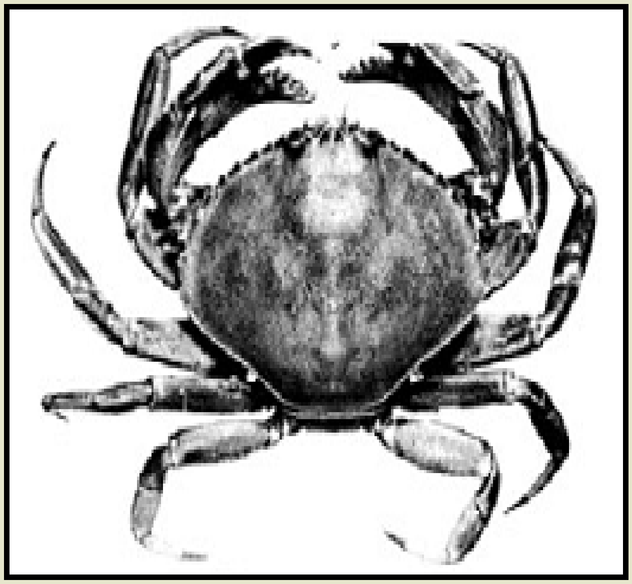
STATE OF WASHINGTON December 2008

Management Recommendations for Washington's Priority Habitats and Species



Dungeness Crab illustration courtesy of California Department of Fish and Game

Dungeness Crab

Cancer magister

By Wendy Fisher and Donald Velasquez

Washington Department of
FISH AND WILDLIFE

GENERAL RANGE AND WASHINGTON DISTRIBUTION

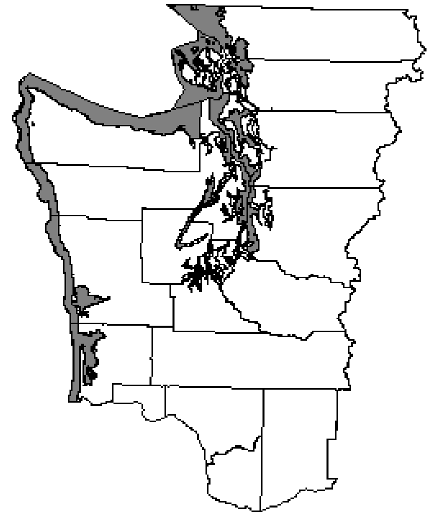


Figure 1. Washington's distribution of Dungeness Crab.

Dungeness Crabs (*Cancer magister)* are found in the coastal marine and estuarine waters of the northeastern Pacific Ocean from the Pribilof Islands, Alaska, to Santa Barbara, California (Jensen 1995). In Washington, Dungeness Crabs live in all marine waters, bays, and estuaries, including Willapa Bay, Grays Harbor, and Puget Sound (Figure 1). Within Puget Sound, they are most abundant in the waters north of Seattle, somewhat abundant in Hood Canal, and much less abundant in southern Puget Sound (Bumgarner 1990).

RATIONALE

The ecological requirements of Dungeness Crabs make them vulnerable to decline. This species is more susceptible to population impacts from harvest, disease, and dredging in areas where it concentrates for mating and egg incubation. It is also susceptible to mortality when caught in derelict fishing gear (e.g., lost or abandoned crab pots and gillnets).

Dungeness Crab is included as a priority species in Washington Department of Fish and Wildlife's (WDFW's) Priority Habitats and Species List (PHS List). They are an important resource for recreational, commercial and tribal harvests. Co-managed by the Washington Department of Fish and Wildlife and Washington's Treaty Tribes, Washington's commercial harvest ranked first among all Pacific states and provinces between 2000 and 2004 (Pacific States Marine Fisheries Commission data). Annual harvest from the Washington coast ranged from 8.6 to 25.0 million lbs from 1995 to 2005 (WDFW Commercial Fish Ticket Database). Over this same period, Puget Sound's annual harvest increased 24% to over 7.7 million lbs (WDFW Commercial Fish Ticket Database, WDFW Recreational Harvest Estimates). Puget Sound accommodates the vast majority of Washington's recreational crabbers (1.5 million lbs harvested annually between 2000-2004).

Dungeness Crabs serve as a critical component in the food web and are a vital food source for many species. Many predators of the Dungeness Crab are important commercial and recreational species, and some are also listed as endangered or threatened by the federal government and Washington State.

HABITAT REQUIREMENTS

Eggs and early larvae

Females extrude egg masses onto their abdomens from October through December along Washington's coast (Cleaver 1949) and in Puget Sound (WDFW trap sampling database). When the eggs are extruded, they are fertilized with sperm stored from mating earlier in the year. Egg-bearing females generally segregate from males and aggregate to burrow into sand/silt substrates of nearshore marine waters. Egg-bearing females are often highly associated with eelgrass beds (MacKay 1942, Armstrong et al. 1988). One study found that females occupying shallower water incubate eggs later than those occupying deeper water (Armstrong et al. 1987). On the Pacific Coast, females incubate their eggs in waters where salinities exceed 30 parts per thousand (Wild 1983). In estuaries like Puget Sound, females incubate their eggs where salinities range from 25-30 parts per thousand (Washington Department of Ecology, long-term marine water quality data). Incubation times range from 64 -123 days depending on water temperature (Wild 1983). Ambient incubation temperature ranges from 12.9-13.9°C (55-57°F) in California (Wild 1983) to 3.1-5.9 °C (38-43°F) in Alaska (Stone and O'Clair 2002a). Temperatures above 16-17°C (61-63°F) are lethal to developing eggs (Wild 1983). While incubating eggs at a site in Alaska, females generally buried themselves in discrete locations of highly permeable, well-sorted sand and returned to the site if moved elsewhere (Stone and O'Clair 2002a). In Puget Sound, females have also beenfound incubating eggs in relatively non-permeable silt/sand (Pam Jensen and Greg Jensen, personal communications).

The rate of egg development increases with temperatures above 10°C (50°F) as does egg mortality (Wild 1983). Eggs generally hatch from January to March along the coast and in portions of Puget Sound (Armstrong et al. 1981, Armstrong et al. 1987, Dinnel et al. 1993). Eggs have been known to hatch as late as April near Everett and Anacortes (Pam Jensen and Donald Velasquez, personal communications), May in Port Townsend, and June in Hood Canal (WDFW trap sampling database). After eggs hatch into larvae, every life stage of Dungeness Crab growth requires that the old shell be shed and a new one be hardened (i.e., molting). There are 6 distinct larval stages, each requiring a molt to move to the next (see figure 2). Larval molts can occur at varying salinities ranging from 10-32 parts per thousand (Buchanan and Millemann 1969). Molt fails when salinity is less than 10 parts per thousand (Buchanan and Millemann 1969). Larvae are sensitive to temperature and salinity changes, with optimal survival at temperatures of 10-14°C (50-57°F) and salinities of 25-30 parts per thousand (Reed 1969, Reilly 1983, Pauley et al. 1989). Larvae migrate daily and are found at the surface by night and at depths of 15-25 m (49 -82 ft) by day (Reilly 1983, 1985).

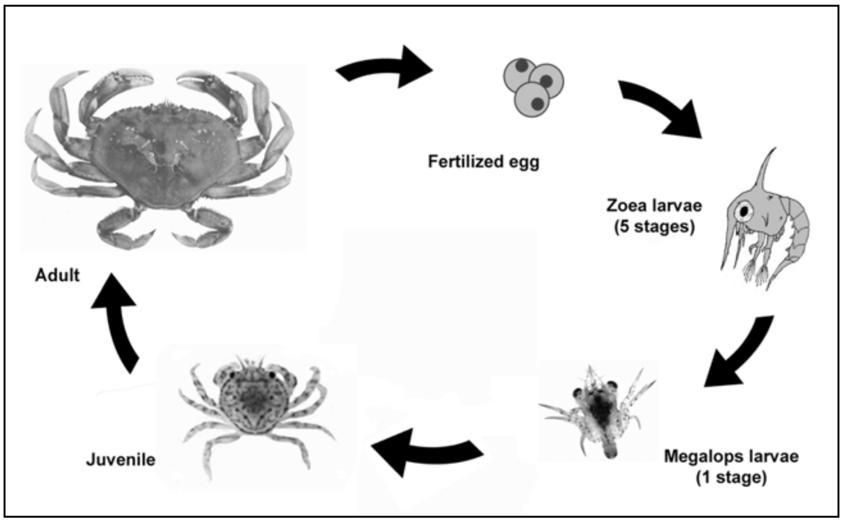


Figure 2. Dungeness Crab life cycle adapted from Pauley et al. 1989.

Late larval and juvenile stages

The megalops or final larval stage prefers salinities similar to those used by early larval crabs. The moderate and more stable temperatures of coastal waters promote a faster progress to the megalops stage than do Puget Sound temperatures. Megalopae migrate daily, moving shallower at night and deeper by day (Booth et al. 1985). Their shallow limit is about 15 m (49 ft; Reilly 1985). Vertical migration varies with location, as those inhabiting Georgia Strait/Puget Sound descend to as deep as 150 m (492 ft) while those on the coast descend to 40 m (131 ft; Jamieson et al. 1989).

Along Washington's coast, megalopae first appear in April and their abundance peaks at about May to June (Cleaver 1949, Lough 1976, Pauley et al. 1989). Three cohorts of megalopae have been described in Washington, each molting into juveniles at different times of the year. Megalopae from the outer coast molt into juveniles from May to June, Hood Canal from June to July, and Georgia Strait/Puget Sound from July to September (Botsford et al. 1989, DeBrosse et al. 1990, Dinnel et al. 1993). Cohorts from Hood Canal may be the most genetically isolated (Dinnel et al. 1993). Temperatures exceeding 18°C (64°F) do not adversely affect megalopae, but such temperatures do reduce early juvenile growth and survivorship (Sulkin et al. 1996).

Molting from late larval through juvenile stages is primarily a nocturnal activity (Fernandez et al. 1994). Early juveniles occupy suitable habitat between +1.22 m (+4 ft) and -0.61 m (-2 ft) mean lower low water (MLLW; Armstrong et al. 1987, McMillan 1991, McMillan et al. 1995) in shallow coastal waters (Orcutt et al. 1975, Stevens and Armstrong 1985) and within estuaries (Tasto 1983, Armstrong and Gunderson 1985, Gunderson et al. 1990). One exception seems to be the river-dominated Columbia River estuary, where Dungeness Crabs often use the subtidal rather than the intertidal zone (McCabe et al. 1988).

Estuaries, particularly large ones (e.g., Grays Harbor, Willapa Bay, Puget Sound), provide essential habitat for juveniles (Carrasco et al. 1985, Armstrong et al. 2003). Juveniles are closely associated with cover in the intertidal that can consist of bivalve shells, eelgrass (*Zostera* spp.), gravel-sand substrates, and/or macroalgae (e.g., sea lettuce; Thayer and Phillips 1977, Dinnel et al. 1986a, Dinnel et al. 1986b). These forms of cover provide juveniles a refuge from birds, fish, and many other predators (Eggleston and Armstrong 1995). In Puget Sound, eelgrass habitat is most abundant in the northern versus the southern basins. One study calculated the percentage of intertidal area covered with eelgrass was 42.2% for the San Juan Islands and north Puget Sound, 32.4% in Hood Canal, 11.6% in the Whidbey Basin, 11.4% for Admiralty Inlet to Tacoma, and 0.2% for southern Puget Sound (Bailey et al. 1998). Cobble or gravel mixed into sand (mixed substrate) can serve as preferred habitat for juvenile crabs even when vegetation is absent. One study conducted in the intertidal zone near Mukilteo, Washington revealed that at this site mixed sand/gravel habitat averaged 8.3 juveniles/m^2 while vegetation/sand habitat averaged 5.6 crab/m^2, and bare sand habitat averaged 0.8 crabs/m^2. This same order of preference was also observed at two other intertidal sites at Edmonds and Picnic Point (WDFW/Snohomish County Marine Resources Committee, unpublished data). Other studies have shown that structurally complex areas composed of bivalve shells and sea lettuce can also be preferred over eelgrass cover (Armstrong and Gunderson 1985, Fernandez et al. 1993a, Dinnel 1986a, Dumbauld et al. 1993). Juveniles use this cover for concealment until their carapace width (CW) reaches about 30 mm (1.18 in; McMillan 1991), after which they can be found on bare sand (Pauley et al. 1989).

Juveniles from the outer coast leave the intertidal for subtidal waters by the first winter, while some smaller juveniles originating from Georgia Strait/Puget Sound remain until spring (McMillan 1991). Juvenile settlement typically starts in late spring and continues into early fall (Dinnel et al. 1993). Juveniles larger than 30 mm (1.2 in) CW migrate daily from subtidal to intertidal in response to prey availability (Stevens et al. 1984). The majority of juveniles that settle outside Grays Harbor and Willapa Bay will later migrate into these estuaries in the spring following settlement (Gunderson et al. 1990). One-year-old crabs predominate at 3 m (10 ft) depth while two-year-old crabs predominate below 12 m (39 ft; Dinnel et al. 1986a). Most crab two years old and older migrate out of coastal Washington estuaries to reside in coastal waters (Gunderson et al. 1990), however this is not the case for crabs that settle in Puget Sound.

Intertidal habitats can have prey densities higher than those in subtidal habitats and are therefore critical for juvenile feeding (Holsman et al. 2003). Juveniles tend to feed on bivalves (Stevens 1982), but also consume smaller crabs (Botsford and Wickham 1978, Fernandez et al. 1993b), shrimps, other crustaceans, fishes, and other mollusks (Gotshall 1977, Stevens et al. 1982).

Subadults and adults

Subadults have been documented in the lower river channels during the summer when river flows are low (e.g., Snohomish River; Pentec 1996, 2004). Intertidal habitats are critical nighttime foraging areas for subadults larger than 40 mm (1.6 in) CW even when these areas lack vegetation or structure (Holsman et al. 2006). Males are sexually mature at about 105-116 mm (4.1-4.6 in) CW, and females at 95-100 mm (3.7-3.9 in) CW (Butler 1960, Orensanz and Gallucci 1988). Most males reach minimum harvest size at about 4 years, when they attain a CW of 159 mm (6.25 in) in Puget Sound or 152 mm (6.0 in) on the open coast. Except during the mating season, adults tend to segregate by sex and prefer sand substrates (Cleaver 1949). Adults are found in waters as deep as 180 m (591 ft), although they prefer depths shallower than 90 m (295 ft; United States Department of Commerce 1991) and they may also forage daily in lower intertidal waters (Stevens et al. 1984, Pauley et al. 1989).

Subadults and adults feed on many of the same prey as juveniles. Dominant prey items consumed vary depending on location. Stevens (1982) reported that as crabs grow they progress from feeding on clams to a diet of shrimp. However, Gotshall (1977) and Butler (1954) reported larger crabs feeding on clams, while Mayer (1973) found larger crabs feeding on shrimp and fish. Gotshall (1977) concluded that adult

Dungeness Crabs are non-specific predators and can readily adjust to various foods. Cannibalism is prevalent, particularly among crabs greater than 60 mm (2.4 in) CW (Stevens et al. 1982).

Adults migrate to shallow waters in spring (March through June) to mate. Males embrace females and mate shortly after the female crab molts and she is in a softshell state (Jensen et al. 1996). Male crabs often mate with multiple females in the same season (Orensanz and Gallucci 1988), and likewise females can also mate with more than one male in a season (Jensen et al. 1996). One study in Alaska indicated that adult crabs occupy depths < 10 m (39 ft) during the mating period and >16 m (52 ft) during the fall and winter (Stone and O'Clair 2002b). Mating pairs can be found as shallow as 0 m MLLW, where they are exposed on extreme low tides. Mating generally occurs in water temperatures of 8 -17°C (46-63°F) in nearshore waters (Pauley et al. 1989). Sexually active adults generally molt once a year, although females occasionally skip molting and can store sperm up to 2 ½ years to fertilize their eggs (Hankin et al. 1989). It takes about two months for an adult crab to fully harden and fill with muscle tissue after a molt (Washington Department of Fisheries, 1978). The maximum life span of Dungeness Crab is 8 to 10 years (Pauley et al. 1989).

LIMITING FACTORS

Oceanographic and biological

Supply of larvae can be a limiting factor in some areas, and survival to metamorphosis is reduced by predation, lack of suitable food items, and currents that may transport larvae away from suitable habitat (Armstrong 1983). Even where larval supplies are not limiting, water temperatures that exceed 18°C (64°F) will reduce growth and induce juvenile mortality (Sulkin et al. 1996). This is one hypothesis that may explain why commercial-scale stocks of Dungeness Crabs do not occur in the middle of Georgia Strait even though adequate larval supply exists.

Global warming has implications for the Dungeness Crab. Global warming may trigger changes in water temperature, salinity, and pH, altering the predators and prey that crabs will encounter. The anticipated rises in sea level will also change the quantity, quality, and location of critical nearshore habitat.

Dungeness Crab populations likely change in response to changing predator populations. In fact, refuge from predation is considered a key post-settlement determinant of subsequent abundance of juvenile Dungeness Crab (Eggleston and Armstrong 1995). Puget Sound salmon, Pacific cod, bottomfish, and Pacific herring stocks are all documented predators (Garth and Abbott 1980, Stevens 1982, Pauley et al. 1989, Reilly 1983, United States Department of Commerce 1991), and changes in these predator populations (which are currently depressed) could affect crab populations. Pauley et al. (1989) summarizes many other documented predators of Dungeness Crab.

Estuarine habitat degradation and shoreline development

Coastal estuaries are home to the highest densities of juvenile Dungeness Crabs (Gunderson et al. 1990) and are important habitat for juveniles and subadults. Given the importance of estuarine habitat, eliminating or degrading estuaries will limit Dungeness Crab populations (Holsman et al. 2003), although specific cases of this cause and effect relationship are not documented. Estuaries are particularly vulnerable to human activities that alter substrate, decrease juvenile cover, increase pollution, and impair water quality (Gunderson et al. 1990). It is estimated that development has altered or eliminated 58% of the original wetlands in Puget Sound (Hutchinson 1988). Four river deltas (Duwamish, Lummi, Puyallup, and Samish) have lost more than 92% of their intertidal marshes (Simenstad et al. 1982, Schmitt et al. 1994). Dikes, port development, shoreline construction, bulkheads, dredging, and the filling of wetlands have all contributed to this decline. One study specifically identified Dungeness Crab as one of the species most impacted by dredging (Tegelberg and Arthur 1977).

Fishery Impacts

Fishery management of Washington's Dungeness Crab is based on the 3 "S" concept, meaning it is regulated by sex, size, and season. Harvest of female crabs is prohibited. Only males above 6 ¼ in CW in Puget Sound or 6 in CW on Washington's coast can be taken because they are considered surplus to the reproductive needs of the population. Fisheries are scheduled to avoid periods when the majority of adult males are softshell to reduce mortality of fragile crabs.

The federal court order of 1994 known as the Rafeedie Decision affirmed that the Federal Treaties of 1865 reserved an equal share of the sustainable harvest of shellfish for the state's Treaty Tribes. Since then, Washington's Dungeness Crab fishery has been co-managed by WDFW and the Treaty Tribes. All State and Tribal crab fisheries use the previously stated regulations on size, sex and season. Ongoing education as well as enforcement of regulations and gear requirements will be necessary to ensure compliance.

Since the Rafeedie Decision, the number of individuals allowed to commercially harvest Dungeness Crab has increased in Puget Sound and Washington's coast. Combined State and Tribal commercial Dungeness Crab harvest from Puget Sound increased from 2.58 million lbs in 1993 to 6.49 million lbs in 2005 (WDFW Commercial Fish Ticket Database). Similarly, Puget Sound's recreational harvest estimates grew from 1.16 million lbs in 1993 to 1.21 million lbs in 2005 (WDFW Recreational Harvest Database). The increase in recreational harvest occurred despite seasons being shortened in some areas from 273 days to as few as 40 days (Donald Velasquez, personal communication). This recreational harvest increase may be related to the increasing human population of the Puget Sound region, improved access to marine waters, and dwindling recreational opportunities in other fisheries.

Handling non-harvestable Dungeness Crabs from traps causes significant mortality, particularly when they are soft-shelled. Mortality from handling soft-shelled crab can range from 15-20% (Tegelberg 1972) to as much as 45% from a single handling of tagged crabs released into the fishery (Kruse et al. 1994). Lost crab pots can continue to kill crab for several years before degrading in marine environments. A Canadian study estimated that the resulting wasted crab was 7% of an area's available harvest (Breen 1987). To limit this wastage, the biodegradable escape cord regulation (WACs 220-72-011 and 220-72-015) was enacted and requires that 100% cotton cord no larger than a thread size of 120 or 1/8 in diameter be incorporated into crab pots to allow crabs to escape if pots are lost. In a local study, cord meeting this requirement took up to 15 weeks to degrade (Snohomish County Marine Resources Committee, unpublished data). Alaska requires lighter gauge cotton, and a review of Washington's cord requirement may be warranted because substantial mortality can occur during 15 weeks of entrapment.

Bottom trawling for finfish or shrimp can also cause significant injury to Dungeness Crabs, particularly when they are in a softshell state. Research done in north Puget Sound estimated that 15% of softshell crab died as a result of handling in otter trawls and 23.9% of the softshell crab had sustained some kind of injury (Washington Dept. of Fisheries 1987). Limiting bottom trawling to depths greater than 36 m (108 ft) reduces the likelihood that large numbers of Dungeness Crabs will be caught in the trawl gear (Washington Dept. of Fisheries 1987).

Toxic contaminants and water quality

Sewage and septic discharges, direct application of chemicals to tidelands, marine dumping, airborne contaminants, and stormwater runoff all introduce toxic substances that may threaten Dungeness Crab survival. Toxic substances can kill Dungeness Crabs, reduce their prey abundance, cause mortality when contaminated prey is ingested, or impair reproduction (Feldman et al. 2000). Certain toxic formulas such as creosote and tributyl tin have been used as treatments to prevent marine life from attaching to pilings and boat hulls. Although use of these chemicals is becoming less common, they are still encountered in the marine environment. The contaminants most toxic to Dungeness Crab are cadmium, organochlorine, organophophorus pesticides, carbamate pesticides, PCBs, and tributyl tin (Eisler 1986, Eisler 1988, Environment Canada 1994, EXTOXNET 1996, United States Environmental Protection Agency 1997, EVS Environmental Consultants 2003). Glyphosate, an herbicide used to combat invasive *Spartina* cordgrass is not concentrated by aquatic life forms and is unlikely to pose a significant risk to estuarine animal life in general (Patten 2003).

Oil spills represent one of the most significant threats to benthic invertebrates including Dungeness Crab (United States Fish and Wildlife Service 2004). The most significant long-term impacts of spill-related poly aromatic hydrocarbons are upon intertidal benthic invertebrates (United States Fish and Wildlife Service 2004). Spills of medium or heavy weight crude oils are particularly damaging to Dungeness Crab because they contaminate the intertidal shorelines where juveniles settle and the sediments where crabs of all ages reside.

Many human activities introduce organic matter into nearshore waters. Heavy loads of organic matter can create conditions of low dissolved oxygen (DO) (Bricker et al. 1999) that can stress and kill many marine species. Waters with low DO can cause Dungeness Crab to become inactive, cease feeding, and die (Bernatis et al. 2007). Low DO was the presumed cause of a mass die-off of Dungeness Crabs off the Oregon Coast (Chan et al. 2008). Animal manure and fertilizers leaching from drainage basins can have devastating effects on nearshore waters by introducing nitrogen and phosphorus. Nitrogen and phosphorus loading can promote algal growth that can deplete oxygen in the water. Animal manure and fertilizers are the two most significant sources of these nutrients to the Puget Sound Basin (Inkpen and Embrey 1998). Heavy growth of *Ulva* spp. algae can result from nutrient loading and can produce a toxin (dopamine) that impairs the growth of juvenile crabs (Harvey unpublished presentation, 2007). Other common sources of organic loading are sewage outfalls (Bowen and Valiela 2001) and marine-based lumber transfer facilities (G3 Consulting Limited 2003).

Activity in nearshore waters can cause suspension of fine sediments that can impair filter feeding and/or oxygen exchange for many forms of marine life including Dungeness Crab (Anchor Environmental 2003). Adult Dungeness Crabs have been shown to experience mortality rates ranging from 5% to 50% when exposed to suspended clays for 8 days at 9,200 mg/L Total Suspended Solids (TSS) and 32,000 mg/L TSS respectively (McFarland and Peddicord 1980).

Impacts of non-native species

The establishment of non-native cordgrasses along Washington's marine shorelines threatens to decrease intertidal habitat. Once established, cordgrasses raise substrate elevation and interrupt sediment flow resulting in the loss of intertidal habitat critical to Dungeness Crabs (Washington State Department of Agriculture 2005).

The non-native Green Crab (*Carcinus maenas*) has populated coastal Washington and Vancouver Island (Behrens Yamada et al. 2005). Green Crab prey on Dungeness Crabs of equal or lesser size (Grosholz and Ruiz 2002) and displace them from refuge habitat. Washington's current Green Crab distribution does not overlap juvenile Dungeness rearing areas (McDonald et al. 2001). As of late 2007 green crabs have not been found in Puget Sound or the inland waters between Vancouver Island and the mainland (Behrens Yamada and Gillespie 2008)

Disease

At least three significant diseases that cause mortality in Dungeness Crab have been identified in Washington waters. A *Chlamydia*-like organism (Sparks et al. 1985) infects blood cells and hepatopancreas and causes death within 15 days in the laboratory. It has been documented in Willapa Bay and Puget Sound and is associated with low water temperatures. A *Mesanophrys* spp. ciliate (Cain and Morado 1991, Morado 1993) causes the destruction of blood cells and muscle tissue and eventual causes mortality. It has been documented in Samish Bay, and these ciliates occur broadly along the Pacific Coast. Infections of a microsporidian parasite called *Nadelspora canceri* causes "Needles Disease" which has been documented in Dungeness Crabs from northern California to southern Washington (Childers et al. 1996). The parasite's needle-like spores replace the host tissue including muscle, heart, gonads, gills, and hepatopancreas. Laboratory experiments have shown significantly higher rates of mortality among crabs infected with "needles disease" versus uninfected crabs (Childers 1994).

MANAGEMENT RECOMMENDATIONS

Shoreline and nearshore protection

Given most of the Dungeness Crab lifecycle occurs in nearshore waters, activities (e.g., construction, dredging) in or around Washington's nearshore can impact vital habitat. To maintain characteristics important to Dungeness Crab, nearshore habitat used by this species should be considered when developing and carrying out applicable federal and state regulations.

Pertinent federal laws administered by the Environmental Protection Agency include the Shore Protection Act, Clean Water Act, and Coastal Zone Management Act (among others). The Corps of Engineers also issues permits for significant work below the mean higher high water line under Section 10 of the US Rivers and Harbors Act and Section 404 of the Clean Water Act. To comply with these laws, shoreline and nearshore construction must meet the requirements to obtain a permit.

Washington State laws that apply to nearshore projects include the Shoreline Management Act (SMA; RCW 98.58), State Environmental Policy Act (RCW 43.21C), Growth Management Act (GMA; RCW 36.70A), and the state's Hydraulic Code (Chapter 77.55 RCW).

Under GMA, SMA, and Washington's Hydraulic Code, Dungeness Crab habitat should be considered when developing local critical areas ordinances and shoreline master programs, as well as when carrying out the Hydraulic Code. GMA provides guidance and protects critical areas that include eelgrass and kelp beds (WAC 365-190-080). It also asserts that "projects shall incorporate mitigation measures as necessary to achieve no-net-loss of productive capacity of fish and shellfish habitat" (WAC 220-10-300). Under SMA, the presence of Dungeness Crab habitat should be included in shoreline inventories and assessments. Shoreline environment designations should consider Dungeness Crab habitat when determining the level and types of development that are permitted. The Washington State Hydraulic Code asserts that "in the event that any person or government agency desires to undertake a hydraulic project, the person or government agency shall, before commencing work thereon, secure the approval of the department (i.e., WDFW) in the form of a permit as to the adequacy of the means proposed for the protection of fish life. A hydraulic project means the construction or performance of work that will use, divert, obstruct, or change the natural flow or bed of any of the salt or freshwaters of the state."

The following recommendations can aid in developing and carrying out these regulations. Local governments and project applicants are encouraged to consult with their local WDFW habitat biologist during project planning to adequately protect this and other species. Projects that permanently alter shoreline, estuarine, and shallow subtidal habitats are the most likely to have long-term impacts to Dungeness Crab and should therefore be most scrutinized in the land use planning process.

Avoid, minimize, and mitigate shoreline and nearshore development impacts

When planning or reviewing shoreline and nearshore development, the following three goals should be undertaken in sequential order. First, avoid impacts if at all possible to Dungeness Crabs or their habitat. Second, plan to minimize construction impacts if they are unavoidable. Third, plan to mitigate for any of those unavoidable impacts. Many of the following recommendations for construction have been taken from existing documents including the white papers on dredging (Nightingale and Simenstad 2001a), overwater structures (Nightingale and Simenstad 2001b), shoreline development (Williams and Thom 2001) and low impact design standards (Hinman 2005). These documents make recommendations meant to protect the nearshore habitats that we have previously identified as being critical to Dungeness Crabs. Any recommendation that is not supported by one of these four documents is supported by literature that was references in the "Limiting Factors" section or will be followed by a supporting citation(s).

Pre-planning

- Conduct multi-season assessments of a specific site's physical and biological characteristics. This should include a survey of benthic substrates, vegetation, sources of pollution, velocities, water temperature, salinity, and rates of sedimentation. A requirement for a crab density/abundance survey will depend on an evaluation of the size and scale of the construction project.
- Incorporate construction setbacks into regulatory framework to avoid impacts.
- Discourage construction of bulkheads and placement of riprap along shorelines. These prevent the natural processes that promote the mixed substrates in the intertidal zone that can serve as important habitat for settlement of juveniles and foraging by larger crabs.
- Discourage any conversion of intertidal habitats that are critical crab nursery and forage areas to terrestrial or subtidal habitat. With this in mind, dike construction should be discouraged because it prevents estuarine lowland flooding and decreases the amount of available intertidal habitat.
- Discourage additions of overwater structures to existing shorelines to prevent shading of nearshore vegetation, disruption of water currents, and altering natural substrate regimes.
- Discourage dredging whenever possible.
- Discourage boat docks, particularly where upland boat storage facilities provide a viable alternative.

Recommendations to minimize impacts due to dredging

- Reduce the volume of dredged materials.
- Where possible, use sheet pilings along the edges of trenching projects to minimize trench widening and prevent crab and other species from entering the construction zone.
- Require clamshell dredges that confine excavated material and prevent its suspension. The entrainment factor (fraction of crab removed) for a clamshell dredge is only 5% of the entrainment factor of hopper and pipeline suction dredges (Armstrong et al. 1991). Loss factors (percent of crab killed of those entrained) are 10% for a clamshell dredge, 5-86% (depending on crab size) for a hopper dredge, and 100% for a pipeline dredge (dredge material deposited elsewhere; Armstrong et al. 1981, Stevens 1981).
- Dredging in intertidal areas should be limited to low tides to avoid potential impacts to foraging crabs and limit suspension of sediments in the water column. Accordingly, dredging in subtidal channels should be limited to high tides when the larger juveniles and subadults have moved into the intertidal areas to feed (Stevens et al. 1984).
- Consider using uncontaminated excavated sediments for nearby habitat restoration and enhancement.
- If not used for enhancement or restoration, dispose sediments at appropriate upland sites.
- Move sediment holding barges periodically to prevent shading nearshore vegetation.

Recommendations to minimize impacts of overwater structures and shoreline modifications

- Use as few pilings as necessary to limit shading and limit the effects of altered current flows along the nearshore.
- Use concrete or metal pilings that reflect light instead of black piles. This will reduce shading and avoid the introduction of toxic chemicals from treated wood pilings.
- Increase height of overwater structures to allow light transmission and prevent shading of vegetation.
- Decrease the length and width of the structure to limit pilings needed and the associated shading effect and disruption of natural currents.
- Place structures in deeper waters and align them north to south (where possible) to avoid unnecessary shading of vegetation.
- Incorporate light transmitting materials in the design, including glass blocks and gratings.
- Use reflective coatings or paints on the undersides of structures.
- Use floating wave attenuators in place of breakwaters or jetties when appropriate. Recognize that these often have limitations because they require maintenance and can experience complete failure.
- If solid structures are necessary, incorporate designs that are open near the bottom to allow water circulation and sediment transport.

Recommendations for construction timing

- The best season for construction in the intertidal and shallow subtidal zones to avoid impacts on mating pairs of crab is August through February (Table 1). Mating of Dungeness Crabs occurs primarily from March to June (Pauley et al. 1989). At this time, females are soft shelled and thus are more vulnerable, and mating pairs are very reluctant to relocate when disturbed.

Table 1. Most favorable months to avoid construction impacts to important Dungeness Crab habitat.

	Month											
	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov
Intertidal and shallow subtidal zones to avoid impacts on mating pairs.	■	■	■						■	■	■	■
Intertidal zone to avoid impacts on smaller juveniles.	■	■	■	■	■	■					■	■
Subtidal sites where egg-bearing females aggregate‡.				■	■	■	■	■	■	■		

‡ Disturbances such as construction in these sites should be avoided if all possible. If impacts to these sites cannot be avoided, work should occur only during the months that they are not occupied (March-September). These sites should be restored to their original substrate, grain size, and slope by the following winter.

- The best season for construction in the intertidal zone to minimize negative impacts on smaller juvenile Dungeness Crab is late fall to early spring (October through May). Even though some juveniles persist in the intertidal over winter, the highest densities occur in July and August and a significant portion have grown large enough to move to subtidal habitat by October (Table 1).
- Subtidal sites where egg-bearing females aggregate should first be identified and avoided if at all possible. Identification of these sites is best accomplished with a diver-based benthic survey performed sometime from mid-November through January. If impacts to these sites cannot be avoided, work should occur only during the months that they are not occupied (March - September). These sites should be restored to their original substrate, grain size, and slope by the following winter (unless dredging).

Recommendations for mitigation and restoration

- Replant impacted eelgrass beds once project is complete.
- Whenever possible, the removal of existing dikes should be encouraged to expand intertidal surface area, particularly in lower estuaries. Some examples of Washington dike removal projects include the Wiley Slough project (Skagit River estuary), Union Slough projects (Snohomish River estuary), Smuggler's Slough project (Nooksack River estuary), Skokomish west bank restoration project, Qwuloolt marsh restoration (Snohomish River estuary), and the lower Nisqually River project. These can serve as models for future dike removal and estuary restoration efforts in the state.
- Whenever possible, projects to remove bulkheads and riprap should be encouraged. Some examples of bulkhead or riprap removal projects are the Seahurst Park bulkhead removal and the Belfair State Park estuary restoration.
- Where possible, wet storage and transport of logs should be replaced by barging/dry transfer and upland storage. Log rafting and transfer activities contribute to habitat degradation through direct impacts from grounding of logs/bundles and boom sticks. The accumulation and subsequent decomposition of bark and wood debris from these operations contributes to anoxic conditions. Restoration of intertidal habitat values and functions can be achieved if rafting is eliminated or moved to deeper, well-circulated waters and the accumulated wood debris is removed.

Reduce impacts of pollutants and impaired water quality

- Discharges of stormwater into estuaries and marine waters should be minimized. If done correctly, the use of Low Impact Development (LID) standards can eliminate or greatly reduce stormwater runoff into estuarine and marine areas. A recent project in Seattle (Street Edge Alternative) resulted in a 97% reduction in total stormwater volume within a two-block area. Extensive details of how LID standards can be put into practice are available in "Low Impact Development: Technical Guidance Manual for Puget Sound" (Hinman 2005).
- Reduce exposure of Dungeness Crab, particularly at the larval and juvenile stages, to contaminants with proven toxicity as identified in the "Toxic Contaminants and Water Quality" section.
- Efforts to reduce the risk of oil spills should be encouraged. All efforts should be made to develop effective oil spill response and containment plans.
- Discharges or dumping of organic material into estuarine and marine waters that reduce DO levels below 5 mg per liter should be discouraged (see Hull and Bryan 2005).
- Projects that decrease nutrient loading in marine/estuarine waters should be encouraged. Support strategies to prevent animal manures from being introduced into water drainages. The use of fertilizers along shorelines should be strongly discouraged. If fertilizers must be used, sufficient setbacks from the shoreline should be established.

Reduce impacts of fisheries

- Support effort to improve compliance with current Dungeness Crab regulations through public education and enforcement.
- Trawling for finfish and shrimp should be limited to depths greater than 36 m to reduce injury and mortality to Dungeness Crab when they are permitted.
- Continued efforts should be made to prevent crab traps from being lost by both commercial and recreational crab fisheries. This should involve distributing information about the preferred routes of larger vessels and log tows that can accidentally cut buoys from traps and drag them to deeper water. Enforcing the existing regulation that requires weighted buoy lines on crab pots will reduce pot loss when boat propellers cut floating lines.
- Support ongoing programs that identify the location of derelict crab traps for removal.
- Whether or not the current regulation requiring escape cord is amended, additional education and enforcement of the existing escape cord regulation is needed. A 2006 survey of lost traps in Port Susan revealed that 42% of commercial traps and 24% of recreational traps recovered did not have the required escape cord (Natural Resource Consultants 2005, 2006). Trap vendors should be encouraged to provide appropriate escape cord when traps are sold.
- Strongly discourage transfers of live Dungeness Crab from one site to another. WDFW Policy POL-C3006 establishes the framework for shellfish transfers and disease control. Proper implementation of this policy should minimize the threat posed by the diseases identified earlier. Quarantine facilities and the expertise to properly diagnose diseases of Dungeness Crab should be expanded.

Avoid and reduce negative impacts of non-native species

- Encourage regulations to prevent the introduction of non-native species.
- Support efforts to evaluate species and regularly update the lists that are classified as regulated and prohibited within the state.
- Support efforts to prevent the European green crab from expanding its range, even though the potential impacts to native *Cancer* crabs are not fully understood.
- Support efforts to remove *Spartina* in Washington. The Puget Sound eradication program from 1997 through 2001 reduced coverage of *Spartina anglica* by an estimated 13% (Hacker et al. 2001).

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WDFW. Unpublished recreational crab harvest data maintained by the Fish Program, Marine Resources Division.

WDFW. Dungeness Crab trap sampling database maintained at the Point Whitney field office.

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