Fishery-at-a-Glance: Pacific Geoduck

Scientific Name: *Panopea generosa*

Range: Pacific Geoduck range from southern Alaska to northern Mexico.

Habitat: Geoducks reside in soft bottom habitats where they can burrow to a depth of 1.0 meter (3.4 feet) into the sediment. They are found in sediment beds ranging from shallow intertidal mud flats to subtidal depths of more than 110 meters (361 feet).

Size (length and weight): Geoducks can reach shell lengths of more than 9.0 inches (22.9 centimeters), with a total body length (from foot to extended siphon) of 59.0 inches (149.9 centimeters), and a weight of more than 10.0 pounds (4.5 kilograms).

Life span: Geoducks can reach 160 years of age.

Reproduction: Geoducks reach sexual maturity between 2 and 5 years of age. During the late spring and early summer Geoducks release their gametes into the water column where fertilization takes place. Females can produce up to 20 million eggs per spawning, and may spawn multiple times in one year.

Prey: Larval Geoduck eat phytoplankton while juveniles and adults filter-feed on plankton and detritus.

Predators: Predators of Geoducks (especially juvenile Geoducks) include crabs, moon snails, sea stars, and flat fishes. The siphon tips of adults are eaten by Cabezon, Spiny Dogfish, and Starry Flounder. Geoducks may also provide a food source for Sea Otters.

Fishery: Pacific Geoduck is targeted by recreational clammers. There is currently no commercial fishery for Geoduck in California.

Area fished: Geoduck are commonly targeted in areas containing shallow mudflats accessible at low tides, including Morro Bay, Bodega Bay, Tomales Bay, and Humboldt Bay. Geoduck may also be targeted in other areas, but the exact locations are unknown.

Fishing season: Geoducks are targeted year-round. However, they are usually only accessible at the lowest tides when mudflat areas are exposed.

Fishing gear: Geoducks must be dug by hand. Fishers may use spades, shovels, hoes, rakes, clam forks or other appliances operated by hand, except spears or gaff hooks, to take Geoduck clams. A PVC pipe or other material is typically used to stabilize holes when digging for Geoducks. Mechanical or electric gear to assist in digging is prohibited.

Market(s): There is currently no commercial fishery for Geoducks in California. However, Pacific Geoducks support lucrative commercial fisheries in Mexico, Washington and British Columbia, and may fetch between $7-26 per pound.

Current stock status: The current population status of Pacific Geoducks in California is unknown. Geoducks are long lived, slow growing animals which makes them vulnerable to overfishing. There is limited evidence suggesting that densities of Geoducks may have declined at a few popular clamming sites. However, given the difficulties in accessing subtidal Geoducks under the current recreational clamming regulations, it is assumed that the majority of California's population is at a healthy level.

Management: The fishery is managed under a bag limit allowing three clams per person per day to prevent unlimited harvest. It is also subject to the general restrictions that apply to all recreational clammers, including restrictions on the use of mechanical gear and clamming at night.

1 The Species

1.1 Natural History

1.1.1 Species Description

The Pacific Geoduck (*Panopea generosa)* is the largest and deepest burrowing species of clam. While it is only fished as a recreational species in California, the Pacific Geoduck supports large, high value commercial fisheries elsewhere along the West Coast, including Washington, British Columbia and Mexico.

The Geoduck is a bivalve, and thus has two external shell halves connected by a hinged plate. Both the outside and inside of its shell are white. The outside of the shell is rough and banded, while the inside is smooth. The shell is rounded towards the bottom, but flatter at the neck end and gaping at all sides due to a large body and neck. The shells can reach up to 9.0 inches (in) (22.9 centimeters (cm)) in length, with the animals weighing over 10.0 pounds (lb) (4.5 kilograms (kg)). The defining feature of the Geoduck clam is its siphon, the long neck-like appendage that connects the buried clam to the substrate surface. Siphons can reach up to 1.0 meter (m) (3.4 feet (ft)) in length. The holes at the tip of the siphon (known as the valve) are the only portion of the clam visible from above the substrate (Figure 1-1). In scientific literature prior to 2010, *Panopea generosa* was at times confused with *Panopea abrupta*, which is extinct (Vadopalas et al. 2010).

Figure 1-1. Pacific Geoduck on the deck of a boat, showing shell and neck-like siphon (left), and the exposed valve of a buried Geoduck in its natural habitat (right) (Photo Credit: Derek Stein, CDFW).

1.1.2 Range, Distribution, and Movement

The range of Geoduck extends from Forrester's Island in southern Alaska to Scammon's Lagoon in Baja California, Mexico (Figure 1-2) (Aragón-Noriega et al. 2012). Geoducks reside in soft bottom habitats where they can burrow up to a vertical depth of 1.0 m (3.4 ft) into the sediment. They are found in sediment beds ranging from shallow intertidal mud flats to subtidal depths of more than 110 m (361 ft) (Jamison et al. 1984), with higher densities found at deeper depths (Bradbury et al. 2000).

Figure 1-2. Range of the Pacific Geoduck, which extends from southern Alaska to northern Mexico.

In California, Geoducks occur in bays and tidal mudflats, as well as in deeper soft-bottom habitats. The exact distribution of Geoducks in California is unknown because most of the population inhabits subtidal waters, making surveys difficult. They are known to occur in Bodega Bay, Tomales Bay, Drakes Estero, Bolinas Lagoon, Humboldt Bay, and Morro Bay (Moore 2001). Some have also been observed in southern California (Navas 2015).

Geoducks are mobile as juveniles, but sedentary as adults. The larvae have a planktonic phase that lasts for approximately 6 weeks (Goodwin and Pease 1989). After that time, they metamorphose into juveniles and settle to the bottom. Juveniles are somewhat mobile, but once they have attained 1.5 to 2.0 millimeter (mm) (0.06 to 0.08 in) shell length they burrow into the sediment where they spend the rest of their lives. Adults are sedentary with limited (or no) mobility because they lack the muscular foot appendage and are unable to re-bury themselves if removed from the sediment.

1.1.3 Reproduction, Fecundity, and Spawning Season

Geoducks reach sexual maturity between 2 and 5 years (yr) old (Feldman et al. 2004). They can produce up to 20 million eggs per spawning, and may spawn multiple times in one year (Feldman et al. 2004). Spawning is seasonal, with a peak in the late spring and early summer (Goodwin 1976; Turner and Cox 1981). Females may exhibit a shorter spawning period than males (Sloan and Robinson 1984). Geoducks are broadcast spawners and release gametes into the water column where fertilization takes place. It is unknown whether the fertilization of Geoducks is density dependent. Geoduck larvae live in the water column for up to 47 days at water temperatures up to 14 degree Celsius (ºC) (57.2 degree Fahrenheit (ºF)) (Goodwin et al. 1979) prior to settling onto a suitable substrate.

Some evidence suggests Geoducks may switch sexes, though this has not been rigorously studied (Anderson 1971). Campbell and Ming (2003) observed one individual in British Columbia that exhibited hermaphroditism. Calderon-Aguilera et al. (2014) noted that in Baja California males outnumbered females in younger age groups of Geoducks, but females outnumbered males by more than two to one in older age classes. They hypothesized this could be the result of protandry, a life history strategy where individuals are born male but switch to female as they age, as has been suggested to occur in other species of Geoducks (Gribben and Creese 2003; Zaidman et al. 2012). A study by Vadopalas et al. (2015) also confirmed this bias towards males in Geoducks ages 2 to 5 yr, as well as low levels of hermaphroditism.

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.

Geoduck adults have extremely low rates of natural mortality, with an estimated maximum age in excess of 160 yr old (Bureau et al. 2002). Geoducks experience high mortality rates due to predation in the first year of life, but mortality declines as they grow and attain greater burial depths (Feldman et al. 2004). The survival of Geoducks to adulthood appears to be spatially and temporally patchy. By 2 yr of age most Geoducks have a relatively low risk of predation, although mortality can occur when adults are prevented from burying themselves due to compacted sediment.

Currently, estimates of natural mortality for Geoduck populations in California are not available. Estimated instantaneous natural mortality rates of Baja California Geoducks ranged between 0.027 and 0.046 (Calderon-Aguilera et al. 2010). In both Washington State and British Columbia, estimates ranged between 0.016 and 0.036 (Sloan and Robinson 1984; Zhang and Campbell 2004). These values are consistent with very long-lived organisms.

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.

Geoduck growth is rapid for the first 10 yr of life and then slows until they reach their maximum size at 20 to 25 yr of age. Geoducks can reach an average weight of 1.9 lb (0.9 kg) in 5 yr. Shells can reach lengths of 9.0 in (22.9 cm) or more, with a total body length (from foot to extended siphon) of 59.0 in (149.9 cm), and a weight of more than 10.0 lb (4.5 kg).

Ages can be estimated from Geoduck shells, making it possible to model length at age. Navas (2015) fit von Bertalanffy length-at-age curves to clams collected from various sites in California and compared them to the growth rates observed in Washington and Baja, and concluded that clams reach larger sizes at locations that are cooler and more productive, providing some evidence for a latitudinal trend in growth (Navas 2015; Wood et al. 2018). Maximum size was positively correlated with chlorophyll *a* and negatively correlated with sea surface temperature, indicating that Geoduck may grow larger in more productive areas (Wood et al. 2018). Others have noted that Geoducks exhibit geographical variation in growth and other demographic parameters (Goodwin and Pease 1991; Bureau et al. 2003; Hidalgo-De-La-Toba et al. 2015), indicating that growth may be influenced by local environmental factors. Table 1-1 shows the von Bertalanffy growth parameters estimated for a number of locations.

Table 1-1. von Bertalanffy growth parameter estimates for Pacific Geoduck from different locations.

Location	**Maximum average length (mm)**	**Growth co-efficient k**	**Reference**
Baja California, Mexico	134	0.191	Calderon-Aguilera et al. 2010
Southern California	138	0.22	Navas 2015
Morro Bay, California	122	0.15	Navas 2015
Bodega Bay, California	137.3	0.25	Navas 2015
Dungeness West, Washington	141.9	0.2	Navas 2015
Washington State	120-168	0.113–0.235	Hoffman et al. 2000
Yellow Bank, British Columbia	147.7	0.189	Campbell and Ming 2003
Gabriola Island, British Columbia	129.6	0.146	Campbell and Ming 2003

Navas (2015) also estimated the relationship between valve length and weight. This relationship is useful because the valve is the only portion of the animal that can be observed while the Geoduck is still buried in the sediment. This study found valve length to be a significant predictor of weight across all sampling locations.

Reported average valve lengths of Pacific Geoducks range from 114 to 139 mm (4.5 to 5.5 in) (Goodwin and Pease 1991; Rocha-Olivares et al. 2010; Hidalgo-De-La-Toba et al. 2015), with the largest lengths observed in British Columbia (Bureau et al. 2002). Average weights range from 512.0 to 1,510.0 grams (g) (1.1 to 3.3 lb), with the heaviest clams found in British Columbia (Goodwin and Pease 1987; Bureau et al. 2002; Rocha-Olivares et al. 2010; Hidalgo-De-La-Toba et al. 2015). Average valve lengths and weights in California fell within these ranges, but showed substantial variability between locations (Navas 2015).

1.1.6 Size and Age at Maturity

Geoducks reach sexual maturity between 2 and 5 yr of age (Feldman et al. 2004). While no maturity studies have been conducted in California, a study from Puget Sound found Geoducks began to mature at age 2 (Vadopalas et al. 2015). Table 1-2 shows the estimated size and age at 50% maturity. Females matured later than males and at a larger size. The majority of 2-yr-old females remained immature, whereas immature 2-yr-old males were in the minority (75% and 33%, respectively). All Geoducks were mature by age 5. Geoducks have been found to be reproductive at ages greater than 100 yr (Calderon-Aguilera et al. 2010).

Table 1-2. Age and shell length at 50% maturity for Pacific Geoduck (Reproduced from Vadopalas et al. 2015).

Category	Age (months)	Length (mm)
All	23.9	63.5
Male	22.5	58.1
Female	28.8	79.8

Size/age at first maturity, like growth, likely varies by location based on environmental conditions. In the Hood Canal in Washington, Andersen (1971) found that Geoduck clams were 50% mature at shell length of 75.0 mm (2.95 in) and 3 yr of age. Whereas Campbell and Ming (2003) reported 50% maturity in Geoducks at 58.0 mm (2.28 in) and 61.0 mm (2.40 in) at two different sites in British Columbia.

1.2 Population Status and Dynamics

The population status of Pacific Geoduck in California is currently unknown. Despite the high fecundity of Geoduck, juvenile recruitment is low and potentially episodic over very long (multi-decade) time periods (Goodwin and Shaul 1984; Orenzanz et al. 2004). However, due to the species' longevity the biomass of the population is not expected to vary significantly from year to year. Given their long lifespan, concentrated spatial distribution, and relatively low and/or sporadic recruitment levels, Geoduck populations can be vulnerable to overfishing and slow to recover. Even under seemingly sustainable harvest rates, declines in recruitment due to natural fluctuations could result in overfishing despite proactive management (Orenzanz et al. 2004). For this reason, a precautionary management approach should be used to manage Geoduck.

1.2.1 Abundance Estimates

Geoduck densities vary widely across spatial scales. They are usually distributed contiguously throughout a bed, with occasional dense aggregations or clusters (Feldman et al. 2004). Despite this clustering, Geoduck population sizes are often estimated by assuming a uniform distribution across a given bed and multiplying the average observed density by the area of the bed (Bradbury et al. 2000).

No formal surveys have been conducted in California to measure Geoduck abundance. However, Department staff have conducted informal surveys in an attempt to better understand the distribution of Geoduck beds in California. In the most densely populated beds observed in southern California, which are presumed to be unfished or lightly fished, Geoduck densities were estimated to be about 1 per meter squared (m^2). However, there were many other areas observed in southern California with very low and patchy densities of clams (Derek Stein personal communication).

Geoduck beds in Bolinas Lagoon and Morro Bay have supported a sport fishery for many years; however, Geoduck and other clam species have declined significantly in abundance in these locations over the past decade due to sport fishing (Moore 2001). The take of marine invertebrates, including Geoduck, is now prohibited in Morro Bay since the establishment of the Morro Bay State Marine Recreational Management Area (SMRMA) and Morro Bay State Marine Reserve (SMR).

1.2.2 Age Structure of the Population

Geoduck clams can be aged by counting growth bands in cross-sections of the shell hinge plate (Calderon-Aguilera et al. 2010; Wood et al. 2018). The method has been shown to be effective for estimating the age of many bivalves, and has been validated for Geoduck by known-age cohort tracking (Shaul and Goodwin 1982; Gribben and Creese 2005) and more recently, cross-dating methods (Black et al. 2008).

To date, the oldest Geoduck ever observed was 168 yr old (Bureau et al. 2002). Geoduck exhibit geographical variation in growth and maximum life span, and it has been posited that Geoduck live longer in northern climes (Hidalgo-De-La-Toba et al. 2015). Navas et al. (2018) aged Geoducks sampled from California. The age structures measured at five sites around California were compared with a reference site in Washington (Figure 1-3). The oldest Geoduck sampled in California was 76 yr old, compared to a maximum age of 104 sampled from Washington. The Santa Cruz Island and Catalina sites were assumed to be unfished, so it is possible that Geoduck do not live as long in this region. For comparison, a maximum age of 96 was observed in Baja California, Mexico (Calderon-Aguilera et al. 2010).

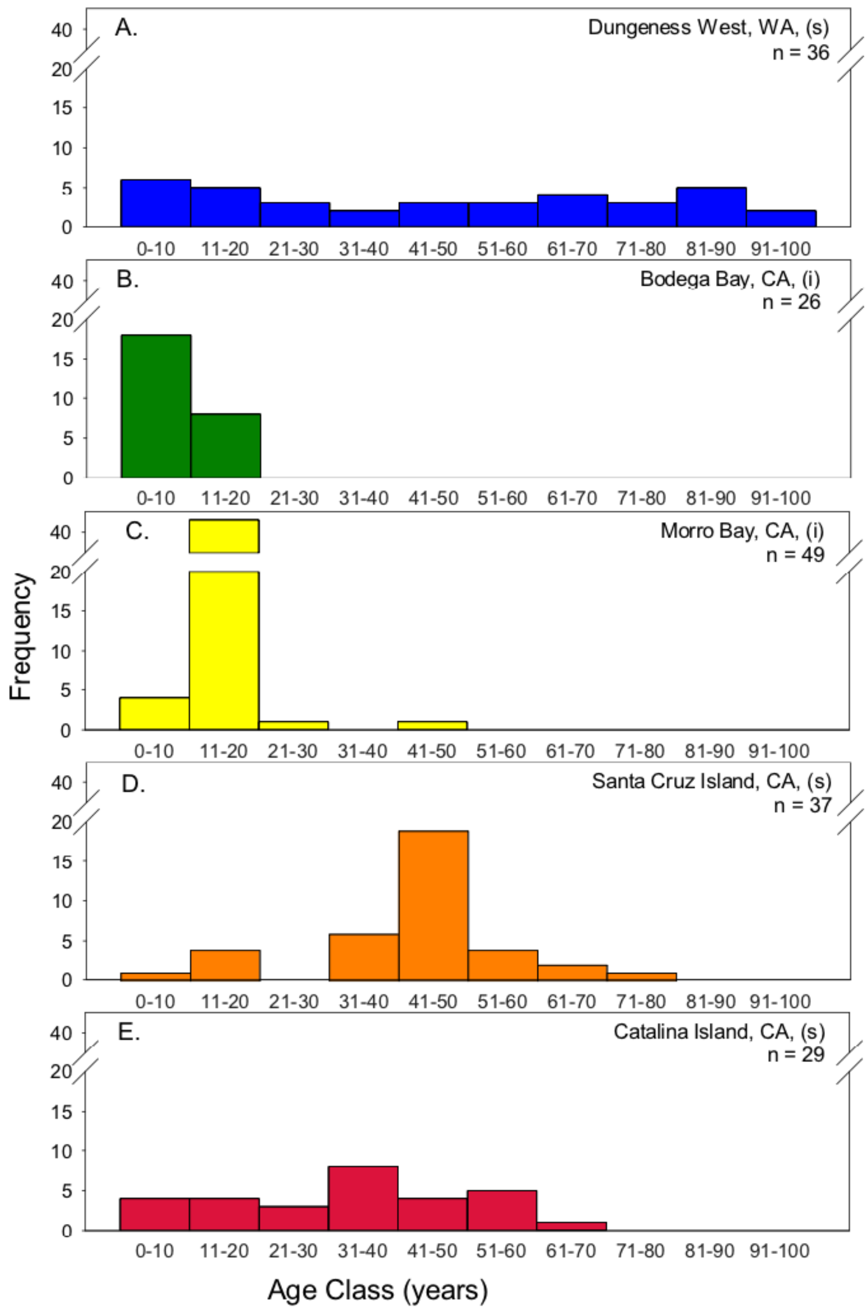

Figure 1-3. Age compositions of Pacific Geoduck populations at four sites in California and one reference site in Washington (Reproduced from Navas 2015).

The age distribution of a population can provide an indicator with which to assess fishing pressure, and Navas (2015) demonstrated that the mean longevity of Geoducks in Bodega Bay was far less (15±1 yr) than unfished areas of southern California (57±4 yr and 57±6 yr), which have likely experienced little to no fishing. The clams sampled from intertidal sites in California exhibited a dramatic reduction in older age classes relative to the subtidal sites. This is likely due to increased mortality from fishing at the intertidal sites, which are more accessible to recreational fishers. In Bodega Bay, a popular area for Geoduck fishing, the oldest individual sampled was only 20 yr old (Figure 1-3). This pattern suggests a potential depth refuge for the clams at the subtidal sites, where they experience higher survivorship compared to the shallower intertidal areas (Navas 2015, Wood et al. 2018).

1.3 Habitat

Geoducks reside in soft bottom substrates of mud, sand, and pea gravel at depths ranging from the intertidal to more than 100 m deep (Figure 1-4). A 2015 study suggests that Geoducks may prefer sand to mud due to ease of burrowing as juveniles (Tapia-Morales et al. 2015).

Figure 1-4. Siphon of a Geoduck buried in fine grain sediment (Photo Credit: Derek Stein, CDFW).

1.4 Ecosystem Role

Little is known about the role of Geoducks in the ecosystem. They may influence surrounding habitat by altering the grain size and stability of the sediment, or through the deposition of fecal matter (Feldman et al. 2004). Clams in general are thought to be ecosystem engineers in soft sediments, meaning they play an important role in the creation, modification, or maintenance of habitat, or otherwise mediate the flow of resources to other species (Peterson 1984). However, the Department is not aware of any directed studies regarding the ecosystem-engineering role of Geoducks.

As filter feeders, Geoduck remove suspended particles from the water column as they feed. It is thought that the removal of filter feeders from an ecosystem can result in increased turbidity and decreased nutrient cycling.

1.4.1 Associated Species

Soft-bottom marine habitats are home to a number of benthic invertebrates such as worms, clams, and crustaceans. In addition, anemones, isopods, copepods, echinoderms, and mollusks may live on the seafloor. The associations between Geoducks and other organisms have not been extensively studied, but Goodwin and Pease (1987) suggest Geoduck settlement might be induced by the presence of polychaete tube worms. Geoducks have been observed in commensal relationships with flatworms and small Pea Crabs (*Pinnotheres pisum*) (Bower and Blackbourn 2003). Department biologists have noted Geoduck are often taken by recreational fishers targeting gaper clams, a large clam that lives in similar habitats (Moore 2001).

As filter feeders, Geoduck clams may accumulate undesirable microorganisms or chemicals into their tissues. In particular, high levels of Paralytic Shellfish Poisoning (PSP) have been found in Geoducks in southeast Alaska, most strongly associated with the viscera. The mantle and siphon are the body parts typically consumed and PSP concentrations are lower in these parts. Geoducks in California are thought to present a low risk of PSP to humans.

1.4.2 Predator-prey Interactions

Larval Geoduck eat phytoplankton while juveniles and adults filter-feed on plankton and detritus.

Predators of Geoducks include epibenthic animals such as crabs, moon snails, sea stars, and flat fishes (Feldman et al. 2004). Juveniles and adults are eaten by Pink Seastars (*Pisaster brevispinus*) and Sunflower Sea Stars (*Pycnopodia helianthoides*) (Mauzey et al. 1968; Sloan and Robinson 1983). Both of these species are more common in subtidal areas than in the intertidal. Various crab species also feed on Geoduck, including Red Rock Crab (*Cancer productus*), Graceful Crab (*Cancer gracilis*), and Dungeness Crab (*Cancer magister*) (Jensen 1995), all of which have been observed in the intertidal at both Bodega Bay and Morro Bay (Navas 2015). Siphon tips are eaten by Bat Rays (*Myliobatis californica),* Cabezon (*Scorpaenichthys marmoratus*), Spiny Dogfish (*Squalus acanthias*), and Starry Flounder (*Platichthys stellatus*) (Andersen 1971).

Geoducks may also provide a food source for Sea Otters (*Enhydra lutris*), which are known to prey on a diverse array of marine invertebrates. Reports from subtidal sites in southeast Alaska and Monterey, California confirm that otters prey on deep-burrowing clams and are able to excavate them as deep as 0.5 m (19.7 in) in the sediment (Hines and Loughlin 1980; Kvitek et al. 1993). Anecdotal reports suggest Sea Otters have reduced Geoduck densities along the west coast of Vancouver Island in British Columbia where Sea Otters have been reintroduced and are expanding in range (Hand and Marcus 2004). Infaunal clams were shown to be the primary prey source of otters in southeast Alaska, but Geoducks were often buried too deep to be captured (Kvitek et al. 1993). Navas (2015) hypothesized that the resident Sea Otter population in Morro Bay could contribute to the lack of older clams observed at that site. More research is needed to understand how otters interact with Geoduck populations in

California, but it is thought that they will be impacted by the expansion of the Southern Sea Otter over its historic range.

1.5 Effects of Changing Oceanic Conditions

There has been very little research conducted on the impacts of changing oceanic conditions on Geoducks. A multi-decade decline in recruitment was observed in British Columbia prior to the 1970s, and a subsequent rebound in the following decades (Orensanz et al. 2004; Valero et al. 2004). This decline began prior to commercial fishing and was correlated to decreases in sea surface temperature and other regional level environmental changes. This suggests that Geoduck populations in California may be similarly influenced by environmental variability, but further research is needed.

Climate change has resulted in an increase in the dissolved carbon dioxide in oceans, lowing the pH of seawater and reducing the amount of carbonate available for mollusks to incorporate into their shells (Ekstrom et al. 2015). These changes in ocean chemistry, known as ocean acidification, are most detrimental at the larval stages of shelled mollusks such as Geoducks, and may result in lower recruitment (Gazeau et al. 2013). Local factors like upwelling, temperature, river discharge, and eutrophication can amplify the effects of ocean acidification, making it difficult to predict what areas will be most affected (Feely et al. 2008; Salisbury et al. 2008; Waldbusser et al. 2011; Cai et al. 2011).

Warmer conditions may cause Geoduck populations to shift northwards or towards deeper waters in search of preferred, cooler temperatures. This type of range shift could occur very slowly because adult Geoduck can handle higher temperatures than larvae (Goodwin and Pease 1989). Under these conditions, Geoduck adults would likely survive but recruitment could be compromised. Warmer waters may also make Geoduck more vulnerable to disease.

2 The Fishery

2.1 Location of the Fishery

Geoduck are commonly fished in areas containing shallow mudflats that are accessible at low tides, including Bodega Bay, Tomales Bay, and Humboldt Bay. Geoduck may also be fished in other areas, but the exact locations are unknown.

2.2 Fishing Effort

2.2.1 Number of Vessels and Participants Over Time

Currently, Geoduck is exclusively targeted by recreational fishers. Fishers do not require a permit beyond a recreational fishing license to harvest Geoduck, so tracking the number of participants is difficult. Department staff currently conduct creel surveys to estimate catch, effort, and Catch Per Unit Effort (CPUE) at known clamming locations in the northern portion of the state, specifically in Bodega and Tomales bays; however, the majority of clammers in these area target gaper clams or other species, which are easier to obtain than Geoducks. However, some creel surveys do encounter clammers who have taken Geoducks. The percent of intercepted clammers with Geoducks for recent survey years is shown in Table 2-1. These data suggest that clammers are more likely to either target or encounter Geoducks in Bodega Bay.

Table 2-1. Percent of interviewed clammers with Geoducks in Department creel surveys in two popular clamming locations. Surveys were conducted on high effort days (holidays or weekends with tides ≦1.0 ft (0.3 m)) (CDFW unpublished data). Ranges represent estimates from multiple survey days.

Year	Bodega Bay (percent)	Tomales Bay (percent)
2012	18	no survey
2013	13	no survey
2015	no survey	0-2
2017	0-15	0-5

2.2.2 Type, Amount, and Selectivity of Gear

Type of Gear Used

Because they must be dug by hand, Geoducks are usually only accessible at the lowest tides when mudflat areas are exposed. Fishermen look for evidence of a Geoduck’s siphon and dig a hole several feet deep to access the Geoduck. PVC pipe or other material is usually necessary to stabilize the sides of the holes (Moore 2001), making it a labor-intensive process. Fishermen may use clam forks or other digging implements.

Although there are no commercial Geoduck landings in California, Geoduck stocks support valuable fisheries in Mexico, Washington, British Columbia, and Alaska.

In these areas, Geoducks are targeted by divers working in pairs using surface supplied air. Divers swim over soft bottom habitat looking for visible Geoduck valves on the sea floor. Using hydraulic gear consisting of a high-pressure water hoses, the divers quickly remove the sediment around the buried Geoduck before it can retract its siphon. This type of gear has not been approved for use in California.

Department staff have received reports of increasing recreational take of Geoduck by SCUBA divers using hand-operated pumps that shoot pressurized water into the hole where the Geoduck is buried – liquifying the substrate and enabling the diver to reach in and grasp the neck and shell for extraction. While the use of mechanical gear to take clams is not allowed, this type of gear is currently lawful as it is considered ‘appliances operated by hand’ in the sport fishing regulations.

Selectivity of the Fishery

Some studies suggest Geoduck siphons only become visible above the surface when the Geoducks have reached 5 to 7 yr of age (Bradbury et al. 2000). For this reason, many studies have assumed that Geoducks are fully vulnerable to fishing by 8 to 10 yr (Harbo et al. 1983). Not all Geoduck siphons are visible to divers, and in Geoduck fisheries in other locations the “show factor” (the number of visible siphons relative to the total number of Geoducks in an area) is estimated to correct survey estimates for this potential bias.

2.3 Landings in the Recreational and Commercial Sectors

2.3.1 Recreational

There are few data on the recreational catch of Geoducks in California. Geoducks have been managed with a bag limit that allows for the take of three individuals per day (Moore 2001). It was long thought that few clammers in California were able to take the sport limit of Geoducks due to the effort required, though catch may have increased with the recent practice of using hydraulic hoses while SCUBA diving. Department staff believe the number of clammers using this method is very small (Derek Stein pers. comm.), but there are currently no data available to assess the level of take by this method.

A study conducted in Morro Bay from 1979-1980 estimated that, over the course of a year, 1,330 clammers took 536 Geoducks (Mello 1981). The clammers surveyed reported targeting a wide number of edible clams, and the catch of Geoduck made up 2% of the total clam catch that year (Mello 1981). In Humboldt Bay, Geoduck clams made up 1.5% of the sport clam catch in 2008, with approximately 300 Geoducks harvested from the area during that year (McVeigh et al. 2010). In Tomales Bay, less than 1% of the catch consists of Geoducks; about one out of 300 clammers take a Geoduck while clamming in this location (Moore 2001). Since 2012 the Department has conducted sporadic creel surveys of clammers in Bodega and Tomales Bays, and estimate catch rates that ranged between 0 and 0.38 Geoducks per clammer in Bodega Bay and between 0 and 0.02 Geoducks per clammer in Tomales Bay.

2.3.2 Commercial

The Geoduck fishery in California has been exclusively a recreational fishery. There have been no commercial Geoduck landings in California.

2.4 Social and Economic Factors Related to the Fishery

Because there is currently no commercial fishery for Geoducks in California, and very little information on the number and distribution of recreational participants, it is difficult to characterize the economic and social factors related to the fishery.

Geoducks are one of the finest food clams in California. They are highly valued for their flavor and large size and are considered a trophy clam by fishermen. Geoducks may be ground for use in fritters or clam chowder or pounded and fried and served as a main dish.

The high price of Geoduck in other locations has led commercial fishermen to request that the Commission consider opening a commercial fishery on an experimental basis. Geoducks are a highly prized delicacy in international markets and support commercial and recreational fisheries in other areas along the Pacific coast of North America. Increasing demand, mainly from Asian markets, has led to high prices in commercial Geoduck markets, which has been supplemented with aquaculture reared Geoducks. Currently the ex-vessel price for Geoducks ranges from $7-26 per lb, depending on the quality of the meat (Bob Sizemore pers. comm.). Geoducks are graded based on their size and color, which can range from white to dark brown. There is a strong market preference for light colored meat. The majority of the Geoducks landed in British Columbia, Washington, and Mexico have been exported to China, where demand is greatest.

Should a commercial fishery for Geoduck be developed in California the price of permits, method of allocation, geographic extent of the fishery, and management approach will heavily influence the number and socio-economic distribution of participants. Should the Commission decide to pursue the development of a fishery, it will need to carefully structure the allocation of permits and catch to best meet the state’s objectives for fisheries in California.

Poaching may be a cause of unaccounted mortality for Geoducks. Geoducks can sell for $100 each in Asia, which can be an incentive for illegal catch and export of wild Geoducks. The presence of farmed Geoducks makes it very difficult to track the origins of Geoducks on the market.

3 Management

3.1 Past and Current Management Measures

The Geoduck fishery has not been actively managed or monitored. Instead, a bag limit of three Geoducks per person per day is used to control harvest, and a requirement to retain the first three clams extracted regardless of size prevents high grading (the practice of discarding smaller clams in favor of larger ones). The regulation for daily bag limit was effective on March 1, 1964 and has not changed since.

3.1.1 Overview and Rationale for the Current Management Framework

The current management framework relies on a bag limit to prevent unlimited harvest. This restriction, in addition to the difficulty of accessing areas that are exposed at low tide, as well as the effort required to dig Geoducks out by hand, is thought to provide substantial protection to the majority of California's Geoduck population from harvest. The rationale for the current bag limit is unclear. The California bag limit was most likely modeled after the Washington State recreational bag limit of three Geoduck clams (established in 1938). Many bag limits in California are developed to maintain a satisfying recreational fishery while limiting fisher efficiency and total catch.

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

Currently there are no formal criteria to identify when the Geoduck population is overfished or subject to overfishing, and no rebuilding targets or established measures to be used to rebuild. A passive management strategy relying on catch limitations has been used because little is known about the current statewide population size. Department staff currently use limited creel surveys to estimate catch, effort, and CPUE at known clamming locations in the northern portion of the state, specifically in Bodega and Tomales bays; however, most of the clams taken there are gaper clams or other species. It is likely only a select group of people target Geoduck clams because extracting them requires more effort and different tools. Therefore, relying on effort trends from general creel surveys of clammers may not accurately represent changes to Geoduck populations or fishing effort.

Given the limited number of areas where recreational harvest of Geoducks is regularly possible, the risk to the population is thought to be low. However, the use of SCUBA gear and hand-held hydraulic hoses to take Geoduck has increased the risk somewhat because now the subtidal population, thought of as a de facto reserve, may be accessible to fishing. Because Geoducks are long lived and are thought to reproduce sporadically, they are vulnerable to localized depletion without conservative management measures in place. Should depletion of the resource occur, the recovery time may take decades (Bradbury et al. 2000).

3.1.1.2 Past and Current Stakeholder Involvement

Any future consideration of management changes or new regulations will require communication with stakeholders to obtain feedback and understand the impacts of those changes on stakeholders. Additionally, any new regulations will be developed through the Commission process, which provides opportunity for public and stakeholder input.

As noted above, stakeholders interested in the development of a commercial fishery have approached the Commission on several occasions seeking experimental gear permits. To date, these requests have not been approved given concerns regarding potential impacts to the population and habitats.

3.1.2 Target Species

3.1.2.1 Limitations on Fishing for Target Species

3.1.2.1.1 Catch

Recreational fishers are allowed to take up to three Geoduck clams per day.

3.1.2.1.2 Effort

There are currently no restrictions on the fishing effort.

3.1.2.1.3 Gear

Fishers may use spades, shovels, hoes, rakes, clam forks or other appliances operated by hand, except spears or gaff hooks, to take Geoduck clams. Mechanical or electric gear to assist in digging is prohibited.

3.1.2.1.4 Time

There are no seasonal restrictions on Geoduck fishing. There is no fishing for any saltwater clams at night (between one-half hour before sunrise to one-half hour after sunset).

3.1.2.1.5 Sex

There are no restrictions on the sex of Geoducks that can be caught. Male and female Geoducks cannot be differentiated externally.

3.1.2.1.6 Size

There are no size restrictions in the Geoduck fishery. Size restrictions are not appropriate for Geoduck management because fishers need to dig Geoduck in order to measure them. Geoducks cannot rebury themselves and will die if discarded on the sea floor.

3.1.2.1.7 Area

There are currently no restrictions on the areas where Geoduck can be fished, other than the general restrictions associated with California's network of Marine Protected Areas (MPAs).

3.1.2.1.8 Marine Protected Areas

Pursuant to the mandates of the Marine Life Protection Act (MLPA) (Fish and Game Code (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 scientifically-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 can 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. 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 Geoducks, some MPAs have significant amounts of soft bottom in depths ranging from tidal flats to 328 ft (110 m), which Geoducks prefer. Along the California mainland and island coasts there are 3,213.20 square miles (mi^2) of soft bottom habitat between 0 and 100 m (0 and 328 ft) and 236.44 linear miles (mi) of tidal flats (Table 3-1).

Table 3-1. Soft bottom habitat for tidal flats (linear miles) and depth of 0-30 meters and 31-100 meters (square miles) off California by region (California Seafloor and Coastal Mapping Project 2017).

Depth (m)	North Coast	North Central Coast	Central Coast	South Coast	Total
Tidal Flats	101.23	60.74	39.49	34.98	236.44
0-30	302.92	148.74	227.17	437.21	1116.04
31-100	455.95	414.06	555.08	672.08	2097.16

The state's network of MPAs shelter a total of 487.50 mi^2 or 15.2% of available soft bottom habitat between 0 and 100m (0 and 328 ft) and 52.12 linear mi or 22.0% of tidal flats (Table 3-2). This network of protected soft bottom and tidal flats habitats may have direct benefits by protecting a segment of the Geoduck population that could contribute to rebuilding the populations around the MPAs should fishery depletion occur.

Table 3-2. Soft bottom habitat for tidal flats (linear miles) and depth of 0-30 meters and 31-100 meters (square miles) within California MPAs by region (California Seafloor and Coastal Mapping Project 2017).

Depth (m)	North Coast	North Central Coast	Central Coast	South Coast	Total
Tidal Flats	2.06	19.28	23.35	7.43	52.12
0-30	33.08	7.42	36.56	36.55	113.61
31-100	68.48	100.78	78.81	125.82	373.89

In 2007 Morro Bay was declared a SMRMA, which restricts the take of living marine resources. Prior to the closure, this was a popular clamming area for Geoducks (Mello 1981). This change has likely provided some protection to Geoduck in that region, though given the long life-span of Geoduck an increase in densities might not be detected for many years.

3.1.2.2 Description of and Rationale for Any Restricted Access Approach

There is no restricted access program in place for the Geoduck fishery.

3.1.3 Bycatch

3.1.3.1 Amount and Type of Bycatch (Including Discards)

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 does not always indicate a negative impact. Because Geoducks are collected by hand, the bycatch in this fishery is expected to be low. Potential bycatch might include other species of large clams. Geoducks look similar to gaper clams, which are a more commonly targeted recreational clam. Additionally, other infaunal species might be displaced by clammers targeting Geoducks.

When a fishery is managed using a bag limit there is the potential for high-grading. Because adult Geoducks cannot rebury themselves once they are dislodged from the sediment, discard mortality is assumed to be 100%. It is possible to check for evidence of high-grading in areas after harvests have taken place because Geoduck bodies and shells will be visible on the sand. However, the Department has not seen any such evidence of high-grading, and discards are believed to be low due to the time and effort required to harvest each Geoduck and because the activity is not legal (Derek Stein pers. comm.)

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

In an effort to reduce mortality, the Department's Sport Fishing Regulations for Geoduck clams specify that the first three Geoduck clams dug must be retained, regardless of size or broken condition. Given the targeted method or harvest and assumed low level of discards there are no additional measures in place to reduce bycatch, and none are needed at this time.

3.1.4 *Habitat*

3.1.4.1 *Description of Threats*

In the recreational fishery, Geoducks are harvested using a shovel in soft bottom areas that are exposed at low tide. Because Geoducks live buried in the sediment and must be dug up to be harvested, there is the potential for the fishery to have adverse impacts on its environment. Other benthic organisms may be unearthed and/or damaged during Geoduck harvest. However, soft-bottom habitats are relatively resilient to disturbances and can recover in a few months (Tuck et al. 2000). Fishing effort is thought to be concentrated into a few bays with exposed mudflats at low tide. For these reasons, cumulative threats to habitat from fishing are considered to be very low.

Should a commercial fishery be opened, the use of hydraulic gear to harvest Geoducks will disturb the sediment and likely displace other organisms at a much greater rate. In addition, sedimentation in the water limits visibility and, when it settles, may adversely affect benthic algae or organisms. Increased turbidity may adversely affect the growth and survival of filter feeders. The extraction of Geoducks using hydraulic gear leaves depressions in the substrate. The time it takes for these depressions to fill in varies depending on the substrate composition and tidal currents, but can take approximately 5 to 7 months (Feldman et al. 2004). Soft-bodied organisms may be damaged by the use of hydraulic gear. Some of these animals represent important food sources for other fish species.

Some soft bottom habitats may be more vulnerable to disturbances than others. These include eelgrass beds, which are known to cushion the impact of waves and currents, preventing erosion, and provide important foraging grounds for both fish and invertebrate species. Eelgrass is also a known spawning ground for important commercial species such as Pacific Herring (*Clupea pallasii*). Nearshore habitats that are composed of gravel or pebbles may also provide nursery grounds for important fish species.

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

The prohibition on the use of mechanical gear to harvest Geoducks likely reduces the impacts of the fishery on the habitat. The Sport Fishing Regulations prohibits the take, cutting, or disturbing of eelgrass (§30.10, Title 14, California Code of Regulations (CCR)), so fishermen cannot dig for clams in eelgrass beds.

National Marine Sanctuaries in California prohibit certain activities that could be related to Geoduck clam harvest (15 Code of Federal Regulations §9.22.72(a)(4)) since the act of extracting Geoduck clams involves disturbing the sediment. Sanctuaries with potential Geoduck populations include the Greater Farallones, Channel Islands, and Monterey Bay. The regulations do not specifically prohibit the use of mechanical water jets to extract organisms, but they do prohibit “drilling into, dredging, or otherwise altering the submerged lands of the Sanctuary.”

3.2 Requirements for Person or Vessel Permits and Reasonable Fees

There are currently no commercial permits available to take Geoduck. Recreational participants require a valid recreational fishing license.

4 Monitoring and Essential Fishery Information

4.1 Description of Relevant Essential Fishery Information

The MLMA requires that Essential Fishery Information (EFI) be identified for each managed stock. EFI is defined as the information that must be collected in order to understand the status of the resource. Below is a description of the types of information necessary to manage the Geoduck fishery.

Spatial Distribution of the Population

The distribution of Geoducks in California is currently unknown. This information will be essential to a) determining where fishing is likely to occur and thus how monitoring efforts should be directed, and b) developing baseline surveys to determine changes in distribution or abundance. Since the majority of the Geoduck population is believed to be subtidal, this will involve dive surveys to map the location and extent of Geoduck beds.

Abundance Estimate

Once the location and spatial extent of Geoduck beds is mapped, it will be necessary to conduct surveys to estimate the density of Geoducks. This density can then be multiplied by the area of the bed to estimate the absolute abundance. This information is necessary for monitoring future fishing impacts on population size. Additionally, this will provide the information necessary to determine whether California has a large enough population to support an economically viable commercial fishery, should that become a management goal in the future. Density surveys would also be necessary for setting catch limits that achieve sustainable harvest rates.

Age Structure of the Population

Because Geoducks reach their maximum size early in their long lifespan, size is not a useful indicator of population health. Age structure is an informative indicator of the mortality a population is experiencing and provides a method to understand how Geoduck biology may differ from location to location. Age structure information can also be used to determine level of recruitment. Age composition data were recently obtained for five areas around California (Navas 2015) and presents a baseline for future comparisons.

Catch Per Unit Effort

Estimates of CPUE are available through general clamming creel surveys. Changes in CPUE in a given area over time can alert managers to changes in abundance.

Total Catch

If an estimate of abundance is available, information on the total catch each year can provide information on the proportion of the stock removed from fishing each year relative to a target harvest rate. However, total catch is difficult to track in a recreational fishery.

4.2 Past and Ongoing Monitoring of the Fishery

Historically there has been very little directed research on Geoduck in California, and the Geoduck stock is considered data-poor. Monitoring this fishery is challenging because it is difficult to intercept clammers that are targeting Geoducks rather than other more common clams. This section describes the monitoring that has been conducted for this fishery.

4.2.1 Fishery-dependent Data Collection

Creel surveys conducted by Department staff are the primary method of monitoring the Geoduck fishery. The goal of these surveys is to estimate recreational catch and effort in known clamming areas. Department staff intercept clammers and ask about all species of edible clams caught, not just Geoducks, but these surveys do provide some information on Geoduck catch and effort in these locations.

From 1979 to 1980, a year-long study was conducted at Morro Bay to estimate clamming catch and effort. Clammers were intercepted and asked about the time spent fishing and their catch. This study indicated that 1,330 clammers spent an average of 2.4 hours clamming on each trip and caught 15 species of clams (Mello 1981). Clammers reported catching 538 Geoduck in this time period, at a rate of 0.40/clammer.

In Tomales Bay clam populations were surveyed by the Department from the 1960s to the 1990s and had some of the highest catch and effort levels in the state (McVeigh et al. 2010). At that time, clammers were primarily targeting gaper clams, but there may be information in those data sets about Geoduck clam catch. This data could provide a baseline with which to understand whether CPUE has changed over time in Tomales Bay Creel surveys were conducted in Tomales Bay in 2015 and 2017 and catch rates between 0 and 0.02 Geoducks per clammer were observed. This CPUE rate is an order of magnitude lower than what has been observed in Bodega Bay and Morro Bay, but it is unknown whether this is due to fishing or natural differences in productivity.

Creel surveys were conducted by Department staff from 1975 to 1989 at low tides in the south arm of Humboldt Bay. Data were collected on clammer effort and catch, and data were bootstrapped to obtain estimates of the number of clammer-days per year, CPUE, total catch by species, and spatial distribution of effort within the bay. This study was repeated in 2008 (McVeigh et al. 2010). Geoducks made up 1.5% of the total catch in 2008 but were not encountered in the surveys from 1975 to 1989.

Since 2013 creel surveys have been conducted by the Department semi-regularly to estimate clamming fishing effort and catch in Bodega Bay. Catch rates range between 0 and 0.38 Geoducks per clammer.

4.2.2 Fishery-independent Data Collection

Department staff conducted surveys to better understand the spatial distribution of subtidal Geoduck beds and their approximate density in California during 2009-2012 in southern California and 2014 in Tomales Bay. The surveys consisted of using SCUBA to observing presence or absence of Geoduck clams in potential habitat in subtidal waters. In southern California, significant populations of subtidal Geoduck clams at intermittent locations were observed (Derek Stein pers. comm). This research suggests that Geoduck may be more widely distributed throughout California than was previously thought.

Department staff also collaborated with a graduate student at Moss Landing Marine Laboratories by providing samples for a study on spatial variation in growth and morphology (results described in Navas 2015). This research was the first biological study on Geoduck populations in California and provided valuable information about growth patterns and age structure (Kai Lampson pers. comm).

5 Future Management Needs and Directions

5.1 Identification of Information Gaps

Table 5-1 describes the informational gaps for the Geoduck fishery and their priority for management. The primary informational need for this fishery is to determine the spatial extent and abundance of the stock. While not a direct estimate of abundance, changes in CPUE can indicate changes in abundance. One step towards understanding how CPUE has changed in certain areas over time would be to compile all available historical creel survey data on Geoducks to provide context for recent and future CPUE estimates. This would not require additional data collection activities, but instead makes use of historical data. Tracking CPUE over time could alert the Department to changes requiring additional monitoring or management measures, such as direct abundance surveys. Continued monitoring of the age composition at fished areas could also provide an indicator with which to assess fishing impacts.

Table 5-1. Informational needs for California Pacific Geoduck and their priority for management.

Type of information	Priority for management	How EFI would support future management
Historical catch and CPUE time series for recreational fishery	High	Use available creel survey data to understand historical CPUE and estimates of total catch for Geoduck fishery locations.
Spatial distribution of Geoduck	High	Broad scale surveys to identify the location and extent of Geoduck beds.
Age composition of the stock	Medium	Shells sampled from various beds (or collected from clammers) could be aged to understand age structure of the stock, improve growth estimates, estimate mortality rates, and model past recruitment.
Abundance	Medium	Fine scale surveys to estimate the average bed density. Abundance is estimated by multiplying the average density by bed area.
Total catch	Medium	Estimates of total catch are used, along with estimates of abundance, to estimate the harvest rate.
Recovery time in a fished area	Low	Abundance surveys in Morro Bay, a popular clamming area that was made a MPA in 2007, could be used to understand how long densities take to recover after fishing.

Note that should there be continued interest in developing a commercial fishery for Geoduck, understanding the spatial distribution and abundance of Geoduck via direct population surveys would become a high priority data need because this information would be essential to setting fishing regulations and measuring the impact of commercial fishing. Tracking the total catch would also be necessary to ensure that sustainable harvest rates are achieved. The types of monitoring required to develop a commercial fishery are described in detail in Appendix A and would require the Department to dedicate substantial staff time and resources. To reduce costs, increased monitoring and management could be done as needed on a bed-by-bed basis. A similar approach is used in Washington state (see Appendix A for more information).

5.2 Research and Monitoring

5.2.1 Potential Strategies to Fill Information Gaps

Historical Catch and CPUE Time-Series

Since the 1970s creel surveys have been conducted sporadically to estimate catch and effort in clamming areas. Many of these surveys have information on Geoduck catch as well as the total number of clammers. This information could be compiled into a single database and analyzed using a consistent methodology to understand how the CPUE of Geoduck has changed over time.

Mapping Geoduck Distributions

It is possible to learn from the approach other fisheries have used to measure the distribution of Geoduck prior to beginning commercial fisheries. In Washington surveys were first conducted over 3 yr prior to beginning commercial fishing. Likely Geoduck beds (areas with soft bottom beds between the mean low tide line and 100 ft) were mapped to quantify the potential Geoduck habitat along the coast. These areas were then surveyed to confirm the existence of Geoducks and to estimate the percentage of beds with densities greater than 0.4 per m^2, which is the minimum density required for a bed to be commercially harvestable in Washington (Bradbury et al. 2000). This two-step survey process was used to confirm that Washington had an extensive Geoduck population that could support a commercial fishery.

Obtaining an Abundance Estimate

Bradbury et al. (2000) provide an excellent and detailed summary of the methodology used in Washington to estimate the absolute abundance within beds. In short, systematically spaced consecutive transects are run perpendicular to shore. Two divers swim on either side of the transect line and count the number of Geoduck “shows” (visible siphon valves) within 1 m (3.3 ft) of the transect line. The density estimate (shows per transect area) underestimates to true number of Geoducks because some clams have their siphons retracted. The counts for each transect are corrected by an assumed “show factor” of 75% that is based on field estimates of show factors. The show factor depends on food availability, water temperature and flow, substrate type, etc. (Goodwin 1976) and would need to be estimated for beds in California.

The number of transects required in a given bed is determined by a target coefficient of variation of 30%, which ensures that the 95% confidence intervals of the resulting density estimate is within 30% of the true density estimate. The abundance in the bed is calculated by multiplying the average density estimate by the total area of the bed. Ten Geoducks are then collected from each transect to determine the average weight of Geoducks in the bed (because Geoduck quotas are issued in weight rather than numbers). Biomass is calculated by multiplying the abundance by this mean weight estimate. The sampled Geoducks could also be used for biological studies, including ageing.

Estimating Age Structure

Accurate age estimates are critical for estimating growth, which likely varies by location, mortality rates, and past recruitment trends – all of which are important parameters for establishing sustainable harvest rates. Age can be estimated using the acetate peel technique of Shaul and Goodwin (1982). Growth rings are imprinted on the acetate peel, which can then be counted using a microscope. Since 2005, improved methods in shell preparation and a shift to a new method called cross dating have increased ageing accuracy for Geoducks (Black et al*.* 2008). Cross dating involves matching high frequency, year-to-year variability in growth between specimens, which allows for a more exact identification of calendar year for each growth ring.

Total Catch

Because Geoducks are long-lived, slow growing animals, they can sustain only very low harvest rates (on the order of 1 to 3% of the total biomass each year) (Bradbury et al. 2000; Zhang and Hand 2006). In Geoduck fisheries, input restrictions such as limited access, size limits, seasons, etc., have been shown to be ineffective at restricting catches to an appropriate level in commercial fisheries (Muse 1998), and may also result in overfishing in recreational fisheries. Output controls, such as Total Allowable Catches (TACs), are the best mechanism to limit removals in situations where it is necessary to ensure that a target harvest rate is not exceeded. In a TAC system, it is necessary to monitor catches in order to prevent fishermen from routinely exceeding the TAC. This is especially important in a species like Geoduck, which, if overfished, may take 50-plus yr to recover.

Post-harvest Density and Recovery Time

The designation of Morro Bay, a popular clamming area for Geoducks and other clams, as a MPA provides a unique opportunity to survey clam densities in these areas and determine how long it takes for densities to recover. This would provide valuable information for management of Geoduck beds in the future. Many Geoduck fisheries consider 0.4 per m^2 the minimum density required for commercial fishing (Aragón-Noriega et al. 2012). While it has been more than 10 yr since the MPA was established, given the long lifespan and low recruitment rates of Geoduck, surveys in the near future could still provide valuable information on rates of increase.

5.2.2 Opportunities for Collaborative Fisheries Research

This fishery has a great deal of potential for collaborative research. Department staff recently collaborated with academic researchers to complete the first biological study of Geoducks in California (Navas 2015). Given how little information is available on the distribution and abundance of Geoducks in California, continued collaboration between the Department and academic groups could be helpful in establishing population baselines. There is also the possibility for collaboration with commercial divers should development of commercial fishery be pursued. And finally, there is an opportunity to collect Geoduck shells from recreational clammers for use in ageing studies. This would reduce the sampling effort and mortality associated with an ageing study.

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 in light of 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 current regulations on Geoduck harvest are thought to provide protection to the majority of the California's Geoduck population, and there is no need for additional management measures at this time. A Productivity-Susceptibility Analysis found the sport fishery for Geoduck in California to be relatively data-poor and moderately vulnerable to fishing (MRAG Americas, Inc. 2016). Table 5-1 outlined a number of opportunities for increased data collection and analysis that could improve the current understanding of fishery, including one that relies on a new analysis of existing data.

There have been concerns that Geoduck densities in popular fishing areas were declining since at least the early 2000s (Moore 2001), but this decline was not viewed as detrimental to the overall population because it was believed to occur in localized areas. More recently, Navas (2015) showed that higher mortality rates at fished sites have resulted in truncation of the age distribution of Geoducks in these areas. More information is required to determine whether the current mortality rates in these areas require additional management attention.

Department staff have also become aware that some recreational fishers are taking other large clams while SCUBA diving by using a hand-operated pump to dig up the clams. This method of take is currently legal for recreational take as long as fishermen abide by the bag limit. While the extent to which this gear has been used to take Geoducks is unknown and assumed to be limited, it increases the likelihood of each fisherman obtaining the bag limit and eliminates the depth refuge that submerged Geoducks were presumed to have. The Department will continue to monitor catch rates and will consider additional steps if necessary.

5.4 Climate Readiness

Little is known about the potential impacts of climate change on Geoducks. However, shellfish fisheries may be uniquely vulnerable to climate change via ocean acidification (Ekstrom et al. 2015). More research is needed to understand how the Geoduck fishery might be impacted by ocean acidification in the future, and ideally to identify early warning signs that the Department can monitor. Geoduck recruitment has also been shown to be influenced by oceanic changes at the regional scale (Valero et al. 2004). Because Geoducks can be accurately aged, it is possible to back-calculate the number of Geoducks that recruited to the population each year and attempt to find correlations between survival and environmental indicators. This could provide the Department with information on how changing conditions are likely to impact Geoduck populations in the future.

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