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Effects of Sand Accumulation on Juvenile Flatfish and Soft-Shelled Dungeness Crab

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Summary

Disposal of uncontaminated dredged material from the mouth of the Columbia River has the potential to impact biological resources upon which material is deposited, particularly to soft-shelled Dungeness crab (*Cancer magister*) and juvenile flatfish. The U.S. Army Corps of Engineers, Portland District, contracted Battelle Marine Sciences Laboratory (MSL) to conduct controlled tests to evaluate the response of juvenile flatfish and Dungeness crab to deposited sediment. This study was conducted between July and September 1998.

Crab and juvenile flatfish were collected by beach seine and beam trawl nets and by divers and held in seawater tanks at the MSL. Juvenile crab were held in trays to enable easy identification of recently-molted individuals. Soft-shelled adult crab were obtained from commercial crabbers. Crab were grouped into three size classes according to carapace width (CW): <50 mm CW, 50 mm to 100 mm CW, and >100 mm CW that correspond roughly to 0^+ juvenile crab, 1^+ juvenile crab, and adult crab, respectively. Most juvenile (0^+ and 1^+) crab tested were recently-molted, less than 24 hours post-molt. Test dumps were accomplished by release of dry sand into 21-in. diameter by 17-in. deep circular tanks containing seawater and a layer of sand a minimum of 3 in. deep. Three depth of accumulation/release duration scenarios were tested: 2.4 in./85 sec, 4.2 in./60 sec, 6.6 in./32 sec, and 10.2 in./10 sec. For most tests, fish and crab survival was monitored for at least 72 hours after test dumps. The main data are comprised of 50 juvenile flatfish in 5 tests, 35 0^+ crab in 16 tests, 25 1^+ crab in 21 tests, and 12 adult crab in 11 tests.

All juvenile flatfish survived all depths of accumulation tested. The fish were visible at the water surface immediately after each dump. No gross physical damage was noted to either fish or crab following test dumps. The overall mean percentage of survival for 0^+ crab was relatively high (85%) and was high at all depths tested (79% to 90%). The overall mean percentage of survival for 1^+ crab was 52% and decreased progressively from 100% to 45% with increasing depth of sand. For adult crab, overall mean percentage of survival was 50%. No adult crab died at 2.4 in. and 4.2 in. sand depths, but adult crab survival was reduced under 6.6 in. and 10.2 in. of sand (20% and 33% survival, respectively). Death after burial was found within 24 hours of burial in the few tests in which survival was checked at 24 hours. Survival in tests appeared to be determined primarily by crab behavior rather than size or depth of sand accumulation. Survival was not clearly attributed to depth of deposited sand or rate of sand accumulation. Crab that were active at the sediment surface before a test dump tended to

survive at higher rates than did crab buried at the surface before a dump. Young crab tended to be more active and easily disturbed and, consequently, survived at higher rates than adult crab.

These results provide a preliminary evaluation of potential impacts to juvenile flatfish and soft-shelled crab from accumulation of sand. However, the data generated constitute a small data set from which statistical analyses were restricted by small sample size. Post-dump turbidity prevented direct observation of crab until overlying water was siphoned off the tank. Moreover, the experimental procedures and design were constrained by restricted time and resource availability. Test tanks were relatively small, particularly for adult crab, and provided a confined space with no potential for an active escape response. The characteristics of the dry sand used in tests also may differ sufficiently from dredged material to make organism response and survival unrepresentative of potential effects at dredged material disposal sites.

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1.0 Introduction

The U.S. Army Corps of Engineers, Portland District (USACE), and the U.S. Environmental Protection Agency are designating disposal sites near the mouth of the Columbia River for disposal of uncontaminated dredged material. Disposal of this material could impact biological resources upon which material is deposited, particularly soft-shelled Dungeness crab (*Cancer magister*) and juvenile flatfish. Dungeness crab and flatfish are important commercial resources that live on the sea floor in nearshore benthic habitats. Crab are crustaceans that molt, or shed their shells to grow larger, throughout the year. Crab shells take several days to harden after a molt. Consequently, soft-shelled crab may be especially vulnerable to entrapment and/or physical damage from dredged material as it settles to the sea floor at disposal sites.

The Battelle Marine Sciences Laboratory (MSL) was contracted by USACE to conduct controlled tests to evaluate the response of juvenile flatfish and Dungeness crab to deposited sediment. This report describes work accomplished between July and September 1998.

2.0 Methods

2.1 Test Organisms

2.1.1 Flatfish

Juvenile flatfish were collected by beach seine and beam trawl from the mouth of Sequim Bay adjacent to the MSL. Trawls were limited to 5 min or less to minimize damage to the catch. The fish were picked from nets, transferred to coolers containing seawater, and transported to the MSL for pre-test holding. Juvenile flatfish were held on a water table containing a layer of Sequim Bay sand and supplied with flow-through seawater at ambient temperature (approximately 12°C to 14°C). The fish were held for 7 to 8 days before testing and supplied with minced bivalve meat for food. All flatfish used in testing were between 35 and 55 mm standard length (i.e., not including the tail fin). Most but not all juvenile flatfish were examined and identified to be English sole (*Parophyrus vetulus*). After a series of tests were completed using English sole, an attempt was made to collect and test with different species of flatfish. However, additional beach seine efforts conducted near the MSL were unsuccessful in producing a sufficient number of juvenile flatfish for testing with an alternative species. Time and funding resources in the summer of 1998 did not allow for more extensive efforts to obtain different fish.

2.1.2 Crab

Dungeness crab were collected by divers, beach seine, and beam trawl at three sites: off Travis Spit at the mouth of Sequim Bay, off Jamestown, Washington, located between Sequim Bay and Dungeness Spit, and at Eagle Harbor, Bainbridge Island, Washington. Trawls were limited to 5 min or less to minimize damage to the catch. Crab were removed from nets or diver collection bags and held in coolers containing seawater for transport to the MSL. At the MSL, juvenile Dungeness crab (<100 mm carapace width [CW]) were held in individual compartments in stacked trays of the type typically used for salmon egg incubation. Flow-through seawater at ambient temperature (approximately 12°C to 14°C) was supplied continuously to the trays. Incubation trays were filled with approximately 1.5 in. of medium-grained sand. Every few days, crab were supplied with brown and green algae plus fish meat for food. On feeding days or days when tests were conducted, crab in incubation trays were monitored for molts. The date and pre- and post-molt CW measurements were recorded for each crab that molted. Crab that molted were assigned a unique number code and tracked through the testing and post-test holding periods. Crab that survived test dumps were transferred to incubation trays for monitoring of survival and additional molts.

Crab were grouped into three size classes: <50 mm CW, 50 mm to 100 mm CW, and >100 mm CW. Although there is considerable geographic variation in the size of juvenile crab at a given age, these size classes correspond roughly to 0^+ juvenile crab, 1^+ juvenile crab, and adult crab, respectively. For simplicity, these size class designations will be used in this report. In general, each test contained one size class of crab; however, a few tests were completed with crab from both juvenile size classes.

During testing with juvenile crab, researchers did not differentiate initially between *C. magister* and *Cancer gracilis*, a crab that is distinguished from *C. magister* by subtle differences in coloration and carapace shape. Molted shells or live specimens from approximately 90% of the crab used in tests had been saved and were evaluated for species identification. These shells were 47% *C. magister* and 53% *C. gracilis*. All *C. gracilis* used corresponded to the two juvenile size classes of crab. The largest *C. gracilis* used in testing was 80 mm CW. It is not likely that the behavior and sensitivity of *C. gracilis* in test dumps differs significantly from that of *C. magister* of the same size. To test this assumption, data were sorted by species and test dumps with juvenile crab conclusively identified to species (traceable to crab number) were analyzed independent from the entire data set. These data were comprised of 16 test dumps and 39 individual crab, or approximately half of all test dumps (n=38) and juvenile crab (n=75). No statistically significant difference was found in survival between the two species (Student's t-test, α=0.05). Only 1 of 19 (*C. magister*) and 2 of 20 (*C. gracilis*) crab died in these tests. Therefore, results from tests using *C. gracilis* were considered to be applicable to *C. magister*, and a distinction between the two species was not made during subsequent data analyses.

Very few adult Dungeness crab (>100 mm CW) were caught in trawls, and no trawl-caught adult crab were soft shelled. Because these collection efforts were ineffective, the MSL's scientific collecting permit from Washington State Department of Fish and Wildlife (WDFW) was modified on August 10, 1998, to allow for receipt of soft-shelled crab from local crabbers. Large soft-shelled crab from commercial traps were segregated by crabbers and delivered in coolers to the MSL float each day. At the MSL, 4 to 6 crab with the softest shells were selected from the day's batch and transferred to holding tables supplied with flow-through seawater at ambient temperature. All adult crab tested were Dungeness crab (*C. magister*).

Shell hardness of all crab was evaluated following the scale used by WDFW (Table 1). This scale provides three major stages, each with two or three sub-grades of shell condition or hardness, and it describes characteristics of each stage that were used for semi-quantitative evaluation of crab shell hardness. All crab tested at the MSL were soft-shelled crab. The holding trays allowed investigators to quickly identify crab that had molted because two shells were present in a chamber. Thus, nearly all testing with juvenile crab (≤100 mm CW) was completed with newly or recently molted crab (Stages 3-2 or 3-1); 89 of the 95 juvenile crab tested (95%) were Stage 3 crab less than 24-hourspost-molt. Two crab in holding at the MSL molted to adult crab size and were tested as newly or recently molted crab (Stages 3-2 or 3-1). The remainder of adult crab tested were received from crabbers and were intermediate stage soft shelled crab, Stage 2-2 (n=4) or Stage 2-1 (n=12).

The number of juvenile crab tested was higher than that for adult crab for two reasons. First, efforts to produce recently-molted juvenile crab at the MSL were successful. A total of 75 juvenile crab molted in holding trays at the MSL between July 31 and September 2, 1998. Two crab molted into the adult size range (>100 mm) in holding at the MSL. These numbers are an effect of size of crab in holding and molt frequency. Greater numbers of juvenile crab were collected and held at the MSL. Adult crab normally molt once per year, and juvenile crab molt more frequently. Therefore, the probability of obtaining recently molted juvenile crab is higher than that for adult crab. Moreover, the first soft-shelled adult crab from commercial crabbers were not available until August 27, 1998, after the MSL's scientific collecting permit had been modified to allow this practice and arrangements were made with crabbers for delivery to the MSL. Eighteen soft-shelled adult crab were used in test dumps in late August and September 1998.

2.2 Test Equipment

Test tanks were white circular plastic tanks, 21 in. inner diameter and 17 in. deep, with a central standpipe for drainage. Standpipes were covered with plastic mesh to prevent crab escape via this route. The tank bottoms were lined with a minimum of 2 in. to 4 in. of fine-grained sand. Each tank was supplied with flowing, unfiltered seawater at ambient temperature (12°C to 14°C). A dump box was fabricated of plywood to sit atop test tanks. The dump box had a slotted bottom that could be opened or closed by sliding a horizontal plate. The box was designed to hold >55 L of sand, an amount that would provide 10.2 in. in the test tanks. To complete a test dump, the box was placed over the test tank, and the volume of sand required for a given target depth was added to the box. To release the sand, the horizontal plate on the box was manually pulled out to release sand at the estimated rate required for the particular test. The horizontal plate was adjusted during the dump to best achieve the desired dump duration. The operator attempted to provide a consistent rate of sand release during the duration of the dump. Water depth in test dumps was approximately 14 in. for test dumps at 2.4 in. and 4.2 in. Because the water level was lowered for tests dumps at 6.6 in. and 10.2 in. to prevent overflow during the dump, water depth was approximately 8 in. to 10 in. for these tests.

The dump box was designed to work with dry sand because dry sand allowed the deposition rate to be accurately controlled. The sand used was a fine-grained, 70-grit industrial quartz sand (Onimin Corp. 7030 sand); 100% was <0.425 mm (40 mesh) and 77% was <0.250 mm (60 mesh). The test sand was similar to the grain size of dredged material from the mouth of the Columbia River, which is predominantly fine sand (0.18-0.29 mm) with about 2-4% fines (smaller than 0.0625 mm).

2.3 Testing Methods

Test dumps were designed to represent disposal by split-hull hopper dredge of dredged material in open water at water depths ranging from 50 ft to 200 ft. Data generated by the STFATE model for vertical extent (depth of accumulation) and time to impact the bottom (descent) and collapse were supplied by USACE (Table 2). Four depths of deposited sand were used: 0.20 ft (2.4 in.), 0.35 ft (4.2 in.), 0.55 ft (6.6 in.), and 0.85 ft (10.2 in.). The anticipated depth of deposited sand is inversely related to the water depth at the disposal site. Shallower depths of deposited sand represented disposal at deeper sites where sand would be dispersed over a larger area of the seabed. After a few initial dumps were completed at different durations within the range provided in Table 2, dump duration (time for release of sand from the dump box) was standardized to a targeted value for remaining tests (Table 2). Dump duration was standardized to eliminate it as a source of variability and to facilitate interpretation of test results. The targeted value was approximately midway in the duration range (time between descent and collapse) and was selected to provide conservative data, or a relatively rapid accumulation of sediment. Test parameters did not represent the worst-case scenarios. Immediately after each test dump, overlying water was siphoned off and renewed to allow for viewing of organism survival and behavior. Control tests were completed with crab and flatfish in which animals were transferred from holding to test tanks and monitored for survival, with no sand dumped on them.

Monitoring of test tanks for survival and emergence of buried animals was continued for 72 to 96 hours following each dump. After 96 hours, live crab at the sediment surface were transferred to holding trays for additional monitoring of survival and molting. Crab that had not emerged were dug out from the sand. After it was discovered that buried crab were consistently dead after 96 h, this period was shortened in a few tests to identify length of survival for buried crab. No flatfish were buried by sand or died during post-test monitoring, so further monitoring of flatfish was not completed.

A single group of four juvenile crab (63 mm to 70 mm CW) was used for a repetitive test dump in which 4.2 in. of sand was repeatedly dumped on these same crab over a short time period. Two hours after each test dump, crab that had not emerged were dug out. These four crab were used in three consecutive dumps on one day of testing and one dump the following day.

On the last day of testing (9/24/98), four test dumps were conducted using adult soft-shelled crab. Crab that did not immediately emerge from the sediment were dug out within 1 hour of the test dump to check for physical damage, clogging of gills with sand, and survival. Crab that survived these dumps and emerged immediately were assumed to be uninjured and were included in the database as surviving. Long-term survival and emergence of crab that remained buried was uncertain, so these data were not included in the database. As described above, survival in most test dumps was monitored for 72 to 96 h.

Still photographs were taken to document different aspects of the testing. Attempts to obtain video images of crab behavior during and immediately after test dumps were thwarted by extreme water turbidity caused by suspended materials.

3.0 Results and Discussion

3.1 Flatfish

Five test dumps and one control test were completed with flatfish (Table 3). All juvenile flatfish survived test dumps at depths ranging from 2.4 in. to 10.2 in. The fish swam up through the water and were visible in the water column above deposited sand immediately after test dumps. The dry sand stuck to the mucous covering on the dorsal surface of some fish but gradually wore off within a few hours. No lasting physical damage to the fish was noted. All fish tested survived for 72 hours after the test dumps, after which they were released to Sequim Bay.

3.2 Crab

Detailed results from all test dumps are provided Table 4, which includes information on dump characteristics and crab survival, and Table 5, which includes data for crab species, pre- and post-molt CW sizes, and shell hardness. The actual depth of deposited sand was measured in tanks and was close to the nominal depth (Table 4; mean percentage difference of 4%). Unless specifically stated, the results presented below are from test dumps in which survival/mortality was monitored for 72^+ hours after the sand dump, or mortality was confirmed in less than 72 hours. In 4 tests included in these results, crab were alive and active at the sand surface after the dump and survival to 72^+ hours was assumed (see Table 4). Two 0^+ crab tested in the same tank with 1^+ crab were seen alive after the test dump but disappeared after 24 hours. When shell fragments were found, these crab were assumed to have been eaten by the larger crab and were counted as surviving crab for data analyses. These data are summarized in Table 6 and Figure 1 and are comprised of 35 0^+ crab (<50 mm CW) in 16 tests, 25 1^+ crab (50 mm to 100 mm CW) in 21 tests, and 12 adult crab (>100 mm CW) in 11 tests. Tests in which crab were dug out of sand and were alive after a short period of burial are discussed separately.

Crab did not suffer obvious physical damage from test dumps. No gross, external physical damage was noted in any crab as a result of test dumps. No detached legs or cracked carapaces were found on crab dug from under deposited sand. All crab at the sand surface after test dumps survived for the entire monitoring period, generally 96 hours or longer.

3.2.1 Survival and Behavior

For all depths of deposited sand combined, the mean percentage of survival was 85% for 0^+ crab, 52% for 1^+ crab, and 50% for adult crab. This trend may seem counter-intuitive because smaller crab were all newly- or recently-molted crab and probably would be more susceptible to injury than larger crab with harder and thicker shells. However, differences in behavior of the different size classes of crab may explain these results. Small crab were generally more active and tended to be easily aroused when buried in the surface sediment than larger crab. Moreover, recently-molted juvenile crab are nearly neutrally buoyant. Their bodies are swelled with water, their shells are thin, and they sink slowly in the water column. Thus, the quick emergence of 0^+ crab from buried positions and their high percentage of survival in test dumps were likely a result of two factors: 0^+ crab were readily stimulated into activity at the start of a dump, and they were susceptible to being lifted into the water column by upwelling of water displaced by sand.

Survival of 0^+ crab was consistently high at all depths of accumulation tested (Figure 1). Survival of 1^+ and adult crab at different depths of accumulation was variable (Figure 1). All 1^+ and adult survived test dumps of 2.4 in. Approximately half of the 1^+ crab survived test dumps ranging from 4.2 in. to 10.2 in. All adult crab also survived dumps of 4.2 in., yet adult crab survival was reduced to 20% and 33% in test dumps of 6.6 in. and 10.2 in., respectively. Survival of the two larger size classes of crab appeared to be dependent on the behavior of crab before initiation of the dump. Crab that were walking on the sediment surface tended to move up through the sand during the test dump and survive. Crab that were buried in sediment at the start of a test dump tended to remain buried, to allow themselves to be covered with sand, and subsequently to die. It is notable that all crab buried by deposited sand remained buried and died, with the exception of one 0^+ crab that emerged from burial after 48 h. Adult and 1^+ crab tended to choose the behavioral response of burial rather than active movement during test dumps more than 0^+ crab, and this response resulted in higher mortality of larger crab.

Ineffective efforts by some crab to move upward through accumulating sand during the dumps were noted in a few tests. Six of 23 crab killed in test dumps were found midway up in the layer of deposited sand, which indicates they were active during the test dump but did not move through deposited sand to the new surface. The position at test dump start (i.e., buried vs. walking) was noted for only 2 of these 6 crab, and both crab were buried at the start. This subset of the data represents a full range of crab and test dump conditions. Crab were between 18 mm and 162 mm CW and had both newly-molted and intermediate shell hardness conditions. They were found in test dumps between 4.2 in. and 10.6 in. ranging from 8 sec to 71 sec duration. Thus, no definitive size, molt stage, sand accumulation depth, or deposition rate can be attributed to these data. One should note, however, that the size of the data set is limited for this analysis.

3.2.2 *Depth of Deposited Sand*

For all crab combined, the mean percentage of survival was 92% in 2.4-in. test dumps, 73% at 4.2 in., 62% at 6.6-in., and 64% in 10.2 in. test dumps. Analysis of variance on arcsine square root transformed data for weighted mean percentage of survival indicated no significant difference in survival at different dump depths. Statistical analyses of data for different crab size class and depth combinations were not completed because of the limited number of replicate tests. Mean percentage of survival for each size class crab and depth of deposited sand is presented in Figure 1. Survival of 0^+ crab was similar at all depths of accumulation tested. Survival of 1^+ crab decreased with increasing depth of deposited sand. Adult crab were unaffected by shallow test dumps but showed high mortality in dumps of 6.6 in. and 10.2 in. As discussed above, survival appears to be a function of behavior, and burial as a response to rapidly accumulating sand can result in mortality. The laboratory test conditions used, however, may not be representative of conditions in the field under natural conditions of disturbance or disposal of dredged material (see discussion below).

3.2.3 *Duration and Rate of Test Dumps*

Duration of test dumps ranged from 4 sec to 100 sec, and the rate ranged from 0.02 in./sec to 2.56 in./sec. Data for each size class of crab are presented in Figures 2 and 3 for duration and rate, respectively. These figures show that there was no consistent pattern for survival over the range of duration or rate of accumulation tested. Many crab survived the most challenging conditions, rapid dumps or dumps with a relatively high rate of accumulation. It should be noted that survival data are limited to a few values (i.e., 0%, 33%, 50%, 75%, and 100%) because the number of crab in test dumps was generally between 1 and 4. For tests with a single crab (n=26), response (i.e., % survival) could only be either 0% or 100%. Of the 21 test dumps with more than one crab, only 6 or 29% resulted in a partial response (i.e., >0% or <100% survival). Thus, in 71% of tests with more than one crab, survival was either 0% or 100%. This implies that crab behavior may be a more critical determinant for survival than rate of sediment accumulation (see discussion above).

3.2.4 *Shell Hardness*

No analysis was completed on differences in survival for different shell hardness categories because the database was relatively small and there was not a wide range of shell hardness conditions for different size classes of crab. Ninety-five percent of juvenile crab were recently-molted (Stage 3) crab, and nearly all adult crab were at intermediate shell hardness (Stage 2). The two recently-molted adult crab tested survived in dumps of 2.4 in. and 4.2 in.

No specific effort was made to monitor the duration of different shell hardness stages. The presence of two species of *Cancer* also would have complicated this task. In general, we found that juvenile crab remained very soft (Stage 3) for approximately 48 hours after a molt. The duration of intermediate hardness stages in juvenile crab was not noted. Adult crab remained at Stage 2 in holding for a more than a week.

3.2.5 *Emergence and Duration of Survival*

Monitoring of crab survival and emergence was continued for 72 hours to 96 hours in the majority of tests (84%). All crab that remained buried under deposited sand were found dead after 72 hours to 96 hours. Only one crab (25 mm CW) buried by deposited sediments emerged during the monitoring period. To evaluate the duration of survival under deposited sand, adult crab at intermediate phase shell hardness in two test dumps of 6.6 in. were dug out after 24 hours. All were dead (n=3). No gross external physical damage was noted in these dead crab. The deposited sand remained relatively fluid and could be easily penetrated with a hand for 24 hours after a test dump. Therefore, it seemed that crab should have been physically able to emerge from burial. Attempts to make an accurate measurement of dissolved oxygen concentration at depth in the sediment were not successful to determine whether anaerobic conditions caused mortality. Although these data were limited to 3 crab, it appears that crab buried under deposited sand in these test dumps typically died within 24 hours of burial. Specific causes of mortality could not be identified. Two crab buried in test dumps were dug out within 1 hour of the dumps and examined for potential causes of mortality. These crab were alive after the short period of burial. The gills in both crab were clear of sand, and no other injuries that could have caused mortality were noted.

3.2.6 *Repetitive Test Dumps*

Repetitive and frequent test dumps on the same group of crab did not appear to cause physical damage to the crab. None of the four crab used in the repetitive test dumps showed gross, external physical damage after the dumps were completed. Although limited in scope, this series of tests showed that crab response to deposited materials is an important factor in determining survival or mortality. For the first test dump, two crab were buried at the start and were found alive under the deposited sand 2 hours later. Two crab walking on the sediment surface at the start moved up through the deposited sediment and were noted on the surface immediately after the dump. For the second test dump, three crab were buried at the start, and two were buried under the deposited sand after the dump. Before the third test dump, crab remained active at the surface and would not bury after 15 min. undisturbed. All four crab were on the surface immediately after the third dump. These three test dumps occurred over a 5-h period. The following day (15 hours later), three crab were buried at the start, but all four crab were on the surface immediately after the dump. Crab were monitored for 7.5 hours after this test, but no crab settled to bury in sediment. Thus, these test results imply that crab become habituated to the test dumps and avoid burial in deposited sediments.

3.3 Limitations of the Testing

Results of these tests should be considered preliminary for a variety of reasons. This testing was completed over a 2-month period with a very short period available for planning, design, and fabrication of test equipment. Consequently, the sample size is relatively small for each size class of crab and depth of accumulation. For example, a total of three adult crab were tested with 10.2 in. of sand. The greatest number of crab tested for a given size and depth combination was 14 (<50 mm CW, 4.2 in.). The greatest number of replicate tests was 7 (50 mm to 100 mm CW, 4.2 in.). Therefore, statistical analysis of the data was not justified, and generalization to a larger population of crab using this limited data set should be made with caution.

Another limitation of the testing was the test tanks used. Test tanks were relatively small and presented a confined space that limited the response of crab to test dumps. Sand was deposited over the entire area of the tanks, and there was no opportunity for crab to actively escape the sand by lateral or sideward movement, the manner in which crab normally walk. Escape was possible only via vertical movement up to the surface of deposited sand. This limitation was more pronounced with larger crab that occupied a significant area in a test tank. Knowledge of crab behavior during test dumps is important for understanding their response(s) and interpreting test results. Unfortunately, the opaque tank walls and turbidity created by sand prohibited direct observation of crab behavior during dumps.

The type of sand used for tests, a white and dry quartz sand, also influenced the response of test organisms. This sand remained relatively fluid after a test dump and could easily be penetrated through 6 in. or more with a person's hand. Yet, no 1^+ or adult crab emerged from burial under a few inches of sand. The sand carried air to the bottom and effervesced for a short period after a dump, particularly after the rapid dumps. While the grain-size characteristics of this sand are similar to those of dredged material from the lower Columbia River, sand used in test dumps was dry and behaved differently from wet dredged material. Yet, it is not clear how the nature of the sand influenced the behavior of crab or their ability to emerge once buried.

3.4 Recommendations for Further Testing

The testing presented here provides initial findings for effects on crab and flatfish of deposited sand, but these findings are inconclusive. Further testing of crab and flatfish behavior and survival to evaluate effects at disposal sites should be considered to augment the existing data and to avoid some of the limitations in these test methods. A fundamental need is for more testing to provide greater replication of selected size of crab at different depths of accumulation. Larger test tanks should be used in which material is deposited over a portion, but not all, of the tank area. This would allow a lateral escape response that was not possible in tanks used for this study and would provide tank area beyond the main footprint of deposition. Visual observations of crab behavior may also be more readily accomplished in larger tanks. Laboratory testing coordinated with test fisheries for Dungeness crab could provide greater numbers of recently-molted adult crab for testing. Use of wet sand for test dumps could provide better visibility to allow for observation of crab behavior and might produce a different response than dry sand. However, testing with wet sand would require significantly greater effort and resources for fabrication of a delivery system.

Table 1. Dungeness Crab Shell Condition Stages

Stage	Shell Condition Description
3-2	Newly molted - The exoskeleton feels like parchment, is very pliable and can be easily deformed without breaking. Endocuticle mineralization has begun.
3-1	Recently molted - The entire exoskeleton has begun to harden but can still be easily deformed. The dorsal side of the carapace will bend or crush under light pressure.
2-2	Early intermediate phase - This is the main period of tissue growth. The dorsal surface of the carapace continues to harden and is now only flexible at the posterior, left and right margins. The anterior ventral edge of the carapace and upper segment of the first walking leg are very flexible but will readily spring back into shape after pressure has been applied.
2-1	Late intermediate phase - Tissue growth continues. The dorsal side of the carapace is now hard. There is little to no flex left in the posterior dorsal edge of the carapace. The anterior ventral edge of the carapace and upper segment of the first walking leg are not yet firm. Additional tissue growth and endocuticle mineralization are needed to firm the exoskeleton at these points.
1-3	New hard shell stage - The entire exoskeleton is now rigid and tissue growth, for the most part, is complete. The carapace is light gray to tan and supports little or no epifaunal growth.
1-2	Late hard shell stage - The anterior ventral edge of the carapace and upper segment of the first walking leg are now firm when moderate pressure is applied. The color of the entire exoskeleton is beginning to darken and the crab is in prime quality for market.
1-1	Pre-molt stage - The color of the ventral surface of the exoskeleton is now dark yellow or brown. The crab may show signs of age, i.e., the exoskeleton may be damaged and may support sessile epifauna and may be starting to separate at the epimeral suture.

C26227

Table 2. STATE Model Data and Parameters for Test Dumps

Disposal Water Depth (feet)	Time for Plume to Affect Seabed: Descent	Collapse	Duration of Release (sec)	Depth of Accumulation (inches)
50	3	35	10	10.2
100	11	72	32	6.6
150	25	120	60	4.2
200	43	170	85	2.4

Table 3. Summary of Results for Test Dumps with Juvenile Flatfish

Depth of Accumulation	Date/Time	Number of Fish	Number Immediately Emerged	Number Alive at 24 h	Number Alive at 48 h	Number Alive at 72 h	Number Alive at 96 h
NA[(a)]	8/4/98	10	10	10	10	10	ND [(b)]
2.4	8/4/98 1540h	10	10	10	10	10	ND
4.2	8/2/98 0903h	10	10	10	10	10	ND
4.2	8/4/1998 1556h	10	10	10	10	10	ND
6.6	8/4/1998 1615h	10	10	10	10	10	ND
10.2	8/4/1998 1632h	10	10	10	10	10	ND

(a) NA Not applicable.
(b) ND Not determined. Monitoring ended at 72 hours after trial dump.

Table 4. Results of Test Dumps with Dungeness Crab, July through September 1998

Crab Size (CW	Nominal Depth of Accumulation (inches)	Measured Depth of Accumulation (inches)	Duration (seconds)	Rate (in/sec)	Desired Range (seconds)	Dump #	Date/Time	#buried at start	#buried that emerged	# Crab	Percent Immediately Visable	Percent Visable @ 24h	Percent Visable @ 48h	Percent Visable @ 72 h	Percent Visable @ 96 h	Percent Survival @ Term	# Survived @ Term
Control	n/a		n/a		n/a	n/a	8/10/98			8	100	100	100	100	100	100	
Control	n/a		n/a		n/a	39	8/28/98			4	100	100					
<50 mm	2.4	2.5	65	0.038	43	2	7/31/98 1710h			2	50	50	50	50	50	50	1
<50 mm	2.4	2	60	0.033	213	4	8/1/98 1103h			2	50	50	100	100	100	100	2
<50 mm	2.4	2.4	84	0.029		18	8/6/98 1303h			1	100	100	100	100	-	100	1
<50 mm	4.2	4.2	60	0.070	25-145	5	8/2/98 0903h			1	100	100	100	100	-	100	1
<50 mm	4.2	4.25	71	0.060	25-145	12	8/5/98 0930h			2	50	50	50	50	50	50	1
<50 mm	4.2	4.2	58	0.072	25-145	22	8/7/98 1127h	2	2	2	100	100	100	100	100	100	2
<50 mm	4.2	4.3	59	0.073	25-145	23	8/7/98 1656h			4	50	50	50	50	50	50	2
<50 mm	4.2	4.2	53	0.079	25-145	25	8/8/98 2057h	5	5	5	100	80 eaten	60 eaten	60	60	100	5
<50 mm	6.6	6.25	30	0.208	11-83	6	8/3/98 1248h	1	0	4	75	75	50 eaten	50	50	75	3
<50 mm	6.6	6	40	0.150	11-83	13	8/5/98 1052h	1	1	1	100	100	100	100	100	100	1
<50 mm	6.6	6	32	0.188	11-83	20	8/7/98 1104h	2	2	2	100	100	100	100	100	100	2
<50 mm	6.6	6.5	42	0.155	11-83	26	8/9/98 1033h	3	3	3	100	100	100	100	-	100	3
<50 mm	10.2	10.25	4	2.563	3-38	7	8/4/98 1503h			1	0	0	0	0	0	0	0
<50 mm	10.2	10.5	14	0.750	3-38	15	8/6/98 1204h			1	100	100	100	100	-	100	1
<50 mm	10.2	10.2	12	0.850	3-38	19	8/7/98 1051h	2	2	2	100	100	100	100	100	100	2
<50 mm	10.2	10.5	9	1.167	3-38	24	8/8/98 0904h	6	6	7	100	100	100	100	100	100	7
50-100 mm	2.4	2.5	90	0.028	43-213	14	8/5/98 1003h	1	1	1	100	100	100	100	100	100	1
50-100 mm	2.4	2.5	78	0.032	43-213	29	8/12/98 1107h			2	100	100	100	100	100	100	2
50-100 mm	2.4	2	84	0.024	43-213	30	8/14/98 1017h	2	2	2	100	100	100	100	100	100	2
50-100 mm	2.4	2.25	78	0.029	43-213	32	8/19/98 1158h	1	1	1	100	100	100	100	100	100	1
50-100 mm	4.2	4.25	100	0.043	25-145	1	7/31/98 1659h	1	1	1	100	-	-	-	-	100	1
50-100 mm	4.2	4.2	60	0.070	25-145	16	8/6/98 1216h	1	1	1	100	100	100	100	-	100	1
50-100 mm	4.2	4	60	0.067	43-213	28	8/11/98 0749h	1	1	1	100	100	100	100	-	100	1
50-100 mm	4.2	4.25	63	0.067	43-213	31	8/18/98 1131h	1	0	1	0	0	0	0	0	0	0

Table 4. (continued)

Crab Size (CW	Nominal Depth of Accumulation (inches)	Measured Depth of Accumulation (inches)	Duration (seconds)	Rate (in/sec)	Desired Range (seconds)	Dump #	Date/Time	#buried at start	#buried that emerged	# Crab	Percent Immediately Visable	Percent Visable @ 24h	Percent Visable @ 48h	Percent Visable @ 72 h	Percent Visable @ 96 h	Percent Survival @ Term	# Survived @ Term
50-100 mm	4.2	4.25	27	0.157	43-213	34	8/25/98 1602h	1	0	1	0	0	0	0	0	0	0
50-100 mm	4.2	4.5	12	0.375	43-213	38	8/27/98 1700h	1	0	1	0	0	0	0	-	0	0
50-100 mm	4.2	4.1	60	0.068	43-213	40	8/31/98 1531h			2	100	100	100	100	100	100	2
50-100 mm	4.2	4	60	0.067	43-213	42	9/2/98 1337h	2	0		50	-	-	-	-		
50-100 mm	6.6	6.5	20	0.325	11-83	3	7/31/98 1737h	1	0	1	0	0	0	0	0	0	0
50-100 mm	6.6	6.25	30	0.208	11-83	6	8/3/98 1248h	1	0	1	0	0	0	0	0	0	0
50-100 mm	6.6	6	40	0.150	11-83	13	8/5/98 1052h			1	100	100	100	100	100	100	1
50-100 mm	6.6	6.5	30	0.217	11-83	21	8/7/98 1115h	2	2	2	100	100	100	100	100	100	2
50-100 mm	6.6	6.75	31	0.218	11-83	33	8/20/98 1343h	1	0	1	0	0	0	0	0	0	0
50-100 mm	10.2	10.25	4	2.563	3-38	7	8/4/98 1503h			1	0	0	0	0	0	0	0
50-100 mm	10.2	10.75	13	0.827	3-38	17	8/7/98 1227h			1	0	0	0	0	0	0	0
50-100 mm	10.2	10.25	9	1.139	3-38	24	8/8/98 0904h	1	0	2	50	50	50	50	50	50	1
50-100 mm	10.2	10	8	1.250	3-38	27	8/10/98 1825h			4	75	75	75	75	75	75	3
50-100 mm	10.2	11	10	1.100	3-38	35	8/26/98 1234h	2	0	3	33	33	33	33	33	33	1
>100 mm	2.4	2	84	0.024	43-213	30	8/14/98 1017h	1	1	1	100	100	100	100	100	100	1
>100 mm	4.2	4	60	0.067	43-213	28	8/11/98 0749h	1	1	1	100	100	100	100	-	100	1
>100 mm	4.2	4.25	60	0.071	43-213	43	9/2/98 1800h	1	1	2	100	100	100	100	100	100	2
>100 mm	4.2	4.2	60	0.070	43-213	47	9/24/98 1158h			1	100	-	-	-		100	1
>100 mm	6.6	7	33	0.212	11-83	36	8/26/98 1716h	1	0	1	0	0	0	0	0	0	0
>100 mm	6.6	6.25	31	0.202	11-83	41	9/1/98 1631h	1	0	1	0	0	-	-	-	0	0
>100 mm	6.6	6.5	15	0.433	11-83	44	9/3/98 1434h	2	0	2	0	0	-	-	-	0	0
>100 mm	6.6	6.6	30	0.220	11-83	48	9/24/98 1122h			1	100	-	-	-		100	1
>100 mm	10.2	10	8	1.250	3-38	27	8/10/98 1825h			1	0	0	0	0	0	0	0
>100 mm	10.2	11	12	0.917	3-38	37	8/26/98 1751h	1	0	1	0	0	0	0	0	0	0
>100 mm	10.2	10.2	10	1.020	3-38	49	9/24/98 1215h			1	100	-	-	-		100	1

Table 5. Summary of Crab Monitoring Data, July through September 1998

Crab #	Holding Position (tray/section)	Dump #	*Cancer magister*=1 *gracilis*=2	premolt CW	postmolt CW	shell stage	at start: buried=1 emerged=2	Live=1 Dead=2	Duration Monitored (h)	Notes
1		1		42	57	3.1	1	1	0.5	
1		3		42	57	3.1	1	2	96	
2		2		31	43	3.1		2	96	
3	1a	2	2	27	36	3.2		1	96	
4	1c	4	1	20	28	3.1		1	96	
5	1b	4			25	3.2		1	96	emerged at 80 h
6	1d	5	2	34	44	3.2		1	72	
7		6		59	76	3.1	1	2	96	
8		6		26	36	3.1	1	2	96	
9		6		15	20	3.2		1	96	
10		6		12	18	3.1		1	96	
11		6		8	9	3.2		1	96	eaten at 48 h
12		7		36	48	3.1		2	96	
13		7		46	61	3.1		2	96	
14		12		17	21	3.1		2	96	1/2 in. above interface
15	1e	12		23	32	3.1		1	96	
16	2a	13	2	29	39	3.2	1	1	96	
17	1f	13	2	38	52	3.2	2	1	96	
18	7a	14	1	68	88	3.1	1	1	96	
19		15		15	20	3.1	2	1	96	
20	7b	16	2	61	80	3.1	1	1	72	
21		17		78	100	3.2	1	2	96	4 in. above interface
22		18		9	11.5	3.2		1	72	<3 h postmolt
23	2b	19	1	29	40	3.1	1	1	96	
24	2c	19	2	15	21	3.1	1	1	96	
25	2d	20		9	11	3.1	1	1	96	
26	2e	20		14	17	3.1	1	1	96	
27	9a	21	1	72	92	3.1	1	1	96	
28	9b	21	1	68	89	3.2	1	1	96	
29	2f	22	2	25	39	3.1	1	1	96	
30	3a	22	1	24	31	3.1	1	1	96	
31		23		27	34	3.2		2	96	test 5 min. after molt
32	3e	23	2	24	32	3.2		1	96	
33	3f	23	2	15	20	3.2		1	96	
34		23		15	18	3.2		2	96	2 in. above interface
35	4c	24	1	16	22	3.2		1	96	
36	4d	24	2	21	29	3.1		1	96	
37	5a	24	1	20	32	3.2		1	96	
38	4a	24	2	24	32	3.1		1	96	
39	6c	24	2	57	75	3.2		1	96	
40	4f	24	1	21	29	3.1		1	96	
41	4b	24	1	12	17	3.1		1	96	
42	4e	24	1	21	28	3.2		1	96	
43		24		4	60	3.2		2	96	
44	5c	25	1	20	25	3.1	1	1	96	
45	5b	25	1	22	29	3.2	1	1	96	
46		25		8	11	3.1	1	1	96	eaten
47		25		8	11.5	3.2	1	1	96	eaten
48	5d	25	2	12	18	3.2	1	1	96	
49	3b	26	2	28	38	3.2	1	1	72	
50	3c	26	1	27	38	3.1	1	1	72	
51	3d	26	1	10	14	3.1	1	1	72	
52		27			90	2.2		2	96	4 in. above interface

Table 5. (continued)

Crab #	Holding Position (tray/section)	Dump #	*magister*=1 *gracilis*=2	premolt CW	postmolt CW	shell stage	at start: buried=1 emerged=2	Live=1 Dead=2	Duration Monitored (h)	Notes
53	8a	27	1		108	2.2		1	96	
54		27			100	3.1		2	96	
55	6d	27	1		85	2.2		1	96	
56	8b	27	1		98	3.1		1	96	
57	5e	C	1	8	9	3.1		1	96	
58	5f	C	2	23	33	3.1		1	96	
59	6a	C	1	13	19	3.1		1	96	
60	6b	C	2	13	18	3.1		1	96	
61	10a	C	1	24	34	3.2		1	96	
62	10b	C	1	24	34	3.2		1	96	
63	10c	C	1	26	34	3.2		1	96	
64	10d	C	2	77	102	3.1		1	96	
65	11a	28	1	63	82	3.2	1	1	72	
66	11b	28	1	83	109	3.2	1	1	72	
67	12b	29	1	74	98	3.2	2	1	96	
68	12a	29	1	76	97	3.2	2	1	96	
69	36b	30	1	58	75	3.2	1	1	72	
70	35c	30		46	64	3.2	1	1	72	
71	36a	30		88	105	3.1	1	1	72	
72		31		43	53	3.2	1	1	96	
73	35d	32	1	64	83	3.2	1	1	96	
74		33		65	80	3.2	1	2	96	
75		34		49	68	3.1	1	2	96	
76		35		52	70	3.2	1	2	96	6 in. above interface
77	33c	35	2	49	65	3.2	2	1	96	
78		35		45	60	3.2	1	2	96	
79		36	1		162	2.2	1	2	96	
80		37	1		173	2.2	1	2	96	
81		38	1	50	64	3.2	1	2	72	
82		39		35	43	3.1		1	96	
83		39		56	71	3.2		1	96	
84		39		59	76	3.2		1	96	
85		39		60	76	3.2		1	96	
86		40		51	65	3.1	2	2	96	
87		40		51	66	3.2	2	2	96	
88		41	1		181	2.2	1	2	24	
89		42		50	64	3.2			2	repeated dumps
90		42		50	65	3.1			2	repeated dumps
91		42		49	63	3.1			2	repeated dumps
92		42		55	70	3.2			2	repeated dumps
93		43	1		184	2.1	1	1	96	
94		43	1		197	2.1	2	1	96	
95		44	1		165	2.1	1	2	24	
96		44	1		191	2.1	1	2	24	
16		45	2		49	3.1	1	2	1.5	crab 99
29		45	2		44	2.1	1	2	1.5	crab 97
48		45			20	2.1	1	2	1.5	crab 98
60		45			21	3.2	2	1	1.5	crab 100, molting
101		46	2		61	2.2	1	1	1	
102		46	1		86	3.1	1	1	1	
103		47	1		184	2.1	2	1	1	
104		48	1		184	2.1	2	1	1	
105		49	1		178	2.1	2	1	1	

Table 6. Summary of Results for Test Dumps with Crab

Crab Size (CW)	Depth of Accumulation (inches)	Number of Tests Completed	Number of Crab Tested	Number Survived	Number Dead
<50 mm	2.4	3	5	4	1
<50 mm	4.2	5	14	11	3
<50 mm	6.6	4	10	9	1
<50 mm	10.2	4	11	10	1
50-100 mm	2.4	4	6	6	0
50-100 mm	4.2	7	8	5	3
50-100 mm	6.6	5	6	3	3
50-100 mm	10.2	5	11	5	6
>100 mm	2.4	1	1	1	0
>100 mm	4.2	3	4	4	0
>100 mm	6.6	4	5	1	4
>100 mm	10.2	3	3	1	2

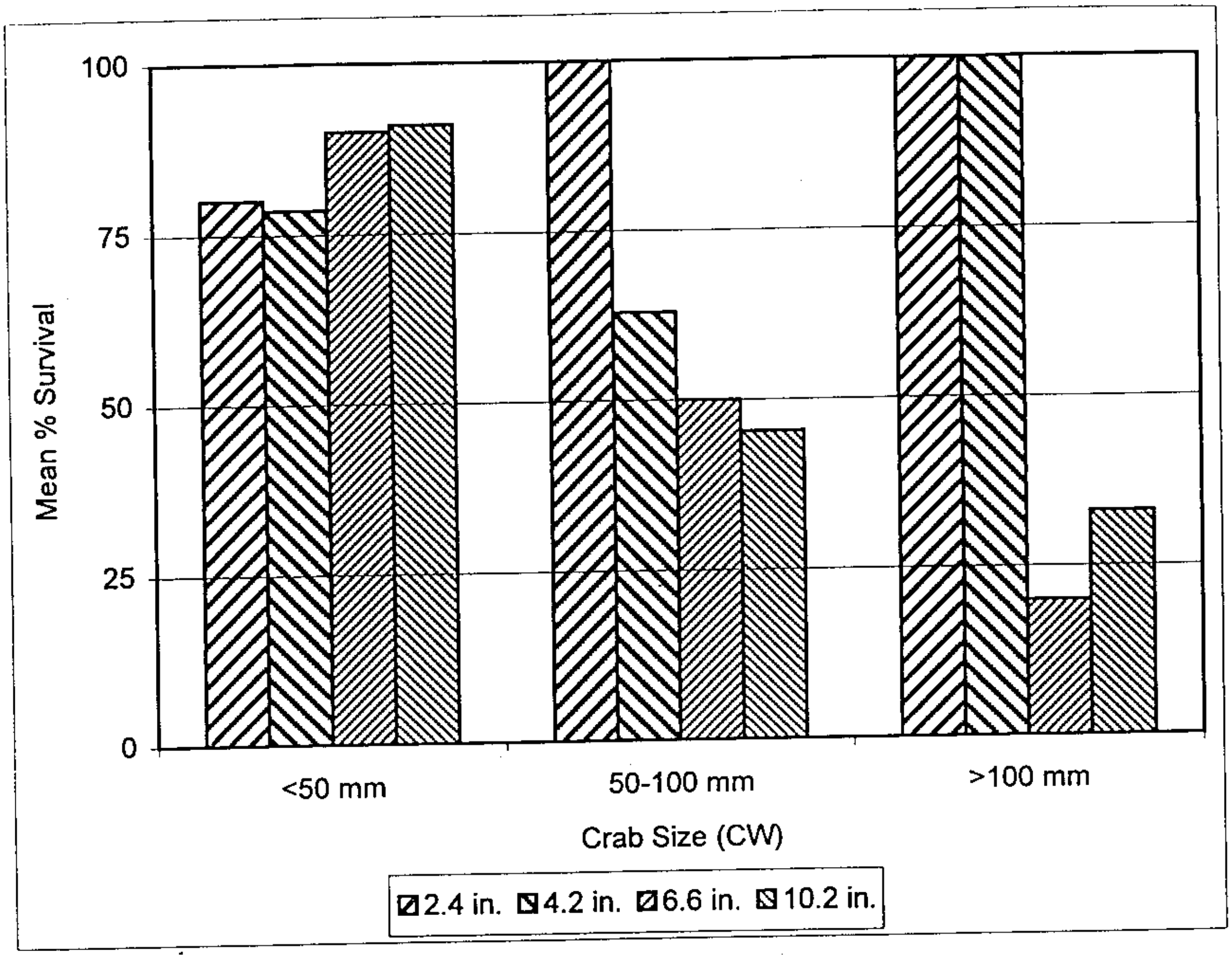

Figure 1. Mean percentage of survival of crab relative to size (CW).

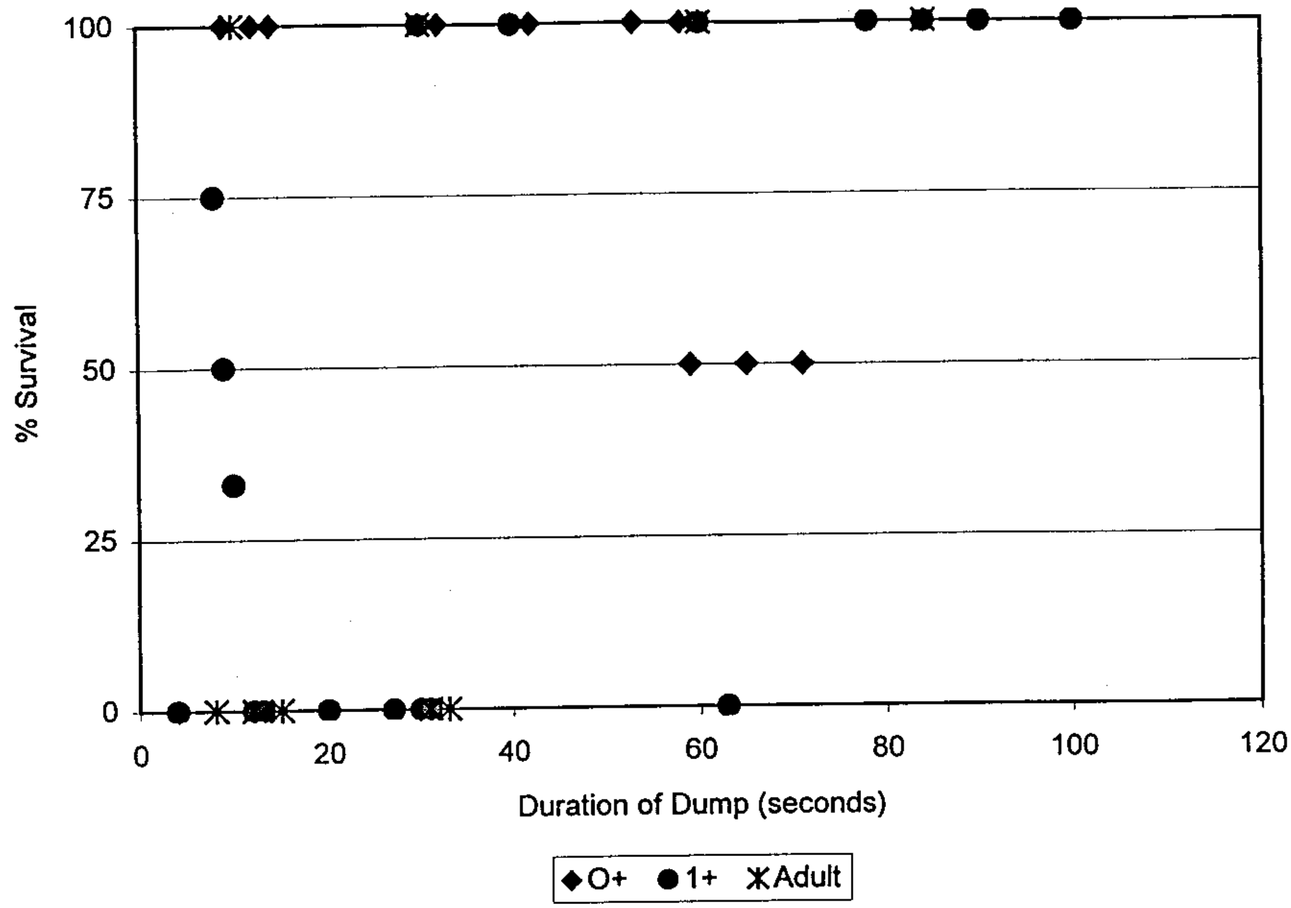

Figure 2. Percentage of survival of all sizes of crab relative to duration of dump.

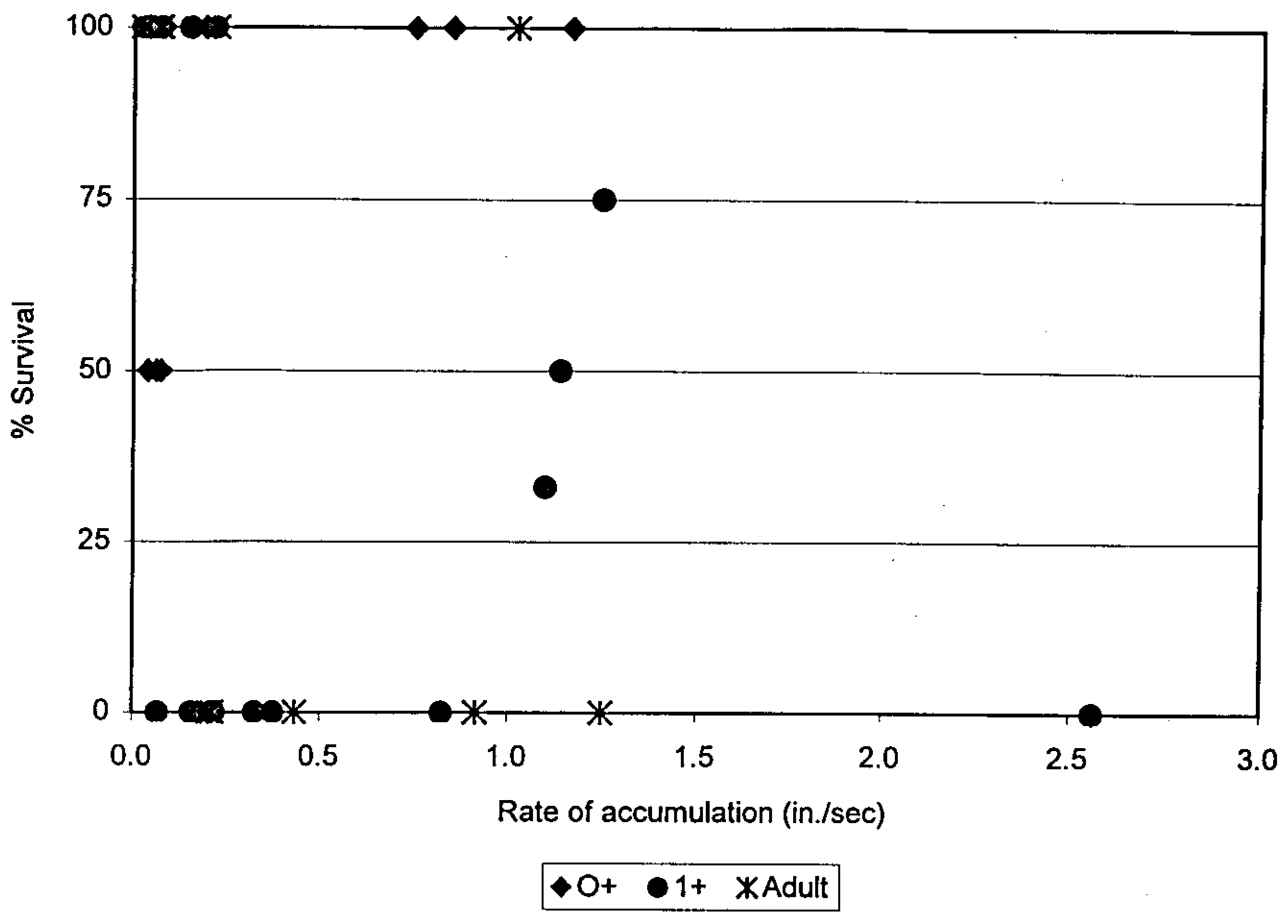

Figure 3. Percentage of survival of all sizes of crab relative to rate of accumulation.

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