura found that internal wire tags were the only tags feasible for use with Hagfish.

Fishing Mortality (F) is an estimate of the rate at which fish are caught and removed from the system. The most common methods for estimating F are either to estimate the total mortality via a catch curve analysis, or to have an estimate of the population size as well as amount landed each year. There are no estimates for F for Hagfish. Typically, all Hagfish retained by Hagfish traps are landed, although it has been reported that fishermen are asked by buyers to cull small Hagfish at sea. The rate of at-sea culling, as well as the survival of discarded individuals, is unknown. If management were to assume that all Hagfish caught by the fishery were retained, F may be overestimated. To accurately estimate F, a fleet-wide inventory of fishermen that cull and the amounts released is required. This can be accomplished with the use of logbooks to document discards.

5.2.1.10. Ecological Interactions

Hagfish serve as nutrient recyclers and facilitate substrate turnover through burrowing. However, in California more attention traditionally has been given to other habitat types that are closer to shore or have significant structure. Research and monitoring of deep mud habitat and associated species are desirable.

5.2.1.11. Habitat Coverage

An accurate estimate of area composed of soft mud bottom, both inside and outside MPAs, would be useful to extrapolate estimated density to total abundance. The Department has mapping data for soft bottom habitat within the State's three-mile jurisdiction, but the resolution does not exist to distinguish mud and sand habitats. There is also a significant area outside of three miles within the depth-range of Black and Pacific Hagfish that has not been mapped, although much of it is likely soft bottom.

5.2.2. Opportunities for Collaborative Fisheries Research

The Department has collaborated in the past and will continue to work with outside entities such as academic organizations, non-governmental organizations, citizen scientists, and both commercial and recreational fishery participants to help fill information gaps related to the management of state fisheries. The Department will also reach out to outside persons and agencies when appropriate while conducting or seeking new fisheries research required for the management of each fishery.

Specifically, the Department has collaborated with fishermen and fishery-independent vessel contractors to obtain some valuable data sets used for management of the Hagfish fishery. These include the following: analysis of trap hole diameter in relation to Hagfish CPUE and sexual maturity of retained Hagfish; relative abundance of Hagfish in unfished areas; CPUE and bycatch using experimental barrel traps. The Department has also received limited voluntary logbook data from a small number of fishermen. Among the topics discussed in Section 5.2.1, stock distribution, indices of abundance, movement patterns, recruitment, and stock composition work would be particularly amenable to collaborative surveys with fishermen and independent contractors.

5.3. Opportunities for Future Management Changes

This section is intended to provide information on changes to the management of the fishery that may be appropriate but does not represent a formal commitment by the Department to address those recommendations. ESRs are one of several tools designed to assist the Department in prioritizing efforts and the need for management changes in each fishery will be assessed considering the current management system, risk posed to the stock and ecosystem, needs of other fisheries, existing and emerging priorities, as well as the availability of capacity and resources.

The Department's monitoring indicates that no management changes or action is required at this time. However, if the standard CPP metric used by the Department suggests that fishermen are taking significant numbers of immature Hagfish meaning that the average CPP shows the catch is primarily immature Hagfish, increased sampling and investigation would be required to verify that the catch reflects what is available in the population before considering management intervention.

To document information such as catch per set, catch location, soak duration, and environmental factors such as current speed, logbooks would become necessary

5.4. Climate Readiness

It is unknown whether cartilaginous, deep water species would experience enough temperature increase or change of pH at depth to alter behavior or survival. Hagfish prefer deep soft bottom habitat due to stability of temperature and salinity. Even with an increase in SST, temperature change at depth may not increase enough to force migration (Norton 1994). pH is a function of depth and CO_2 in that pH decreases with depth due to increase in CO_2 produced by decay. At 500 to 1,000 m (1,640 to 3,280 ft), well within the depth range for Hagfish, pH is at its lowest (National Research Council 2010). The effect on Hagfish is unknown since acidification has the greatest impact on calcifying organisms. However, decrease in pH may negatively affect the invertebrates that Hagfish may feed.

Hagfish processors and fishermen may also experience negative impacts from climate change, which may necessitate some adaptation or innovation on their part. Since Hagfish are kept alive in tanks prior to sale, the processors need to circulate seawater that is typically pumped directly from the surface. During exceptionally warm water periods, Hagfish mortality is increased at port while they await shipment. Hagfish also experience high levels of mortality during dockside storage during low salinity that result from high levels of rainfall in nearshore environments. The industry may incur greater operating costs by circulating seawater through a chiller to reduce stress on stored Hagfish. Some operations may seasonally close during warming events.

There is a possibility that fishing pressure for Hagfish could increase in the future as a result of displaced effort from other fisheries which are more vulnerable to the impacts of climate change. For example, poor ocean conditions resulted in a closure of the commercial ocean salmon season in both 2008 and 2009, which resulted in increased participation in the Hagfish fishery. This increase in participation was short lived, and once salmon reopened the fishermen left the Hagfish fishery. Long-term participation increases may not be possible due to the infrastructure requirements to store and ship Hagfish.

Literature Cited

California Department of Fish and Wildlife (CDFW) 2015. Initial statement of reasons for regulatory action: amend section 180.6 Title 14, California Code of Regulations. Re: Allow Hagfish take in 40-gallon barrel traps. State of California Fish and Game Commission. 10 p.

California Department of Fish and Wildlife (CDFW) 2018. Commercial fishing license update. January 2018. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=42095&inline

Barss WH. 1993. Pacific Hagfish, *Eptatretus stoutii*, and Black Hagfish, *E. deani*: the Oregon fishery and port sampling observation, 1988-92. Marine Fisheries Review 55(4):19-30.

Cailliet GM, McNulty M, Lewis L. 1991. Habitat analysis of Pacific Hagfish (*Eptatretus stoutii*) in Monterey Bay, using the ROV Ventana. Western Groundfish Conference. Union, WA. P. Abstract.

Fleury A. 2016. Reproductive biology and ecology of Pacific Hagfish (*Eptatretus stoutii*) and Black Hagfish (*Eptatretus deani*) off the coast of Vancouver Island, BC. British Columbia: University of Victoria. 47 p.

Gorbman C. 1990. Sex differentiation in the Hagfish *Eptatretus stouti*. Gen. Comp. Endocrinol. 77(2):309-323.

Gorbman A, Dickhoff WW. 1978. Endocrine control of reproduction in Hagfish. Pages 49-54 *in* P.J. Gaillard and H.H. Boer, editors. Comparative endocrinology. Elsevier/ North Holland Biomedical Press, Amsterdam, The Netherlands.

Hanson LC. 1993. The foraging ecology of Harbor Seals, *Phoca vitulina,* and California Sea Lions, Zalophus *californianus*, at the mouth of the Russian River, California. Calistoga: Sonoma State University. 80 p.

Hart TD, Clemons JER, Wakefield WW, Heppell SS. 2010. Day and night abundance, distribution, and activity patterns of demersal fishes on Heceta Bank, Oregon. Fishery Bulletin. 108: 466-477.

Hastey JP. 2011. Effects of acute salinity and temperature change on Pacific Hagfish, *Eptatretus stoutii*; implications for bycatch post release survival. Vancouver: University of British Columbia. 56 p.

Hoenig JM. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin. 82: 898-903.

Johnson EW. 1994. Aspects of the biology of the Pacific (*Eptatretus stoutii*) and black (*Eptatretus deani*) hagfishes from Monterey Bay, California [M.S. Thesis]. Fresno CA: California State University. 130 p.

Kato S. 1990. Report on the biology of Pacific hagfish, *Eptatretus stouti*, and the development of its fishery in California. Report, National Oceanic and Atmospheric Administration, National Marine Fisheries Service-Southwest Region. 39 p. Available from: National Marine Fisheries Service, Tiburon, CA.

Lisa Wise Consulting, Inc. 2015. Morro bay commercial fisheries: 2015 economic impact report working waterfront edition. San Luis Obispo, CA: Morro Bay Commercial Fishermen's Organization. 23 p.

Love M. 1996. Probably more than you want to know about the fishes of the Pacific coast. Santa Barbara, CA: Really Big Press. 381 p.

Martini FH. 1998. The ecology of hagfishes. Pages 57-77 *in* Jorgensen JM, Lomholt RE, Weber and Malte H. editors. The biology of hagfishes. Springer-Science, London, United Kingdom.

Melvin EF, Osborn SA.1992. Development of the west coast fishery for Pacific Hagfish –Final Report to the Saltonstall-Kennedy Program, National Marine Fisheries Service. WSG-AS 92-02, Washington Sea Grant Program.

Miller DJ, Lea RN. 1972. Guide to coastal marine fishes of California. California Department of Fish and Game. Fisheries Bulletin 157.

Nakamura R. 1991. A survey of the Pacific Hagfish resource off the central California coast. Secretary of Environmental Affairs, Office of Environmental Protection, Marine Fisheries Impacts Programs. Final Report. 63 p.

Nakamura R. 1994. Growth and age of Pacific Hagfish *Eptatretus stoutii* off the central California coast. National Oceanic and Atmospheric Administration, National Marine Fisheries Service- Saltonstall-Kennedy Research Grant NA27FD0169-01. Final Report. 67 p.

National Oceanic and Atmospheric Administration (NOAA) Fisheries. 2016 List of Fisheries. April 8, 2016. Accessed 15 November 2017. http://www.nmfs.noaa.gov/pr/interactions/fisheries/2016_list_of_fisheries_lof.html.

National Research Council 2010. Ocean Acidification: A National Strategy to Meet the Challenges of a Changing Ocean. Washington, DC: The National Academies Press. https://doi.org/10.17226/12904.

Norton JG, McLain DR. 1994. Diagnostic patterns of seasonal and interannual temperature variation off the west coast of the United States: Local and remote large-scale atmospheric forcing. Journal of Geophysical Research 99:C8: 16,019-16,030.

Reid R. 1990. Research on the fishery and biology of the Hagfish. California Environmental Protection Agency. 33 p.

Tanaka TH. 2015. Final report: Evaluation of the use of 40-gallon barrel traps for the take of Hagfish. Used as reference for 2015 Hagfish regulatory process to amend Title 14, sec 180.6. Unpublished. 10 p.

Tanaka TH, Crane K. 2014. Influence of bucket trap hole diameter on retention of immature Hagfish. California Department of Fish and Game. 100(2): 310-318.

Wakefield WW. 1990 Patterns in the distribution of demersal fishes on the upper-continental slope off central California, with studies on the role of ontogentic vertical migration on particle flux. Doctoral dissertation, Scripps Institute of Oceanography, San Diego, CA.

Worthington J. 1905. Contribution to our knowledge of the Myxinoids. Am. Nat. 39(465): 625-663.