

Fishery-at-a-Glance: Dungeness Crab

Scientific Name: *Metacarcinus magister*

Range: Dungeness Crab are found in nearshore and estuarine waters from the eastern Aleutian Islands, Alaska, to Santa Barbara, California, although they are rarely found south of Point Conception, California.

Habitat: Dungeness Crab inhabit a wide variety of ocean floor habitats, but they generally prefer sandy- or soft-bottom areas.

Size (length and weight): High fishing pressure on males makes it difficult to estimate maximum size for males since most are harvested by age 4, however male Dungeness Crab have been observed to reach a maximum size of over 229 millimeters (9 inches), with an estimated weight of over 1.0 kilograms (~2.5 pounds). Females have been observed to reach a maximum size of 178 millimeters (7 inches).

Life span: It is difficult to estimate age since adult male Dungeness Crab face heavy fishing pressure, so their natural life span is not well understood. It has been estimated that adult male and female Dungeness Crab can live between 8 and 10 years.

Reproduction: Dungeness Crab reach sexual maturity within 2 to 3 years. They mate annually between February and June. A single female may extrude and carry up to two million fertilized eggs during one mating season.

Prey: Dungeness Crab are opportunistic predators and scavengers, feeding on bivalves, fish, shrimp, isopods, and other organisms. They also engage in cannibalism.

Predators: Many species and taxa prey on Dungeness Crab, including Wolf Eels, rockfishes, Cabezon, Green Crab, octopus, and Sea Otters.

Fishery: Both commercial and recreational fisheries exist in the state. The fisheries have slightly different seasons within the two distinct management areas: Northern and Central, these areas are divided at the Sonoma/Mendocino County line.

Area fished: Dungeness Crab are harvested from Point Conception to the Oregon border. Fishing effort in the north is concentrated between Crescent City and Eureka and north of Fort Bragg. While in the central coast region, fishing occurs near Morro Bay, Monterey Bay, Half Moon Bay, San Francisco, and Bodega Bay.

Fishing season: The commercial fishery is closed from July 16 to November 30 in the Northern Management Area and from July 1 to November 14 in the Central Management Area. The recreational fishery is closed from July 31 to the first Friday in

November in the Northern Management Area and from July 1 to the first Friday in November in the Central Management Area.

Fishing gear: The primary gear type utilized by the commercial fishery is a rigid, round steel mesh trap. Crab traps are also used in the recreational fishery, but they are not as large as commercial traps, can be rectangular in shape and typically weigh less; hoop nets, hand harvesting and crab snares are also used.

Markets: California Dungeness Crab are sold both domestically and exported, primarily to China. Crab typically are cooked and are either sold whole in the shell or the cooked meat is picked prior to sale and sold fresh or frozen. Crab can also be sold live.

Current stock status: Natural variability in fished populations have been attributed to environmental factors as opposed to fishing pressure. Recruitment in the fished stock may be a result of the strength of localized juvenile recruitment in the region several years prior. There are no current estimates of population abundance in California, but the stock appears to be healthy.

Management: The State Legislature regulates the commercial fishery and take of crab is based on sex, size and season. The Commission regulates the recreational fishery and take of crab is based on size and season. Both fisheries also have specific gear restrictions limiting take.

1 The Species

1.1 Natural History

1.1.1 Species Description

Dungeness Crab are oval-shaped, with an armored carapace that ranges in color from yellowish-orange to brown or purple (Figure 1-1). They possess four pairs of walking legs, as well as a pair of claws, or “chelae”, used for feeding, defense, and mating purposes. The claws are distinguished by serrated teeth along the claw with light-colored hooks at the tip of the claw (DFO 2017). Dungeness Crab use eye stalks and antennules at the front of their heads to sense their surroundings.



Figure 1-1. Dungeness Crab measuring 7.1 in (181.0 mm) with distinguishing features labeled: carapace, claw, cheliped or chelae, and walking legs (Photo Credit: CDFW).

Dungeness Crab male adults reach larger shell diameters than females and can be distinguished by the shape of the abdominal flap on the ventral side of their bodies. The abdominal flap in males is narrow and columnar-shaped while females have a broader, semi-circular-shaped flap (Figure 1-2).



Figure 1-2. Male and female Dungeness Crab; left image male Dungeness Crab with a narrow columnar-shaped abdominal flap and image female Dungeness Crab with a broad, semi-circular shaped abdominal flap (Photo Credit: CDFW).

1.1.2 Range, Distribution, and Movement

Dungeness Crab range from the Unalaska, Alaska to Santa Barbara County, California and are rarely found south of Point Conception (Wild and Tasto 1983; ADFG 2005) (Figure 1-3). Dungeness Crab engage in some level of random movement, but typically travel within areas of less than 10.0 miles (mi) (16.1 kilometers (km)). Individual males may travel up to 100.0 mi (160.9 km) (Hankin and Warner 2001). Dungeness Crab may also participate in inshore or offshore migrations (Hankin and Warner 2001). Larvae can be transported up to 3.7 mi (5.9 km) offshore, before returning to shallow, nearshore waters or estuaries as juveniles (OST 2013).



Figure 1-3. Range of Dungeness Crab from Unalaska, Alaska to Point Conception, Santa Barbara County, California (Wild and Tasto 1983; ADFG 2005).

1.1.3 Reproduction, Fecundity, and Spawning Season

Mating occurs shortly after females molt, typically between February and June. Prior to females molting, males will carry a female in a protective “pre-molting embrace” until she molts. A male may carry a female in this manner for up to 2 weeks (Rasmuson 2013). The female stores the male’s sperm internally, and fertilization doesn’t occur until the internally developing eggs are extruded (Figure 1-4), generally between October and December. Females can store viable sperm for up to 2.5 years (yr) and fertilization has been shown to occur in non-molting or skip-molt females (Hankin et al. 1989). Depending on size, a gravid female may carry between 500,000 and two million fertilized eggs beneath her abdominal flap. Eggs hatch into larval crab between November and February (Hankin and Warner 2001). Female molting events decline in frequency with age, which in turn leads to a reduction in fecundity over time (Higgins et al. 1997).



Figure 1-4. Female Dungeness Crab with extruded eggs (Photo Credit: CDFW).

Following hatching, larvae are released into the water column as prezoaea, before transitioning to free-swimming zoea within minutes of hatching. Larvae grow through five zoeal stages and one megalopa stage before settling to the seafloor as juveniles (Figure 1-5). Zoea and megalopae stages display vertical migration in the water column, moving to shallower depths at night before moving deeper during the day. The depth that larval Dungeness Crab migrate to is not well understood. Zoea feed on protists suspended in the water column, and transition to omnivorous feeding as megalopae (Rasmuson 2013). The timing of megalopae found in bays and estuaries along the California coast occurs between March and July (CDFW personal communication), but are primarily concentrated in the spring months that are associated with intense coastal upwelling.

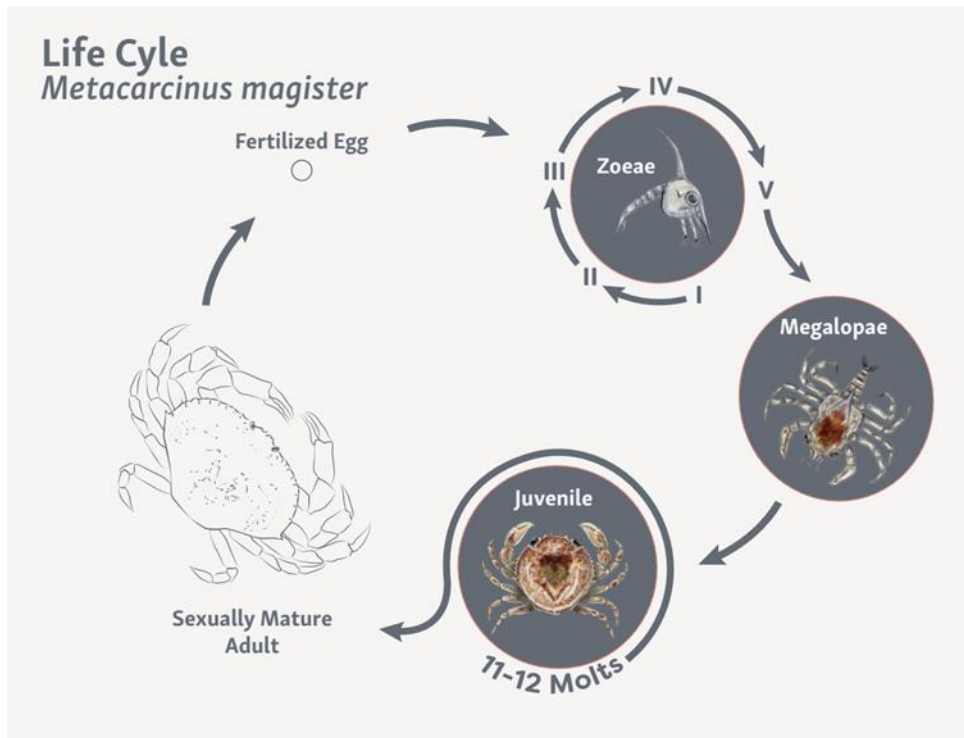


Figure 1-5. Life cycle of Dungeness Crab (Photo Credit: Natalie Renier).

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.

Larval Dungeness Crab display relatively consistent mortality rates, with an average daily survival rate of 0.066 day^{-1} (Hobbs et al. 1992; Rasmuson 2013). Annual mortality rates for adults are challenging to quantify but have been estimated at 2.5% for sublegal males and 1.3% for females (Butler and Hankin 1992; Rasmuson 2013). The lifespan of Dungeness Crab has been estimated at 8 to 10 yr using modeled metabolic rates (Gutermuth and Armstrong 1989; Rasmuson 2013). As adult Dungeness Crab enter senescence typically between ages 4 and 7 yr, there is an increased rate of mortality (Botsford and Wickham 1978). High fishing pressure on adult males makes it difficult to obtain an accurate measurement of mortality and life span of the species, and data on the subject remains sparse. Understanding natural mortality rates of adults would help to inform management.

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.

Larval Dungeness Crab settle on the substrate after 4 months and having reached an approximate size of 5.0 millimeters (mm) (0.2 inches (in)) (Rasmuson 2013). Juvenile and adult Dungeness Crab grow in steps as a result of molting. Growth rates/sexual maturity have been shown to be a function of ocean temperature as crab in San Francisco Bay reached sexual maturity at age 1 yr an entire year before their cohorts outside of the bay in the colder waters of the open coast at age 2 yr (Wild and Tasto 1983). Periods of molting occur more frequently prior to crab reaching sexual maturity and then slowdown in later stages of life. Males and females grow at equal rates through their first two years, after which males grow at a faster rate (Botsford and Wickham 1978). Males and females both molt roughly six times in their first and second years, reaching sizes of approximately 1 in (25 mm) and 4 in (101 mm) in width at the end of each respective year (Hankin and Warner 2001). Dungeness Crab weigh approximately 50.0 and 200.0 grams (g) (0.1 to 0.4 pounds (lb)) at these respective years (Botsford and Wickham 1978). Adult males molt less often but grow to a larger maximum size than females. Males molt twice in their third year, and once per year in subsequent years, reaching a maximum size of roughly 9 in (229 mm) in length (Hankin and Warner 2001), but these sizes are rare due to fishing pressure. Following sexual maturity, females molt once per year, reaching a maximum size of roughly 7 in (178 mm) in length.

1.1.6 Size and Age at Maturity

Dungeness Crab of both sexes achieve sexual maturity as early as 1 yr of age, but more commonly by 2 yr of age at a carapace length of roughly 4 in (101 mm) for females and 4.5 in (108.0 mm) for males (Hankin and Warner 2001; Rasmuson 2013). This can vary by latitude, as Dungeness Crab in Alaska typically do not reach sexual maturity until 3 yr of age (Scheding et al. 2001; Rasmuson 2013).

1.2 Population Status and Dynamics

The Department, along with other state management agencies on the west coast, generally does not conduct formal stock assessments as Dungeness Crab recruitment appears disconnected from fishing pressure (OST 2013). Limited information on stock status is derived from seasonal landings. The Department has been tracking landings since the 1915-1916 season (Figure 1-6) and during this time, huge fluctuations of Dungeness Crab landings have been observed. This cyclical nature may be driven somewhat in part by larval recruitment and favorable oceanographic conditions (Wild and Tasto 1983). Despite depressed landings in the southern range of

the fishery starting in the early 1960s until the mid-1980s, there have not been any recent long-term declines.

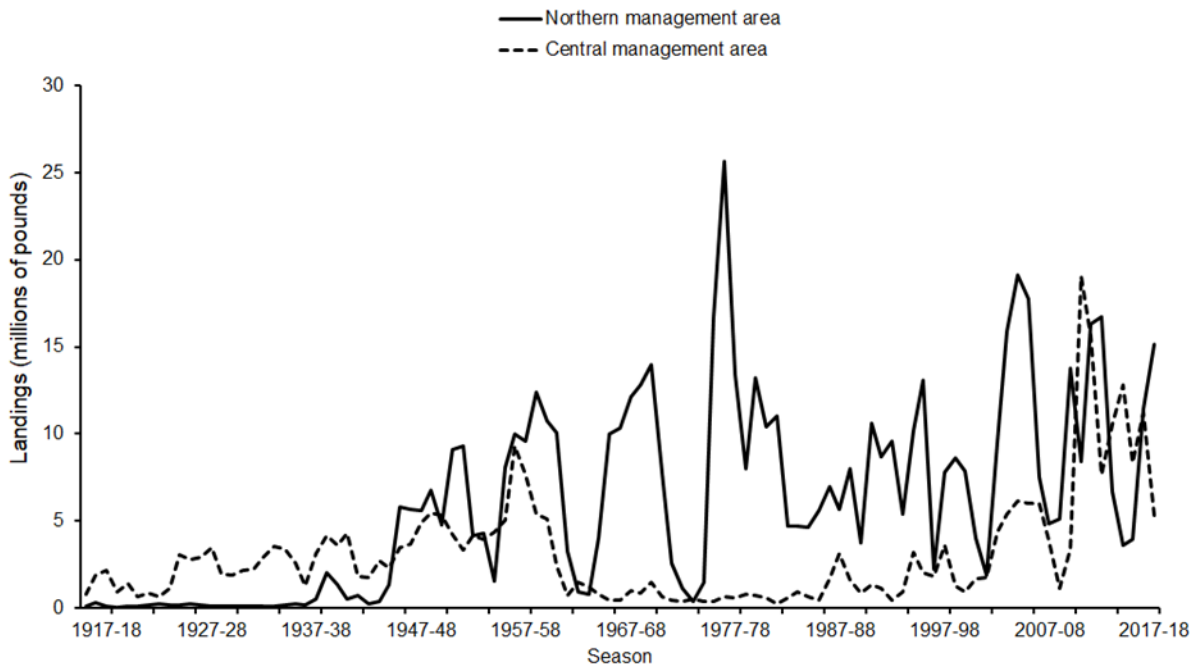


Figure 1-6. Dungeness Crab landings by fishing season and management area between 1915 to 1916 and 2017 to 2018 seasons (CDFW Marine Landings Database System (MLDS)).

Larval settling success has been strongly linked to early spring transitions, when predominant northwesterly winds mark the upwelling season in the California Current. This in turn has been correlated to higher commercial landings 4 yr later (Shanks and Roegner 2007). Yearly age 0 Dungeness Crab caught in San Francisco Bay as part of the Department's trawl surveys showed a strong correlation to models that incorporated two ocean-atmosphere phenomena: Pacific Decadal Oscillation (PDO) and North Pacific Gyre Oscillation (NPGO) (Cloern et al. 2010). Specifically, juvenile Dungeness Crab catch was higher during negative phases of the PDO and positive phases of the NPGO, physical oceanographic conditions characterized by stronger upwelling and cooler sea surface temperatures that contribute to higher primary productivity.

Recent genetic analyses of adult Dungeness Crab along the U.S. West Coast, including sites in central and northern California, showed very little genetic diversity between sites, while interannual differences did emerge between crab collected from the same locations two years apart (Jackson et al. 2017). This suggests strong connectivity among the West Coast population, and that variations in prevailing oceanographic conditions from year to year are driving the localized transport of recruiting larvae.

1.2.1 *Abundance Estimates*

Landings can serve as a proxy for crab abundance since it has been shown in other Dungeness Crab fisheries outside of California that about 80 to 90% of harvestable males are removed by the fishery each season (Smith and Jamieson 1989). However, overall abundance estimates of Dungeness Crab populations (as well as the occurrence of overfishing) are unknown in California and the western U.S.

1.2.2 *Age Structure of the Population*

Since individual crab are difficult to age, it is generally inferred by size. Due to exploitation, the population of mature male Dungeness Crab is almost entirely made up of young males. Males typically reach the minimum legal size between 3 and 4 yr of age, resulting in one or two year classes dominating the majority of annual landings (Warner 1987; Hankin et al. 1997). Despite this high rate of exploitation, female mating success is likely not impacted, as nearly all sexually mature females are fertilized each year (Hankin et al. 1997). Males reach sexual maturity at roughly 4.0 in (1.6 cm) length, meaning that most males have at least one breeding season before they reach the legal minimum of 5.8 in (2.3 cm) and first become vulnerable to the recreational fishery. This size refuge contributes to the reproductive capacity and stability of the stock.

A gravid female may carry as many as two million fertilized eggs and their ability to store sperm in cases when they do not molt, allows for large recruitment classes to replenish disproportionate male removals year after year. Furthermore, the timing of the early part of the fishery (late-fall and early-winter) when a large majority of legal-sized males are harvested typically does not occur around the mating season that concludes in June and otherwise could reduce mating success (Hankin and Warner 2001).

1.3 *Habitat*

Dungeness Crab can be found across most ocean floor substrates, although they have a demonstrated preference for soft or sandy-bottom habitats (Hankin and Warner 2001). While Dungeness Crab megalopae preferentially settle in estuaries in other portions of their range, they are primarily found in the open ocean off California due to limited availability of estuarine habitats (Rasmuson 2013). Nevertheless, Humboldt Bay and San Francisco Bay serve as important nursery habitats (Hankin and Warner 2001).

The distribution of Dungeness Crab is likely influenced by water temperature. Adult crab are generally found between the 38° to 65° F (3° to 18° C) isotherms. These constrictions are most likely the result of thermal restrictions of larvae, as optimal larval growth and development fall within 50° to 57° F (10° to 14° C).

Dungeness Crab are commonly found in depths ranging from the intertidal to 300.0 feet (ft) (91.4 meters (m)) and have been observed to occupy depths as deep as 750.0 ft (228.6 m) (Hankin and Warner 2001). Dungeness Crab display some avoidance behaviors towards low salinity habitats and prefer areas with salinities between 25 and 32 parts per thousand. However, Dungeness Crab have been observed moving to areas of lower salinities and less than optimal temperatures to obtain food, especially following periods of starvation (Curtis and McGaw 2012).

1.4 Ecosystem Role

Dungeness Crab play an important ecosystem role as both an opportunistic predator and prey item. Dungeness Crab are secondary consumers, feeding on a wide range of prey items, including bivalves, fish, and shrimp. Dungeness Crab also scavenge for prey items buried within the sediment. Based on gut content analyses, bivalves constitute one of the most important prey items in Dungeness Crab diets. All life stages of Dungeness Crab are important prey items for many species of fish, octopus, other crab, and Sea Otters (*Enhydra lutris*) (Rasmuson 2013).

1.4.1 Associated Species

Dungeness Crab inhabit coastal and nearshore bottom habitat, and are associated with many species, including those listed in Table 1-1.

Table 1-1. Associated species with Dungeness Crab.

Common Name	Species Name
Lingcod	<i>Ophiodon elongatus</i>
Cabezon	<i>Scorpaenichthys marmoratus</i>
Chinook Salmon	<i>Oncorhynchus tshawytscha</i>
Coho Salmon	<i>Oncorhynchus kisutch</i>
Rockfishes	<i>Sebastes</i> spp.
Wolf Eel	<i>Anarrhichthys ocellatus</i>
Staghorn sculpin	<i>Leptocottus armatus</i>
Sea Otter	<i>Enhydra lutris</i>
Green Crab	<i>Carcinus maenas</i>

1.4.2 Predator-prey Interactions

Dungeness Crab are opportunistic, non-discriminatory feeders that eat a variety of other organisms (Rasmuson 2013). Dungeness Crab are known to prey on bivalves, clams, small fish, shrimp, isopods, and amphipods (Gotshall 1977; Stevens et al. 1982; Hankin and Warner 2001; Rasmuson 2013). Dungeness Crab feed by searching the substrate with their chelae for live or dead prey items (Rasmuson 2013). Cannibalism occurs across all age groups, particularly in females preying on recently molted juveniles (Stevens et al. 1982; Hankin and Warner 2001; Rasmuson 2013).

Dungeness Crab, especially larvae and juveniles, are prey for many species across a variety of taxa. Fish predators include Lingcod, Cabezon, Chinook Salmon and Coho Salmon, rockfishes, Wolf Eels, and flatfishes (Wild and Tasto 1983; Hankin and Warner 2001; Rasmuson 2013). Octopus is an invertebrate predator that may prey on Dungeness Crab (Hankin and Warner 2001). In estuaries, Dungeness Crab face predation from Staghorn Sculpin (*Leptocottus armatus*) and the invasive Green Crab (McDonald et al. 2001; Armstrong et al. 2003; Rasmuson 2013). In portions of their range, predation by sea otters may influence the depth distribution of Dungeness Crab

with depths greater than 60 m (197 ft) acting as refuge (Shirley et al. 1996; Bodkin et al. 2004; Rasmuson 2013).

1.5 Effects of Changing Oceanic Conditions

Given the ability of adult Dungeness Crab to reside in a wide range of habitats and their ability to move and seek out preferred habitats (Rasmuson 2013), they are not expected to be directly impacted by climate change. However, geographic distributions of predators and competitors of Dungeness Crab caused by increasing ocean temperatures could shift, as species move to higher latitudes and deeper waters in response to increasing temperatures (McConnaughey and Armstrong 1995; Rasmuson 2013).

Changing oceanic and atmospheric conditions could have negative impacts on larval recruitment success since elevated nearshore water temperatures may cause Dungeness Crab to move to deeper waters for most of their lives. This could potentially impact the timing of larvae if females extrude eggs earlier in the year and are not transported nearshore during the critical time period when coastal upwelling conditions prevail typically in the spring months. Alterations to estuarine and coastal habitats could impact the development of both larval and juvenile Dungeness Crab, but further research is needed to identify and quantify potential impacts in these areas (see section 5.4).

Increasing ocean temperatures, nutrient pollution, and other factors are expected to lead to increased occurrences of harmful algal blooms in coastal and nearshore waters. In recent years, the diatom *Pseudo-nitzschia* spp. has proliferated through algal blooms. This diatom produces domoic acid, a neurotoxin, that bioaccumulates in fish, shellfish, and crustaceans, including Dungeness Crab. Although there is limited understanding of the impacts of this toxin on the crab themselves, high contamination levels in crab meat can lead to fatal poisoning in humans. Elevated levels of domoic acid have caused a delay in the season openers for some if not all areas of the Dungeness Crab fishery in recent years resulting in significant economic impact to the fishery. Increased understanding of the impacts of harmful algal blooms on Dungeness Crab will better inform how climate change may affect this species.

2 The Fishery

2.1 Location of the Fishery

The Dungeness Crab fishery in California is divided into two management areas (the Northern and the Central) that are demarcated by the Sonoma/Mendocino County line (Figure 2-1). The ports between Point Arena and Crescent City encompasses the Northern Management Area; prime fishing grounds occur offshore from Eureka to the Oregon border. The Central California fishery extends from the Gualala River, Mendocino County to Morro Bay. The major fishing areas in this management area are located offshore of Bodega Bay, San Francisco and Half Moon Bay. A minority of landings are landed from Monterey Bay to Morro Bay. The fishery occurs in state and federal waters with the deepest depths ranging from 420 to 600 ft (128 and 183 m) (Hankin and Warner 2001; OST 2013; CDFW pers. comm.).



Figure 2-1. Ports of landing from Crescent City to Morro Bay within the two management areas of the California commercial Dungeness Crab fishery (Basemap provided by ESRI 2019).

On a larger scale, the U.S. Dungeness Crab fishery includes state waters off California, Oregon, Washington, and Alaska, as well as portions of the U.S. Exclusive Economic Zone (EEZ) (OST 2013). Under the Magnuson Stevens Act, each of the three continental U.S. states have the authority to manage their respective fisheries within the EEZ.

2.2 Fishing Effort

2.2.1 Number of Vessels and Participants Over Time

The California fishery consists of a wide size range of Dungeness Crab vessels, such as 22.0 ft (6.7 m) dorries, 30.0 to 60.0 ft (9.1 to 18.3 m) converted salmon trollers,

and trawlers larger than 100.0 ft (30.5 m) in length (Hankin and Warner 2001). The northern region generally supports a larger fishing fleet with larger vessels (Figure 2-2) able to handle the more challenging winter ocean conditions. Salmon trollers are frequently used by the fleet in both management areas. Vessel size restrictions preventing permits from being transferred to larger vessels has generally maintained the fleet characteristics of the fishery. Of the Dungeness Crab vessels that were permitted in 2015, approximately 70% were between 30.0 and 50.0 ft (9.1 to 15.2 m), 12% were over 50 ft (15.2 m), while the remaining 18% were less than 30.0 ft (9.1 m).



Figure 2-2. A large Dungeness Crab fishing vessel leaving Crescent City harbor (Photo Credit: CDFW).

The number of active vessels in the northern and central California Dungeness Crab fisheries have varied over time. The northern fishery has traditionally had a greater level of participation. During the high production seasons in the 1950s, the central California fishery consisted of 200 to 230 vessels, but declined to roughly 100 vessels following decreasing production by the late 1960s. The northern California fleet consisted of 100 to 200 vessels during the 1950s and 1960s, before experiencing large fluctuations in the 1970s, with a low of 61 vessels in 1973 followed by a peak of 410 vessels in 1976.

These fluctuations mirror the dynamics of fishery production at the time. In the 1980s and 1990s, an average of 330 vessels participated per fishing season (Hankin and Warner 2001). Between 2000 to 2001 and 2009 to 2010 seasons, on average 400 vessels made at least one landing. Over the last decade, the average has increased to

over 440 vessels (about 80% of total permitted vessels). This upward trend of more vessels actively participating in the fishery may be a result of the record high seasons of value between 2010-2011 and 2012-2013 (Figures 2-3 and 2-2).

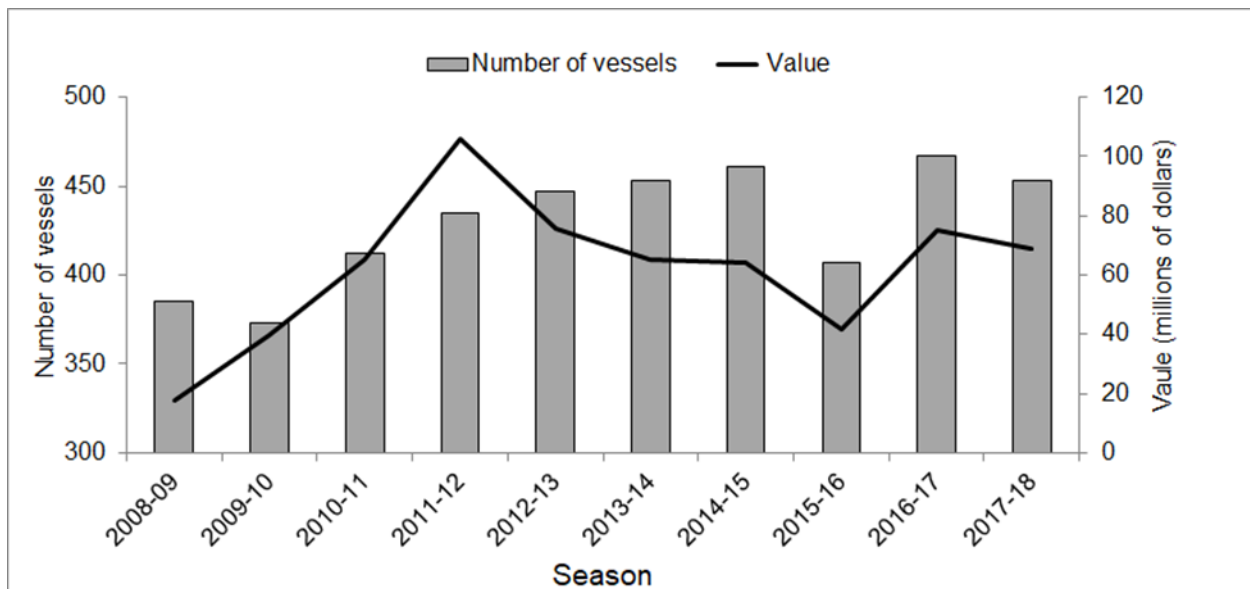


Figure 2-3. Number of vessels that have made at least one landing and ex-vessel value (millions of dollars) (adjusted for inflation from December 2018) for the last ten seasons between 2008 to 2009 and 2017 to 2018 (CDFW MLDS).

A limited entry program was established by the Legislature in 1995 and capped the number of permitted vessels. Since then, the number of permits has declined due to attrition. A total of 552 permits were renewed in 2018, a decline of 10% since 2008 when 616 permits were renewed (Table 2-1). Trap limits established in 2013 placed each permit into one of seven trap tiers based on landings history and capped the total number of traps used by the fleet.

Table 2-1. Number of Dungeness Crab permits renewed in 2018 by Trap Tier (CDFW ALDS 2019).

Tier	Number of allowed traps	Number of permits
1	500	58
2	450	53
3	400	56
4	350	54
5	300	55
6	250	164
7	175	112

The fishery consists of a mobile fleet that not only participates in the two management areas of the California fishery, but also Oregon. The commercial fishery is subject to a “fair start” provision. If the scheduled opening date for a given area is delayed, vessels which fished in another area that season are prohibited from landing, possessing, or taking Dungeness Crab for 30 days in the delayed area. Fair start applies whether the delay was due to low crab quality or human health concerns (see section 3.1 and Figure 3-1). When fishery seasons are delayed, vessels may choose to wait until the delayed area opens since this is the prime time to access crab fishing grounds and waiting 30 days may otherwise reduce their fishing opportunity.

The recreational fishery consists of both shore-based and vessel-based user groups. Shore-based fishing occurs from shore on jetties and piers, whereas vessel-based users will fish from kayak or motorized vessels including charter operations. The fishery is very popular at the start of the season before the commercial fishery opens. It is unknown how many crabbers participate in a given season.

2.2.2 Type, Amount, and Selectivity of Gear

The Dungeness Crab commercial fishery uses traps, referred to as crab pots, that are constructed with two circular iron frames 3 to 3.5 ft (0.1 to 0.3 m) in diameter connected by spokes on the outer edges. The frame is wrapped with strips of rubber and the entire frame is enmeshed with stainless steel wire (Figure 2-3). Each trap must have two escape ports to decrease the likelihood of catching female and sublegal male crab (see section 3.1.2.1.3) and other animals. Commercial crab traps must also contain a “destruct device” designed to degrade over time. This ensures that any crab caught in lost or abandoned gear will eventually be able to escape. The selective nature of the size of the openings, as well as the bait used in the traps, results in trap bycatch rates that are considered comparatively low, to the point that bycatch is not often quantified (Hankin and Warner 2001; OST 2013). A presoak period of 18 hours (for the Central Management Area) or 64 hours (Northern Management Area) prior to the start of the season allows baited traps to be placed in the water. The longer soak time in the north allows the fleet to work around rougher ocean conditions as a result of winter storms. Once the season commences, soak times between trap servicing intervals differ, but requirements stipulate that traps be serviced once every 4 days, weather-dependent.



Figure 2-4: Closed (left) and open (right) Dungeness Crab traps with buoys and float lines (Photo Credit: CDFW).

Every crab trap is required to be marked with a surface buoy. Trailer buoys, which are intended to keep vertical lines buoyant and visible at the surface, are commonly used in addition to the main buoy to facilitate trap servicing.

Because a logbook is not required for this fishery, it is not possible to quantify the actual number of traps fished each season. Maximum trap estimates by fishing season can be derived by adding up each active vessel's trap allotment based on landings activity. For the 2017-2018 season, this maximum was estimated to be 148,425 traps. The actual value could be lower since it is unknown how many vessels fish their maximum trap allotment.

The recreational fishery uses a combination of gear types. The most common are rigid crab traps which are smaller in size and shape (rectangular versus round) compared the commercial fishery. Recreational crab traps are required to have escape ports and a "destruct device," similar to commercial crab traps. Recreational fishers use hoop nets and crab snares (also called loop traps) with up to 6 loops or harvest by hand with the aid of Self-Contained Underwater Breathing Apparatus (SCUBA) gear.

2.3 Landings in the Recreational and Commercial Sectors

2.3.1 *Recreational*

Recreational landings of Dungeness Crab have been estimated to be less than 5% of commercial landings. However, this estimate is based on a concentrated sampling effort by California Recreational Fisheries Survey (CRFS) staff limited to one region of the fishery at the start the 2013-2014 and 2014-2015 seasons. No consistent statewide sampling has been conducted in recent seasons. Collecting recreational catch per unit effort data would provide the Department with a better understanding of the effects of any proposed management changes.

2.3.2 Commercial

Landings in the fishery are characterized by decadal cycles with large fluctuations in yields from one season to the next. Historically, the Northern Management Area comprised the majority of total statewide landings (Figure 2-5).

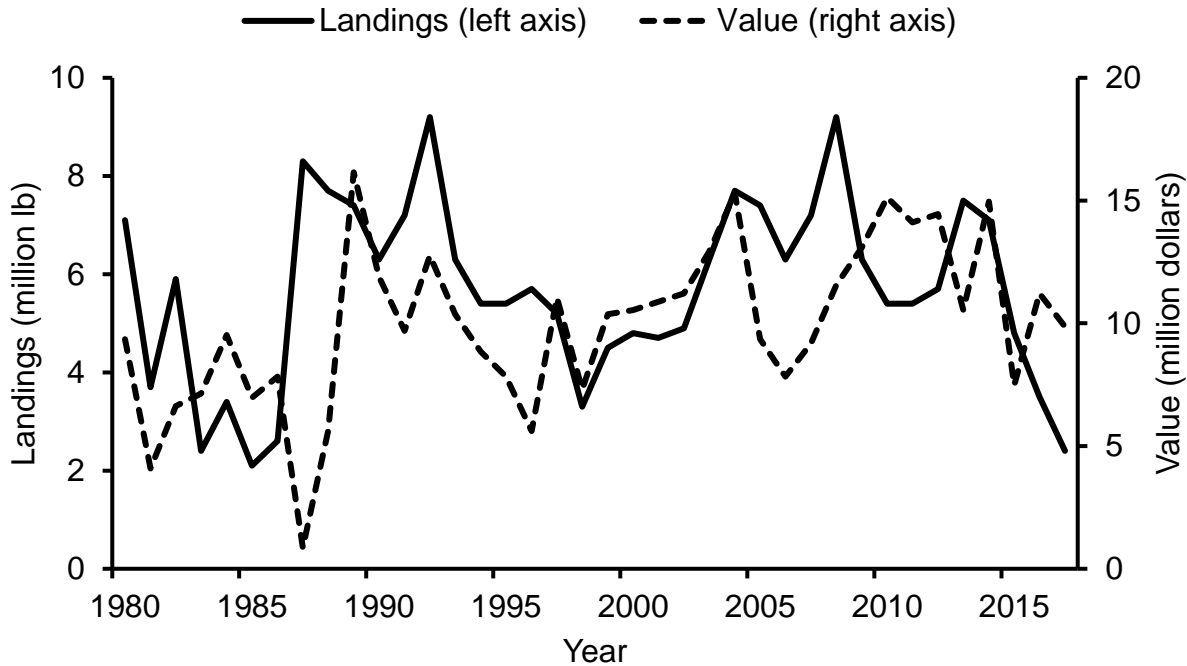


Figure 2-5. Dungeness Crab commercial fishery landings (million lb) and value (million dollars), 1980 to 2017 (CDFW Commercial Fisheries Information System (CFIS)).

Since the 21st century, the California fishery has experienced very productive years with landings averaging 19.6 million lb between 2008 to 2009 and 2017 to 2018 seasons. High landings from both management areas, each contributing about 50% of the state's total, were responsible for the 2011 to 2012 record season of 31.9 million lb. Ten-yr averages for both areas were relatively similar (Northern Management Area: 10.1 million lb; Central Management Area: 9.5 million lb.)

Five record seasons, ranging from 10.5 to 19.1 million lb, have occurred in the Central Management Area since 2010 to 2011. Landings in the Central Management Area prior to this period had never exceeded 10 million lb with the last record set during the 1956 to 1957 season (9.3 million lb). Landings during the most recent season (2017-2018) totaled 5.3 million lb demonstrating the cyclic behavior of the fishery.

The Northern Management Area also experienced higher landings in the recent ten seasons, with the highest five seasons ranging from 11.4 to 16.7 million lb. These high landings are comparable to those in the mid-2000s.

2.4 Social and Economic Factors Related to the Fishery

As opportunities in other fisheries have been reduced in recent decades, the Dungeness Crab fishery has remained a reliable fishery for the state despite significant seasonal fluctuations in production. An increased trend in new fishery entrants may be attributed to recent productive seasons. In the northern, rural part of the state, fishing communities are heavily dependent on Dungeness Crab. A California Sea Grant report showed that between 2003 and 2007, Dungeness Crab accounted for over a third of total ex-vessel value of all fisheries, and the largest share of revenue brought into Northern California ports by any fishery (Pomeroy et al. 2011).

The Central Management Area includes fishing communities located in both rural and urban settings. Many permitted vessels (46%) are registered in home ports within this management area. San Francisco Bay is considered the birthplace of the fishery and Bay Area residents have long-standing traditions of consuming crab during the November and December holidays.

Most vessels and participants of the crab fishery are also permitted for other fisheries. About two-thirds of Dungeness Crab vessels are also permitted salmon vessels. Participants also engage in other state fisheries for Ocean Pink Shrimp (*Pandalus borealis*), rock crab and federal fisheries for Black Cod/Sablefish (*Anoplopoma fimbria*).

Just under 13% of permitted vessels have home ports located outside of California. Many of these are from Oregon, with a smaller contingent from Washington. Some out-of-state vessels fish along the California/Oregon border in both states or move and fish in multiple areas of the state. Vessels that have home ports out-of-state or in-state may be dually permitted and can participate in other states' Dungeness Crab fisheries.

Most landings in the Northern Management Area are made in Crescent City (Del Norte County). The fishing grounds in this area are shared by both California fishermen and those based out of Brookings, Oregon. The Eureka port complex within Humboldt Bay shares similar fishing grounds with the Trinidad port and generally accounts for the second largest landings in the region. The Fort Bragg port complex includes all ports within Mendocino County and is generally less productive due to limited habitat of sand and mud bottom on this part of the coast.

Many landings in the Central Management Area occur in San Francisco Bay, followed by Bodega Bay and Half Moon Bay. Of interest, are landings in the southern portion of the fishery from Monterey Bay to Morro Bay that recently broke 1 million lb for five straight seasons ending in the 2016 and 2017 season. Figure 2-6 shows the contribution of each port complex as an average over the last five seasons from 2013 to 2014 and 2017 to 2018. Crescent City and San Francisco port complexes combined represent about half of total landings while Eureka and Bodega Bay each roughly contribute about 15% (Figure 2-6).

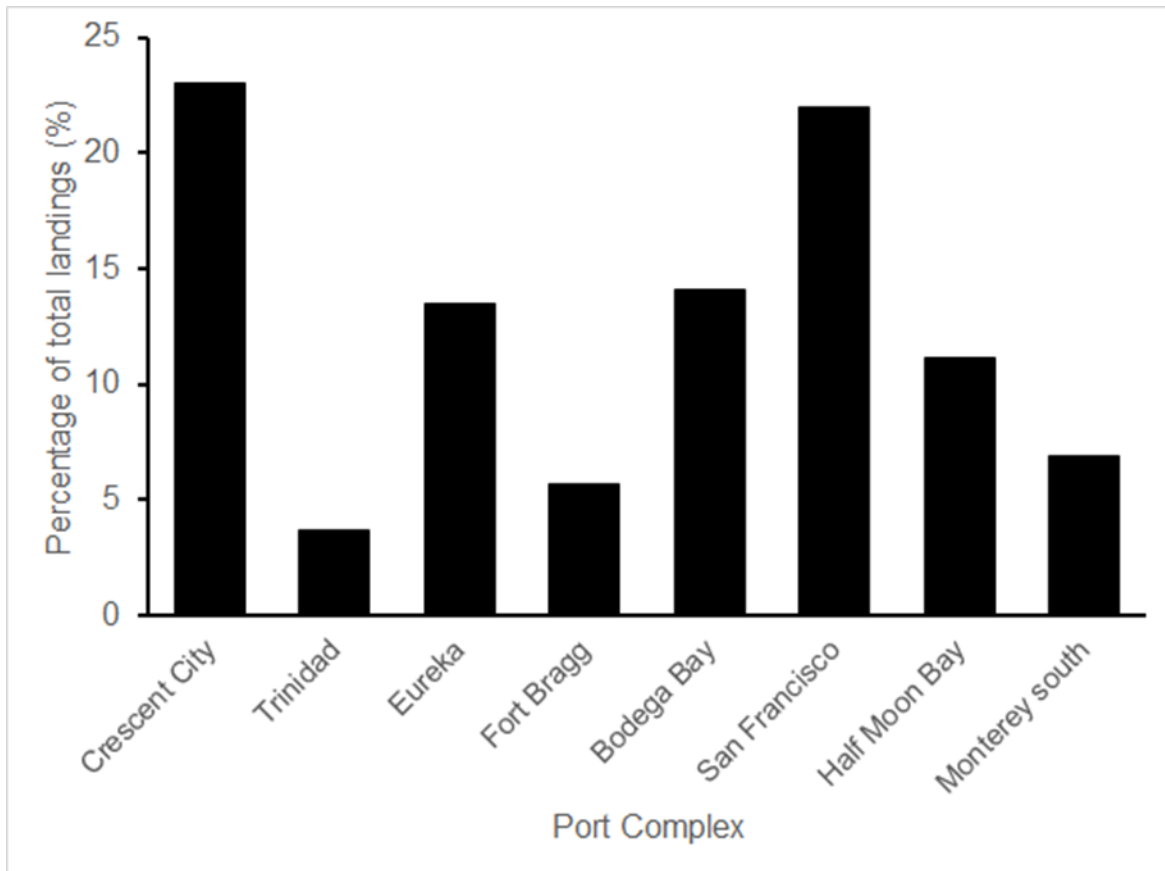


Figure 2-6. Percentage of Dungeness Crab total landings by port complex between 2013-2014 and 2017-2018 seasons (five season average) (CDFW MLDS).

Over the last ten seasons (from the 2008 to 2009 season to the 2017 to 2018 season), Dungeness Crab has remained a highly valuable fishery as a result of both high production and increasing market value (Figure 2-3). The average price per pound increased from \$2.30 to \$4.00 per pound (price adjusted for 2018) and ex-vessel value during the same period averaged \$61.9 million (price adjusted for 2018 dollars). Dungeness Crab was the most valuable commercial fishery in California, exceeding \$80 million annually (CDFW CFIS) in 2012, 2013 and 2016.

Unfortunately, prior fishing seasons have been delayed due to public health concerns of high domoic acid concentrations in crab from harmful algal blooms. To prevent adverse health risks, the opening of the commercial fishery was delayed during the 2015 to 2016, 2016 to 2017, and 2018 to 2019 seasons. A federal disaster was declared for the 2015 to 2016 season due to a 4 month delay in the fishery opener, resulting in a shortened fishing season and lost revenue. Disaster relief funds are not expected to fully reimburse losses incurred by fishery participants from the delay and the difference is meant to promote resilience in the industry. Funds were disbursed to eligible participants starting in June 2019. The full economic impact to industry from these seasonal delays is currently being studied and may not be fully quantified for some time.

3 Management

3.1 Past and Current Management Measures

Regulation of the commercial Dungeness Crab fishery began in 1895, after the State Board of Fish Commissioners (a forerunner of the modern-day Fish and Game Code (FGC)) submitted a report to the California State Legislature describing decreasing catch in historic fishing areas and subsequent expansion into new fishing areas to meet increasing consumer demand (Wild and Tasto 1983). In response to the report's request for management measures to protect and restore the fishery, the Legislature prohibited harvest of female crab in 1897, followed by a seasonal closure in 1903 and a minimum size limit in 1905. These three management measures are collectively known as the "3 S" principle ("sex", "size", and "season") and still form the core of Dungeness Crab fishery management.

Commercial Fishery

The commercial fishery is limited to the harvest of male crab with a minimum carapace length of 6.25 in (15.88 cm), and the fishery is closed when legal-sized crab are mating and molting during the summer and early fall. As described in section 2.1, the state divided into two management areas (Northern and Central) at the Sonoma-Mendocino County line. Only the Northern Management Area is subject to the Tri-State Agreement between California, Oregon and Washington (see section 3.1.1). The fishing season differs slightly between the two areas. The Central Management Area is open from November 15 to June 30 and the Northern Management Area is open from December 1 to July 15. The seasons are established to allow harvesting only when crab are in prime market condition. Typically, crab in central California molt earlier and reach prime condition sooner than in the north.

The season opening date in either area can be delayed due to human health risks (such as elevated levels of domoic acid in crab meat or viscera), while the Northern Management Area can also be delayed due to low crab quality pursuant to Tri-State testing protocols (see section 3.1.1).

In 1995, the Legislature (AB 3337; Hauser) implemented a limited entry system and issued 681 permits (CDFG 2001). For more information on current number of permits see section 2.2.1.

The early Dungeness Crab fishery used hoop nets. Baited traps (section 2.2.2) were introduced in the Crescent City/Eureka area in 1938, and by the mid 1940s became the primary method of take (Wild and Tasto 1983). Current regulations specify requirements for their use (see section 3.1.2.1.3).

Recreational Fishery

The recreational fishery opens on the first Saturday of November in both management areas. The Central Management Area closes June 30 and the Northern Management Area closes July 30. Both male and female crab may be taken in the

recreational fishery, and fishers are limited to ten crab with a minimum carapace length of 5.75 in (14.6 cm).

The smaller minimum size limit and earlier opening date for the recreational fishery is intended to allow recreational fishers an opportunity to catch Dungeness Crab before the more efficient commercial fishery begins competing efforts.

3.1.1 Overview and Rationale for the Current Management Framework

Dungeness Crab is an important fishery along the entire West Coast, and management measures in California, Oregon and Washington are coordinated through the Tri-State Dungeness Crab Committee, overseen by the Pacific States Marine Fisheries Commission pursuant to §302(e) of the Magnuson Stevens Act (16 USC 1856 note). The Tri-State process fosters interstate cooperation in management of the Dungeness Crab fishery and allows the states to consult on issues affecting the commercial fishery.

An element of this collaborative approach is pre-season testing for crab quality. Starting with the 1995-1996 commercial season, the Legislature authorized delays due to crab quality test results for the Northern Management Area conducted concurrently with tests in Oregon and Washington. Based on this testing, the states then decide whether the scheduled season start date should be delayed allowing crab to accumulate more body meat weight. Meat to total body weight ratios less than 25% generally result in a delay.

Historically, crab quality testing has been relegated to the northern portion of the state. This is likely due to the variation in the crab molt period resulting in low condition crab being harvested by the December 1 season start date. In addition, industry in the Central Management Area that rely on the end-of-year holiday markets view quality testing procedures as a potential loss of fishing opportunity during that time period. While others in the region are concerned about an influx of fishery effort during seasons when there are no delays in the north nor in other states' fisheries so are not subject to Fair Start Provisions. In 2014, both the Tri-State Dungeness Crab committee and the Dungeness Crab Task Force (DCTF) reviewed the possibility of including the central management area in the testing protocol. One of the Tri-State Committee's conditions included a uniform start date of the whole west coast fishery, but the DCTF did not reach consensus on this divisive topic. Therefore, the legislature has not considered including the central management area to the preseason testing protocol, and it continues to be an issue that requires further exploration.

The primary management authority for the Dungeness Crab fishery rests with the California Legislature, although recent legislation (SB 1309; McGuire 2018) delegated additional authority to the Department, increasing its ability to be responsive to emerging management concerns, such as increased marine life entanglement risk.

A key advisory body to the Legislature's Joint Committee on Fisheries and Aquaculture, Department, and the Commission is the DCTF. Established in 2008 (SB 1690; Wiggins), the DCTF's charge is to review and evaluate Dungeness Crab fishery management measures. A key recommendation of the DCTF, which was enacted by SB 369 (Evans 2011), was establishing a trap limit program for the commercial fishery. The program was created in response to increased fishing effort by active participants

(resulting in more traps fished by each vessel), and the potential for latent permits (active permits which had not made recent landings) to resume fishing given high market prices for Dungeness Crab and limited opportunities in other fisheries. Similar programs exist in Washington (1999) and Oregon (2006).

As part of the program, Dungeness Crab vessel permit holders were ranked into one of seven tiers based on their total California Dungeness Crab landings during the 2003-2004 through 2007-2008 seasons. Those in the highest tier were allotted 500 traps, and those in the lowest tier were allotted 175 traps (see Table 2-1). Trap allotments are enforced by requiring Dungeness Crab vessel permit holders to purchase buoy tags every 2 yr, which are marked with the permit number and must be affixed to each trap that is fished (see section 3.2).

The “3 S” management approach, limiting the fishery by size, sex and season, has been in place for over a century and supports a sustainable fishery. Statewide catch over much of this period shows the cyclical population dynamics of the species. While the fishery potentially removes 80 to 90% of the older, larger males each year, enough sublegal males remain to fertilize females and males can mate several times before reaching legal size (Hankin et al. 1997). The seasonal closure also protects crab from harvest during the soft-shell (recently molted) and primary breeding periods (see section 1.1.3).

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

There is no current reference point to specify a level of fishing effort or harvest that would be considered overfishing, or to specify a level of biomass which would be considered overfished. There are no current regulations in place to halt overfishing, or to rebuild populations when they fall below biomass thresholds.

Effort in the commercial fishery is regulated through the limited entry and trap limit programs as well as restricting permit transfers to vessels within 5.0 ft (1.5 m) of the original vessel's size. Bag limits in the recreational fishery limit per angler catch. The Department will monitor trends in catch and effort and if concerns should arise will consult with stakeholders on any recommended actions.

3.1.1.2 *Past and Current Stakeholder Involvement*

For over a century, the Legislature's oversight of the Dungeness Crab fishery meant that fishery participants and other interested entities interacted directly with legislators regarding management changes. The DCTF was established as a formal conduit through which fishery participants and resource managers could communicate and is currently the primary mechanism for commercial stakeholder involvement. Membership, specified in FGC §8276.4, includes elected representatives from the following port areas: Crescent City, Trinidad, Eureka, Fort Bragg, Bodega Bay, San Francisco, Half Moon Bay, and South of Half Moon Bay (e.g. Monterey, Moss Landing, Avila/Port San Luis and Morro Bay). The DCTF responds to requests from the Legislature and Department, including review of proposed regulations, and can forward additional recommendations regarding new or amended management measures.

In contrast to the commercial fishery, engagement of the recreational sector is primarily through the Commission.

The California Dungeness Crab Fishing Gear Working Group (Working Group) is another avenue for stakeholder input. The Working Group includes commercial and recreational Dungeness Crab fishermen, environmental groups, and agency (state and federal) representatives. The Working Group was convened in 2015 by the Department, in partnership with the National Oceanic and Atmospheric Administration (NOAA) and California Ocean Protection Council (OPC), to address a recent increase in large whale entanglements in Dungeness Crab gear. The advisory role of the Working Group was recognized in SB 1309 (McGuire 2018), and the group is helping to develop a management framework for addressing marine life entanglements. While there is some overlap in membership between the DCTF and Working Group, the groups have different charges and authorities and largely operate independently.

3.1.2 Target Species

3.1.2.1 Limitations on Fishing for Target Species

3.1.2.1.1 Catch

There is no commercial quota in place, and no pre-determined procedure available for setting or changing a quota. A bag limit is in place for the recreational fishery.

3.1.2.1.2 Effort

A limited entry Dungeness Crab vessel permit is required to participate in the commercial fishery, and under the trap limit program each permit is allocated a maximum number of traps which can be fished.

In addition, when delays in the start of the season trigger fair start provisions (see section 3.1), fishing effort at the start of the season is divided between delayed areas. This is particularly noticeable in the Central Management Area where the first season opener begins. When the Northern Management Area or elsewhere in the Central Management Area is expected to be delayed, vessels will refrain at the start of the season in the Central Management Area, so they are not subject to waiting an additional 30 days once the Northern Management Area or other delayed area opens. Figure 3-1 below highlights the reduction in the number of vessels that participated at the start of the Central Management Area season (lower panel) during the 2012 to 2013 and 2017 to 2018 seasons (when the Northern Management Area season opener was delayed to crab quality) compared to 2014 to 2015 season (when both management areas opened on their scheduled start dates) and fair start did not prevent vessels from participating in both season openers. Of interest during the 2017 to 2018 season, vessels waited an additional period until early February so that crab could reach better market condition, and by mid-February the 30 day clock ended for the January 15 delayed opener. This explains the relatively few numbers of vessels in January and the large increase by February in the Northern Management Area (upper panel).

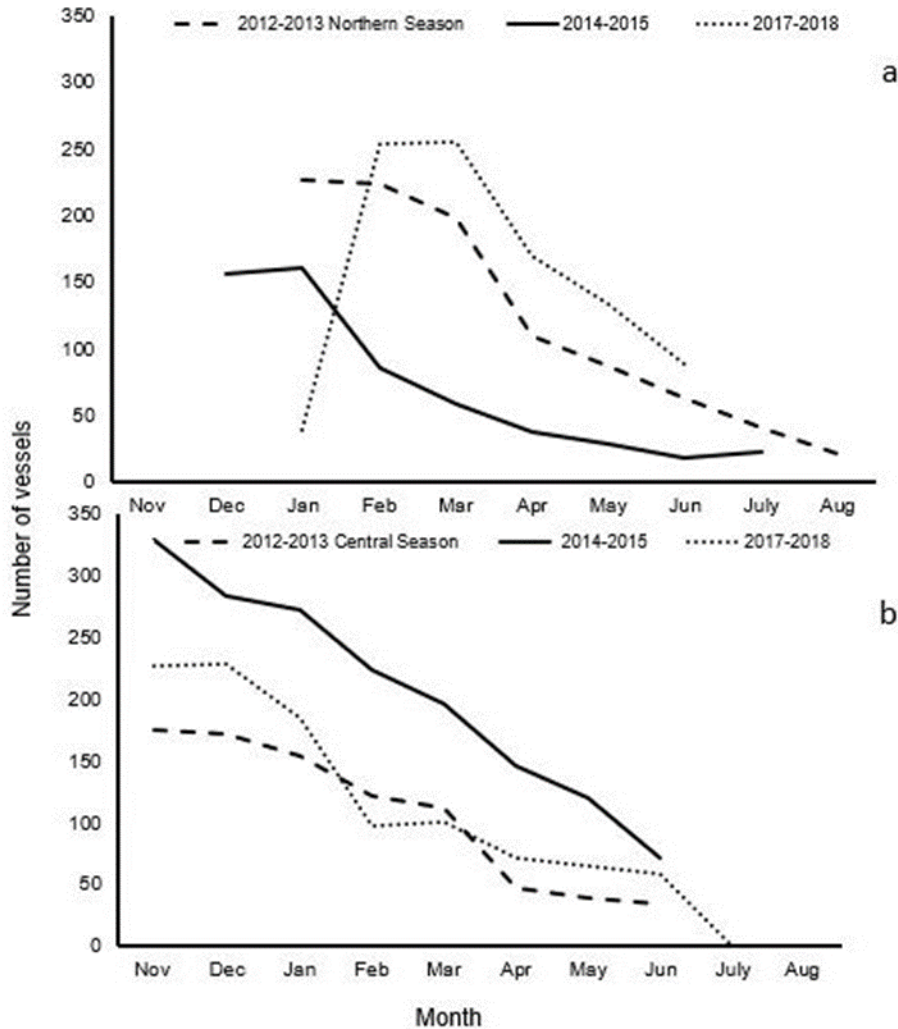


Figure 3-1. Number of vessels that landed each month in each management area, a) Northern and b) Central, by season. A quality delay in Northern Management Area until January 15 with the application of fair start occurred during 2012-2013 (dotted line) and 2017-2018 (dashed line) seasons while no season delay occurred in 2014-2015 season (solid line) (CDFW MLDS).

3.1.2.1.3 Gear

Commercial crab trap configuration is specified in FGC §9011. Traps must contain at least two rigid circular openings not less than 4.25 in (10.80 cm) diameter on the top of side of the trap. Traps must also contain at least one destruct device (defined in §180.2(a), Title 14, CCR), which creates a minimum 5.0 in (12.7 cm) diameter opening in the top or upper half of the trap when the device corrodes. Each trap must be marked with a buoy, buoy tag, and trap tag. The buoy must be marked with the commercial fishing license number of the operator of the trap, and the trap tag must include contact information of the trap owner.

North of Point Reyes, commercial fishing vessels with trawl gear on board can possess up to 500 lb (226.8 kilograms (kg)) of Dungeness Crab (FGC §8834 and §8834.5), creating the potential for a small-scale fishery and establishing a de-facto incidental take allowance for vessels targeting other species. Commercial catch reported on landing receipts suggests virtually all (99.9%) Dungeness Crab in the commercial fishery is caught with trap gear.

The recreational fishery relies on hoop nets, crab traps, crab snares and, to a lesser extent, collection by hand while diving. Recreational crab trap configuration is specified in §29.80(c), Title 14, CCR. The trap must contain at least two rigid circular openings not less than 4.25 in (10.80 cm) diameter, with the lowest portion of each opening no lower than 5.0 in (12.7 cm) from the top of the trap. Traps must also contain at least one destruct device (defined as a single strand untreated cotton twine, size No. 120 or less), which creates a minimum 5.0 in (12.7 cm) in diameter opening in the top or upper half of the trap when the device corrodes. Recreational crab traps are required to have a buoy marked with the operator's ten-digit GO ID (the unique number associated with their sport fishing license). Recreational crab traps can be shared between multiple fishers provided the other individuals have written permission, which may be transmitted via email or text, from the owner that includes the owner's GO ID number.

3.1.2.1.4 Time

Commercial

The Northern Management Area is closed from July 16 to November 30, and the Central Management Area is closed from July 1 to November 14. The scheduled start of the season can be delayed due to low crab quality in the Northern Management Area in 15-day increments until January 15 and due to human health concerns in either Management Area. The Director also has the authority to extend the season in any portion of the two Management Areas, although the season may not be extended beyond July 31 in the Central Management Area or beyond August 31 in the Northern Management Area.

Recreational

The Northern Management Area is closed from August 1 to the first Friday in November, and the Central Management Area is closed from July 1 to the first Friday in November.

3.1.2.1.5 Sex

Only male crab can be retained in the commercial fishery. Both male and female crab can be retained in the recreational fishery.

3.1.2.1.6 Size

Size limits are defined in relation to the carapace length, meaning the shortest distance through the body from edge of shell to edge of shell directly in front of and excluding the lateral spines. The minimum size in the commercial fishery is 6.25 in (15.88 cm), although up to 1% of any load sold may be between 5.75 and 6.25 in (14.61 and 15.88 cm). The minimum size in the recreational fishery is 5.75 in (14.61 cm).

3.1.2.1.7 Area

Commercial fishing is allowed in all ocean and coastal waters, except for the Eel River, Trinidad Bay, Humboldt Bay, Bodega Harbor (FGC §8279) and Crescent City Harbor (FGC §8276).

Recreational fishing with trap gear is allowed north of Point Arguello, except for San Francisco Bay (§29.85(a), Title 14, CCR).

3.1.2.1.8 Marine Protected Areas

Pursuant to the mandates of the 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 scientifically-based ecologically connected network of 124 MPAs. The MPAs contain a wide variety of habitats and depth ranges.

Although MPAs were not designed for fisheries management purposes, they present related opportunities and considerations including the following:

1. They serve as long-term spatial closures to fishing if the species of interest is within their boundaries and is prohibited from harvest.
2. They can function as comparisons to fished areas for relative abundance and length or age/frequency of the targeted species.
3. They can serve as ecosystem indicators for species associated with the target species, either as prey, predator, or competitor.

To varying degrees, MPAs displaced fishing effort when they were implemented. Take of Dungeness Crab is restricted at the following MPAs that were traditional fishing grounds for Dungeness Crab: Pyramid Point State Marine Conservation Areas (SMCA), Point Arena SMR, Stewarts Point SMR, and Bodega Head SMR.

Adult Dungeness Crab which are vulnerable to the commercial fishery typically inhabit sandy or muddy benthic habitats in waters 30 to 200 m (90 to 600 ft) deep. The recreational fishery targets similar substrate types in shallower 10 to 30 m (30 to 90 ft) waters. Along the California mainland and island coasts there are 3,873.5 square mi (10,032 square km) of soft bottom habitat between 0.0 and 200.0 m (0.0 to 656.2 ft) (Table 3-1).

Table 3-1. Soft bottom habitat in depths of 0 to 30 m, 31 to 100 m, and 101 to 200 m (square mi) off California by region (California Seafloor and Coastal Mapping Project 2017).

Depth (m)	North Coast	North Central Coast	Central Coast	South Coast	Total
0-30	391.10	221.47	269.98	528.59	1411.1
31-100	416.30	429.07	555.05	754.63	2155.1
101 - 200	68.75	5.43	67.73	165.41	307.3

While many of the SMCA Areas in the Northern and North-Central Regions specifically allow for commercial and/or recreational harvest of Dungeness Crab, the state’s MPA network prohibits Dungeness Crab harvest from a total of 991.28 square mi of soft bottom habitat (Table 3-2).

Table 3-2. Soft bottom habitat in depths of 0 to 30 m, 31 to 100 m, and 101 to 200 m (square mi) within California MPAs that prohibit Dungeness Crab take by region (California Seafloor and Coastal Mapping Project 2017).

Depth (m)	North Coast	North Central Coast	Central Coast	South Coast	Total
0-30	15.58	13.87	41.94	45.46	233.7
31-100	32.76	79.65	79.65	121.56	627.24
101 - 200	2.87	3.79	17.23	41.28	130.34

3.1.2.2 Description of and Rationale for Any Restricted Access Approach

Due to concerns about excessive harvest capacity in the commercial Dungeness Crab fleet, the Legislature implemented a moratorium on new fishery entrants in 1992. Fishery participation was limited to individuals who had made at least one landing of Dungeness Crab in California within the previous 10 yr (AB 3189; Hauser 1992). The same legislation directed the Department, in consultation with industry and the Tri-State

Crab Committee, to determine whether a limited entry program should be implemented. A restricted access program was subsequently implemented in 1995 pursuant to AB 3337 (Hauser 1994).

3.1.3 *Bycatch*

3.1.3.1 *Amount and Type of Bycatch (Including Discards)*

The FGC (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.

There is currently no monitoring program for bycatch in the Dungeness Crab fishery (i.e. human observers, electronic monitoring, or logbooks), however anecdotal information and catch reported on landing receipts suggests rock crab, octopus, and groundfish species are incidentally taken in Dungeness Crab traps. Provided an individual possesses the appropriate permits, this incidental catch is generally retained and sold. There are known regulatory discards of female and undersized male Dungeness Crab, due to regulations prohibiting possession. Anecdotal reports from fishermen suggest that sea stars (*Pisaster* spp.) and Sunflower Sea Star (*Pycnopodia helianthoides*) are occasionally caught in trap gear, although they have been sighted infrequently since the 2013 sea star wasting epidemic.

Marine mammal interactions with Dungeness Crab gear have become a greater concern in recent years. Starting in 2014, the number of large whale entanglements reported off the West Coast has increased. This increase may be attributed in part to a more frequent reporting by the public as well as from a “rebuilding paradox”, meaning there would be an expectation of encountering a greater number of animals as a stock rebuilds or a populations grows in size. In most cases, the entanglement cannot be attributed to a particular fishery, however in some cases Dungeness Crab gear from California, Oregon or Washington has been specifically identified (NOAA 2016). This is due in part to the distinctive buoy tags attached to commercial Dungeness Crab trap gear. The California Dungeness Crab commercial pot fishery is currently considered a Category II fishery under the Marine Mammal Protection Act (83 FR 5349 2018).

In 2015, the Department, NOAA, and OPC began taking steps to address the issue of whale entanglements in Dungeness Crab gear, including establishment of the Working Group (see section 3.1.1.2). The Department has implemented several regulations aimed at reducing entanglement risk, including reducing the amount of surface gear (lines and buoys) that can be used in the commercial fishery and creating a lost and abandoned trap gear recovery program.

SB 1309 (McGuire 2018) added FGC §8276.1, granting the Director of the Department interim authority to restrict commercial take of Dungeness Crab to mitigate risk of marine life entanglements. This interim authority expires on November 1, 2020 or upon implementation of equivalent regulations. The Working Group has been

instrumental in the design and testing of a pilot model of the Risk Assessment and Mitigation Program (RAMP). The Department has also initiated preparation of an application for an Incidental Take Permit under Section ten of the federal Endangered Species Act (ESA), which would address marine life entanglements in fixed gear fisheries such as Dungeness Crab.

As of June 2019, the Department is preparing regulations to implement the RAMP, under which additional restrictions to time, area, or gear fished may be implemented to address marine life entanglement risk. The Department has also initiated preparation of an application for an Incidental Take Permit under Section ten of the federal ESA, which would address marine life entanglements in fixed gear fisheries such as Dungeness Crab. A Habitat Conservation plan is currently being drafted as part of the incidental take permit process and the RAMP regulations are intended to form the basis of the conservation management strategy.

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

Dungeness Crab trap escape ports, destruct devices, and tending requirements (commercial traps must be pulled and serviced every 96 hours, weather dependent) are intended to minimize mortality of female or undersized male crab regulatory discards. While discard mortality rates vary between studies, post-release survival is generally high. A recent study in Oregon found the lowest discard mortality rates (0.012, 98.8% survival) among hard-shelled male crab, with the highest mortality rates (0.092, 90.8% survival) among soft-shelled males, and intermediate survival rates among female crab (Yochum et al. 2016). Quality testing in the Northern Management Area allows the Department to ensure that crab have sufficiently hardened prior to harvest to ultimately reduce mortality.

The most common bycatch in the Dungeness Crab fishery is rock crab. There are no trip limits or quotas for either the Dungeness Crab or rock crab fisheries, although a limited entry permit is required by the fisherman when fishing for rock crab south of 36° N latitude (lat). Rock crab fishing north of this latitude requires a Northern Rock Crab permit, however the fishery is open access rather than limited entry. Rock crab taken in Dungeness Crab traps (as well as Dungeness Crab taken in rock crab traps) may be retained, provided that the commercial season is open, and the appropriate permits are in place. Unlike the commercial Dungeness Crab fishery, the commercial rock crab fishery is open year-round.

Without logbook data, it is difficult to quantify the amount of rock crab caught incidentally in the Dungeness Crab fishery; however, it is unlikely to impede the ability of the species to fulfill its ecosystem function.

Octopus and groundfish are also caught incidentally in Dungeness Crab traps. There is no targeted commercial fishery for octopus; it can only be retained in trap gear when caught incidentally in rock crab, Dungeness Crab and lobster fisheries. Octopus is occasionally seen mixed with Dungeness Crab on landing receipts, but it is difficult to assess the relative amounts of octopus that are retained versus discarded. Retention of incidentally caught groundfish is allowed if an individual possesses the appropriate state or federal licenses and permits, the fish meets all required size limits, and is caught

during the open season in that area. Sablefish and Lingcod are the two most common groundfish species reported on Dungeness Crab landing receipts, although other rockfish species are occasionally seen. These species are managed directly by NOAA and the Pacific States Fishery Management Council (PSMFC).

3.1.4 Habitat

3.1.4.1 Description of Threats

Dungeness Crab rely on a variety of habitats throughout their life cycle. The zoeal and megalopae stages are pelagic, juveniles settle in shallow estuarine areas, and adults are found in soft-bottomed estuarine and coastal habitats. Anthropogenic threats to estuarine and nearshore areas include urban development and runoff, which impact water quality and habitats (such as eelgrass beds). In particular, the heavily developed San Francisco Bay is known to be an important nursery ground for newly settled Dungeness Crab which later recruit to the San Francisco fishery (Wild and Tasto 1983). For a description of threats posed by climate change see section 5.4.

The soft-bottom habitats inhabited by adult Dungeness Crab are prone to natural disturbance and generally considered more resilient to fishing impacts than more structurally complex habitats. Dungeness Crab fishing occurs in sand and mud-bottom habitats, which are less affected by trap gear than areas with submerged aquatic vegetation or other biogenic structures (Barnette 2001). Dungeness Crab trap gear is passively fished, and on a per-unit basis results in less disturbance than mobile gear such as trawl or dredges. However, large swells or strong tides can move traps along the seafloor, increasing the impact. In addition, the California fishery can deploy nearly 150,000 traps each season, creating the potential for a substantial cumulative impact.

Abandoned and lost fishing gear is a known issue with the Dungeness Crab fishery; however, it is difficult to quantify the amount of gear lost each season. Limited data regarding the extent of lost or abandoned commercial trap gear are only available from 2013 to 2014 season. Under the trap limit program, Dungeness Crab vessel permit holders are not required to report lost gear; however should they wish to replace lost buoy tags (presumably because the gear is lost or abandoned) they may must submit an affidavit to the Department with the number of requested replacement tags. They are only allowed to replace up to 10% of their trap allotment in-season and can replace any number of tags between the two seasons that cover each biennial period. Requested numbers of between season replacement tags has been <10% of maximum potential traps fished as estimated from vessel activity.

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

The Department has limited authority to implement management measures aimed at reducing anthropogenic impacts to Dungeness Crab habitat. Impacts from fishing gear are due to seafloor disturbance from deployment of crab traps during the season, as well as from lost or abandoned trap gear.

Vessels can retrieve lost or abandoned gear belonging to another Dungeness Crab vessel permit under §132.2, Title 14, CCR. Vessels are limited to six traps per trip

without a waiver from the Department, except that an unlimited number of traps can be retrieved from July 16 to October 31 (when the commercial and recreational fisheries are closed in both management areas). Gear retrieval programs operating under section 132.2 have collectively removed over 1,500 lost or abandoned crab traps since 2014. The Department recently implemented a program to permit and incentivize retrieval of lost and abandoned commercial gear after the end of the fishing season under §132.7, Title 14, CCR, which will hopefully reduce the habitat impacts from lost gear. Under this program, Dungeness Crab vessel permit holders are liable for the costs of recovering their lost or abandoned trap gear.

3.2 Requirements for Person or Vessel Permits and Reasonable Fees

Commercial Fishery

In addition to a general California commercial fishing license (\$145.75 for residents in 2019 and 2020) and commercial vessel registration (\$379.00 for residents in 2018 and 2019), participation in the commercial Dungeness Crab fishery requires an annual Dungeness Crab vessel permit, which is assigned to a specific vessel. The permit was \$305.25 for residents and \$601.75 for non-residents for the 2020 and 2021 season. Every other year, fishery participants must pay Biennial Tag Fees for their assigned tier (which includes a \$5.00 per-tag fee and biennial crab trap limit permit fee). Biennial tag fees for each tier are shown in Table 3-3 below:

Table 3-3. Biennial Dungeness Crab trap limit permit and buoy tag fees. Current commercial fishing license and permit information can be found at the Department website. (Accessed on June 24, 2019 www.wildlife.ca.gov/Licensing/Commercial/Description).

Tier	Dungeness crab trap limit permit	Buoy tag fee	Total cost
1	\$1,000	\$5 * 500	\$3,500
2	\$1,000	\$5 * 450	\$3,250
3	\$1,000	\$5 * 400	\$3,000
4	\$1,000	\$5 * 350	\$2,750
5	\$1,000	\$5 * 300	\$2,500
6	\$1,000	\$5 * 250	\$2,250
7	\$1,000	\$5 * 175	\$2,875

Permitholders who wish to replace buoy tags that are lost during the biennial period must pay a \$1.00 fee for each requested replacement tag.

Commercial landings of Dungeness Crab are also subject to a \$0.0333 per pound landing fee

Recreational Fishery

Participation in the recreational fishery requires possession of a general sportfishing license (\$49.94 for California residents in 2019). While an ocean enhancement stamp is required to fish south of Point Conception, the Dungeness Crab fishery largely occurs north of Morro Bay. Current recreational fishing license and permit information can be found at www.wildlife.ca.gov/Licensing/Fishing.

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4 Monitoring and Essential Fishery Information

4.1 Description of Relevant Essential Fishery Information

In response to declining Central California Dungeness Crab landings in the early-1960s through the mid-1980s, the Department initiated a comprehensive Dungeness Crab Research Program (Wild and Tasto 1983) to determine the underlying causes of this decline. Department staff and other partners conducted intensive life history, environmental, and mariculture studies from 1975 to 1979. The findings were synthesized in a Department Fish Bulletin 172 (Wild and Tasto 1983) and this work provides key Essential Fishery Information (EFI) for California Dungeness Crab life history stages. Highlights of the research recorded the timing of the various larval crab stages as well growth rates for juveniles. Monitoring this type information can be useful in understanding whether a relationship exists between larval recruitment and potential crab production several years later, however no biological information currently collected is used to manage the Dungeness Crab fishery (see section 4.2.2).

Information reported on commercial landing receipts is used to calculate seasonal catch, and this limited information is generally summarized for managers to track trends over time and to provide data to stakeholder groups to facilitate understanding of fishery management concerns.

Quality testing is conducted prior to the opening of the Northern Management Area to determine if the season opener should be delayed. This testing addresses marketability concerns from both industry (wanting to harvest good quality crab for price negotiations) and management (wanting crab to have hardened sufficiently to survive handling mortality). All legal-sized crab are collected from commercial traps baited and soaked overnight from two locations north and south of each port sampled at three depth strings: 15 fathoms (fm), 25 to 30 fm and 35 to 40 fm. These crab are weighed at the dock and then cooked and processed for picked meat weights to determine a meat recovery percentage. In addition, an observer on board during the collection day randomly samples crab from two of the six traps in each of the three depth strings by measuring, sexing and counting all crab found in the trap. This annual sampling provides a continuous dataset on size structure for male Dungeness Crab entering the fishery as well as data on bycatch at the ports where quality testing is required. Only the result of the processed crab meat is used in management.

4.2 Past and Ongoing Monitoring of the Fishery

4.2.1 *Fishery-dependent Data Collection*

Historically, fishery managers and enforcement officers used state-issued sales receipts, referred to as fish tickets, to monitor fishery landings. Beginning in July 2018, landings data were transitioned from paper fish tickets to electronic reporting, with mandatory use of E-Tix (maintained by PSMFC as of July 1, 2019). Data collected by both paper and electronic fish tickets include: market category, weight, price paid, date and port of landing, gear used, and commercial fishing block where catch occurred. For

Dungeness Crab, the “market category” is species specific. There are no logbook or observers currently required for this fishery.

The Working Group’s solar logger pilot testing relies on the cooperation of whale watching companies and commercial fishery participants which are using the device on their vessels. The PSMFC is a key partner in this effort as well and are developing an automated process to produce heat maps of vessel fishing or whale watching activity based on these data. The intent is for this process to be automated to readily produce maps in a relatively short period of time to track fishery effort over the course of the season.

4.2.2 Fishery-independent Data Collection

Since the conclusion of the Dungeness Crab Research Program in the 1970s, fishery-independent data collection has been limited. The Department has collected megalopae abundance data at various sites since 2007 (Figure 4-1). A light trap is deployed overnight to capture the megalopae, which are enumerated daily during the settlement season between March and July. Similar research from Coos Bay, Oregon has shown megalopae abundance to be positively correlated with commercial landings 4 yr later and the earlier timing of the spring transition (Shanks and Roegner 2007). Additional analyses could be conducted to determine whether relationships with seasonal ocean conditions are also impacting larval recruitment success in California to potentially develop a recruitment index for Dungeness Crab.

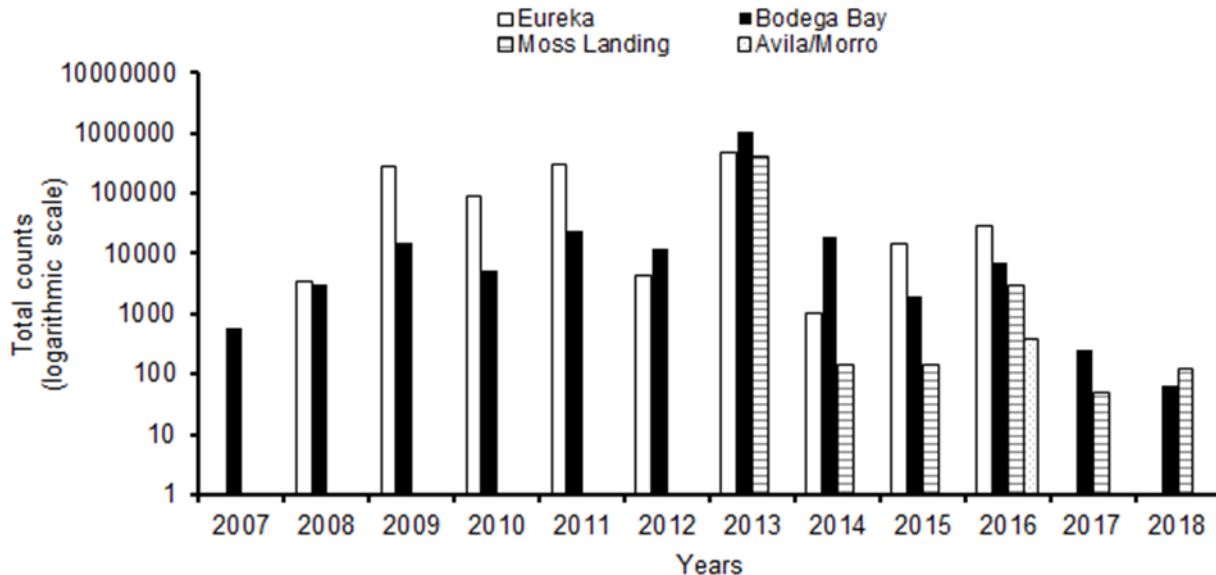


Figure 4-1. Total counts of Dungeness Crab megalopae in the Central Management Area (3 sites) and Northern Management Area (1 site) from 2007 to 2018.

Pre-season quality testing occurs annually, and data on crab numbers, size and sex are available since 2012 except for 2015 when domoic acid concentrations prevented quality tests.

Yearly trawl surveys in the San Francisco Estuary have been conducted by the Department's Bay/Delta region since 1980. Juvenile (age 0) crab collected are enumerated and measured and trends over time have been linked to favorable ocean conditions (see section 5.1).

The California Cooperative Oceanic Fisheries Investigations (CalCOFI) program collects plankton samples in Central and Northern California which may include Dungeness Crab larvae or megalopae, however samples are not routinely assessed for Dungeness Crab presence. The last review of CalCOFI samples (310 samples from 13 surveys conducted between 2008 and 2014) included only 24 Dungeness Crab megalopae.

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5 Future Management Needs and Directions

5.1 Identification of Information Gaps

The final report of the research documented in Department Fish Bulletin 172 in 19XX concluded that unfavorable physical ocean conditions in the region likely played a role in reducing recruitment of larval crab. Decades later, fisheries oceanography has provided tools which establish links between ecosystem indicators and stock dynamics. For example, Peterson et al. (2014) have developed a tool to forecast salmonid recruitment. Developing an ecosystem indicator tool that directly relates to recruitment success of Dungeness Crab megalopae within the California Current Large Marine Ecosystem could provide an estimate of catch about 3 to 5 yr later when adult males enter the fishery (Warner 1987), especially when coupled with size structure of harvestable males at the start of the season. The foundation of this work is supported by other studies that have correlated annual Dungeness Crab megalopae settlement in Oregon and juvenile crab in San Francisco Bay (surveys done by the Department's Bay/Delta Region) to both oceanographic indices and climate forcing models (see section 1.2) (Shanks and Roegner 2007; Cloern et al. 2010). Correlating the California survey of annual megalopae recruits could complement these efforts by providing trends on recruitment variability over a more extensive geographic region.

Fishery-dependent information that the Department does not currently collect for the commercial fishery includes location of traps and Catch Per Unit Effort (CPUE) data over the course of the season. Currently, tracking of fishery landings relies on landing receipt information, which is generally summarized at the port-level. Location of traps during the season and number of crab caught per trap would provide fishery managers with a better understanding of evolving fishing behavior and changes in effort over time within and across seasons to allow for more adaptive future management measures.

The size and number of males in crab traps has been quantified during pre-season quality tests (see section 3.1.1), but sampling does not currently take place during the season. Dockside sampling at the start of the season across the full geographic range of the fishery would provide data on the size structure of commercial landings, allowing the Department to determine potential number of year classes entering the fishery each season and detect spatiotemporal trends.

In addition, no estimates of recreational catch or effort are calculated. There has been growing interest in understanding how many participants comprise this sector and how it contributes to the overall take of the fishery when compared to the commercial sector. Utilizing CRFS, recreational catch data was collected from San Mateo County to Sonoma County for the first 2 months of the 2013-2014 and 2014-2015 recreational season. Over that period, the recreational fishery constituted less than 5% of overall catch for commercial landings at ports within the same region. Effort and catch data reflective of the entire recreational fishery would allow for more informed management decisions when changes to the recreational fishery are necessary.

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

Type of information	Priority for management	How essential fishery information would support future management
Megalopae recruitment ecosystem indicator tool	Medium	Used to determine favorable ecosystem indicators and oceanographic conditions for recruiting young of the year.
Location and CPUE of commercial catch	Medium	Inform adaptive future fishery management decisions; enforcement tool to manage Fair Start and partial fishery closures
Dockside sampling of commercial Dungeness Crab	Medium	Assess size structure of year classes entering the fishery each season and trends over time
Estimate of recreational effort and catch	Medium	Inform potential impacts to recreational fishery participants due to proposed management changes

5.2 Research and Monitoring

5.2.1 Potential Strategies to Fill Information Gaps

Department research on megalopae recruitment (see section 4.1) has not yet been analyzed in relation to physical oceanographic conditions. Quantifying variation in megalopae size in relation to oceanographic conditions would allow testing of the hypotheses that size is a function of nutrient availability and oceanographic conditions. The larvae that are collected are preserved in ethanol and genetic analyses would improve understanding of interannual recruitment differences.

There are various methods available to capture fishery effort information, but tradeoffs in instituting these options. A logbook can document trap numbers by location and crab per trap to track both movement of traps and crab numbers throughout the season. This type of self-reporting by fishermen, however, can be unreliable when information is either incorrectly inputted or when logbooks are not submitted, while data entry and QAQC can be time intensive for staff. Fishing effort can also be assessed through electronic vessel tracking logger devices, which have become more user-friendly and cost-effective in recent years. A solar-powered logger which records vessel positioning and speed information at a relatively fast ping rate of about 1 m⁻¹ is currently being tested by Dungeness Crab fishery participants. This type of mapping can be generated relatively easily once a program script is written to filter for speeds and days (derived from landing receipts) when a vessel is servicing trap gear. This logger data would not be able to provide information on numbers of deployed traps nor crab CPUE.

Recreational data can be ascertained using a report card form, and this type of reporting is employed for other recreational fisheries in the state. Regulations generally require that fishers document effort and/or catch on each fishing day, providing a method to estimate catch and participation in the fishery. Recreational fishers can

submit their report cards through the Department's licensing website, alleviating the burden of data entry by staff. There are similar limitations of self-reporting with the report card as there are with logbooks. Generally, non-compliance of submitting report card data can result in an overestimate of recreational catch since fishers without any catch or effort are generally underreported. Report card data coupled with randomized interviews via phone surveys can help adjust for this error. Improved estimates of recreational fishery catch, and participation could also be obtained by including Dungeness Crab as a priority sampling target for the Department's CRFS program that would require more Department resources to fulfill under the program's current sampling protocols.

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.

Dungeness Crab recruitment studies would benefit from collaborations with biology laboratory programs at universities to both collect and analyze data. Collaborators at California State University, Monterey Bay have been instrumental in collecting daily samples from the Moss Landing light trap, and various undergraduate research projects have used this data to correlate abiotic factors like tide height and temperature with daily abundance. Developing an ecosystem indicator tool with the current Dungeness Crab larval collection dataset would benefit from partnering with a graduate student or post-graduate researcher with modeling expertise.

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.

Since the severely delayed 2015 to 2016 Dungeness Crab season, the start of the Dungeness Crab fishing season has been determined not only by quality testing (for the Northern Management Area), but also by domoic acid concentrations in the viscera of crab sub-sampled across the entire range of the fishery. Domoic acid has continued to delay regions of the fishery both in the 2016-2017 and 2017-2018 seasons.

Section 5523 was recently added to the FGC and describes the authority the Director has in closing or delaying fisheries because of public health hazards like domoic acid. These declarations are based on recommendations issued by the Office of

Environmental Health Hazard Assessment, a division of the California Environmental Protection Agency, in consultation with the California Department of Public Health (CDPH). The Department coordinates with CDPH for the pre-season sample collections and CDPH's Food and Drug Laboratory conducts the domoic acid testing.

After the 2015 to 2016 commercial season, the state of Oregon addressed domoic acid impacts to their Dungeness Crab fishery by dividing the state into biotoxin management zones for testing crab, and they also have the ability to open fishery under evisceration order requiring the removal of guts prior to cooking harvested crab within a designated zone(s). California could adopt a similar sampling protocol for Dungeness Crab in order to establish consistent fishery closure boundaries based on test results. To operate the California fishery under evisceration order would require more in-depth planning and discussion with both health agencies and industry, in addition to legislative and regulatory changes.

Another recent management concern for the fishery involves reducing marine life entanglement risk with Dungeness Crab fishing gear. A recent regulation change, effective the 2018 to 2019 season, restricted the amount of surface gear (ropes and buoys) allowed to be attached to each trap. Working Group members had observed large amounts of rope and multiple buoys removed from entangled whales and suggested that limiting the amount of surface gear might reduce entanglement risk.

A best fishing gear practices guide has encouraged commercial and recreational Dungeness Crab fishermen to maintain their gear in a manner that reduces the likelihood of entanglement interactions. A growing area of interest by both industry and gear innovators is gear modifications that would reduce or eliminate entanglements, while remaining practical and enforceable. The Department is supporting experimental gear testing, including neutral line, splicing line intermittently with lower tensile strength line, and remote deployment of line and buoys at depth (commonly known as "ropeless" gear) in order to determine on the water feasibility of gear modification, which could reduce entanglement risk.

The Working Group is also actively engaged in developing a list of factors which assess whale entanglement risk throughout the Dungeness Crab fishing season and identifying management measures which can be employed to effectively mitigate this risk. As of June 2019, the factors being evaluated as part of the RAMP include modeling of ocean conditions and forage availability, whale concentrations, dynamics of the commercial Dungeness Crab fleet, and recent whale entanglement reports. The risk score for each of these factors is informed by best available data at the time of the assessment.

More research and work to develop these factors further include automation of a forage/ocean model which would forecast whale forage species distributions along the coast based on predicted spring oceanographic conditions, as well as generating fine-scale maps of fishery effort coinciding in time with whale presence. As described in section 3.1.2.1, recent legislation requires the Department to formalize the RAMP in regulations while these research projects will continue to be refined after the implementation of this program.

5.4 Climate Readiness

Understanding the effects of climate change on the Dungeness Crab fishery would help both managers and the fishing community better prepare for both current and future consequences brought about by increasing carbon in the atmosphere. The following provides some limited information on how increasing ocean temperatures, ocean acidification and hypoxia, all predicted to be exacerbated by climate change, may impact the fishery. By no means are the topics listed here complete or fully understood, but are meant to be descriptive of potential impacts currently being studied.

In the short-term, the fishery is already experiencing a new management paradigm of unpredictable season delays due to domoic acid. This neurotoxin is the product of a toxic algal bloom bolstered by warmer than average ocean temperatures. High domoic acid concentrations found in Dungeness Crab in late 2015 were a result of a pervasive bloom of *Pseudo-nitzschia australis* along the West Coast driven by anomalously warm ocean conditions (McCabe et al. 2016). The widespread 2015 event delayed the opening of the season in both management areas and diverted fishery effort into the spring months. During that time, warmer ocean temperatures also resulted in high nearshore concentrations of anchovies, attracting Humpback whales (J. Santora pers. comm.). The delayed season therefore resulted in overlap of intense fishing effort and whales.

Since the federally declared disaster season of 2015 to 2016, “hot spots” for domoic acid have persisted right before and into the scheduled start of the Dungeness Crab season. Shifting ocean temperature regimes, especially within the Dungeness Crab range, may continue to produce algal blooms of *Pseudo-nitzschia* spp. Developing better analytical tools to predict the location, scale, and magnitude of future nearshore blooms could allow the Department, and the fleet, to better plan for and respond to likely domoic acid delays (i.e. are the blooms a coastwide event or localized to a region of the coast).

Lower recruitment success may also be attributed to a warming ocean depending on how climate change affects seasonal oceanic and atmospheric conditions that drive major transport mechanisms like currents and upwelling intensity in the winter and spring months. Since the recent warming trends of 2014 and 2015, local Bodega Bay recruitment numbers of Dungeness Crab megalopae continue to be orders of magnitude less than years (Figure 4-1) associated with the colder water ocean phase of the PDO (Mantua and Hare 2002) that persisted between 2008 and 2013.

Acidic ocean conditions are predicted to occur over the next several decades, and its effects will be actively researched. Many laboratory experiments have exposed the life history stages of larvae to acidic treatments, including Dungeness Crab. One study has shown that survival and development of larval Dungeness Crab was impeded by acidic environments (Miller et al. 2016). While adult Dungeness Crab may be able to withstand ocean acidification impacts by stabilizing their internal pH following exposure to acidic waters, more research is needed on this topic (Ruttimann 2006; Pane and Barry 2007; Rasmuson 2013). Calcium carbonate shell-building molluscs like mussels and clams have also been shown to be highly susceptible to lower pH conditions (Gazeau et al. 2013). An ecosystem model was applied to various West Coast fisheries

to assess future acidic effects on both biomass and fisheries revenues and demonstrated that the indirect costs of declining bivalve prey species for Dungeness Crab may play a role in both declining populations and large economic losses (Marshall et al. 2017). However vulnerable Dungeness Crab may be, the model's findings underscore the need for further work to understand the population's response to ocean acidification.

Lastly, another area of concern is the presence of hypoxia zones developing in shallower, nearshore environments (<50 m (164 ft)) that are expected to intensify due to increases in ocean temperature (Keeling et al. 2010). Large-scale events were experienced in the summers of 2006 and 2007, with scores of Dungeness Crab washing ashore along the Oregon coast. In California, lethargic or dead crab, either in crab traps or washed up along shore, have been reported but it is unknown whether these occurrences are due to localized oxygen depleted zones. Nevertheless, benthic-dwelling nearshore organisms like Dungeness Crab are especially susceptible to hypoxia (Vaquer-Sunyer and Duarte 2008).

Although much research has been conducted to better understand climate change effects on Dungeness Crab, many uncertainties remain regarding the magnitude, timing, and potential synergies of these impacts. The challenges posed by domoic acid impacts have highlighted the importance of adaptive management measures.

Literature Cited

- Alaska Department of Fish and Game (ADFG). 2005. Commercial Fisheries of Alaska. Special Publication No. 05-09.
- Armstrong D, Rooper C, Gunderson D. 2003. Estuarine production of juvenile Dungeness crab (*Cancer magister*) and contribution to the Oregon-Washington coastal fishery. *Estuaries* 26: 1174-1188.
- Bodkin J, Esslinger G, Monson D. 2004. Foraging depths of sea otters and implications to coastal marine communities. *Marine Mammal Science*. 20: 305-321.
- Botsford LW, Wickham D. 1978. Behavior of age-specific, density-dependent models and the northern California Dungeness crab (*Cancer magister*) fishery. *Journal of the Fisheries Research Board of Canada*. 35: 833-843.
- Butler T, Hankin D. 1992. Comment on mortality rate of Dungeness crabs (*Cancer magister*). *Canadian Journal of Fisheries and Aquatic Science* 49: 1518-1525.
- California Department of Fish and Game (CDFG). 2001. California's Living Marine Resources: A Status Report, A Review of Restricted Access Fisheries.
- California Department of Fish and Game (CDFG). 2009. California's Dungeness Crab Fishery: Report to the DCTF - Oct 2009. Marine Invertebrate Management Project. [Presentation].
- California Department of Fish and Game (CDFG). 2011. Annual Status of the Fisheries Report through 2011, Dungeness crab.
- Cloern JE, Hieb KA, Jacobson T, Sansó B, Di Lorenzo E, Stacey MT, Largier JL, Meiring W, Peterson WT, Powell TM, Winder M, Jassby AD. 2010. Biological communities in San Francisco Bay track large-scale climate forcing over the North Pacific. *Geophysical Research Letters* 37: L21602.
- Curtis DL, McGaw IJ. 2012. Salinity and thermal preference of Dungeness crabs in the lab and in the field. Effects of food availability and starvation. *Journal of Experimental Marine Biology and Ecology*. 413: 113-120.
- Department of Fisheries and Oceans Canada (DFO). 2017. Dungeness Crab. Accessed 13 March 2019. <http://www.dfo-mpo.gc.ca/species-especes/profiles-profils/dungeness-crab-crabe-dormeur-eng.html>.
- Gazeau F, Parker LM, Comeau S, Gattuso JP, O'Connor WA, Martin S, Portner HO, Ross PM. 2013. Impacts of ocean acidification on marine shelled molluscs. *Marine Biology* 160: 2207-2245.

Gotshall D. 1977. Stomach contents of northern California Dungeness crabs, *Cancer magister*. California Department of Fish and Game Journal 63: 43-51.

Gutermuth F, Armstrong DA. 1989. Temperature-dependent metabolic response of juvenile Dungeness crab *Cancer magister* Dana: ecological implications for estuarine and coastal populations. Journal of Experimental Marine Biology and Ecology 126(2): 135-144.

Hankin DG, Diamond N, Mohr MS, Ianelli J. 1989. Growth and reproductive dynamics of adult female Dungeness crabs in northern California. ICES Journal of Marine Science 46: 94-108.

Hankin DG, Butler H, Wild PW, Xue QL. 1997. Does intense fishing on males impair mating success of female Dungeness crabs? Canadian Journal of Fisheries and Aquatic Sciences 54(3): 655-669.

Hankin D, Warner RW. 2001. California's Living Marine Resources: A Status Report. *Dungeness Crab*. California Department of Fish and Game. 107-111.

Higgins K A, Hastings J, Sarvela, Botsford LW. 1997. Stochastic dynamics and deterministic skeletons: population behavior of Dungeness crab. Science 276: 1431-1435.

Hobbs R, Botsford LW, Thomas A. 1992. Influence of hydrographic conditions and wind forcing on the distribution of Dungeness crab, *Cancer magister*, larvae. Canadian Journal of Fisheries and Aquatic Science 49: 1397-1388.

Jackson TW, Roegner GC O'Malley KG. 2017. Evidence for interannual variation in genetic structure of Dungeness crab (*Cancer magister*) along the California Current. Molecular Ecology 27(2): 352-368.

Keeling RF, Körtzinger A, Gruber N. 2010. Ocean Deoxygenation in a Warming World. Annual Review of Marine Science 2(1): 199-229.

Mantua, N.J. and S.R. Hare. 2002. The Pacific Decadal Oscillation. Journal of Oceanography 58: 35 p.

Marshall KN, Kaplan IC, Hodgson EE, Hermann A, Busch DS, McElhany P, Essington TE, Harvey CJ, Fulton EA. 2017. Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections. Global Change Biology 23(4): 1525-1539.

McCabe R M, Hickey B M, Kudela R M, Lefebvre K A, Adams NG, Bill BD, Gulland FMD, Thomson TE, Cochlan W P, Trainer VL. 2017. An unprecedented coastwide toxic algal bloom linked to anomalous ocean conditions. Geophys. 43(10): 366-376.

McConnaughey RA, Armstrong DA. 1995. Potential effects of global climate change on Dungeness crab (*Cancer magister*) populations in the northeastern Pacific Ocean. Canadian Special Publication of Fisheries and Aquatic Sciences. 121: 291-306.

McDonald P, Jensen G, Armstrong D. 2001. The competitive and predatory impacts of the nonindigenous crab *Carcinus maenas* (L.) on early benthic phase Dungeness crab *Cancer magister* Dana. Journal of Experimental Marine Biology and Ecology. 258: 39-54.

Miller J, Maher M, Bohaboy E, Friedman CS, McElhany P. 2016. Exposure to low pH reduces survival and delays development in early life stages of Dungeness crab (*Cancer magister*). Marine Biology 163. 118 p.

National Oceanic and Atmospheric Administration (NOAA). 2016. 2015 whale entanglements off the West Coast of the United States. 4 p.

Ocean Science Trust (OST). 2013. Dungeness Crab (*Metacarcinus magister*) Rapid Stock Assessment. Prepared for the California Ocean Protection Council.

Pacific States Fishery Management Council (PSMFC). 1997. Exhibit D: Dungeness Crab/Shellfish Management – Need for Federal Management. 90 p.

Pane E, Barry J. 2007. Extracellular acid-base regulation during short-term hypercapnia is effective in a shallow-water crab, but ineffective in a deep-sea crab. Marine Ecological Progress Series. 334:1-9.

Peterson WT, Fisher JL, Peterson JO Morgan CA, Burke BJ, Fresh KL. 2014. Applied fisheries oceanography: Ecosystem indicators of ocean conditions inform fisheries management in the California Current. Oceanography 27(4): 80-89.

Pomeroy C, Thomson CJ, Stevens MM. 2011. California's North Coast Fishing Communities Historical Perspective and Recent Trends. Final Report to the California State Coastal Conservancy Award 06-128, Publication No. T-072a. 14 p.

Rasmuson LK. 2013. The Biology, Ecology and Fishery of the Dungeness crab, *Cancer magister*. Advances in Marine Biology. 95-148.

Ruttimann J. 2006. Oceanography: sick seas. Nature. 442: 978 p.

Scheding K, Shirley T, O'clair C, Taggart S. 1999. Critical habitat for ovigerous Dungeness crabs. In: Kruse GH, Bez N, Booth A, Dorn M, Hills S, Lipcius R, Pelletier D, Roy C, Smith S, Witherell D. Spatial Processes and Management of Marine Populations: Proceedings of the Symposium on Spatial Processes and Management of Marine Populations; October 27-30, 1999; Anchorage, Alaska. Anchorage, AK: University of Alaska Sea Grant. 720 p.

Shanks L, Roegner GC. 2007. Recruitment limitation in Dungeness crab populations is driven by variation in atmospheric forcing. *Ecology* 88(7): 1726-1737.

Shirley T, Bishop G, O'Clair C, Taggart S, Bodkin J. 1996. Sea Otter predation on Dungeness crabs in Glacier Bay, Alaska. *High Latitude Crabs: Biology, Management and Economics*. Anchorage, Alaska: University of Alaska Sea Grant. 720 p.

Smith BD, Jamieson GS. 1989. Exploitation and mortality of male Dungeness crabs (*Cancer magister*) near Tofino, British Columbia. *Canadian Journal of Fisheries and Aquaculture Science* 46: 1609-1614.

Stevens B, Armstrong D, Cusimano R. 1982. Feeding-habits of the Dungeness crab *Cancer magister* as determined by the index of relative importance. *Marine Biology* 72: 135-145.

Vaquer-Sunyer R, Duarte CM. 2008. Thresholds of hypoxia for marine biodiversity. *PNAS*.105 (40): 15452-15457,

Warner R. 1987. Age and growth of male Dungeness crabs, *Cancer magister*, in northern California. *California Fish and Game Journal* 73(1): 4-20.

Wild PW, Tasto RN. 1983. Life History, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. California Department of Fish and Game. *Fish Bulletin* 172. 352 p.

Yochum N, Stoner AW, Sampson DB, Rose C, Pazar A, Eder R. 2017. Using Reflex Impairment to Assess the Role of Discard Mortality in "Size, Sex, and Season" Management for Oregon Dungeness crab (*Cancer magister*) fisheries. *Canadian Journal of Fisheries and Aquatic Sciences* 74: 739-750.