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Issues Concerning Dungeness Crabs and the Demonstration Project for the Columbia River Nearshore Beneficial Use Project

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Abstract: To address concern about the depletion of sand along the coasts of Washington and Oregon, the Nearshore Beneficial Use Project has proposed to use locally dredged materials to replenish nearshore sands and provide protection to the south jetty of the Columbia River from wave impacts and associated erosion. Dungeness crabs, *Cancer magister*, are a valued resource on the west coast of the United States, well known for commercial and recreational harvests. There are concerns about the potential effects of dredged material placement on Dungeness crabs. This white paper reviews the biology of Dungeness crabs and what is known about the effects of disposal of dredged materials on Dungeness crabs and then discusses what needs to be considered in the design of monitoring for effects during the demonstration project.

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Introduction

Dungeness crabs, *Cancer magister*, are a valued resource on the west coast of the United States, well known for their commercial and recreational harvests. Open-water disposal of dredged materials is a necessary part of the process by which dredging of navigation channels brings the depth of those channels to their authorized levels. Concern for the effects of dredging and disposal of dredged materials on Dungeness crabs has been long-standing and has generated research studies since the 1970s.

Recently, a new concern has arisen: the depletion of sand along the coasts of Washington and Oregon. Sand depletion in nearshore areas leads to erosion that threatens economic and ecological resources of the Washington and Oregon coasts. Concerns for sand depletion and protection of nearshore economic resources, such as the south jetty of the Columbia River, led to the development of the Nearshore Beneficial Use Project. The intent of this collaborative project is to explore how the placement of dredged materials could be used to offset the depletion of naturally occurring sand in the nearshore littoral cell. The Nearshore Beneficial Use Project has proposed to use dredged materials to rebuild nearshore sands and to provide protection to the south jetty from wave impacts and associated erosion.

A limited demonstration project proposed for the summer of 2005 intends to place approximately 30,000 cubic yards of sandy dredged materials from the Columbia River at a site 0.5 miles to 3 miles south of the south jetty in water depths from -40 feet to -60 feet Mean Lower Low Water (MLLW). A larger demonstration project is proposed for subsequent years that would place approximately 150,000 cubic yards of dredged materials in the same general location. After the demonstration projects, a full-scale project could place as much as 1 million cubic yards per year in the selected area. There are concerns about the potential effects of placement of dredged materials on Dungeness crabs. The Institute of Natural Resources (INR) of Oregon State University is working with the Nearshore Beneficial Use Project to discern and resolve resource issues associated with the project. INR requested that the Marine Sciences Laboratory examine the issues concerning Dungeness crabs and the project. This white paper provides a review of the biology of Dungeness crabs and what is known about the effects of disposal of dredged materials on Dungeness crabs and then discusses what needs to be considered in the design of monitoring for effects during the demonstration project.

Dungeness Crab Biology

Dungeness crabs, *Cancer magister*, occur from the Aleutian Islands in Alaska to Magdalena Bay in Baja California (MacKay 1942; Waldron 1958). Dungeness crabs show a preference for sandy bottoms but can be found on other bottom types. The depths of occurrence are from the intertidal zone to over 500 feet, although the commercial fishery for Dungeness crabs generally occurs at depths less than 150 feet.

Dungeness crabs use both the nearshore ocean environment and the estuary in their life cycle (Waldron 1958; Tasto 1983; Armstrong et al. 1987; Gunderson et al. 1990; Rooper et al. 2002; Armstrong et al. 2003). Mating, egg development, and most of the larval stages occur in the ocean. Growth from the first true crab stage to age 1+ years can occur in either the ocean or the estuary. Sexual maturity for both males and females occurs at age 2+ and entry into the commercial fishery at age 3+ or age 4+. A recently molted female and a hard-shell male Dungeness crab mate in spring and summer. Adult female crabs extrude fertilized eggs in the fall and carry the extruded eggs until hatching. Egg-bearing female crabs can be found in offshore Oregon waters from October through March. Hatching occurs in the ocean in the winter. The crab larvae or zoeae spend about 4 months as plankton in the water column. In the spring (April to June), the last larval stage, the megalopae, settles to the bottom to become the first true crab (non-larval) stage (young of the year or YOY). Large numbers of YOY enter the estuaries of the west coast as late megalopae and perhaps as first true crabs. YOY crabs grow faster in the estuary than in the ocean. Juvenile crabs (age 1+) found in the estuary derive either from age 0+ crabs that over-wintered in the estuary or from age 1+ crabs entering the estuary in the summer. Age 1+ crabs are thought to leave the estuary for the ocean in the fall. In shallow areas along the northern side of the mouth of the Columbia River, Williams et al. (2004) observed that the density of age 1+ crabs increased abruptly in mid-September and the increased density continued through November. This observation is thought to represent the fall outmigration of age 1+ crabs from the Columbia River.

Tagging, release, and recapture techniques have been used to study the movement of Dungeness crabs in California, Oregon, Washington, and British Columbia (MacKay 1942; Waldron 1958; Gotshall 1978; Tasto 1983; Diamond and Hankin 1985; Smith and Jamieson 1991). The results of these studies suggest that the majority of adult Dungeness crabs show limited movement (less than 4 miles) in the 4- to 18-month period between release and recapture. There is evidence of seasonal movements both along the coast and offshore and onshore. Female crabs appear to move onshore in spring for molting, mating, and extrusion of egg masses and offshore for egg development and hatching. The work of Armstrong and his associates (Armstrong et al. 1987; Rooper et al. 2002; Armstrong et al. 2003) has provided substantial insight into habitat use by Dungeness crabs. Within the estuary, Dungeness crabs use not only estuarine navigation channels but also other estuarine habitat areas. Age 0+ crabs are found in intertidal and shallow subtidal areas on substrates with shell hash, eelgrass, or other shelter (Armstrong et al. 1987). After growing to 20-mm carapace width, the age 0+ crabs move to subtidal areas. Age 1+ crabs use subtidal areas and forage over intertidal areas during high tide. A recent survey of four west coast estuaries by Rooper et al. (2002) indicates that Dungeness crabs show consistent use of some estuarine habitat types. Side-channel habitat near the estuary mouth has the highest age 1+ crab densities, with the lower estuarine main channel and upper estuary having significantly lower densities (Table 1). The characteristics of the preferred lower side channel habitat include shell, macroalgae, shallow depths, high food abundance, temperatures <18 degrees Celsius, and salinities above 25 practical salinity units.

Although the work of Armstrong and his associates (Armstrong et al. 1987; Rooper et al. 2002; Armstrong et al. 2003) has provided substantial insight into habitat use by Dungeness crabs in four west coast estuaries, lesser amounts of data are available on habitat use by Dungeness crabs specifically for the Columbia River. In spring and summer, 0+ crabs can be found in the mouth of the Columbia River with annual average densities varying over two orders of magnitude from year to year (Larson 1993). In the Columbia River, Dungeness crabs are found from the mouth to about River Mile 17 (McCabe et al. 1985, 1986; McCabe and McConnell 1989).

In estimating the contribution of estuarine nursery areas to subsequent year-class strength and fisheries, Armstrong et al. (2003) found that the relative contribution by different estuaries in Washington and Oregon varied with the amount of lower side-channel habitat, the habitat with highest age 1+ crab densities. The smaller estuaries of Oregon contribute an estimated 5% to 7% to the annual landings (commercial harvest of Dungeness crab is tracked by recording the weight of crabs landed in west coast ports). Oregon estuaries may contribute a maximum of 15% to 20% to annual landings. The larger estuaries of Washington contribute an estimated 25% to 30% to annual landings and may contribute over 50% in some years. The work of Armstrong et al. (2003) provides evidence that the estuaries appear to provide relatively steady contributions to annual crab production that can sustain the overall population when the crab production in nearshore ocean environments decreases to low levels.

Distribution and Abundance of Dungeness Crabs

Studies of the distribution and abundance of Dungeness crabs in the ocean and estuary are relatively comprehensive for Grays Harbor and offshore areas (Stevens and Armstrong 1984; Armstrong et al. 1987; Pearson et al. 1987; Armstrong et al. 1991), but the studies are limited for the nearshore areas off Grays Harbor (Antrim et al. 1992, 1994). For the Columbia River, the studies of McCabe et al. (1985 and 1986) and McCabe and McConnell (1989) provide a long term database for the estuary but quite limited data on crab density in the ocean environment. There are no site-specific data for crab densities at the proposed project site. Some typical values for crab densities from the above studies range from zero to over 30,000 crabs per hectare (Table 2).

The wide range of crab density values seen in Table 2 derive from several factors. First, there is considerable variation in crab density by age class. Within any one year, age 0+ crabs can decrease by 1000 times between spring and summer (Armstrong et al. 1987). Second, there is substantial variation from year to year (Armstrong et al. 1987; Rooper et al. 2002; Armstrong et al. 2003). The density of age 0+ crabs taken at the same location and time of year, the north reference site off Grays Harbor in June, varied from a high of over 91,000 crabs per hectare in 1985 to a low of 49 crabs per hectare in 1992 (Table 2). Third, as discussed above, some habitats have been found to have higher densities of crabs than others (Rooper et al. 2002, Tables 1 and 2). For the Columbia River, crab densities in the ocean are significantly lower than at some locations in the estuary (McCabe et al. 1985, Table 2). Fourth, for the ocean, crab density varies by depth (McCabe et al. 1985; Pearson et al. 1987; Armstrong et al. 1987; Antrim et al. 1994). Pearson et al. (1987) found that a large peak in juvenile crab density occurred between 101 and 120 feet water depth in the southwest navigation lane off Grays Harbor. For adult crabs in the southwest navigation lane, depth distribution varied with season, being highest shallower than 120 feet most of the year. Also, recent studies by Pearson et al. (2002, 2003, 2004) provide observations of crab entrainment rates in the Columbia River and indicate that Dungeness crab distribution is influenced by salinity under estuarine conditions but not under oceanic conditions. Seasonal movements of adult crabs undoubtedly also contribute to the variability of crab density at any one location.

In the absence of density data specific to the demonstration disposal site, the next most relevant data are those of Antrim et al. (1992, 1994), who studied crab distribution in the ocean off Grays Harbor. Studies of the southwest disposal and companion reference sites provide data on the distribution of crabs at depths between 100 feet and 120 feet (Antrim et al. 1992). Studies of crab density in the proposed South Beach Berm Site occurred in September 1993 and 1994 (Antrim et al. 1994). Similar to the project under consideration here, the South Beach Berm Site was part of a beneficial use project in which dredged materials from Grays Harbor were to be deposited at the site to form a berm that in turn would protect the south jetty at Grays Harbor from wave erosion. At the berm site, Antrim et al. (1994) found that while adult crab densities did not vary by depth, juvenile crab (age 0+ and 1+) densities did increase with depth. The crab density at the 40-foot depth station within the berm site was dominated (81%) by age 0+ crab (Table 2). At the berm site, almost all (97%) of the adult crabs were female, and 23% were soft-shelled. The time frame (September), depth range (25 feet to 40 feet), and site location (south of a south jetty) from Antrim et al. (1994) are comparable to the time frame (August and September), depth range (40 feet to 60 feet), and site location (south of a south jetty) of the demonstration project. Whether the bottom types are comparable is not known.

The comparability of the two situations suggests that while extrapolation to produce conclusions must be done with extreme caution (if at all) because the Grays Harbor site and the South Jetty site may not have the same distribution of bottom types with depth. However, the results of Antrim et al. (1994) offer a reasonable starting point for testable hypotheses. Extrapolation of results of the Antrim et al. (1994) data and general information on crab biology suggests that testable hypotheses concerning Dungeness crabs and the proposed demonstration project include the following:

H1: Dungeness crabs of all age classes would be present within the site.
H2: Juvenile crab densities would vary with depth.
  H2a: For age 0+, densities would vary from 0 to over 300 crabs per hectare.
  H2b: For age 1+, densities would vary from 0 to 45 crabs per hectare.
H3: Adult crab densities would not vary with depth and be about 70 crabs per hectare.
H4: Adult crabs would be predominantly female.
H5: Adult crabs would be about 25% soft-shelled.

In discussing the development of tiered approaches to disposal site monitoring, Fredette et al. (1986) advocates developing testable hypotheses that could be assessed during monitoring. The above hypotheses can become such testable hypotheses concerning crab abundance and population characteristics.

Dungeness Crab Fisheries

The annual commercial harvest as measured by landings for the Dungeness crab fisheries on the west coast are known to vary substantially from year to year. The Washington and Oregon fisheries for Dungeness crab are male only fisheries, with the majority of the male crabs reaching the minimum size to enter the fishery at age 3+ years. The modeling study by Higgins et al. (1997) of the population dynamics of the Dungeness crab indicates that environmental variations interact with a complex of biological mechanisms to produce the large year-to-year fluctuations in commercial harvests. Recently, Armstrong et al. (2003) has estimated the contribution of the estuaries to commercial crab harvests. Although recent landings data are not broken down by area caught, Armstrong et al. (2003) have used port landings data to provide landings from the large estuarine zone of Washington and the small estuarine zone of Oregon. Armstrong et al. (2003) estimate the 50-year average for the annual crab landings from the large estuarine zone to be greater than 5 million crabs per year and for the small estuarine zone to be about 3 million crabs per year. Maximum landings from the large estuarine zone range from 10 to 12 million crabs. The potential contribution of the demonstration site to the overall or regional commercial crab landings can not be estimated from the available data, but the site is extremely small (455 hectares).

Effects of Disposal of Dredged Materials on Dungeness Crabs

The effects of disposal or placement of dredged materials on Dungeness crabs as a resource can be grouped into three categories. First, direct effects on Dungeness crabs are those that act directly on the crab to injure the crab or otherwise increase mortality.

Second, indirect effects can influence survival through effects on habitat or other factors. Third, disposal can influence harvest through gear conflicts (see *Effects on Resource Use* below) or effects on the bait odor response of Dungeness crabs. Before discussing the effects of disposal, we review the processes that occur in the disposal event.

The Disposal Event

The disposal of dredged materials is a dynamic process. During disposal, the characteristics of the dredged materials (e.g., size distribution, cohesiveness), the water column (e.g., depth, stratification, currents), and the bottom (e.g., slope, grain size distribution) interact to determine the characteristics of the disposal plume, the impact of falling materials on the bottom, the horizontal spread of materials, and the resulting disposal mound. In terms of potential effects on Dungeness crabs, the three aspects of the disposal event of interest are the following:

- *Bottom encounter*. During bottom encounter, the falling materials impact the bottom. At bottom encounter, the conversion of the momentum attained during the fall (convective descent) produces compression and shear forces on the bottom.

- *Dynamic collapse*. During dynamic collapse, the vertical momentum of the falling materials is converted to the horizontal, and the dredged materials are transported along the bottom away from the point of bottom encounter.

- *Mounding*. As falling and spreading materials come to rest, the materials form a disposal mound, which may bury crabs.

Specific studies of the effects of bottom encounter and dynamic collapse on crab survival have not been conducted, but several studies have attempted with limited success to address effects from burial by disposal mounds.

Direct Effects

Some information to partially address potential effects from dynamic collapse is available from the Palos Verdes disposal study. Studies of the Palos Verdes disposal site were undertaken to determine the extent to which disposal would erode sediments from the bottom by inducing a bottom surge current that would transport material a significant distance from the disposal location (McDowell et al. 2002; Bratos et al. 2002). *In situ* measurements of surge currents of experimental disposal events at Palos Verdes demonstrated that, for six disposal events, surge currents between 0.75 and 1.36 meters per second occurred at 75 m downslope from the disposal location (McDowell et al. 2002; Bratos et al. 2002). Surge currents at the disposal location would have been higher but to what extent is unknown. Bottom currents of about 2.5 meters per second can initiate sediment motion for grain sizes of 4 cm (Miller et al. 1977), which is about the size at the start of age 1+ for Dungeness crabs in August in Yaquina Bay, Oregon (Armstrong et al. 2003). Taken together, the Palos Verdes surge current measurements and the sediment mobilization analyses of Miller et al. (1977) provide circumstantial evidence to reasonably hypothesize that surge currents during the dynamic collapse phase of some disposal events may be capable of eroding at least juvenile Dungeness crabs from bottom sediments. Specific experimental studies are needed to confirm or deny the hypothesis that surge currents from some disposal events can adversely affect Dungeness crabs.

Three studies have attempted to determine the effects of burial by dredged materials on Dungeness crabs. In the first study, Chang and Levings (1978) simply added dredged sand to 45-cm diameter pails or oval tanks (64 cm by 45 cm) that contained adult male Dungeness crabs, presumably hard-shelled. Burial is a natural behavior of Dungeness crabs (MacKay 1942 provides a basic description of burial behavior), and when buried naturally, Dungeness crabs establish a respiratory current with the overlying water to enable oxygen bearing water to be drawn over the crab's gills. For burial depths of 5 cm and less, all crabs were able to re-establish respiratory currents to the overlaying water within 6 hours (Chang and Levings 1978). For a burial depth of 10 cm, crabs did not re-establish a respiratory current but emerged from burial within 24 hours. For a burial depth of 20 cm, crabs did not re-establish a respiratory current and only two emerged from burial within 24 hours. Crabs buried for 24 and 48 hours were recovered alive, but crabs buried for 120 hours were recovered dead.

The second study was performed at Scripps Institute of Oceanography using adult hard shelled crabs placed in a 10 foot by 2 foot by 6 foot deep tank with a layer of sand on the bottom (U.S. Army Corps of Engineers 1999). Crabs were allowed to bury themselves before wet or dry sand was released from a louvered dump box designed to mimic the duration of typical disposal events. In experiments during which 0.7 feet of sand was deposited over the full width of the tank, about 75% of the crabs emerged from burial within one hour. In one experiment in which 0.85 feet of sand was deposited as a mound in the center of the tank, 100% of the crabs emerged from burial within 1 hour. Among crabs that emerged, there was no mortality over the several weeks following the experiments. Crabs that remained buried did suffer mortality, but the rate and time frame were not clearly reported.

The third study by Antrim and Gruendell (1998) examined the responses of three size classes of Dungeness crabs, *Cancer magister*, and graceful Cancer crabs, *Cancer gracilis*, to burial by sand in cylindrical tanks 21 inches in diameter and 17 inches deep. Both hard and soft-shelled crabs were tested but not for all burial depths. For all burial depths tested between 2.4 inches and 10.2 inches, the mean survival rates were 85% for age 0+, 52% for age 1+ and 50% for adult crabs. The patterns of survival by depth also differed by age class. All crabs that remained buried for 72 to 96 hours were recovered dead. The age 0+ crabs were recently molted and presumably more susceptible to injury. Therefore, it was not expected that the highest survival rate would be for the age 0+ crabs. The behavioral response of the crabs appeared to vary by age class with the age 0+ crabs being more active and more readily emerging from burial at the start of disposal. Also, the neutral buoyancy of the age 0+ crabs enabled them to be readily lifted by water currents. Antrim and Gruendell (1998) stated that their experiments were too preliminary to draw any conclusions, primarily because the size and configuration of the test chambers allowed no opportunity for the crabs to actively escape the descending sand through the crab's normal horizontal movements. Thus, the results of Antrim and Gruendell (1998) suggest that crab behavior during the disposal event may influence crab survival more than crab size or depth of burial.

It is clear from the studies that Dungeness crabs can respond to falling sand and to burial, but it is now equally clear that the experimental apparatus and procedures employed to date have two serious and major flaws. The small sizes of the test chambers did not permit the experiments to mimic the disposal event and did not allow the full range of behavioral response. Surge currents from dynamic collapse could not be present in such apparatus. Furthermore, the test chamber configurations essentially precluded crabs from responding to the surge currents and other disposal conditions with appropriate escape behavior. Thus, the results of the presently available experiments do not permit us to draw any conclusions concerning the conditions under which the disposal event or burial lead to mortality or to survival. Firm conclusions still await experiments in larger apparatus that can mimic the dominant processes in the disposal event and permit the full range of escape responses by the Dungeness crabs.

Indirect Effects

Indirect effects from ocean disposal on Dungeness crabs have not been directly studied, but such effects were the subject of monitoring efforts for the disposal site in the southwest navigation lane off Grays Harbor. The site is at depths from about 100 feet to 120 feet. In pre-disposal studies, Pearson et al. (1987) had found that a specific location off Grays Harbor showed exceptionally high densities of Dungeness crabs, especially for age 0+. There was concern that the disposal mound in the candidate site would change the bathymetric and sediment characteristics in such a way as to degrade the site's quality as habitat or migratory pathway. Disposal site boundaries were adjusted to avoid this area of high density and monitoring at the southwest disposal site and a companion north reference site were undertaken under a tiered site monitoring plan. The intent of the monitoring plan was to determine whether the area of high crab density had shifted into the disposal site. Three years of monitoring demonstrated that the area of high crab density remained to the north of the southwest disposal site and that the boundaries of the southwest disposal site had been appropriately established. The lesson from the Grays Harbor experience for the demonstration project is to conduct surveys not only at the proposed placement site but in the adjacent areas so that the survey results can be used to assess whether the proposed site has any usually high aggregations of Dungeness crab. Experience also suggests that such surveys should be conducted over a suitable time frame rather than all at once.

Effects on Resource Use

Resource use conflicts occur when an activity such as the disposal of dredged materials occurs in the same location where fishing activities occur. Gear conflicts are one type of use conflict that occur when gear, such as, nets, longlines, or pots, are set in an area where disposal operations are to occur. Potential gear conflicts between dredging and fishing are usually resolved through communication and scheduling of activities. Communication and scheduling concerning the demonstration would be expected to reduce or eliminate gear conflicts.

A second type of resource use impact occurs when the disposal operation change the bottom morphology or other site characteristics in such a way that fishing operations become less effective. Changes in bottom type or wave climate might change the ability of the crab fishers to place their crab pots or change the effectiveness of the pots. The effects of changes in wave climate and bottom contours on crab pot effectiveness has not been studied to our knowledge.

One study by Pearson and Woodruff (1987) has addressed whether dredged materials can disrupt crab fishing. Disruption of crab pot fishing by dredged materials disposal operations has been a stated concern of Washington coast crab fishers. Before the Grays Harbor Navigation Improvement Project, crab fishers had complained that disposal of materials from maintenance dredging at the Point Chehalis site inside the jetties at Grays Harbor had disrupted their crab fishery. The “souring of crab pots” reported by the crab fishers included a sharp decline in catches 1 to 2 days after disposal at Point Chehalis and a discernible odor to pots recovered during the period of depressed catches. At the request of the Army Corps of Engineers, Pearson and Woodruff (1987) conducted laboratory mesocosm experiments concerning the effects of dredged materials on bait odor response in the Dungeness crabs. Pearson and Woodruff (1987) demonstrated that the ability of adult male Dungeness crabs to detect a bait odor plume and track the odor to its source was impaired when the crab was placed on some, but not all, sediments to be dredged. The time taken by crabs to find the odor source was doubled for Sequim Bay and Grays Harbor sediments with high contents of silt and clay, volatile solids, and sulfides. Sandy sediments did not impair the response to bait odor. The precise mechanism causing the problem was not discovered. To address the issue, the Grays Harbor Navigation Improvement Project designated a separate disposal site for sediments with high silt and clay and sulfide contents and located the site in an area of demonstrated low crab abundance. For the 2005 demonstration project, the dredged materials from the mouth of the Columbia River are expected to be sandy. Therefore, the likelihood of an impairment of bait odor response in the 2005 demonstration project is low if the dredged materials contain low silt and clay and are not anoxic.

Considerations for Design of Monitoring

Disposal sites are monitored to provide assurances that an unforeseen adverse effect on a resource is not occurring. Fredette et al. (1986) calls for tiered monitoring plans that have four elements:

- *Prospective and specific predictions with specific thresholds.* The intent is to have beforehand predictions about effects and associated thresholds at which effects might be expected.

- *Testable null hypotheses.* The intent is to transform concerns, issues, and questions into specific hypotheses that can be confirmed or denied by field measurements.
- *Multiple tiers with triggers for moving from tier to tier and options for management actions.* The intent is to have inexpensive and rapid measures that can lead to more intensive studies or management actions. Tiering enables activities to focus on suspected problems and triggers enable pre-planned actions to be taken if issues arise during operations.
- *Multidisciplinary technical designs teams*. A multidisciplinary approach enables integration of knowledge from engineering with the physical, chemical, geological, and biological sciences. Such integration enhances the chances of finding innovative cost-effective solutions.

For Dungeness crabs at the proposed site, the potential effects of dredged material placement on Dungeness crab appear to reside in two unresolved areas: effects of surge currents and effects of burial. With no presently available quantitative model of the relationship between the physical parameters in disposal events (surge currents and burial) and crab mortality, data to establish specific thresholds for a tiered monitoring approach are simply lacking.

Also, we currently have no data on crab distribution and abundance that are specific to the project site. The hypotheses listed in the above section on crab distribution and abundance can provide a starting point for the testable hypotheses concerning crab abundance at the site. The nearshore area is known to be important to female crab for mating and molting. One important task that should precede the full-scale project would be to determine the relative importance of the project site to reproductive females. A habitat or bottom type map of the site and the general area about the site is needed to aid this assessment as well as other assessments in the overall project.

Experience has shown that the design of monitoring studies should include statistical analyses to determine the sample sizes and other conditions necessary to detect the amount of change deemed to be biologically or geologically meaningful. Studies undertaken without such statistical considerations often provide inadequate power to accomplish study objectives.

Basic information to assess potential effects of surge currents and burial may become available from physical measurements. Two appropriate first tier measurements would be the degree of erosion and depth of deposition during individual placement events. Determining the locations and areal extent of any erosion or deposition would also be beneficial first steps to understanding potential effects on Dungeness crabs.

The demonstration projects will place relatively small amounts of dredged materials (30,000 and 150,000 cubic yards) whereas the full scale project will place about 1 million cubic yards per year. The assessment of effects on Dungeness crab and other biota needs to include an explicit examination of how to scale observations made at the level of the demonstration projects to the potential for effects at the level of the full-scale project.

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Table 1. Age 1+ Crab Densities by Habitat Type from Rooper et al. (2002). Densities interpreted from graphs in Rooper et al. (2002) and other data taken from tables in Rooper et al. (2002).

		Mean 1+ Density (crab/ha)		
Bay	**n**	**Lower Main Channel**	**Lower Side Channel**	**Upper Estuary**
Grays Harbor	9	483	1722	228
Willapa Bay	9	270	772	216
Yaquina Bay	3	630	830	296
Coos Bay	3	571	1300	695
Mean		489	1156	359
Mean Salinity (o/oo)		28.5	26.1	25.1
Tide Flat (%)		20.7	53	40.1

Table 2. Typical Values of Crab Density (Crabs per hectare) Summarized from Various Studies in Washington and Oregon.

Study	Location	Season/Year	Category	Mean Density (crab/hectare) by Location/Station					
Pearson et al. 1987	Grays Harbor Ocean			SW Lane	West Lane	Eight Mile			
		Fall 1984	Juvenile	2,502	2,280	467			
			Adult	9	14	0			
		Spring 1985	Juvenile	30,086	ND	196			
			Adult	37	ND	1			
		Fall 1985	Juvenile	283	748	863			
			Adult	16	11	0			
Armstrong et al. 1987	Grays Harbor Ocean			5 m to 15 m	15 to 40 m	40-60m			
		1983-1986	All Ages	14	39	38			
McCabe et al. 1985	Mouth of the Columbia River	1983/1984	All Ages	Station 1	Station 2	Station 24	Station 25	Station 26	
			Annual minimum	0	0	0	0	0	
			Annual maximum	33	288	120	116	216	
	Columbia River Estuary	1983/1984	All Ages	Station 3	Station 4	Station 5	Station 6	Station 7	
			Annual minimum	22	5	12	60	0	
			Annual maximum	2714	290	471	4441	357	
	Ocean Off Columbia River	1983/1984	All Ages	Station 90	Station 91	Station 92	Station 93	Station 94	Station 95
			Annual minimum	0	0	0	0	0	0
			Annual maximum	27	22	7	6	1872	93

Table 2. Continued.

Study	Location	Season/Year	Category	Mean Density (crab/hectare) by Location/Station				
Antrim et al. 1992	Grays Harbor Ocean	1985, 1990-92		SW Site	Refer. Site			
		Jun-85	Age 0+	3653	91,217			
		Jun-90	Age 0+	193	609			
		Jun-91	Age 0+	1922	8809			
		Apr-92	Age 0+	20	13			
		Jun-92	Age 0+	20	49			
		Jun-85	Age 1+	0	0			
		Jun-90	Age 1+	0	0			
		Jun-91	Age 1+	0	1			
		Apr-92	Age 1+	4	0			
		Jun-92	Age 1+	0	0			
		Jun-85	Adult	15	90			
		Jun-90	Adult	40	51			
		Jun-91	Adult	4	15			
		Apr-92	Adult	10	40			
		Jun-92	Adult	2	33			
Antrim et al. 1994		Sep-94		South Beach Berm Site				SW Site
				25 feet	30 feet	35 feet	40 feet	
			Age 0+	17	0	63	305	3
			Age 1+	0	0	45	42	0
			Adult	78	83	81	28	105